

SALT AFFECTED SOILS AND THEIR RECLAMATION

**Dr Muhammad Akram Kahlown
Muhammad Haroon Chang
Dr Muhammad Ashraf
Muhammad Sadiq Hassan**



**Pakistan Council of Research in Water Resources
P O Box 1849, Islamabad**

2003

The Authors

Dr Muhammad Akram Kahlowan is Chairman, Pakistan Council of Research in Water Resources, Islamabad

Mr. Muhammad Haroon Chang is Director, Drainage Research Centre, Tando Jam

Dr Muhammad Ashraf is Director, Pakistan Council of Research in Water Resources, Islamabad

ISBN 969-8469-10-9

© PCRWR 2003

H/No.3, Street 17, F-6/2, Islamabad – Pakistan

Email: pcrwr@isb.comsats.net.pk

Acknowledgement

The authors would like to thank Mr. Naheed Ajaz and Mr. Javed Akhter for assisting in editing and formatting the report.

STAFF ASSOCIATED

1. Mr. Muhammad Yaseen Director
2. Mr. Mazharuddin Shaikh Deputy Director
3. Mr. Qadir Ali Sipyo Assistant Director/Deputy Director
4. Mr. Zamir Ahmed Soomro Assistant Director/Deputy Director
5. Mr. Noor Muhammad Arain Assistant Director/Deputy Director
6. Mr. Muhammad Naeem Research Officer
7. Mr. Amir Muhammad Laghari Research Officer
8. Mr. Tahir Saleem Assistant Scientific Officer
9. Mr. Muhammad Amin Field Assistant
10. Mr. Ghulamullah Field Assistant

CONTENTS

Table of Contents	i
List of Tables	vi
List of Figures	vii
Summary	ix

CHAPTER 1

INTRODUCTION	1
1.1 Pakistan Council of Research in Water Resources and Its Mandate	1
1.1.1 The Mandate	1
1.2 Background	1
1.3 Deterioration of Land Resources.....	1
1.4 Waterlogging and Salinity Effects.....	2

CHAPTER 2

REVIEW OF LITERATURE	3
2.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices	3
2.2 Biological Reclamation of Saline-Sodic Soils	4
2.3 Management of Reclaimed Lands.....	4
2.4 Irrigation Practices Effect on Soil Salinity.....	5
2.5 Saline and Drainage Water Use for Crop Production	6

CHAPTER 3

OBJECTIVES AND SCOPE OF WORK	7
---	----------

3.1	Rationale for Soil Reclamation Research	7
3.2	Soil Reclamation Research Conducted by DRC, Tando Jam ..	7
3.3	Objectives of the Research	7
3.4	Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices	8
3.5	Biological Reclamation of Saline and Saline-Sodic Soils	8
3.6	Management of Reclaimed Lands	8
3.7	Irrigation Practices Effect on Soil Salinity	8
3.8	Saline and Drainage Water Use for Crop Production	8
3.9	Present Report	9

CHAPTER 4

METHODOLOGY	11
4.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices	11
4.1.1 Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System.....	11
4.1.2 Comparative Effect of Inorganic, Organic and Biological Reclamation of Saline-Sodic Soils under Tile Drainage	11
4.1.3 Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System	12
4.1.4 Improvement of Salt Affected Lands through Continuous Cropping	12
4.2 Biological Reclamation of Saline-Sodic Soils	12
4.2.1 Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodders	12
4.2.2 Reclamation of Saline-Sodic Soils by Rice Husk	13
4.2.3 Biological Reclamation of High Saline-Sodic Soils	13
4.2.4 Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System	13

4.2.5 Comparison of Physical and Biological Methods for Reclamation of Fine Textured Saline Soils	14
4.3 Management of Reclaimed Lands	14
4.3.1 Resalinization of Recently Reclaimed Land	14
4.3.2 Soil and Crop Management under Reclaimed Land	14
4.3.3 Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Land	15
4.4 Irrigation Practices Effect on Soil Salinity	15
4.4.1 Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton	15
4.4.2 Reclamation of Medium Textured Saline Soils by Conventional Irrigation under the Tile Drainage Conditions	15
4.4.3 Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil	16
4.5 Saline and Drainage Water Use for Crop Production	16
4.5.1 Crop Production with Saline Drainage Effluent	16
4.5.2 Management of Poor Quality Irrigation Water	17
4.5.3 Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production	17

CHAPTER 5

RESULTS AND DISCUSSIONS	19
5.1 Soil Reclamation by Organic, Inorganic Material, Physical and Cultural Practices	19
5.1.1 Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System	19

5.1.2	Comparative Effect of Inorganic, Organic and Biological Reclamation of Saline-Sodic Soil under Tile Drainage	22
5.1.3	Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System	24
5.1.4	Improvement of Salt Affected Lands through Continuous Cropping	26
5.2	Biological Reclamation of Saline and Saline-Sodic Soils	28
5.2.1	Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodder	28
5.2.2	Reclamation of Saline-Sodic Soils by Rice Husk	30
5.2.3	Biological Reclamation of Highly Saline-Sodic Soils	32
5.2.4	Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System	34
5.2.5	Comparison of Physical and Biological Methods for Reclamation of Fine Textured Saline Soils	36
5.3	Management of Reclaimed Lands	38
5.3.1	Resalinization of Recently Reclaimed Lands	38
5.3.2	Soil and Crop Management under Reclaimed Lands	38
5.3.3	Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Land	41
5.4	Irrigation Practices Effect on Soil Salinity	45
5.4.1	Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton.....	45
5.4.2	Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions	48
5.4.3	Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil	50
5.5	Saline and Drainage Water Use for Crop Production	52

5.5.1 Crop Production with Saline Drainage Effluent	52
5.5.2 Management of Poor Quality Irrigation Water	54
5.5.3 Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production	56

CHAPTER 6

MAIN FINDINGS	59
6.1 Soil Reclamation by Organic, Inorganic Material, Physical and Cultural Practices	59
6.1.1 Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System	59
6.1.2 Comparative Effect of Inorganic, Organic and Biological Reclamation of Saline-Sodic Soils under Tile Drainage	59
6.1.3 Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System	60
6.1.4 Improvement of Salt Affected Lands through Continuous Cropping	60
6.2 Biological Reclamation of Saline and Saline-Sodic Soils	61
6.2.1 Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodders	61
6.2.2 Reclamation of Saline-Sodic Soils by Rice Husk	61
6.2.3 Biological Reclamation of Highly Saline-Sodic Soils	62
6.2.4 Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage	62
6.2.5 Comparison of Physical and Biological Methods for Reclamation of Fine Textured Saline Soils	62
6.3 Management of Reclaimed Lands	63

6.3.1	Resalinization of Recently Reclaimed Lands	63
6.3.2	Soil and Crop Management under Reclaimed Lands	63
6.3.3	Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Lands	64
6.4	Irrigation Practices Effect on Soil Salinity	64
6.4.1	Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton	64
6.4.2	Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions	64
6.4.3	Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soils	65
6.5	Saline and Drainage Water Use for Crop Production	66
6.5.1	Crop Production with Saline Drainage Water	66
6.5.2	Management of Poor Quality Irrigation Water	66
6.5.3	Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production	66

CHAPTER 7

RECOMMENDATIONS	69
7.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices	69
7.2 Biological Reclamation of Saline Sodic Soils	69
7.3 Management of Reclaimed Lands	70
7.4 Irrigation Practices Effect on Soil Salinity	70
7.5 Saline and Drainage Water Use for Crop Production	70
REFERENCES	71

LIST OF TABLES

Table 1:	<i>Crops Yield by Treatment and Season</i>	21
Table 2:	<i>Crop Yields under Various Treatments</i>	22
Table 3:	Effect of Cultural Practices on Cotton and Wheat Yield	26
Table 4:	<i>Crop Yields by Season</i>	28
Table 5:	<i>Crop Yields by Season and Change</i>	30
Table 6:	<i>Yields of Cotton and Wheat with the Application of Rice Husk</i>	32
Table 7:	<i>Crop Yields by Crop Season</i>	33
Table 8:	<i>Crop Yields by Season</i>	34
Table 9:	<i>Crop Yields by Treatment and Season</i>	36
Table 10:	<i>Change in Soil EC_e and SAR Parameters</i>	39
Table 11:	<i>Effect of Various Treatments on Crop Yields</i>	39
Table 12:	<i>Wheat and Sorghum Yields and Related Agronomic Variables</i>	41
Table 13:	<i>Soil Analysis Results Before and After Study</i>	42
Table 14:	<i>Wheat and Cotton Yields by Treatments</i>	45
Table 15:	<i>Crop Yields and Water Use Efficiency</i>	46
Table 16:	<i>Crop Yields by Treatment</i>	48
Table 17:	Wheat and Cotton Yields by Treatment and Season	52
Table 18:	Effect of Canal and Saline Drainage Water on Soil Properties	53
Table 19:	Cotton and Wheat Yields by Treatment	54
Table 20:	<i>Crop Yields by Treatment</i>	56
Table 21:	Soil EC _e , pH and SAR Trend under the Treatment	57
Table 22:	<i>Yields of Wheat and Cotton as Affected by Various Treatments</i>	58

LIST OF FIGURES

Figure 1:	<i>Reclamation of Saline-Sodic Soil by Gypsum under Tile Drainage System</i>	20
Figure 2:	<i>Comparative Effect of Organic, Inorganic and Biological Reclamation</i>	23
Figure 3:	<i>Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System</i>	25
Figure 4:	<i>Improvement of Salt Affected Lands through Continuous Cropping</i>	27
Figure 5:	<i>Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize & Sudan Grass Fodder</i>	29
Figure 6:	<i>Reclamation of Saline-Sodic Soils by Rice Husk</i>	31
Figure 7:	<i>Biological Reclamation of Highly Saline-Sodic Soils</i>	33
Figure 8:	<i>Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System</i>	35
Figure 9:	<i>Comparison of Physical and Biological Methods for Reclamation of Fine Texture Saline Soils</i>	37
Figure 10:	<i>Soil and Crop Management under Reclaimed Lands</i>	40
Figure 11:	<i>Tillage and Irrigation Effects on Movement of Individual Salts under Reclaimed Lands</i>	44
Figure 12:	<i>Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton</i>	47
Figure 13:	<i>Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions</i>	49
Figure 14:	<i>Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil</i>	51
Figure 15:	<i>Effect of Different Treatments on Soil Salinity</i>	55

SUMMARY

Background

The principal manifestation of irrigated agricultural lands under the Indus Basin Irrigation System (IBIS) of Pakistan, is the salinization of soil due to inadequate leaching of salts contained in the soil. Salinity/sodicity of soil generally occurs under the climatic characteristics as that of Pakistan, where water developments had been intended to bring more land under irrigation. Besides, destroying the dynamic equilibrium between the groundwater recharge, discharge and expanding soil salinity, the situation has been further aggravated by the factors *inter alia* poor soil drainage, insufficient water, inefficient irrigation methods and improper use of poor groundwater quality.

The preponderance of evaporation over drainage in the water budget (a condition conducive for salts build up), has accelerated the soil salinization process on the irrigated areas. Despite, a series of the Salinity Control and Reclamation Projects (SCARPs), the extent of waterlogged area is estimated about 30 percent of canal gross command area (GCA), with 13 percent as severely waterlogged. The effects of soil salinity have been expressed categorically, that of GCA about 25 percent is salt affected with 8 to 10 percent as severely salt affected. The (exclusively negative) impacts of waterlogging and salinity on the agricultural production reflect that: (i) under water-table depth within one foot (30 cm), the reduction in yields is 2 percent for cotton, 9 percent for sugarcane and 21 percent for wheat; and (ii) soil salinity causes a reduction of about 25 percent in the production of major crops.

Soil Reclamation Research

The causes of irrigated land deterioration and harmful consequences, thereof, are understandable to a great extent, in the country. The impacts particularly, of land salinization on the productivity of the irrigated agriculture, are fully realized and are not debatable any more. The concerns are: (i) to use the upgraded knowledge and understanding for technological, ecological and economic sustainability in soils reclamation; (ii) to conduct the objectives oriented research for developing appropriate and location specific soil reclamation technologies to solve the soil-water related issues; (iii) to provide assistance to the farmers, in diagnosing the nature/extent of soil deterioration in the context of salinization; and (iv) to provide supporting initiatives, workable and cost effective soils reclamation methods and related management practices, to the farmers for solving their problems at farm level to achieve the optimal use of land and water resources.

No doubt, a lot of research has been carried out in the areas of soil salinity and sodicity but the major restraint has been the slow adoption of research findings by the farmers. Perhaps it was due to the insufficient dissemination and motivation efforts. PCRWR has now initiated a systemized programme of dissemination of its research and development activities.

Drainage Research Centre, Tando Jam of PCRWR undertook a programme of research to solve the problems of soil salinity/sodicity. Objectively, this research programme has two main components: (i) evolving cost-effective methods of reclamation of salt-affected soils and examining the trends of their effectiveness in relation to soil status and crop yield; and (ii) use of

saline groundwater for crop production and related remedial measures and management practices.

The major research activities were concentrated to two methodological approaches of salt-affected soils: (i) organic, inorganic materials, physical and cultural practices; and (ii) biological methods. The related investigational areas were: (i) management of reclaimed lands; (ii) irrigation practices effects; and (iii) saline groundwater use for crop production. In the context of these research areas, a total number of 19 studies were completed. Overwhelmingly, the research studies were carried out in the areas under the operative tile drainage systems.

Recommendations

A combined delineation of the recommendations based on the findings of the research studies under each of deployed reclamation methods is presented as below:

Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices

- Medium textured moderately saline-sodic soils can be reclaimed by applying 100 percent gypsum requirement for 30 cm soil depth, adopting rice-berseem crop rotation. Gypsiferous saline-sodic soils may be reclaimed simply through continuous (three years) rotation of rice-berseem.
- Press mud can be a cost-effective alternative to gypsum, for reclaiming saline-sodic soils though it takes more time for soil reclamation.
- Leguminous crops can be cultivated to restore the soil fertility of salt-affected soils and improve the other related physical conditions. The crops such as sesbania, cluster beans and berseem should be cultivated as green manuring during reclamation process.
- Medium textured, well drained and moderately saline soils can be reclaimed through wheat-cotton crop rotation, applying the conventional irrigation to crops.
- Deep ploughing is recommended for soil reclamation, with high seed rates for wheat and sowing of cotton on ridges when the water is limited for leaching.
- Bed and furrow method of planting crops should be promulgated in saline areas.

Biological Reclamation of Saline-Sodic Soils

- For reclaiming the calcareous saline-sodic soils, low cost biological reclaimants including sorghum, maize and *Kallar grass* be adopted.
- The saline land should be kept under continuous cropping rather than keeping it fallow for long period (more than one crop season).
- Rice husk can be used to mitigate the soil salinity and sodicity. The application rates of 0.2 and 0.4 percent of rice husk are equally good in this regard.
- Highly saline soils can also be reclaimed quite effectively, by adopting the rice-berseem crop rotation.
- Fine-textured soils may be reclaimed through the cultivation of Jantar and Berseem, with deep ploughing and green manuring.
- The lands with less sodicity problem, can preferably be reclaimed by biological as

compared to chemical methods.

Management of Reclaimed Lands

- Resalinization of reclaimed land can be checked by applying a leaching fraction in addition to the respective recommended irrigation.
- In the reclaimed soils, a favourable salt balance can be maintained in the root zone under an overall management of soil, water and crop (*e.g.* wheat sowing at proper time coupled with recommended levels of irrigation water and fertilizer).
- The maximum tillage coupled with a leaching fraction (125% of consumptive use of water), under a cotton-wheat rotation can be used for recently reclaimed lands.

Irrigation Practices Effect on Soil Salinity

- With the application of 75 percent water consumptive use prominently to wheat, higher water saving can be achieved without any notable adverse effect on soil and crop yields. Accordingly, the saved water may be used to increase the cropped area and/or for leaching purpose.
- Leaching of soluble salts to the lower layers of soil can be practised depending on the availability of irrigation water.
- Reclamation of moderately saline soils of medium texture can be carried out (with cotton and wheat crops), through the respective recommended irrigation levels coupled with a canal water leaching fraction.
- An effective reduction of soil salinity and sodicity in relation to wheat and cotton crops, can be achieved through the application of 100 percent water consumptive use combined with 247-124-0 kg/ha of NPK fertilizers.

Saline and Drainage Water Use for Crop Production

- Saline water (drainage or tubewell) should not be used for irrigation purposes on saline land for longer period if drainage is provided. A well defined management strategy for saline water use needs to be drawn under water shortage condition.
- Saline water (EC of 3.0 dS m⁻¹) may be used once for irrigation to wheat and cotton after four weeks of sowing while other requisite irrigations to these crops should be applied from canal water.
- Canal water and saline drainage water in 1:1 may be used (where possible), when shortage of water is not acute.
- The modes of conjunctive use of canal and saline water, including mixing and alternate irrigation can be used for wheat and cotton crops, supported by other useful practices (bed and furrow planting, *etc.*).

Chapter 1

INTRODUCTION

1.1 Pakistan Council of Research in Water Resources and its Mandate

1.1.1 *The Mandate*

Pakistan Council of Research in Water Resources (PCRWR), is a national institution, engaged in conducting, and promoting research and development activities on various aspects of water and land resources. Administratively and technically, PCRWR is headed by a Chairman. In addition to its Headquarters at Islamabad, the organizational set up of PCRWR comprises six Water Resources Research Centres (WRRCs)/Regional Offices, each one located at Islamabad, Peshawar, Lahore, Bahawalpur, Tando Jam and Quetta.

The mandate of PCRWR has recently been modified in the context of firstly, the optimizing use of water and land resources of the country and secondly, evolving the collaboration of end users of pertinent research outcomes. This collaboration in the PCRWR's research and development (R&D) endeavours, is intended to evolve and find out the objectives oriented, workable, economical and sustainable solutions to numerous diversified problems and issues of water and land resources. The ultimate aim is to strengthen the overall economic development of the country through sustainable agriculture productivity.

Under the above manifestations, the conceptual framework of the modified mandate of PCRWR concentrates on end user oriented research with well defined, attainable objectives and quantifiable results. The R&D activities/projects undertaken by PCRWR are competitive and tailored in conformity with priorities of the country.

The fundamental concepts as noted above, serve as guiding principles for designing, planning and executing the technologically varying R&D activities undertaken and/or to be undertaken by PCRWR. The sub-organizations to a great extent, have distinctly varying mandates and objectives. Their respective well defined objectives reflect the essentiality of the relevant R&D activities as solutions that closely correspond to the problems and issues of water and land resources in the (provincial) areas where the sub-organizations are located and functioning.

1.2 Background

Pakistan's agriculture contributes significantly to other sectors and is the main source of growth of the economy. However, the agriculture sector largely, depends on irrigation due to arid to semi-arid climate. Out of cultivated area of 21.99 million hectare (Mha) of the country, the total irrigated area (from canals, tubewells and canal plus tubewells), is 17.65 Mha and the net cropped area is 16.32 Mha of the total cultivated area. The total water availability figures out 97.0 MAF for agriculture.

1.3 Deterioration of Land Resources

The principal cause of deterioration of irrigated lands under the Indus Basin Irrigation System (IBIS) is the salinization of soils due to the inadequate leaching of salts contained in soil or

added through irrigation water. In Indus Basin (flat topography, poor natural drainage, porous soil, low rainfall, high evaporation, *etc.*), the irrigation without adequate drainage had resulted in gradual rising of watertable. It has been estimated that on an average, the water-table depth in 1.62 to 2.03 Mha of irrigated area persistently remains within 5.0 feet (152 cm). The high watertable has concentrated salts in the root zone.

Salinity and sodicity of soil generally, occurs under the climatic conditions as that of Pakistan, where water developments had been intended to bring more land under canal irrigation systems. Besides destroying the dynamic equilibrium between the groundwater recharge, discharge and expanding soil salinity, the situation has been further aggravated by the factors *inter alia*, poor soil drainage, insufficient water, inefficient irrigation methods and improper use of poor quality groundwater. These factors have jointly impeded the salts leaching from soil. It has been estimated that the total salt-affected area in the Indus Basin is about 25 percent of canal command gross area.

1.4 Waterlogging and Salinity Effects

Waterlogging and salinity pose serious threats to the agriculture economy that exclusively depends on the irrigated agriculture. In canal command areas, the increase in diversion of river flow for irrigation, continuous seepage from the water distribution systems, water loss in the watercourses and farm lands, have caused waterlogging problems. Despite, a series of the Salinity Control and Reclamation Projects (SCARPs), the extent of waterlogged area is estimated about 30 percent of command's gross area and 13 percent as severely affected by waterlogging.

The preponderance of evaporation over drainage in the water budget (a condition conducive for salts buildup), has resulted in salinization of the irrigated agriculture areas. The effects of soil salinity have been expressed categorically, that out of total canal commands area, about 8 percent is severely salt affected, 6 percent moderately and 11 percent is slightly affected.

The (negative) impact of twin menace of waterlogging and salinity on the productivity of agricultural land are very severe. An estimate indicates that as the depth of watertable decreases to within 5 feet (1.52 m), yield of all major crops begins to decline. Within one foot of watertable depth, the reduction in yield is 2 percent for cotton, 9 percent for sugarcane and 21 percent for wheat. On account of salinity, a reduction of about 25 percent in the production of major crops has been estimated. The critical threshold at which the salinity begins to affect the productivity of the agricultural land varies by crop.

The persistent trend of land resources deterioration by soil salinity/sodicity has resulted in either a low production level or no production from a considerable area. The land deterioration has appeared more in southern part of Punjab and northern area of Sindh province. The situation therefore, demands for undertaking research to explore the technically feasible and cost effective land reclamation methods conducive to the local environment.

The Drainage Research Centre (DRC), Tando Jam has completed a number of research studies in the area of reclamation of salt affected lands. These studies have broadly been covered under three methods of reclamation including: (i) reclamation by organic/inorganic and physical materials; (ii) biological reclamation; and (iii) management of reclaimed soils. The report presents the results of these research studies and main findings.

Chapter 2

REVIEW OF LITERATURE

This chapter gives a brief description regarding the literature reviewed on the soil reclamation research carried out at national and international level. The reviewed literature has been classified by varying methods of reclamation of soils affected by salinity and sodicity and other remedial measures deployed and tested by DRC.

2.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices

Abrol and Bhmbala (1979) observed that for rice, the reduction in soil exchangeable sodium percentage (ESP) was quicker and extended to deeper depths and it was highly tolerant to exchangeable sodium as compared to wheat. Verma and Abrol (1980) found that improvement in soil properties with the application of gypsum was always greater than that with pyrites. Aziz (1980) reported that saline soils were reclaimed with the cultivation of rice. Sainberg *et al.* (1982) stated that to reclaim a sodic soil, the amount of gypsum required depended on amount of exchangeable sodium in soil. Ramzan *et al.* (1982), observed that in reclamation of saline sodic non-gypsiferous soils having pH 8.62-9.10, EC_e 4.37-9.97 dS m^{-1} and SAR 41.81-1205.23. Hundred percent gypsum requirement of soil plus farm yard manure had the maximum reclamation efficiency. However, it was recommended that press mud was a cheap source of reclamation that decreased the EC_e of the soil significantly. Hussain and Asghar (1985) found that application of gypsum even at 25 percent of total requirement, the reclamation of saline-sodic soil was accelerated and achieved within limited time. Roy and Braum (1988) stated that the legumes contributed to soil fertility directly through their unique ability to fix atmospheric nitrogen in association with Rhizobia. Raising of leguminous plants and burying them after 45 to 60 days has been practised by the farmers for a long time. IWASRI (1988) reported that by growing dhancha-barley when dhancha was green manured in the first year, EC_e of the saline-sodic non-gypsiferous silty clay soil decreased by 48 percent. SAR of the soil decreased by 53 percent in the upper soil layer (0-15 cm). Hussain and Karamat (1989) obtained the highest yield of rice and berseem, probably attributed to their resistance to sodicity. Superiority of gypsum was also found to increase infiltration rate. Abdullah *et al.* (1990) reported that *Leptochloa fusca* was ecologically widely distributed in the salt affected areas of Pakistan. The specie was easily propagated through seeds, stems and roots, and exhibited successful growth under saline, sodic and saline-sodic soils. Estimated yield of green fodder during monsoon season was between 20 and 40 tons per hectare. Memon and Khan (1995) reported that saline lands could be reclaimed with higher seed rate to increase plant population. The dense plants could intend to update the salts through roots to reclaim the soil. Chhabra (1996) recommended the continuous cropping on the land to keep intact the downward movement of replaced Na^+ and soluble salts as the following acts reversely. It was further supported to use green manure for enhancing organic matter content, increasing partial pressure of CO_2 , lowering pH, increasing solubility of native $CaCO_3$ and adding plant nutrients in the soil (sesbania as an ideal crop). He also found that increased depth of ploughing coupled with other tillage operations showed a prominent effect on crop yields and reduction in soil salinity. Muhammad (1996) commented that to reclaim the salt affected soils, the growing and green manuring the leguminous crops, add organic matter in the

soil, improves the permeability of sodic soil, provides a deeper zone for growth and extension of crop roots.

2.2 Biological Reclamation of Saline-Sodic Soils

In the past more research studies were carried out in relation to biological reclamation of soils affected by salinity/sodicity. Indulkar and More (1985) reported that with growing of sorghum at four salinity levels, the reduction in dry matter production was more pronounced under chloride than sulphate dominant salinity. More and Malewar (1988) showed that sorghum and cotton could be grown up to 8 dS m^{-1} and 15 dS m^{-1} , respectively. Rauf *et al.* (1989) based on an experiment on three sorghum geno types (J-263, KS-18 and S-8) observed a significant decrease in fodder fresh weight with increasing soil salinity. A 50 percent yield reduction was found at EC_e of 11.9, 12.1 and 12.00 dS m^{-1} for J-263, KS-18 and S-8, respectively. Varieties had no significant differences for salt tolerance. Patrick and Lauchii (1990) reported that with the increased soil salinity level from 2.1 to 5.9 dS m^{-1} the dry matter yield of sorghum decreased. Parvez (1992) on the basis of a biological reclamation experiment concluded that under calcareous saline-sodic conditions, the fodders gave a high amount of carbon dioxide that dissolved calcium carbonate causing release of calcium ions and replaced sodium ions from clay complex. Resultantly, sodium sulfate was formed a soluble and easily leached salt, provided the soil is porous and has a good drainage conditions. Rauf *et al.* (1990) reported that biological method of reclamation is less effective as compared to chemical method. Takumi Izuno (1992) from a research on Sindh Forages observed that the Sudan grass gave the multicut feature and profuse tillering and sorghum provides the copious quantities of larger seed tendency or prussic acid poisoning. He reported the Sudan grass and sorghum as the good choices for a multicut annual crop. Shakoor (1993) found that maize and sorghum could be grown successfully in *Kharif* season for grain as well as for dry matter production. Maskina *et al.* (1993) reported that rice husk could be utilized for reclamation of saline-sodic soils, on account of its tendency to improve the physical conditions of the soil and its fertility.

2.3 Management of Reclaimed Lands

Special and cautious management efforts were essential to realize the crop production from saline and sodic soils (USDA Hand Book, 60). Haider *et al.* (1977) observed that reclaimed soils tended to be salinized again when kept fallow for three years. Arad and Glueckstern (1981) reported that if a sub-soil contained a large amount of soluble salts, shallow watertable also caused salinization and further reduced the productivity of the land. Hussain and Sadiq (1982) mentioned that with cropping throughout the year, if the water requirement of crops were satisfied and drainage was accomplished properly, the risk of soil salinization could be avoided. Kallar grass reduced EC_e from 40 dS m^{-1} to 2.5 dS m^{-1} within 18 months in the top soil (NIAB, 1987). Akhter *et al.* (1988) after one year growth of *L. fusca* with the use of brackish water obtained improvement in hydraulic conductivity of the soil. Awan (1989) recommended that the water requirement of crops should include the quantity of water to check the concentration of harmful salts in the root zone. Niazi *et al.* (1990) concluded that additional supplies of water provided to the farmers were not being used for reclamation. Ahmad (1991) found that gypsum was the most effective for reclamation of sodic soils because of its low cost and easy availability. Chang *et al.* (1991) achieved significant yield of rice and berseem from the plots receiving 50 percent gypsum requirement in saline-sodic soils. Sadiq (1992) concluded that growing of sesbania on the salt affected moderately fine textured soils (EC_e more than 15 dS m^{-1} and pH 8.6 to 8.8), for reclamation through green manuring, proved more effective to reclaim the soil from

sodicity. But salinity was reduced only with double dose of 27.65 ton forage per hectare green manuring. Ansari and Khanzada (1995) reported that periodic cultivation of alfalfa, clover, sesbania, berseem, lucern and deep incorporation of these as green manuring and cattle manure improved the saline lands greatly.

2.4 Irrigation Practices Effect on Soil Salinity

The irrigation practices research studies have been carried out to evolve and examine their relationship to the soil salinity. In this regard, the review of pertinent literature includes the following:

Mac Donald (1965) reported the reclamation of medium-textured soils (within one and half year) with intensive cropping and because of the great influence of the soil permeability on leaching process. Javaheri (1975) concluded that heavy leaching dose of irrigation caused decrease in soil salinity of 80 cm of soil depth from 12.8 to 3.8 dS m⁻¹, within 180 days under the drainage system. MONA (1975a) reported that the highest yield of wheat could be obtained with the dose of 125-50-25 lbs per acre of NPK and application of 16 acre inch irrigation. MONA (1975b) based on a study of water consumptive use of major crops, showed that highest wheat yield was achieved at 1.4 and 7 bar moisture tension with the dose of 150-75-30 lbs per acre of NPK. Chaudhry and Sabir (1975) concluded that excess irrigation beyond the recommended irrigation requirement was unproductive because higher yield of wheat was obtained from the recommended irrigation requirement of the crop. However, Sabir (1976) recorded highest cotton yield when urea fertilizer was applied in excess doses with low irrigation level. Dilemma (1979) reported that slightly and moderately saline soils caused no serious problem and the excess salts in these soils could be leached down by irrigating the field. However, ultra saline soils (EC_e more than 40 dS m⁻¹) required leaching fraction plus crop water requirement for reclamation. Jurinake and Wagenet (1981) concluded that in most cases moderately levels of soil salinity could be reclaimed by increased fertilization (when salinity not excessively high and the crop not particularly salt sensitive). Bresler (1981) reported that existing knowledge on salinity-irrigation relationships could play a major role for improving the use of irrigation water while minimizing the deterioration of soils and degradation in groundwater quality. Department of Agriculture Canada (1982) reported that most of the salts present in the upper 180 cm of the soil, could move downward after five years, by leaching with irrigation water under low initial sodicity of the soil. Khan and Channa (1988) on the basis of an experiment found the application of 150-150-50 kg/ha of NPK the most effective in terms of soil reclamation and crop yield. Rhoades (1990) estimated 0.1 to 0.4 kg of salts per cubic metre or 0.1 to 0.5 ton salts per acre foot of irrigation water and Wenberg (1990) suggested that under the permanent irrigated agriculture, the salts introduced by irrigation should be removed in totality. Shawky and Saber (1992) concluded that with irrigation fraction of 0.75 using canal water, soil salinity would decrease after the first year, then a balanced accumulation of salts would be achieved. However, for irrigation fraction of 0.5 using canal water there would be no change in soil salinity. Hameed and Channa (1993) while comparing the use of brackish groundwater with canal water found that soil salinity decreased in entire profile in three years under the canal irrigation. Hussain *et al.* (1993) reported that 10 cm irrigation application on a medium-textured soil was quite effective. Proper leaching and improved management have been considered essential especially under arid to semi-arid climatic conditions to alleviate salt build up in the root zone.

2.5 Saline and Drainage Water Use for Crop Production

Hoorn (1971) concluded that irrigation with saline water with good drainage facility was far less dangerous compared to irrigation with sweet water without proper irrigation and drainage management. Qureshi *et al.* (1977) studied the effect of highly saline-sodic tubewell water use with gypsum stone, on heavy-textured soil. One irrigation without the amendment and one to two irrigations after amendments were safe. Jerald *et al.* (1977) reported with adequate drainage and ample applications of water at relatively frequent intervals, the use of fairly saline groundwater without accumulating high concentrations of salt in the soil profile was possible. Kovda *et al.* (1978) reported that irrigation water of low and medium salinity (EC 0-0.25 & 0.25-0.75 dS m⁻¹, could be used for growing crops. Water having EC between 2.25 and 500 dS m⁻¹ was reported as very high saline and unfit for irrigation, under normal conditions. Dhir *et al.* (1980) found that even though crops were irrigated with highly saline-sodic water (dominantly sodium chloride water) there was no progressive buildup of alkali hazard in the soil. Tripathi and Pal (1980) concluded that the wheat could tolerate the salinity of water up to EC of 8.4 dS m⁻¹ on sandy loam soils without any significant loss in yield. Ahmad and Ahmad (1987) reported that it was possible to raise agricultural intensity from a low level of about 60 percent to nearly double by conjunctive use of surface water and saline groundwater. Further, increase in intensity (up to 150 percent or more), was also possible with proper soil and water management practices. IWASRI (1988) reported that in Pakistan, good quality water was not available to meet full crop water requirements especially during peak demand period. To augment this inadequate water supply and to save crop from soil moisture stress, poor quality groundwater could be utilized as it was available in abundance in many areas. But indiscriminate use of such water could deteriorate soils and affect crop yield. Hussain *et al.* (1990) found that SAR of soil under wheat and cotton crop rotation was decreased in all the treatments of canal and saline drainage water but their cyclic use was superior to their continuous or blending use for crop production and decreasing soil salinity and sodicity. Javaid and Channa (1990) found concluded successful use of brackish water (EC 4.0 dS m⁻¹) under good management without much loss in yield of wheat (on short term basis). However, cotton yield reduced even on short term basis. Chaudhry and Chaudhry (1990) reported that brackish water having EC 2.4 dS m⁻¹ and SAR 12 used with proper management did not have notable effect on the yield of wheat crop and salinity/sodicity of soil profile. Rhoades (1992) concluded that it was impossible to set precise standards of irrigation water quality for wide applicability. The suitability of irrigation water needed evaluation, in relation to crops to be grown, soil properties, irrigation management, cultural practices and climatic conditions. Rhoades (1998) stated that the disposal of poor quality water constitutes a major percentage of the overall cost of any irrigation and drainage project however, with suitable crops and water management practices, this water can be reused on agriculture land for crop production, on a commercial basis.

Chapter 3

OBJECTIVES AND SCOPE OF WORK

3.1 Rationale for Soil Reclamation Research

Over the last few decades, a considerable work into the problems of waterlogging and salinity and soil reclamation had been carried out in the country. However, due to high magnitude and diversified nature of the problems, there is need to find out workable and economically viable solutions in relation to the national level implementation plans. Sometimes, there appear limited opportunity of the methods or technologies for adaptation to local conditions. Another important restraint is slow adoption of the research results by the farming community perhaps due to the insufficient dissemination and motivation efforts.

Therefore, it is important: (i) to use the upgraded knowledge and understanding for technological, ecological and economic sustainability in soil reclamation; (ii) to conduct research for developing appropriate and location specific soils reclamation technologies (emphasized with drainage), to solve the problems of waterlogging and salinity in canal commands; (iii) to provide assistance to the farmers in diagnosing the nature and extent of soil deterioration; and (iv) to provide practicable and cost effective soil reclamation methods to the farming community to solve the soil problems at farm land level for the optimal use of their land and water resources.

3.2 Soil Reclamation Research Conducted by DRC, Tando Jam

DRC, Tando Jam launched a programme of research to probe the problems of soil salinity and sodicity. Mainly, the research programme has two components: (i) evolving of cost effective methods of reclamation of salt affected soils and examining the trends of their effectiveness in relation to soil status and crop yields; and (ii) use of saline groundwater for crop production and other related remedial measures and management practices.

3.3 Objectives of the Research

The soil reclamation programme envisaged the following main objectives:

- Design and conduct research on soil salinity and sodicity;
- Evaluation of various methods of reclamation in relation to the effects on soil status and crop yields;
- Dissemination of research results for the end users and policy planners; and
- Provide guidelines and assistance to the farmers to reclaim their salts affected farmlands.

Under the designed research programme, the major activities were concentrated to two areas of soil reclamation: (i) organic, inorganic material methods, physical and cultural practices; and (ii) biological method of soil reclamation. The other investigational areas were: (i) management of reclaimed lands; (ii) effect of irrigation practice on soil salinity; and (iii) saline and drainage water use for crop production. Accordingly, the studies accomplished in the overall context of reclamation of salt affected soils are given below:

3.4 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices

This method of reclamation includes four studies as titled below:

- Reclamation of saline-sodic soil by gypsum under tile drainage system;
- Comparative effect of organic, inorganic and biological reclamation of saline-sodic soils under tile drainage;
- Reclamation of saline-sodic soil through cultural management under tile drainage; and
- Improvement of salt affected land through continuous cropping.

3.5 Biological Reclamation of Saline and Saline-Sodic Soils

The following five studies have been conducted:

- Biological reclamation of calcareous saline-sodic soils by growing sorghum, maize and sudan grass fodders;
- Reclamation of saline-sodic soil by rice husk;
- Biological reclamation of highly saline-sodic soils;
- Reclamation of strongly saline soils by different methods under tile drainage system; and
- Comparison of physical and biological methods for reclamation of fine textured saline soils.

3.6 Management of Reclamation Lands

Under this research programme, following three studies have been completed:

- Resalinization of recently reclaimed lands;
- Soil and crop management under reclaimed land; and
- Tillage and irrigation effect on movement of individual salts under reclaimed land.

3.7 Irrigation Practices Effect on Soil Salinity

The completed studies under this aspect include the following:

- Effect of different irrigation levels on soil salinity and production of wheat and cotton;
- Reclamation of medium textured saline soils by conventional irrigation under tile drainage conditions; and
- Irrigation and fertilizer interaction in a moderately saline-sodic soil.

3.8 Saline and Drainage Water Use for Crop Production

Following four studies have been completed under this area of research:

- Crop production with saline drainage effluent;
- Management of poor quality irrigation water; and
- Conjunctive use of canal water and saline drainage effluent for crop production.

3.9 Present Report

The structure of this report on salts affected soils and their reclamation presents a synthesized and summed up delineation of methodologically relevant accomplished research studies while emphatically focusing on their salient quantified findings and outcomes. The recommendations have been drawn in the context of workability and cost effectiveness of the soil reclamation methods and the effective management of saline soil and water.

Chapter 4

METHODOLOGY

This chapter presents the summarized resume of methodologies used for different completed research studies, while focusing mainly on chemical and biological methods for reclaiming the salt-affected soil and experimenting the various preventive measures and approaches to control the soil salinity and sodicity. Most of the studies were conducted under the existing tile drainage system at different locations.

4.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices

4.1.1 Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System

The study was conducted (1988-1991) on a tile drainage area of 1.4 hectares at Atomic Energy Agricultural Research Centre (AEARC) Farm Tando Jam, where the tile drains were installed at 1.8 m depth and the water-table depth was controlled at 0.8 m below ground surface. The soil was porous, medium textured and saline-sodic with infiltration rate of 65 mm day⁻¹ and dry bulk density was 1.4 g cm⁻³.

The gypsum requirement (GR) of soil was 14 tonnes per acre foot. The treatments in accordance with gypsum requirements were: T₁ = control; T₂ = 100 percent GR; T₃ = 75 percent GR; and T₄ = 50 percent GR. All the treatments were repeated thrice under the randomized block design experiment. The calculated quantity of gypsum was spread before ploughing.

Two crops viz berseem (*Rabi*) and rice (*Kharif*) were sown. The water of EC 0.45 dS m⁻¹, SAR 2.4 and RSC nil, was applied amounting to 70 cm for berseem, 150 cm for rice in addition to 44 cm a leaching fraction during the first two seasons. The yearly average rainfall was 3.0 cm. Soil samples were analyzed before the experiment at the end of each crop season and seasonal crops yield were recorded.

4.1.2 Comparative Effect of Organic, Inorganic and Biological Reclamation of Saline-Sodic Soil under Tile Drainage

The study was carried out (1989-91) at the DRC tile drainage site (Bughio Agricultural Farm, Mirpur Khas) with the water-table depth controlled at 1.0 m. Before experiment, the silty loam soil indicated EC_e of 13.13 dS m⁻¹, pH 8.78, SAR 34.35, infiltration rate 0.85 m day⁻¹ and bulk density 1.48 g cm⁻³. Besides control (T₈), the experimental treatments were: 100 percent GR of the soil (T₁), 50 percent GR, (T₂), kallar grass (T₃), press mud at the rate of 50 ton/ha, (T₄), press-mud at the rate of 25 ton/ha, (T₅), press mud at the rate of 50 ton/ha + 50 percent GR (T₆) and press mud at the rate of 25 ton/ha + 50 percent GR (T₇).

The treatments were replicated under randomized block design in each plot size of 10 x 12. The estimated quantities of the amendments were mixed in the soil. Excluding kallar grass plots, berseem (*Rabi*) and rice (*Kharif*) were grown. The amount of water seasonally applied to berseem was 45 cm and 150 cm to rice with a recorded average rainfall of 3.0 cm. Recommended doses of fertilizer were applied to the two crops. The soil analysis and the yield data were determined as usual.

4.1.3 Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System

The study was conducted (1996-1999) at Nuclear Institute of Agriculture (NIA) Farm, Tando Jam on a DRC tile drainage site of 4.0 ha. Cotton and wheat crops were experimented and each of them was cultivated for three respective crop seasons.

In view of the overall objectives of the study, the treatments were: T₁ as control; T₂ as three ploughing/leveling, T₃ as deep ploughing/leveling and T₄ was high seed rate of wheat while sowing of cotton on ridges. Under the randomized block design, the treatments were replicated thrice. The treatment-wise plot size was 411 m² having porous, medium textured and moderately saline and sodic soil. Infiltration rate of soil was 0.95 cm/hour and dry bulk density of 1.5 g cm⁻³.

Five and seven irrigations of canal water (EC 0.35 dS m⁻¹) were applied to wheat (*Sarsabz*) and cotton (NIAB-78) crops with total irrigation of 375 mm to wheat and 550 mm to cotton. Fertilizers to wheat and cotton were applied at the rate of 250-125-75 and 300-175-100 NPK kg/ha, respectively. Besides, all necessary cultural practices and pest control measures were undertaken. Composite soil samples at depths 0-15, 15-30, 30-60 and 60-90 cm were taken before the experiment and at the end of each crop season and were analysed for EC_e, pH, SAR and ESP. The crops yield were recorded by plot and aggregated by crop season.

4.1.4 Improvement of Salt Affected Lands through Continuous Cropping

This research study was conducted at NIA Farm, tile drainage site during the years 1997-2000 (six crop seasons). The experiment was based on usual randomized block design. The soil was porous, medium-textured and moderately saline. Infiltration rate of soil was 0.95 cm/hour and dry bulk density was 1.5 g cm⁻³. Composite soil samples at depths, 0-15, 15-30, 30-60 and 60-90 cm were analyzed before the experiment and after each crop season.

The experimental treatments were: T₁, berseem followed by sorghum; T₂, mustard followed by cluster beans; T₃, barley followed by sesbania and T₄, alfalfa followed by pearl millet. Each treatment was replicated thrice. The crops were irrigated with canal water (EC 0.4 dS m⁻¹). The irrigation water for the crops varied from 25 cm/ha (millet and cluster beans) to 136/140 cm/ha (sesbania/berseem). The applied fertilizer doses were 18-46-0 NPK kg/ha each for berseem, sorghum, sesbania and alfalfa, 23-46-0 NPK kg/ha each for mustard, cluster beans, barley and 32-23-0 NPK kg/ha for millet. In addition, the recommended cultural practices were carried out and the crops yield were recorded.

4.2 Biological Reclamation of Saline-Sodic Soils

4.2.1 Biological Reclamation of Calcareous Saline-Sodic Soil by Growing Sorghum, Maize and Sudan Grass Fodders

This research study was carried out (*Kharif* 1991 to *Kharif* 1993) at AEARC Farm on an area having tile drains constructed by DRC. The soil texture was silt loam. Each plot size was 88 m² under randomized block design. The soil samples up to 90 cm depth, were analysed once before the experiment and then repeated after each crop season. Prior to experiment, soil EC_e was 9.75 dS m⁻¹, pH 8.23, SAR 15.06 and ESP was 16.18, up to 90 cm depth.

The treatment were: T₁, control (without crop); T₂, maize; T₃, sorghum; and T₄ was Sudan grass. Each treatment was repeated for four times. These crops were cultivated twice in each year due to their short duration. The crops were irrigated with water of 0.450 dS m⁻¹, SAR 2.4 and RSC

nil. The recommended doses of fertilizer were applied and essential cultural practices were undertaken. Crop season-wise data of yields were recorded.

4.2.2 Reclamation of Saline-Sodic Soils by Rice Husk

The study was conducted at NIA Farm, Tando Jam on an area with tile drains, water-table depth controlled at 1.0 m. The soil was porous, medium textured and moderately saline-sodic. Other characteristics included; infiltration rate of 0.95 cm/hour and dry bulk density 1.5 g cm^{-3} . Pre and post (seasonal basis) data on soil EC_e , pH, ESP, cations, anions and organic matter were determined.

The experiment was extended to a gross area of about 0.65 ha with 12 plots, each of 391 m^2 . The crops under experiment were cotton and wheat. The weight of rice husk applied was calculated from the percentage of the weight of 15 cm soil depth. Accordingly, rice husk was applied at the rate of 0.1 percent (272 kg), 0.2 percent (545 kg) and 0.4 percent (1000 kg) as T_2 , T_3 and T_4 , respectively. The treatment T_1 was control (without rice husk). Each treatment was replicated thrice.

Canal water ($\text{EC } 0.45 \text{ dS m}^{-1}$) was applied with irrigation of 375 mm to wheat and 550 mm to cotton in a crop season. Fertilizers were applied at the rate of 200-125-50 NPK kg/ha to cotton and 142-73-0 NPK kg/ha to wheat. The cultural practices as per recommendations for the two crops were undertaken. The yields of the two crops were recorded by seasons.

4.2.3 Biological Reclamation of High Saline-Sodic Soils

The research study was conducted at AEARC Farm, Tando Jam where tile drainage system has been installed. The study period spanned over six crop seasons *i.e.* from *Kharif* 1996 to *Rabi* 1998-99. The experiment concentrated to four reclamative crops including rice, berseem, Kallar grass and berseem. T_1 , rice in *Kharif* and berseem in *Rabi*, T_2 , Jantar in *Kharif* and berseem in *Rabi*; T_3 , Kallar grass, and T_4 , fallow land were the treatment. The randomized block design was adopted with each plot size of 14 x 24. The soil was clay loam and highly saline-sodic.

The canal water with $\text{EC } 0.4 \text{ dS m}^{-1}$ was used with irrigation of 1200 mm to rice, 300 mm to Kallar grass, 450 mm to Jantar and 600 mm to berseem. Soil analysis was carried out before and after each crop season. The crop yields of rice and Kallar grass were recorded on plot basis and that of berseem and Jantar from selected plot each of 5 x 5 m size.

4.2.4 Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System

This study was conducted for two seasons (*Rabi* 2000-2001 and *Kharif* 2001), on the area having tile drains at NIA Farm, Tando Jam. Two methods were used for reclaiming the soil of medium textured and strongly saline ($\text{EC} > 15 \text{ dS m}^{-1}$). The first method involved cropping of three crops: dhancha (jantar) and rice in *Kharif* and berseem in *Rabi*. The second method was the continuous leaching of fallow area.

Accordingly, the treatments were: T_1 , control (no crop/no irrigation); T_2 , without crop/continuous leaching; T_3 , dhancha in *Kharif* and berseem in *Rabi* and T_4 , rice in *Kharif* and berseem in *Rabi*. Each treatment was replicated thrice. Water at crop consumptive use was applied in case of continuous leaching (T_2). However, canal water applied for the grown crops, accounted for 675 mm to berseem, 1200 mm to rice and 450 mm to dhancha. Soil samples at 0 to

90 cm were analyzed once before the experiment and then after each crop season. Crop yields were recorded on the basis of selected plots each of 5 x 5 m size.

4.2.5 Comparison of Physical and Biological Methods for Reclamation of Fine Textured Saline Soils

This study was conducted over six crop seasons (*Rabi* 1998-99 to *Kharif* 2001), at NIA Farm area having tile drainage system. The soil was fine-textured and saline with a hard layer at three metre depth. The experiment in randomized block design with three replications was consisted of 12 plots and size of each plot was 13.7 x 10.5 m.

The applied treatments were: T₁, control (wheat/cotton); T₂, deep ploughing (wheat/cotton); T₃, berseem/dhancha and T₄, deep ploughing (berseem/dhancha). Besides irrigation to crops, the soil analysis at the depth of 0 to 90 cm was carried out, once before the experiment and at the end of each crop season. Crop-wise yields were recorded, however, the last cutting of berseem and dhancha was green manured.

4.3 Management of Reclaimed Lands

4.3.1 Resalinization of Recently Reclaimed Land

This study was undertaken on an area reclaimed by gypsum, at NIA Farm, Tando Jam. The experimental crops were wheat and cotton in rotation from *Rabi* 1991-92 to *Khairf* 1994 (six crop seasons). Watertable was maintained at 0.8 metre depth below ground surface during the reclamation process as well as under post reclamation.

The irrigation applied were 37 cm to wheat and 55 cm to cotton. The contribution of rainfall was 39 cm in 1992 and almost negligible in 1993, however, in 1994, a rainfall of 37.7 cm was received. There was no application of leaching fraction of irrigation water. In addition, the recommended doses of fertilizer were applied to the crops and necessary cultural practices for the crops were undertaken. The data on soil salinity status and crop yields were recorded on crop season basis.

4.3.2 Soil and Crop Management under Reclaimed Land

The study was conducted for two seasons (*Rabi* 1995-96 & *Kharif* 1996). The site of the experiment was the DRC's drainage system, Block 2-A of East Khairpur. The soil had already been reclaimed by different leaching doses of saline and conjunctive use of water. The soil was medium texture and newly reclaimed, non-saline (EC 0.4 dS m⁻¹). Wheat-sorghum crop rotation was carried out for the experiment.

The experimental treatments under randomized block design were: T₁ for the seasonal crop (sowing at proper time), with recommended doses of fertilizer, T₂ for early crop with low doses of fertilizer, T₃ for late crop with high doses of fertilizer and T₁ was control (seasonal crop without fertilizers). Canal water (EC 0.3 to 0.4 dS m⁻¹) was used for irrigation with 375 mm and 300 mm for wheat and sorghum, respectively, rainfall contribution was negligible. The applied fertilizer doses (NPK, kg/ha), to wheat were: low, 150-75-0; recommended, 250-125-75; and high, 350-175-125. The fertilizer doses (NPK, kg/ha), applied to sorghum were: low, 100-50-0; recommended, 150-75-25; and high, 200-100-50.

The detailed soil analysis was carried out on the basis of samples from 0-100 cm depth at an interval of 25 cm before planting and after crop harvesting. The observations such as plant

growth rate (weekly), number of tillers/m², plant height, length of ear head, number of grains/ear head were collected. The crop yields were recorded in relation to the applied treatments.

4.3.3 Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Land

The study was conducted on a reclaimed area under a tile drainage system (Sultanabad) near Hyderabad. The reclamation of land had already been carried out with leaching doses. The experiment involving a cotton-wheat crop rotation was carried out for four crop seasons (*Rabi*-1995-96 to *Khairf* 1997).

There were four experimental treatments: T₁ as control; T₂ for minimum tillage plus 75 percent consumptive use (CU) of crops; T₃ for optimum tillage plus 100 percent CU and T₄ for maximum tillage plus 125 percent CU of the crops. For irrigation, canal water having EC 0.45 dS m⁻¹ was used and the irrigations were applied at 550 mm to cotton and 375 mm to wheat in their respective seasons. The tillage operations as per treatments were undertaken. The rainfall as recorded was very low (4.0 mm) during the first three crop seasons while 45 mm during the last season (*Kharif* 1997). Water-table depth remained at 1.0 m below the land surface. Five samples from 0 to 90 cm were taken for analysis. The yields of the two crops were recorded.

4.4 Irrigation Practices Effect on Soil Salinity

4.4.1 Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton

This study was conducted at DRC Farm and spanned over six crop seasons (*Rabi* 1989-90 to *Kharif* 1992). Wheat and cotton were cultivated each in three seasons under wheat-cotton rotation. The soil of experiment site was loam to silt-loam in texture.

Three treatments including: T₁ = 75 percent CU of water; T₂ = 100 percent CU; T₃ = 125 percent CU of water were replicated four times under randomized block design on plot size of 10 x 12 m². Canal water (EC 0.4 dS m⁻¹) was used for irrigation. The irrigation water for wheat as estimated corresponding to the above CUs was: 337 mm under T₁; 450 mm under T₂; and 562 mm under T₃. For cotton, the irrigation water was 412, 550 mm and 687 mm, under T₁, T₂ and T₃ treatments, respectively.

The irrigation schedule for wheat was as soaking dose at 75 mm and the estimated amounts of water for four subsequent irrigations, were applied after 3, 6, 11 and 15 weeks of sowing. For cotton, the soaking dose was of 100 mm and the estimated amounts of water in six subsequent irrigations were applied after 4, 7, 10, 13, 15 and 18 weeks from sowing this crop. The recorded rainfall was 224, 251, 32 and 463 mm in 1989, 1990, 1991 and 1992, respectively. The fertilizers (NPK nutrients) were applied as recommended for the two crops.

Soil analysis was carried out at the beginning of the study and after each crop season, at the depth from 0-15 to 60-90 cm. All requisite cultural practices and plant protection measures were carried out for both the crops and the crop yields were recorded on plot basis and aggregated by crop season.

4.4.2 Reclamation of Medium Textured Saline Soils by Conventional Irrigation under the Tile Drainage Conditions

This study was conducted for six crop seasons (1992-1995) for cotton and wheat crops at DRC tile drainage unit near Mirpur Khas. The soil was porous, medium-textured and highly saline

(EC_e 11.24 dS m^{-1} , pH 7.5 SAR 21.87 and ESP 22.65). The soil infiltration rate was 0.91 cm/hour and dry bulk density was 1.5 gm cm^{-3} . Water-table depth was as controlled at 1.0 m under the existing tile drainage system.

The three treatments were: T_1 , irrigation of 55 cm for cotton and 45 cm for wheat without leaching fraction; T_2 , T_1 + leaching fraction to decrease the original soil salinity up to 8.0 dS m^{-1} and T_2 , T_1 + leaching fraction to bring down the soil salinity up to 4.0 dS m^{-1} . Each treatment was replicated four times for each plot size of 210 m^2 . Crop-wise leaching fractions were calculated using the well known formula (Dielman, 1963). The estimated leaching fractions applied to cotton by crop seasons were 58, 51 and 55 cm under T_2 and 107, 134 and 94 cm under T_3 , in *Kharif* 1992, 1993 and 1994, respectively. In case of wheat, the applied leaching fractions were 59, 49 and 54 cm under T_2 and 102, 127 and 80 cm under T_3 , during Rabi 1992-93, 1993-94 and 1994-95, respectively.

Water having EC 0.440 dS m^{-1} , SAR 2.2 and RSC nil, was applied for irrigation and leaching purposes. The recommended fertilizer doses applied to cotton was 300-175-100 NPK kg/ha and that to wheat was 250-125-75 NPK kg/ha. Rainfall amounting to 39.0, 1.0 and 37.7 cm was recorded during the study period. The soil salinity analysis before the experiment and after each crop season were carried out. The crop yields were estimated as usual.

4.4.3 Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil

The study was undertaken at NIA Farm on the area with tile drains, from *Rabi* 1993-94 to *Kharif* 1996 with wheat and cotton as the experimental crops. The soil was porous, medium-textured and moderately saline sodic. The infiltration rate of soil was 0.82 cm/hour and dry bulk density 1.4 g cm^{-3} . The chemical soil analysis showed EC 2.45-8.21 dS m^{-1} , pH 7.60-8.05, SAR 10.84-18.18 and ESP 12.76-18.88 (up to 90 cm depth). The water-table depth was maintained at 1.0 m below land surface.

For the experimental crops, there were two input factors *i.e.* irrigation level (water consumptive use) and fertilizers application rate. The contributions of different levels of these factors were tested. The water consumptive use levels were T_1 of 75 percent, T_2 100 percent and T_3 125 percent. The fertilizer levels were F_1 as 247-124-0 NPK kg/ha and F_2 as 371-186-72 NPK kg/ha. Accordingly, the treatments in combination were: T_1F_1 ; T_1F_2 ; T_2F_1 ; T_2F_2 ; T_3F_1 ; and T_3F_2 . In the randomized block design, the treatments were replicated four times in 24 plots each of size 12 x 15. The irrigations were applied with canal water quality of EC 0.4 dS m^{-1} . The consumptive use of water at 100 percent was 375 and 550 mm for wheat and cotton, respectively. The field data collection included the soil salinity status before and after study and crop yields after each crop season.

4.5 Saline and Drainage Water Use for Crop Production

4.5.1 Crop Production with Saline Drainage Effluent

This study was undertaken over six crop seasons (*Kharif* 1989 to *Rabi* 1991-92), in the area of East Khairpur Tile Drainage Pilot Project. A crop rotation of cotton-wheat was experimented. The soil was medium textured, silty-clay loam and non-saline (EC_e 2-3 dS m^{-1}) and porous and permeable in nature.

The treatments were: T_1 control (canal water use); T_2 saline drainage water use; T_3 saline drainage water with 15 percent leaching fraction from canal water; and T_4 as saline drainage

water use but with 20 percent leaching fraction from canal water. Each treatment was repeated four times under randomized block design with each plot size of 15 x 12 m.

In relation to irrigation, the canal water quality was EC 0.4 dS m⁻¹ while the drainage effluent EC was 3.0 dS m⁻¹. The water applied for cotton in three seasons, was calculated 195 cm each of canal water and saline drainage water under all the treatments (T₁ to T₄). However, 195 cm water of saline drainage was added with 29 cm of canal water under T₃ and 39 cm under T₄. Therefore, the total water applied was 224 cm under T₃ and 234 cm under T₄. As regards wheat in three seasons, the calculated amount of water was 165 cm each of canal and saline drainage, under all the treatments. The saline drainage water (165 cm) was added with 25 and 33 cm of canal water under T₃ and T₄, respectively. Therefore, the total water applied to wheat was 190 cm and 198 cm under T₃ and T₄, respectively. The leaching fraction of canal water under T₃ and T₄ treatments for both the crops was 15 and 20 percent, respectively. In addition to the irrigation from the two sources, the monsoon rainfall amounted to 224, 251, 32 and 25 mm respectively, during the years 1989 to 1992. The applied fertilizers dose to cotton was 200-125-50 kg/ha of NPK and to wheat 142-73-0 kg/ha.

4.5.2 Management of Poor Quality Irrigation Water

This study was conducted at NIA Farm's tile drainage area with wheat and cotton crops from *Rabi* 1994-95 to *Kharif* 1997. The soil was porous, medium textured and moderately saline. The chemical properties of soil showed (before experiment), EC 3.10-5.52 dS m⁻¹, pH 7.9, SAR 11.90-21.19, ESP 13.98-22.61. The infiltration rate was 0.82 cm/hour, bulk density 1.4 g cm⁻³. Water-table depth was maintained at 1.8 m.

Four treatments used were: T₁ for canal irrigation, T₂ for one irrigation of 75 mm with saline drainage water at four weeks of sowing, T₃ and T₄ were of the same quantity and quality of saline drainage water as under T₂ but applied at 7 and 10 weeks of sowing, respectively. Each treatment was applied thrice on each plot size of 10 x 12 m. The recorded total rainfall was 122.6, 2.1 and 50.5 mm during 1995, 1996 and 1997, respectively. The EC and SAR of the canal water was 0.4 dS m⁻¹ and 2.9, respectively. The EC, SAR and RSC of saline drainage water was 3.0 dS m⁻¹, 10.43 and 0.60 meq/l, respectively. The total depth of water applied (including drainage effluent), by season in each treatment was 482 mm to wheat and 713 mm to cotton. Fertilizers application rate for wheat was 142-79-0 kg/ha of NPK and 200-125-50 kg/ha of NPK for cotton. Cultural practices, crop yields estimation and soil analysis were undertaken as usual.

4.5.3 Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production

This study was undertaken with wheat and cotton rotation from *Rabi* 1992-93 to *Kharif* 1995. The experiment site was located in the East Khairpur Tile Drainage Pilot Project. The soil was medium-textured, non-saline (EC 2-3 dS m⁻¹), non-sodic and porous and permeable in nature.

The treatments were: T₁, canal water irrigation; T₂, saline drainage water use; T₃, mixed irrigation (1:1); and T₄, alternate irrigation with canal water and saline drainage effluent. Each treatment was repeated thrice for each plot size of 15 x 12 m. The EC of canal water was 0.4 dS m⁻¹, saline drainage water 3.0 dS m⁻¹ and that of mixed water as 1.45 dS m⁻¹. In the same order of used water, the pH values were 7.4, 8.3 and 7.7 and SAR values were 0.9, 7.32 and 2.06. The calculated water for wheat in three seasons was 1446 mm for wheat and 2140 mm for cotton. The rainfall recorded was 1.0 mm in 1993, 37.7 mm in 1994 and 123 mm in 1995. The fertilizers were applied at the rate of 140-73-0 and 200-125-50 kg/ha of NPK to wheat and cotton, respectively. The pertinent information on soil analysis and crop yields was collected as usual.

Chapter 5

RESULTS AND DISCUSSIONS

This chapter presents the results and discussion of the studies conducted in the same order as discussed in the preceding chapters.

5.1 Soil Reclamation by Organic, Inorganic Material, Physical and Cultural Practices

5.1.1 Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System

5.1.1.1 Effect of Gypsum on Soil Properties

Two crops starting from berseem in *Rabi* 1988-89 to rice in *Kharif* 1991 were cultivated alternately. The treatments were: T₁ as control; T₂, T₃ and T₄ as the 100 percent GR, 75 percent GR and 50 percent GR, respectively. On the average, the pre study EC_e, pH, SAR and ESP of the soil profile were 10.5 dS m⁻¹, 8.3, 23.3 and 24.2, respectively.

Figure 1 shows that a considerable decrease in soil salinity occurred after rice in *Kharif* 89 under all the treatments but the values of some parameters were increased slightly after berseem in 1989-90. However, the increase of EC_e was comparatively low against the control plots where EC was increasing more or less, after berseem in *Rabi* 1988-89. A comparison between the treatments shows that 100 percent GR had an edge in reducing the soil salinity and sodicity with the cultivation of rice and 50 percent GR with berseem crop.

The parameter of pH showed its increase after berseem of *Rabi* 1988-89 whereas, it remained within normal limits during the subsequent crops seasons. Under 100 percent GR, the value of SAR showed a persistent decrease by all the crops seasons. A similar trend was observed for ESP. In totality, under the drainage system, 100 percent GR showed some little edge in reclaiming the saline-sodic soil. Another observation revealed that the chemical status of soil of the control plots was also improved. This effect may be attributed to gypsiferous nature of the soil and also to berseem crop which helped to lower the sodicity.

5.1.1.2 Effect on Crop Yield

Table 1 shows that the yield of berseem was considerably higher under the treatment of 100 percent GR (T₂) during the three seasons, as compared to that of control (T₁) as well as to the other two treatments of GR (75% and 50%). The mean yields under these two treatments were not significantly different from each other.

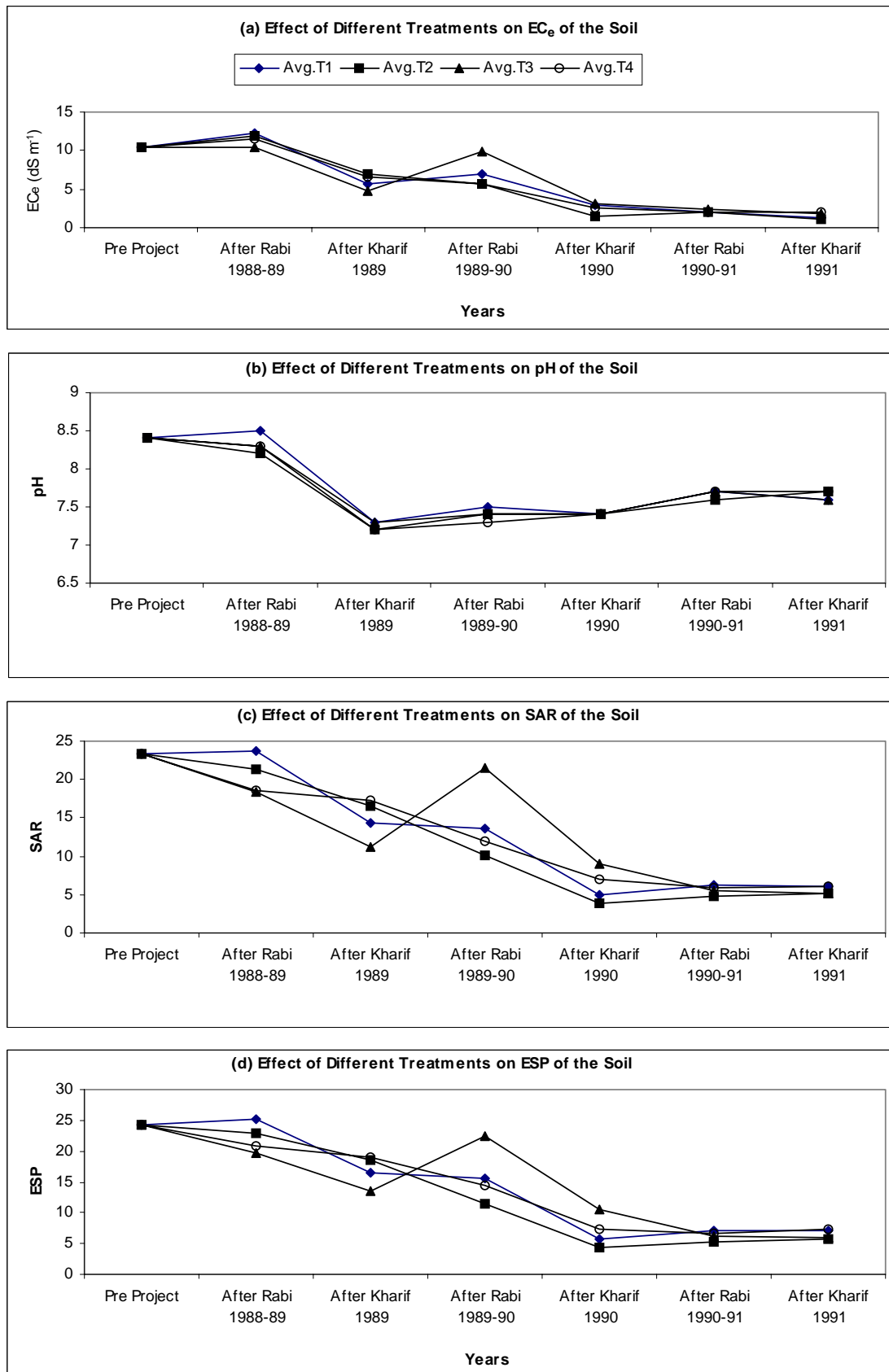


Figure 1: Reclamation of Saline-Sodic Soil by Gypsum under Tile Drainage System

The average yield of rice under T_2 , varied from 1.96 ton/ha (1989) to 3.06 ton/ha (1990) with 2.99 ton/ha in *Kharif* 1991. Amongst the treatment of GRs, it is evident from Table 1, that the yield of rice to an extent was quite comparable between the crop seasons of *Kharif* 1990 and 1991. During these two *Kharif* seasons, higher rice yield under control condition (T_1) was also achieved.

Table 1: *Crops Yield by Treatment and Season*

Crop	Treatment			
	T_1 (Control)	T_2 (100% GR)	T_3 (75% GR)	T_4 (50% GR)
Berseem (1988-89)	0.75	1.14	0.99	0.3
Rice (1989)	0.60	1.96	0.70	0.0
Berseem (1989-90)	17.75	30.36	25.54	23.45
Rice (1990)	2.70	3.06	2.85	2.64
Berseem (1990-91)	61.07	80.04	72.94	70.06
Rice (1991)	2.59	2.99	2.95	2.87

The overview of the average (mean) yield rates though apparently indicates that the 100 percent gypsum application resulted in the high yields of berseem and rice. However, the least significant difference test (LSD), showed that this treatment was not significantly different from the others.

The infiltration rate was increased from 65 mm/day to 100, 135, 93 and 38 mm/day, under T_1 to T_4 , respectively. Evidently, under 100 percent GR, the infiltration rate was increased by two times. It was reported by Abrol and Bhumbla (1979) that rice being tolerant to sodicity, performed well under such conditions. Hussain and Karamat (1989) concluded that the higher yields of berseem and rice under control conditions (without application of gypsum) were due to the resistance capability of the two crops.



Plate 1: *Reclamation of Saline-Sodic Soil under Rice Crop*

5.1.2 Comparative Effect of Inorganic, Organic and Biological Reclamation of Saline-Sodic Soil under Tile Drainage

Under the use of different treatments (levels of GR, Kallar grass, press mud and combinations of GR and press mud), the study was conducted with the cultivation of berseem and rice as experimental crops each for two seasons. The results regarding soil reclamation and crop yields are summarized as follows.

5.1.2.1 Soil Reclamation Effect

Table 2 shows that the maximum reduction in EC_e of the soil occurred under the treatment of 50 percent GR (T_2). The EC_e was reduced from 13.13 to 2.87 $dS\ m^{-1}$ by 87 percent after the study. The minimum reduction of EC_e of 5.59 $dS\ m^{-1}$ (57.4%), was shown by T_7 (50% GR & 25 ton/ha of press mud). Apparently, the EC_e of the soil was reduced under all the treatments.

The reduction of pH was also higher under T_2 as it was decreased by about 16.7 percent. For the treatments, pH reduction varied from 8.80 (T_8) to 7.31 (T_2). The parameter of SAR showed its maximum reduction by about 63.4 percent under T_2 having a difference of 12.1 between before and after the study. Similarly, the decrease of ESP was also higher by about 57 percent, under T_2 as compared to that under other treatments.

It therefore, may be concluded that the treatment applying 50 percent of GR of the soil provided larger magnitude of soil reclamation than that reflected by other treatments. However, under the control condition (without amendment), there was also a decreasing trend of EC_e , pH, SAR and ESP as well, though at the minimum level. Figure 2 depicts the effects of different treatments on the soil properties.

5.1.2.2 Effect on Crop Yields

The treatments showed the positive effects on the yield of rice and berseem when the reclamative process advanced progressively. As evident from Table 2, there was no effect on yield of the experimental crops in the first year (1989-90). In the second year (1990-91), the treatments T_1 , T_2 , & T_4 showed the higher average yield of rice. Under these three treatments, the respective yields were 2.92, 2.89 and 3.01 ton/ha. In relation to the other treatments including control (T_5 to T_8), the average yield of rice was about two tonnes per hectare. The difference of mean yields between T_1 , T_2 and T_4 was not statistically significant. Similarly, the yields showed no statistical difference with respect to the treatments T_5 to T_8 .

Under T_2 the average yield of berseem was much higher (41.42 ton/ha) than T_1 (28.98 ton/ha), T_7 (16.14 ton/ha) and control (16.79 ton/ha). Statistically, the treatment T_2 in relation to berseem yield, was significantly different from the other used treatments. The treatments T_4 to T_8 did not show any significant statistical difference of berseem yield between them. It may therefore, be concluded that on highly saline soil, the use of 50 percent gypsum requirement was more effective to achieve the higher yields of rice and berseem under tile drainage system.

Table 2: Crop Yields under Various Treatments

Crop	Treatments							
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Rice 1989	0.22	0.10	0.00	0.00	0.00	0.00	0.00	0.05
Berseem 1989-90	0.47	0.19	0.00	0.00	0.00	0.00	0.00	0.27
Rice 1990	2.92	2.89	0.00	3.01	2.09	1.97	1.97	2.00
Berseem 1990-91	28.98	41.42	0.00	20.14	18.29	17.03	16.14	16.79

Note: NE for not estimated (Kallar grass).

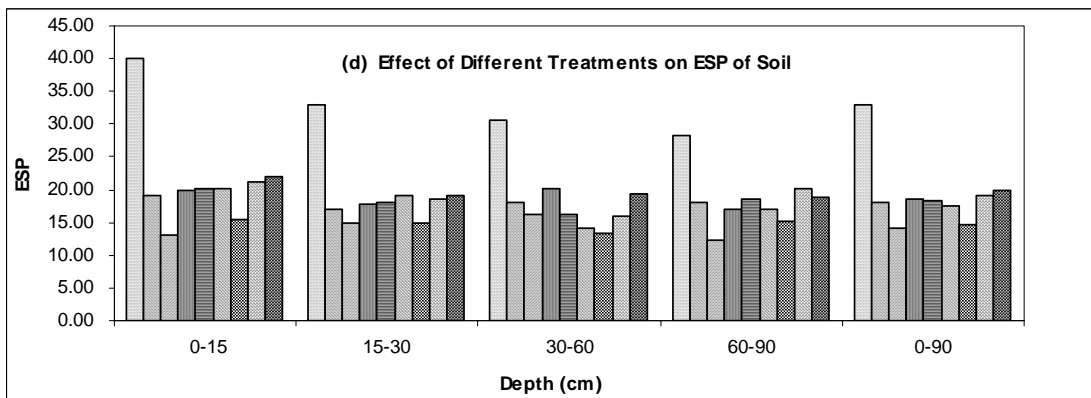
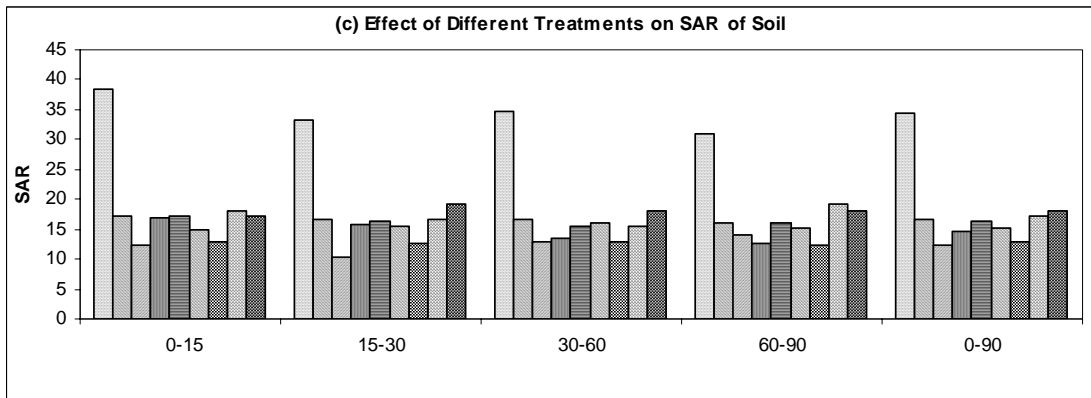
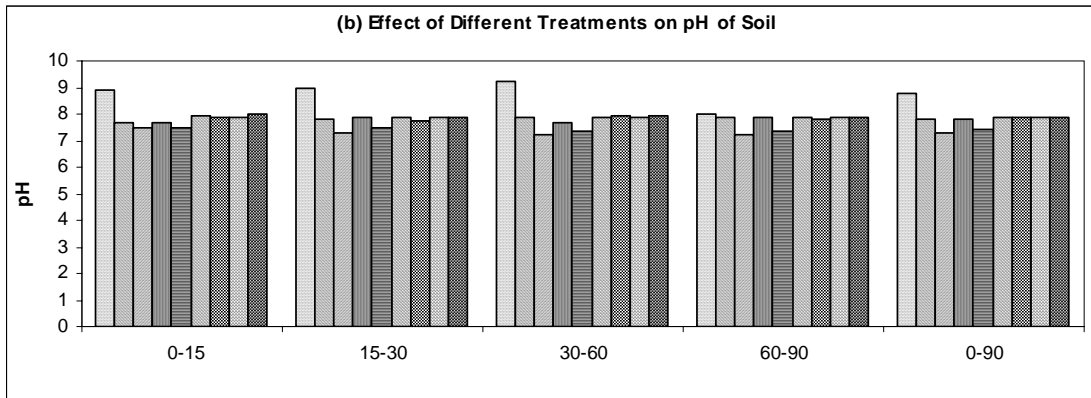
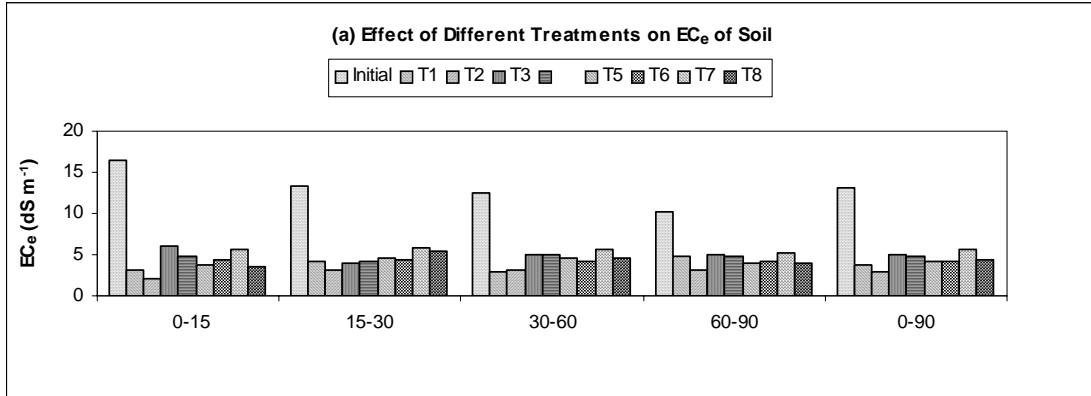


Figure 2: Comparative Effect of Organic, Inorganic and Biological Reclamation

5.1.3 Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System

The study was concentrated to cotton and wheat crops each for three seasons. The treatments as used were: three ploughings and levelling (T_2), deep ploughing (50 cm) with levelling (T_3) and high seed rate for wheat and cotton on ridges (T_4). T_1 was the control without any amendment.

5.1.3.1 Effect of Cultural Management on Soil

Figure 3 shows the effect of various agricultural practices on soil salinity. Soil salinity analysis before and after the study indicated that under the treatment T_3 , the EC_e value was decreased considerably. This decrease was maximum (49%) at the depth of 30-60 cm. At the soil depths of 15-30 cm and 60-90 cm, the decrease in EC_e was of the same order i.e. 37 and 38 percent, respectively. These decreases in EC_e may be attributed to deep ploughing that helped in leaching salts down. There were also reasonable decreases in EC_e under T_2 , (23%) and T_4 (38%). But these decreases in EC_e occurred in the upper soil layer. On the contrary, under the control condition (T_1), the increase of EC_e was higher (82%) at soil depth of 60-90 cm than that at the upper depths.

T_3 also resulted in decrease of the soil pH at all the soil depths particularly, in the upper soil depth it was decreased by 10 percent. There was also a tendency of decreased pH under the treatments T_2 and T_4 . After the study however, pH increased at all the soil depths, under T_1 (control).

At the end of study, SAR showed highest increase (71%) on the control plots, at the soil depth of 0-15 cm. SAR was decreased by 33 and 26 percent under T_3 and T_4 , respectively, at the lower depths. T_2 , however, resulted in relatively less reduction of SAR.

The ESP value after the study, was reduced at all soil depths under T_3 . While with T_2 and T_4 the reduction of ESP was of lower order. On contrary for control, ESP increased at all soil depths and the highest increase of about 67 percent was occurred 0-15 cm depth and the lowest was about 30 percent at 30-60 cm depth.

5.1.3.2 Effect on Yields of Cotton and Wheat

Table 3 gives the effect of various treatments on crop yields. The average yield of cotton was the highest (2.63 ton/ha) under T_3 , followed by T_4 (2.15 ton/ha) and T_2 (1.91 ton/ha). The lowest average yield of 1.5 ton/ha resulted in control (without cultural management) and was lower by 67 percent than that of T_3 . The seasonal yield of cotton varied between 1.45 ton/ha (*Kharif* 1996, under T_2) and 3.12 ton/ha (*Kharif* 1998, under T_3). The differences of mean yields between the treatments and between the seasons, showed their statistical significance at 5% level of significance.

The highest average yield of 2.85 ton/ha of wheat was achieved under T_3 and the lowest of 2.25 ton/ha under T_4 . The yield under T_1 (control) was 1.85 ton/ha. Relatively, this yield was lower by about 54 percent than that achieved under T_3 (deep ploughing/levelling). Between the three *Rabi* seasons, the minimum rate of wheat yield was 1.04 ton/ha (*Rabi* 1996-97 under T_4) and the maximum was 3.38 ton/ha (*Rabi* 1998-99 under T_3). The mean yield differences between the treatments and crop seasons were statistically significant.

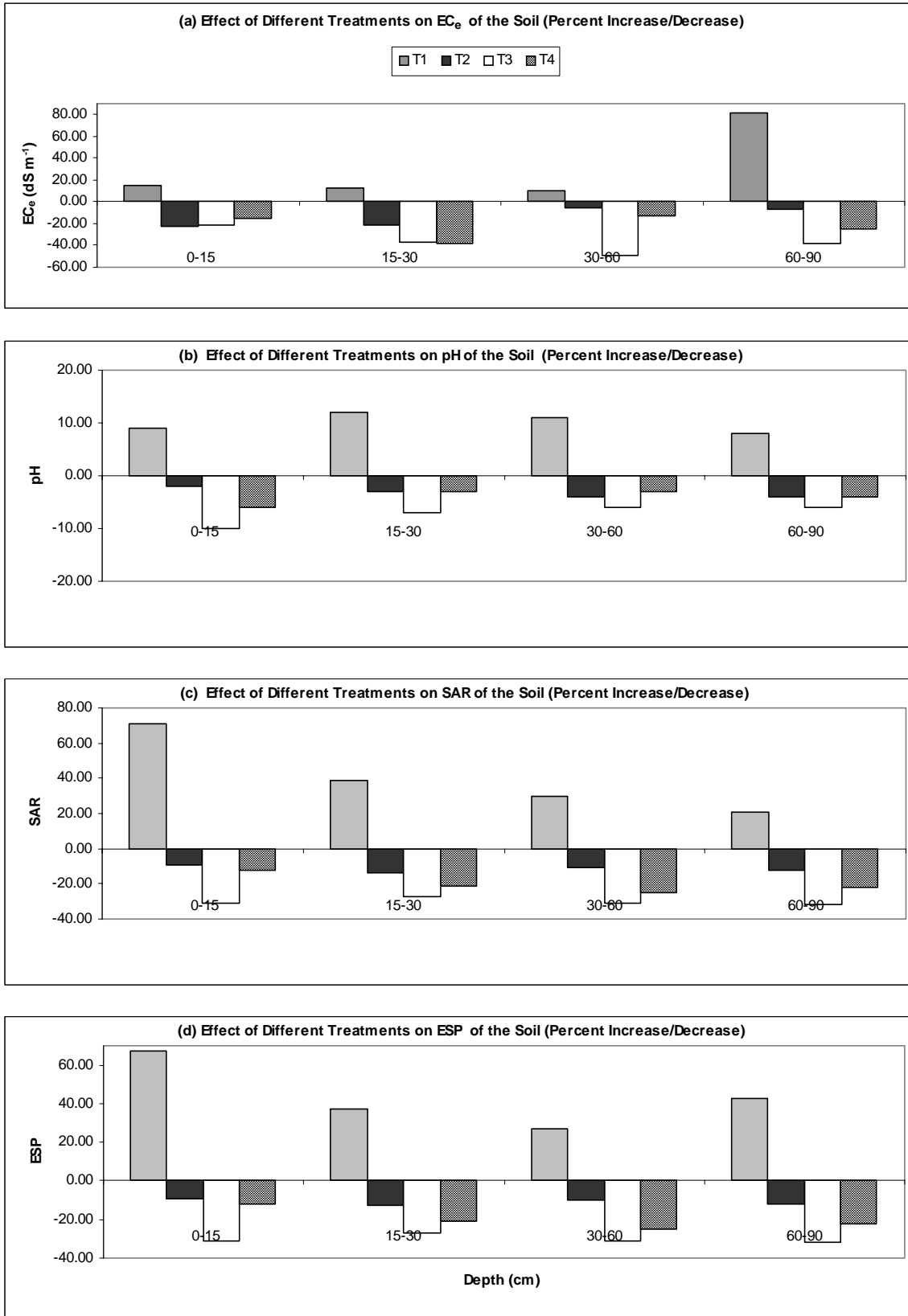


Figure 3: Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System

Table 3: *Effect of Cultural Practices on Cotton and Wheat Yield*

(ton/ha)

<i>Treatment</i>	<i>Cotton</i>		
	<i>1996</i>	<i>1997</i>	<i>1998</i>
T ₁	1.10	1.70	1.92
T ₂	1.35	2.00	2.38
T ₃	1.92	2.85	3.12
T ₄	1.73	2.20	2.53
	<i>Wheat</i>		
	<i>1996-97</i>	<i>1997-98</i>	<i>1998-99</i>
T ₁	1.51	1.95	2.08
T ₂	2.08	2.20	2.66
T ₃	2.38	2.80	3.38
T ₄	1.04	2.60	3.10

5.1.4 *Improvement of Salt Affected Lands through Continuous Cropping*

In this study the treatments were: T₁, berseem-sorghum, T₂, mustard-cluster beans, T₃, barley-sesbania and T₄, alfalfa-pearl millet.

5.1.4.1 *Effects on Soil Salinity*

The effect of various treatments on soil salinity is depicted in Figure 4. The soil analysis before and after the study revealed that the treatment of barley followed by sesbania (T₃), resulted in the maximum reduction (40.8%) by EC_e at the soil depth of 0-15 cm. T₁ reduced the EC_e by 32.8%. The reduction of EC_e was relatively less at other depths under the two treatments. In these two treatments sesbania and berseem were also green manured. The second treatment of mustard followed by cluster beans (green manured), was the least effective in reducing the salinity at all depths particularly at 0-15 cm. Apparently, the extent of salinity reduction was attributed to continuous cropping rather than green manuring to leguminous crops. Sesbania was reported as the best green manuring (IWASRI, 1988 and Husain, 1996). Berseem and sorghum were found as salt tolerant/reclaimant crops (Ansari, Khanzada, 1995, and Hussain and Haider, 1997).

There was a persistent reduction of pH in general and particularly at 0-15 cm depth, under all the treatments. However, T₃ was found more effective for reducing pH than the other treatments (T₁, T₄ and T₂, in descending order).

The ESP was decreased under all the treatments and its maximum reduction was observed under T₃, at 0-15 cm depth. The other treatments in reducing the ESP were T₁, T₄ and T₂ in order of their extent of effectiveness.

It may, therefore, be concluded that the continuous cropping with green manured sesbania showed the highest reduction in EC_e, pH and ESP values. The next prominent continuous cropping resulting in reduction in the said values, was sorghum followed by green manured berseem. The effect on soil organic matter under these two treatments (T₃ followed by T₁), was also prominent.

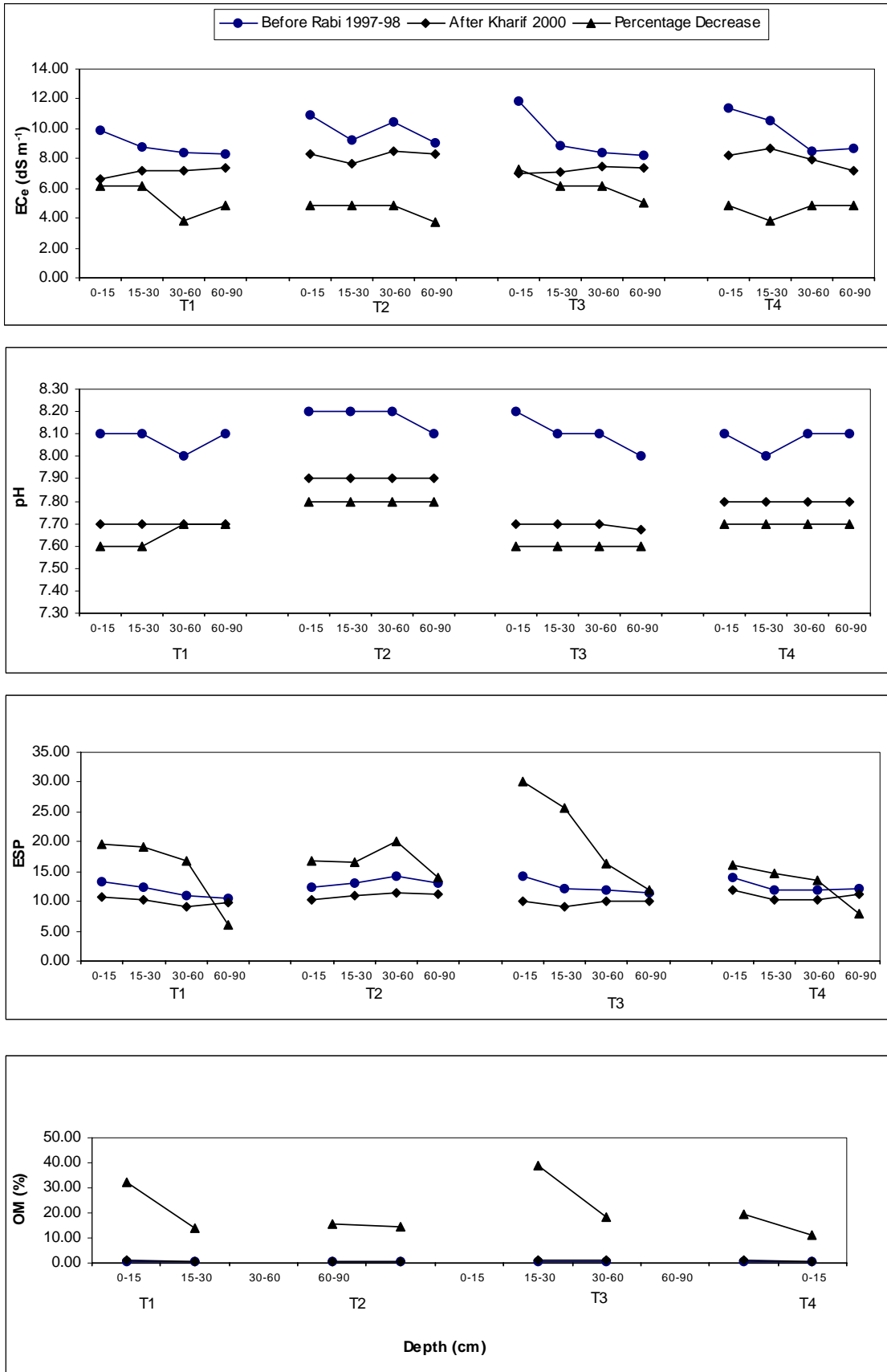


Figure 4: Improvement of Salt Affected Lands through Continuous Cropping

5.1.4.2 Effect on Crop Yields

In the crop seasons under the study, berseem, alfalfa in *Rabi* and cluster bean, sesbania in *Kharif*, were used as green manure therefore, the yield of these crops were not recorded. The seasonal yield of the remaining crops including sorghum, millet as fodders and mustard, barley as grain, were recorded and are shown in Table 4. The perusal of Table 4 reveals that increased yield of the crops could not be achieved. The main reasons were moderately saline soil and shortage of irrigation water.

Table 4: *Crop Yields by Season*

<i>Crop</i>	<i>Season</i>		
	<i>1997-98</i>	<i>1998-99</i>	<i>1999-2000</i>
<i>Rabi</i>			
Mustard	0.02	0.03	0.04
Barley	0.90	1.47	0.53
<i>Kharif</i>	<i>1998</i>	<i>1999</i>	<i>2000</i>
Sorghum	3.06	3.46	2.22
Millet	0.15	0.25	0.27

5.2 Biological Reclamation of Saline and Saline-Sodic Soils

5.2.1 Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodder

Under this study, the treatments were: T₁, control (without crop), T₂, T₃ and T₄ were the cultivation of maize, sorghum and Sudan grass, respectively. These crops were cultivated twice in each year due to their short duration.

5.2.1.1 Effect on Soil Salinity

Figure 5 depicts the effect of the used treatments on the soil salinity. The EC_e value were decreased in all the treatments considerably. The maximum reduction (56.39%) of EC_e was occurred under T₃ (sorghum cultivation). The other treatments of T₂ (maize cultivation) and T₄ (Sudan grass), caused the reduction of EC_e by 39.18 percent and 40.70 percent, respectively. On contrary, EC_e was increased by 14.90 percent under treatment T₁ (control).

The pH value showed its higher decrease (8.46%) than that accounted for by T₂ and T₄. The pH of land without crop was increased by 15.14 percent. The maximum reduction in SAR (41.28%) occurred under T₃ (sorghum). The next treatment of T₄ (Sudan grass), showed the SAR reduction by 35.88 percent while under T₂ (maize), the SAR reduction was 9.71 percent. SAR under control condition (T₁) was increased by 14.30 percent. The value of ESP was decreased by 45.66 percent (maximum) under T₃ while T₄ and T₂ resulted in ESP reduction by 37.94 percent and 37.33 percent, respectively. Whereas, ESP under T₁, was increased by 10.47 percent. From these results, it appeared that sorghum cultivation is more effective biological approach for reclaiming the saline-sodic soils.

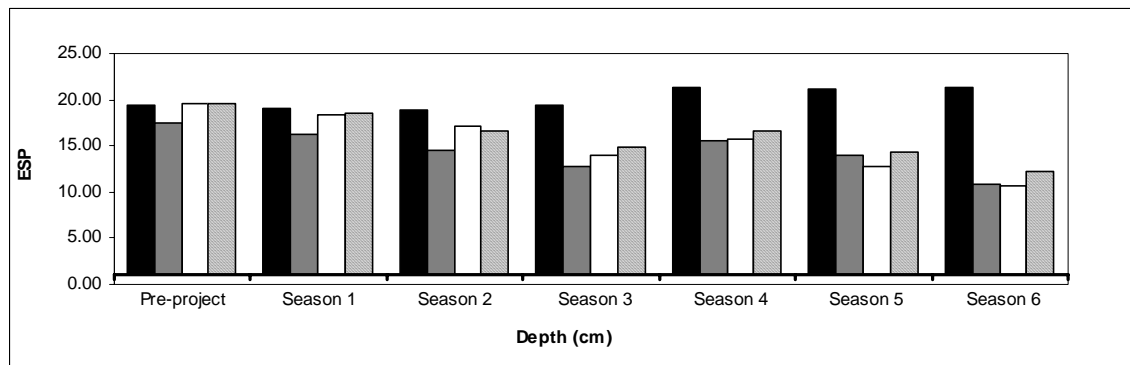
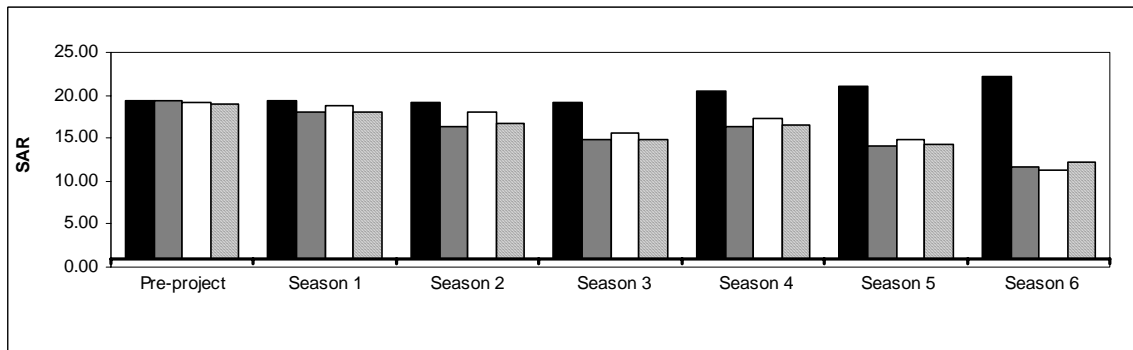
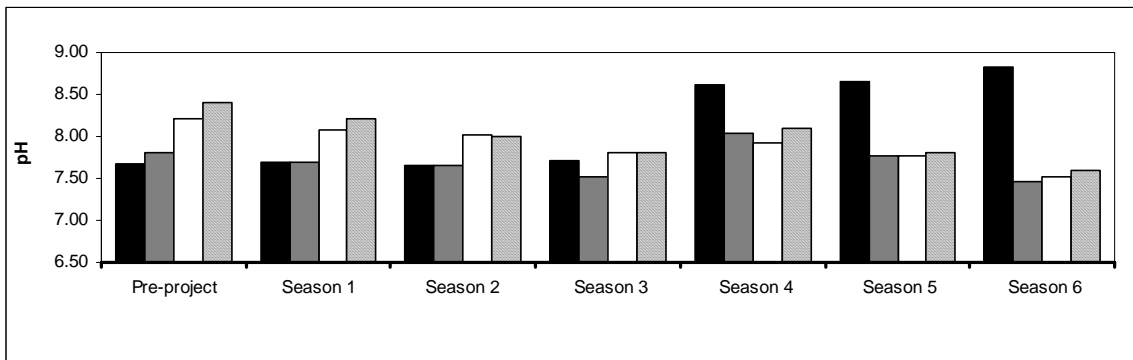
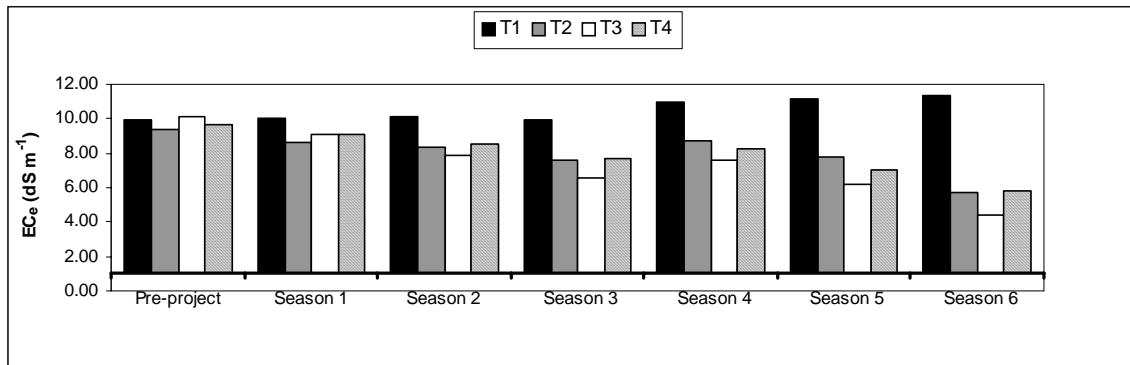


Figure 5: Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodder

5.2.1.2 Effect on Crop Yields

Table 5 gives the yield rates by crop and season as averaged on plot basis. The net increase in yield has been worked out on the basis of each first crop in *Kharif* 1991 and the second crop in *Kharif* 1993. Accordingly, the maize showed a net increase of about 47 percent, sorghum 92 percent and Sudan grass 53 percent. LDS test applied showed that the yields were different at 5 percent and 1 percent levels of significance.

Table 5: *Crop Yields by Season and Change*

Crop	(ton/ha)						Net Percent Increase (y/x)
	Kharif 1991		Kharif 1992		Kharif 1993		
	First crop (x)	Second crop	First crop	Second crop	First crop	Second crop (y)	
Maize	10.05	11.21	12.18	12.95	13.46	14.79	47
Sorghum	24.31	25.95	28.81	31.13	38.10	46.64	92
Sudan Grass	18.12	19.19	21.39	22.57	25.41	27.61	53

5.2.2 Reclamation of Saline-Sodic Soils by Rice Husk

For this study, the treatments were defined in terms of used weights of rice husk as explained earlier under methodology. Accordingly, T₁ was without rice husk, T₂ (at 0.1%) *i.e.* 272 kg, T₃ (at 0.2%) *i.e.* 545 kg and T₄ (at 0.4%) *i.e.* 1090 kg.

5.2.2.1 Effect on Soil Salinity/Sodicity

Broadly, the EC_e was decreased under the three rice husk treatments (T₂ to T₄), at both the experimental soil depths of 0-15 and 15-30 cm. Relatively, under T₄ the reduction of EC_e was higher *i.e.* about 30 and 42 percent at 0-15 and 15-30 cm depths respectively, at the end of study. A lower order of reduction of EC_e was observed under T₃ and then under T₂. This indicated the reduction of EC_e was directly related to the applied amount of rice husk *i.e.* increased application caused more reduction. The land without the use of rice husk (control), showed a little increase in EC_e at 0-15 cm soil depth but beyond that probably, it was checked by continuous cropping.

There was a considerable decrease in pH under all the rice husk treatments but a little reduction (4.0%) was also observed under the control situation (T₁). The results also indicated a significant decrease of ESP value at both the depths (0-15 cm and 15-30 cm), under the used treatments. Especially, under T₄ (maximum application of rice husk), the reduction of ESP was more than 49 percent at both the depths. On the contrary, under the T₁, ESP tended to increase by about each 2 percent at both the depths. It appeared that the decrease in soil salinity under the application of rice husk probably, was on account of factors such as increase in the organic matter, improvement of porosity and water holding capacity of soil that helped leaching of soluble salts below 30 cm depth. Comparatively, less reduction in salts at 0-15 cm depth, was due to more evaporation from the upper layer that rendered salts to remain in this layer. While the applied water caused more leaching of salts from 15-30 cm soil depth. These influencing factors were resulted in the reduction of salinity especially, from the soil layer beyond 15 cm. Graphically, the changes in soil properties are shown in Figure 6.

Relatively, there was the highest increase (31.9%), of organic matter with the maximum application of rice husk (T₄), in 0-15 cm layer of soil apparently, the other two treatments of rice husk (T₂ and T₃), the increase in organic matter was of the same order at both the soil layers. However, T₁ (without rice husk), also showed some small increase in organic matter, as varying

from 4 to 9 percent, respectively in 0-15 cm and 15-30 cm layers of soil. The reason to this small increase, was that the roots, stubbles and leaves of crops ploughed in soil, tended to enhance organic matter contents.

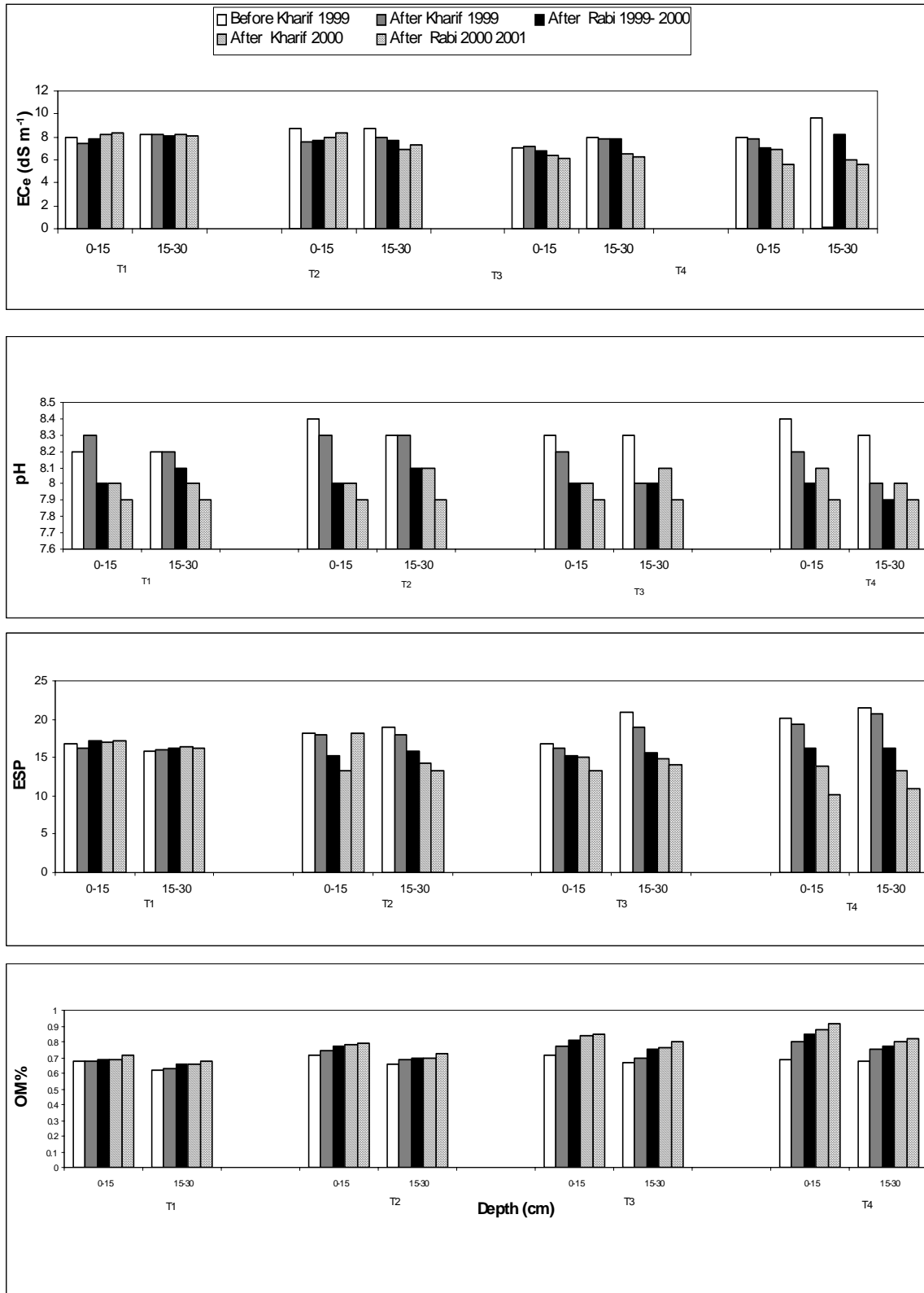


Figure 6: Reclamation of Saline-Sodic Soils by Rice Husk

5.2.2.2 Effect on Crop Yields

The results on yield rates of the two crops are presented in Table 6. It shows that the highest yield of cotton and wheat were achieved under the treatment T₄ (maximum use of rice husk). Statistically, there was no significant difference of mean yields of the two crops, firstly, between T₁ and T₂ and secondly, between T₃ and T₄. It appears that crop yields were increased notably with the higher rate of rice husk particularly, in the second crop season.

Table 6: *Yields of Cotton and Wheat with the Application of Rice Husk*

<i>Treatment</i>	<i>Cotton</i>		<i>Wheat</i>	
	<i>1999</i>	<i>2000</i>	<i>1999-2000</i>	<i>2000-2001</i>
T ₁ (control)	0.46	0.60	0.88	1.09
T ₂ (0.10% rice husk)	0.58	0.72	0.98	1.46
T ₃ (0.20% rice husk)	0.68	0.86	1.15	1.69
T ₄ (0.40% rice husk)	0.72	0.92	1.75	1.99

5.2.3 Biological Reclamation of Highly Saline-Sodic Soils

The used treatments were: cultivation of rice in *Kharif* and berseem in *Rabi* (T₁), Jantar in *Kharif* and berseem in *Rabi* (T₂) and Kallar grass (T₃). T₄ was fallow land. The results are summarized below:

5.2.3.1 Effect on Soil Properties

The Figure 7 shows that more decrease of EC_e occurred under T₁ (rice-berseem rotation). This decrease was the maximum (81.6%), at 0-15 cm depth where T₃ (Kallar grass) also reduced the EC_e of lower order. The rotation of Jantar-berseem (T₃), resulted in more decrease of EC_e in the lower layers (60-90 cm). Whereas the EC_e of soil was increased by 85.8 percent under T₄ (fallow land). Decrease in pH was more at upper depth (10-15 cm) under T₁ and at lower depths under T₃. This value was however, increased at all depths under T₄, the fallow land.

The ESP under T₁, T₂, T₃, decreased by 42.0, 45.9, 34.3 and 29.3 percent at the soil depths of 0-15, 15-30, 30-60 and 60-90 cm, respectively. On the contrary, under T₄ (fallow land), the relative increase in the ESP was 10.3, 16.4, 4.1 and 1.6 percent, respectively, in the soil depths of 0-15, 15-30, 30-60 and 60-90 cm. Under T₁ (rice-berseem) the decreases in ESP were relatively higher (45.0, 48.8, 37.0 and 29.8%), respectively in soil depths of 0-15 to 60-90 cm. Therefore, the biological reclamation of saline-sodic soils by cultivation of rice and berseem in rotation was more effective among the applied treatments.

5.2.3.2 Effect on Crop Yields

Table 7 indicates that the crops yield increased progressively after the first crop season. This increased yield of rice varied from 0.20 to 0.76 ton/ha under T₁ (rice-berseem). The yield of berseem under T₂ (Jantar-berseem), ranged from 0.20 to 1.10 ton/ha between respective three crop seasons.

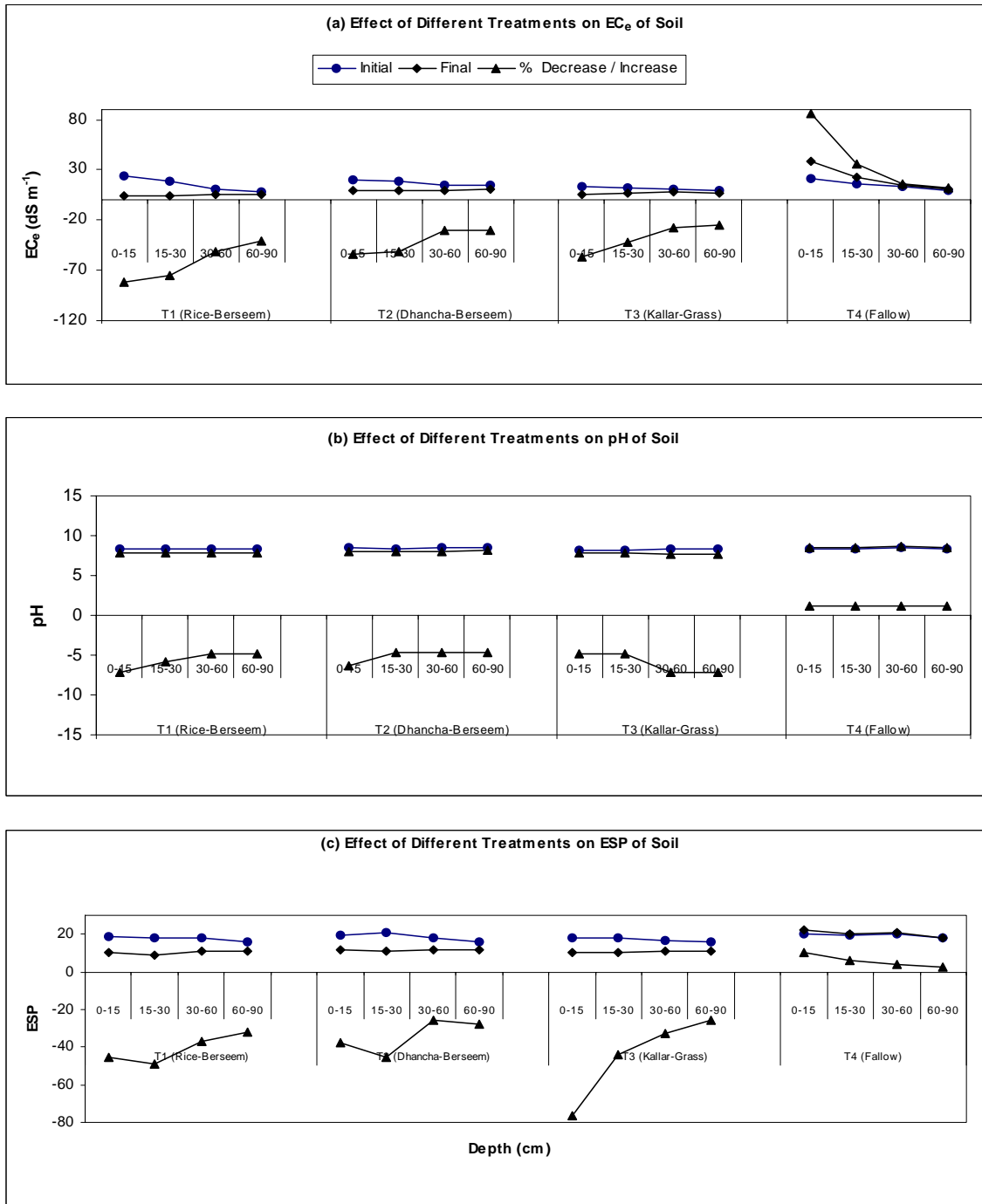


Figure 7: Biological Reclamation of Highly Saline-Sodic Soils

Table 7: Crop Yields by Crop Season

(ton/ha)

Crop	Kharif 1996	Kharif 1997	Kharif 1998
Rice under T ₁	0.20	0.51	0.76
Jantar under T ₂	0.32	0.42	0.70
	<i>Rabi 1996-97</i>	<i>Rabi 1997-98</i>	<i>Rabi 1998-99</i>
Berseem under T ₁	0.31	0.87	1.32
Berseem under T ₂	0.20	0.55	1.10

5.2.4 Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System

The reclamation of soils was experimented deploying three approaches of cropping as treatments. These treatments were: T₁ as control (with no crop and no irrigation); T₂ (without crop/continuous leaching); T₃ (dhancha and berseem in *Kharif* and *Rabi*, respectively); and T₄ (rice in *Kharif* and berseem in *Rabi*). The results are discussed below:

5.2.4.1 Effect on Soil Properties

Figure 8 shows that under T₄ (rice-berseem rotation), the EC_e of the soil was reduced at all the depths and the maximum reduction was 34.9 percent for 0-15 cm depth. The next effective treatment for reducing EC_e was T₃ (dhancha-berseem) but more at lower depths (25.4%). T₂ though reduced the EC_e by 23.7 percent in the upper two layers but an increased EC_e was found at the lower depths. Whereas, progressive increase in EC_e was observed under the control and the maximum increase was 11.4 percent at 0-15 cm depth.

As in the case of EC_e, the pH decreased under T₄ at all the soil depths. However, the maximum reduction of pH was noticed under T₃ (dhancha-berseem rotation), in the top layer of soil. ESP of soil decreased under T₂ to T₄ treatments at all the soil depths and the highest decrease was under T₄ (0-15 cm depth). Under the pH and ESP, the increase was varying by soil depths.

5.2.4.2 Crop Yields

The results on yield are shown in Table 8. The higher yield of the crops are found with crops which are salt tolerant.

Table 8: Crop Yields by Season

<i>Season/Crop</i>	<i>Yield (ton/ha)</i>
<i>Rabi 2000-2001</i>	
Berseem under T ₃	1.00
Berseem under T ₄	1.20
<i>Kharif 2001</i>	
Berseem under T ₃	1.00
Rice under T ₄	0.50

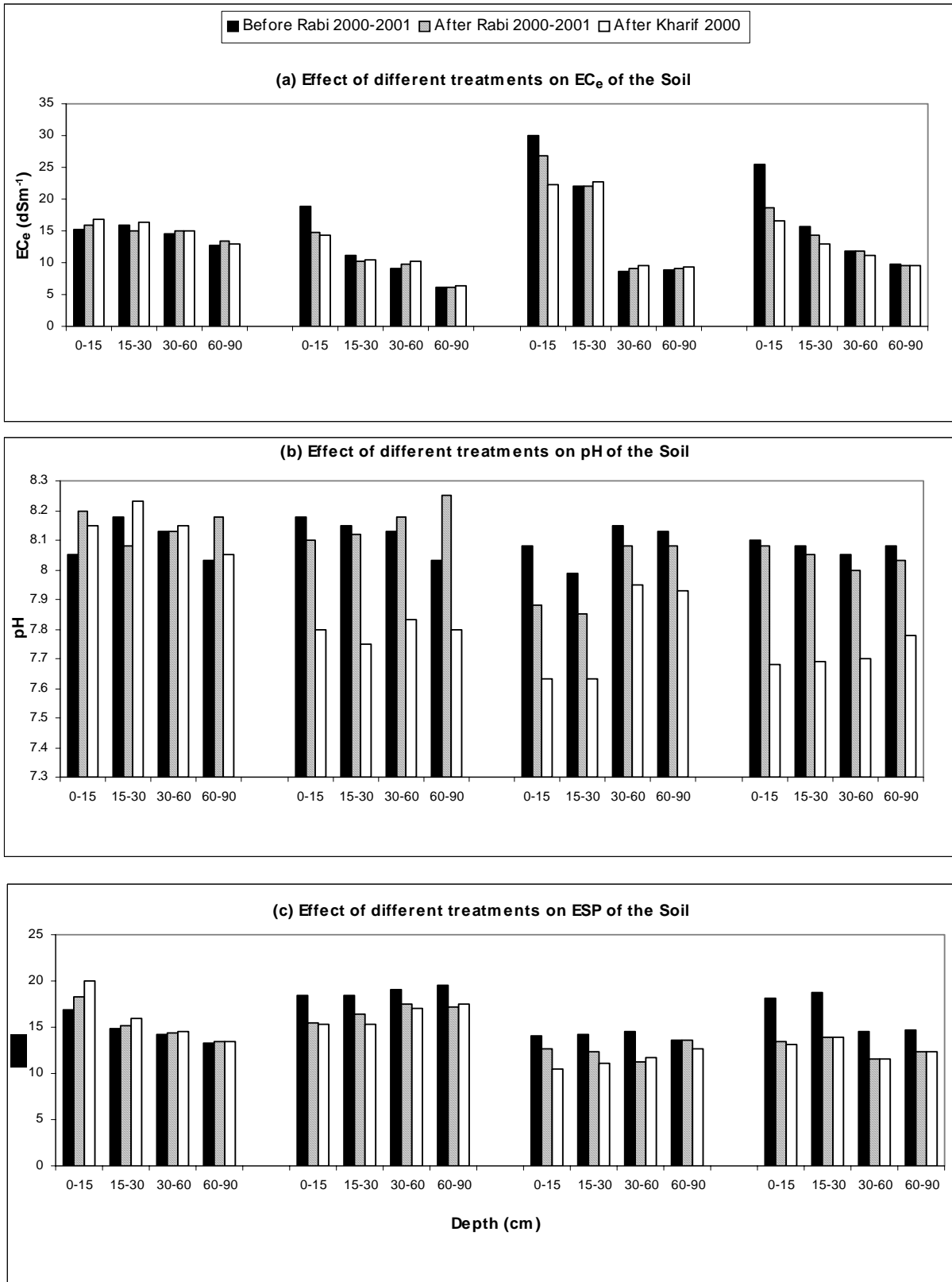


Figure 8: Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System

5.2.5 Comparison of Physical and Biological Methods for Reclamation of Fine Textured Saline Soils

In this study, four crops (wheat, cotton, berseem and dhancha) were under experiment in relation to two ploughing operations *i.e.* without deep ploughing and with deep ploughing. The treatments were: T₁, control (wheat and cotton); T₂, deep ploughing (wheat and cotton); T₃, (berseem and dhancha); and T₄, deep ploughing (berseem and dhancha). The results are discussed below:

5.2.5.1 Effect on Soil Salinity

Season-wise changes in EC_e, pH and ESP are shown in Figure 9. The EC_e at 0-15 cm depth of soil was reduced most effectively under T₄ and then by T₃ followed by T₂. The treatment T₁ was the least effective in decreasing the EC_e. This treatment caused a small reduction (8.0%) in 30-60 cm soil layer. The decrease of pH and ESP of soil reflected the similar trends as that of the EC_e. Apparently, the T₄ of deep ploughing for berseem and dhancha (green manured crops), was successful for reclaiming the fine textured saline soil.

5.2.5.2 Effect on Crop Yields

Table 9 indicates that the *Kharif* crops of cotton and dhancha had higher yield under the treatments T₂ and T₄, than that by the other two treatments. In relative terms, the net increase in cotton yield in three seasons varied from 22.0 to 38.0 percent, under T₂ over T₁. Similarly, the yield of wheat increased by 19 to 49 percent under T₂ over T₁.

Table 9: Crop Yields by Treatment and Season

Treatment	Crop	<i>Kharif</i>		
		1999	2000	2001
T ₁	Cotton	0.37	0.50	0.32
T ₂	Cotton	0.45	0.69	0.66
T ₃	Dhancha ^a	1.28	1.35	1.12
T ₄	Dhancha ^a	1.42	1.48	1.28
		<i>Rabi</i>		
		1998-99	1999-2000	2000-2001
T ₁	Wheat	1.99	1.81	1.36
T ₂	Wheat	2.78	2.70	1.62
T ₃	Berseem ^b	2.03	3.31	2.82
T ₄	Berseem ^b	4.05	4.12	3.45

^aCompletely green manured. ^bPartly green manured.

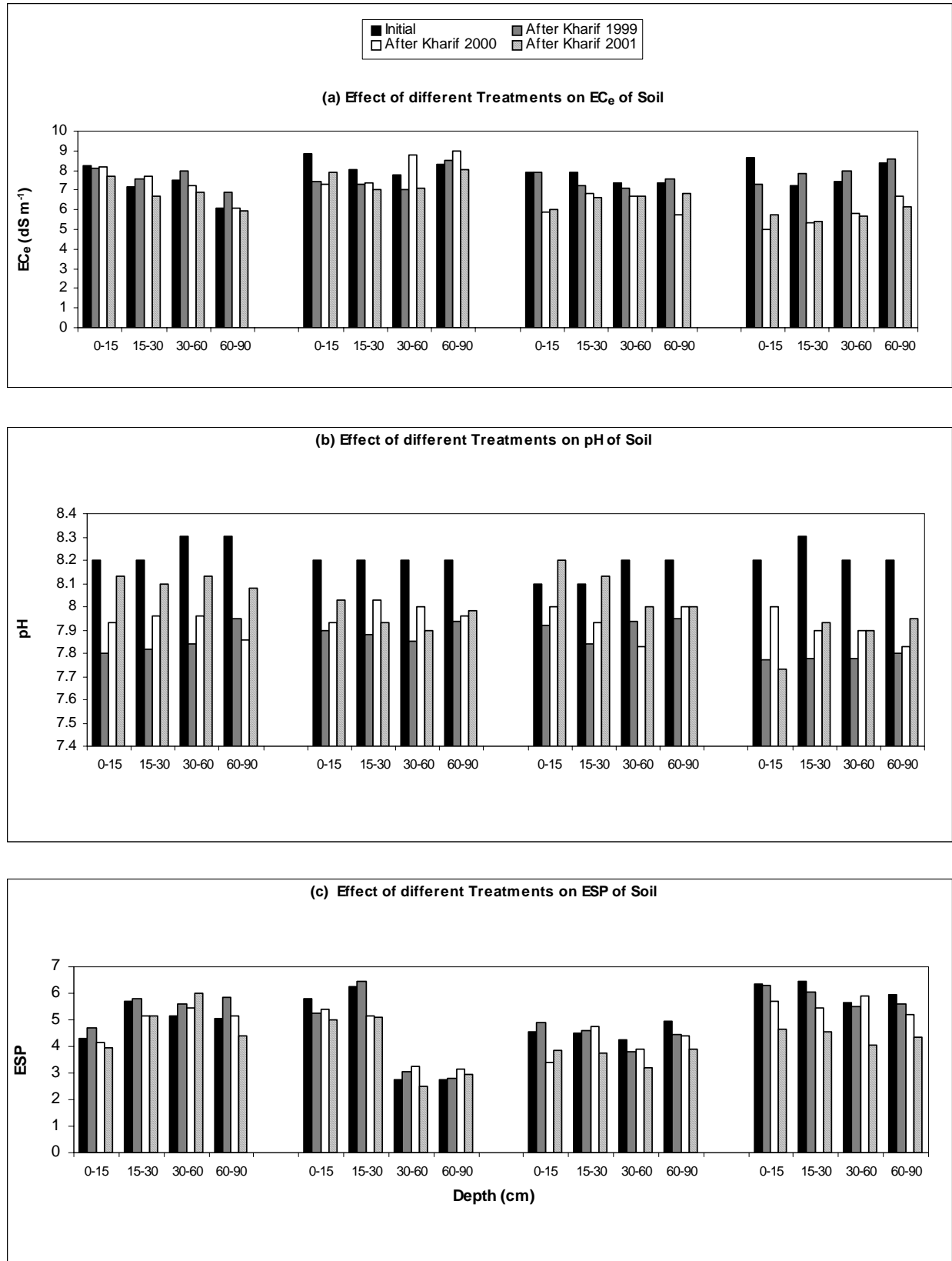


Figure 9: Comparison of Physical and Biological Methods for Reclamation of Fine Texture Saline Soils

5.3 Management of Reclaimed Lands

5.3.1 Resalinization of Recently Reclaimed Lands

A crop rotation of wheat-cotton was studied on the soil reclaimed by three levels (100%, 75% and 50%) of gypsum requirement, defined as treatments T₂, T₃ and T₄, respectively. The control T₁ was without reclamation by gypsum. As elaborated earlier (methodology), soil analysis was carried out after gypsum reclamation (start of study) and after each of six crop seasons (*Rabi* 1991-92 to *Kharif* 1994) to examine the resalinization of soils.

5.3.1.1 Change in EC_e and SAR of Soil

Table 10 gives the net increase in EC_e and SAR. It indicates that over the time increase in EC_e was observed under T₄ (50% GR). By soil depth, this increase varied from 37 percent (60-90 cm) to 132 percent (15-30 cm). On the contrary, under T₁ the EC_e increased from 152 percent (15-30 cm) to 370 percent (30-60 cm depth). Under T₄ the minimum (67%) increase in the SAR value was observed at the depth of 0-15 cm and the maximum (144%) at the depth of 60-90 cm. Under control situation, SAR increased varying from 132 percent (15-30 cm) to 218 percent (60-90 cm depth).

The increase in EC_e and SAR may be attributed to less irrigation water applied to wheat and cotton. The insufficient applied water ultimately could not leach down the salts adequately. Nevertheless, the EC_e and SAR remained more or less, within threshold value. Haider *et al.* (1977) reported that the land under low delta corps had medium salt content.

5.3.1.2 Change in Wheat and Cotton Yields

Table 11 reveals that the application of 100 percent gypsum requirement resulted in the higher yield. Accordingly, the yield of wheat varied from 2.23 to 4.08 ton/ha. Similarly, cotton yield under the above said treatment, varied from 1.09 to 1.93 ton/ha. Under each crop season wheat and cotton yields were directly related to the applied gypsum requirement *i.e.* the highest yield was accounted for by 100 percent GR and the lowest by 50 percent GR. The net increase of crop yields over that of control (with out GR) are 57, 32 and 32 percent for wheat and 43, 22 and 12 percent for cotton, accounted for by the used levels of 100, 75 and 50 percent GR, respectively. It may be concluded that the salinization process did not hamper the crop yields because the increase in soil salinity was restricted to the extent beyond which the yields can be adversely affected.

5.3.2 Soil and Crop Management under Reclaimed Lands

This study was conducted on a soil that was reclaimed by different leaching doses with saline and conjunctive use of water. The first crop was wheat (*Rabi* 1995-96) and the second was sorghum (*Kharif* 1996). The treatments were: T₁, seasonal crop with the recommended fertilizers dose; T₂, early crop with low dose of fertilizer; T₃, late crop with high dose of fertilizers and T₄, control *i.e.* seasonal crop (sowing at specified time) without fertilizers.

5.3.2.1 Effect of Sowing Periods and Fertilizer Doses on Soil Properties

Figure 10 shows that a relatively higher magnitude of EC_e was found under T₁ and the maximum reduction of 11.0 percent was found at 0-15 cm depth of soil. T₂ (early crop with less fertilizers) decreased the EC_e by about 7.0 percent (0-15 cm depth). Under T₃ (late sowing with high dose of fertilizers), slight reduction in the EC_e occurred.

Table 10: Change in Soil EC_e and SAR Parameters

Gypsum Application	Initial (before Wheat 1991-92)		Final (after Cotton 1994)		Percent Increase (Final over Initial)	
	EC_e (dS m ⁻¹)	SAR	EC_e (dS m ⁻¹)	SAR	EC_e (dS m ⁻¹)	SAR
0-15 cm Depth						
T ₁ (control)	1.72	6.32	5.09	17.66	196	179
T ₂ (100% GR)	1.53	6.54	3.89	13.74	154	110
T ₃ (75% GR)	2.48	6.81	5.52	17.86	123	162
T ₄ (50% GR)	1.84	6.05	3.15	11.90	71	67
15-30 cm Depth						
T ₁ (control)	1.22	6.05	3.08	14.04	152	132
T ₂ (100% GR)	1.34	5.88	4.08	15.64	204	166
T ₃ (75% GR)	1.45	4.74	5.24	21.19	261	347
T ₄ (50% GR)	1.78	6.13	4.13	12.91	132	110
30-60 cm Depth						
T ₁ (control)	1.15	6.34	5.41	18.97	370	199
T ₂ (100% GR)	1.03	4.85	2.75	12.92	167	166
T ₃ (75% GR)	1.52	4.54	3.50	15.11	136	233
T ₄ (50% GR)	1.78	5.93	2.69	13.17	51	122
60-90 cm Depth						
T ₁ (control)	1.14	5.72	3.99	18.19	250	218
T ₂ (100% GR)	0.85	4.34	3.10	13.10	265	202
T ₃ (75% GR)	1.84	5.24	4.01	18.17	118	265
T ₄ (50% GR)	2.47	6.43	3.38	15.67	37	144

Table 11: Effect of Various Treatments on Crop Yields

Crop/Treatment	Yield (ton/ha)				Percent Increase (Average over Control)*
	1991-92	1992-93	1993-94	Overall Average	
Wheat					
T ₁ (control)	1.93	2.83	1.13	1.96	
T ₂ (100% GR)	2.90	4.08	2.23	3.07	57
T ₃ (75% GR)	2.25	3.61	1.93	2.59	32
T ₄ (50% GR)	2.87	3.28	1.64	2.59	32
Cotton					
T ₁ (control)	0.75	1.68	0.79	1.07	
T ₂ (100% GR)	1.09	1.93	1.58	1.53	43
T ₃ (75% GR)	1.00	1.75	1.18	1.31	22
T ₄ (50% GR)	0.91	1.71	1.00	1.20	12

* Based on the average values.

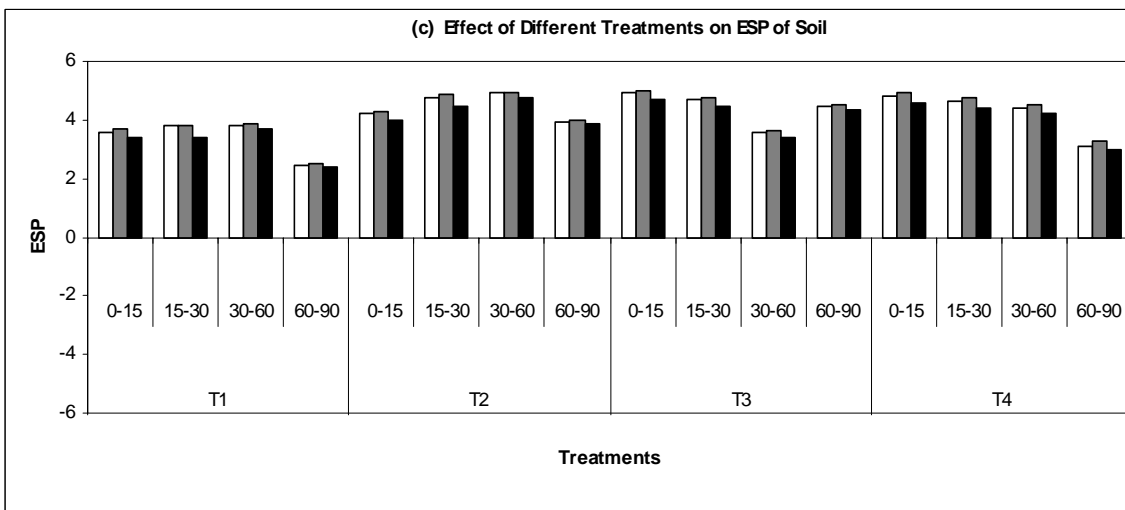
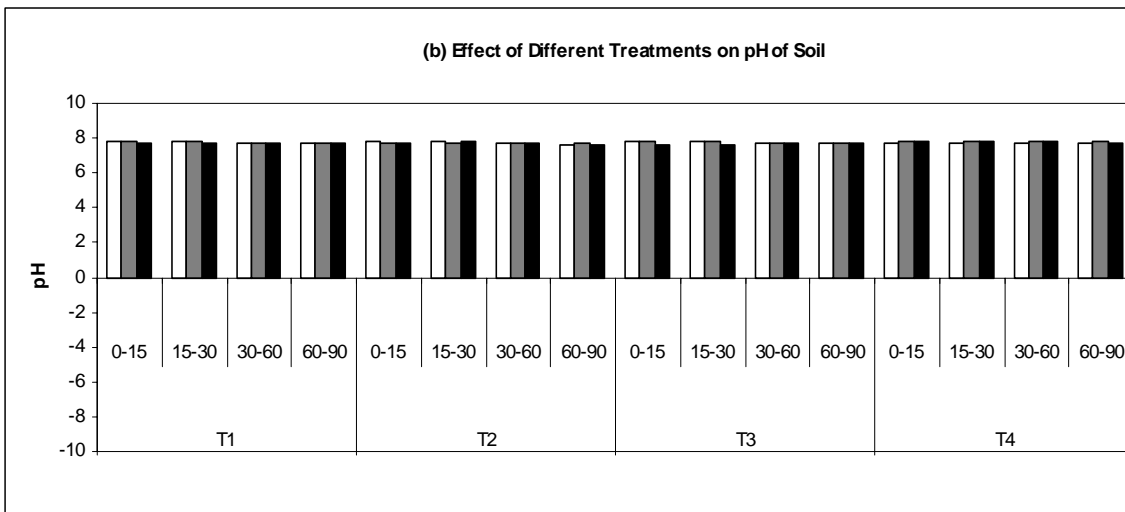
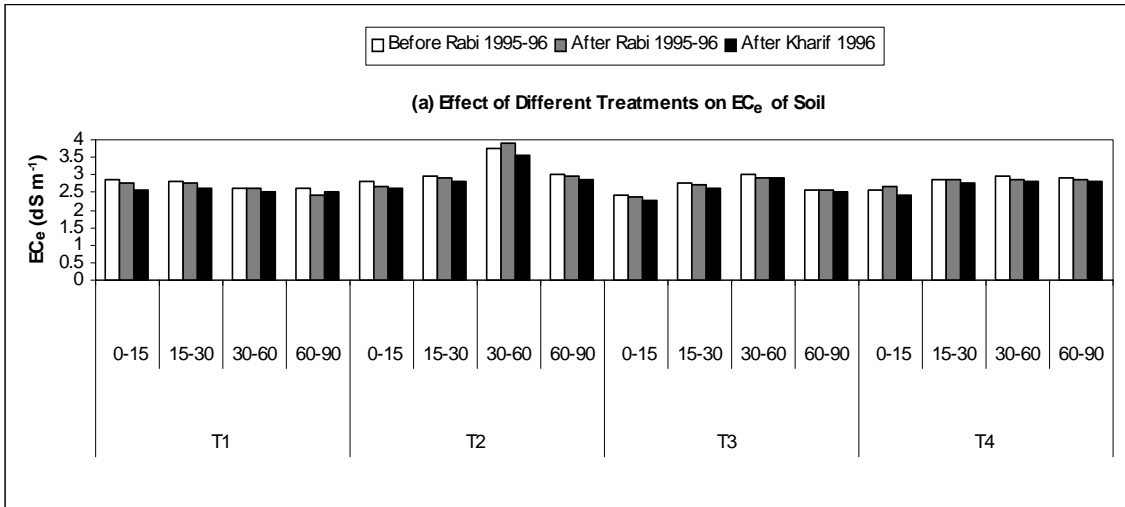


Figure 10: Soil and Crop Management under Reclaimed Lands

The value of pH was decreased by different order of magnitude in the upper soil depth. Apparently, T₃ decreased the pH by 2.6 percent equally between the upper tow layers of soil. T₁ and T₂ reduced the pH smaller than that under T₃ at 0-15 and 15-30 cm depths. Under T₄, the pH increased by less than 2 percent at all the depths excluding 60-90 cm depth. The ESP showed similar trend as that of EC_e. Under the applied treatments, pH showed more decrease (> 5%) in the upper layers of soil. Under the control treatment (T₄), the ESP also decreased 3 to 4 percent almost uniformly at all the soil depths.

5.3.2.2 Effect on Crop Yields by Sowing Periods and Fertilizer Doses

Table 12 indicates that the treatments T₁ and T₂ resulted in higher yield of wheat *i.e.* 2.86 and 2.41 ton/ha, respectively. T₃ and T₄ gave equal yield of wheat (2.0 ton/ha). In case of sorghum, its higher yield (1.8 ton/ha) was achieved from T₁. It may be concluded that both wheat and sorghum gave maximum yield amongst the treatments.

Table 12: *Wheat and Sorghum Yields and Related Agronomic Variables*

Description	Treatments			
	Seasonal Crop/ Recommend Fertilizer (T ₁)	Early Crop/ Low Fertilizer (T ₂)	Late Crop/ High Fertilizer (T ₃)	Seasonal Crop/ Without Fertilizer (T ₄)
Wheat				
Yield (ton/ha)	2.86	2.41	2.0	1.95
Grains per spike	71	63	53	52
Spike length (cm)	11.4	11.3	9.3	8.6
Plant height (cm)*	104	100	95	94
Sorghum				
Yield (ton/ha)*	1.8	1.16	1.44	1.20
Plant height (cm)**	113	105	109	106
Grains per head	402	294	350	296
Head length	17.5	9.9	13.6	13.1
Tillers per m ² meter (No)	120	84	110	92

* After 100 days. ** After 8 weeks.

5.3.3 Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Land

As mentioned earlier, this study involved four treatments: T₁, control; T₂, minimum tillage with 75 percent CU; T₃, average tillage with 100 percent CU; and T₄, for maximum tillage plus 125 percent CU for crops. Wheat and cotton rotation was experimented from *Rabi* 1995-96 to *Kharif* 1997. The results are discussed below:

5.3.3.1 Effect on Soil Salinity

From Figure 11 it is evident that the applied treatments resulted in the decrease of EC_e at each soil depth. The maximum decrease (21%) of EC_e was observed under T₄. On the basis of average

of all depths, the decrease of EC_e varied from about 21 percent (T_4) to 7 percent (T_2) with 16 percent decrease under T_3 . Under T_1 there was a considerable increase of about 21 percent. The overview of Figure 11 and Table 13 indicate similar trends regarding pH and ESP.

Figure 11 shows that there was more accumulation of cations and anions at all the soil depths under control treatment. In all, HCO_3 and SO_4 did not move down to the lower depths but Cl settled down at these depths. So, Na settled down at lower depths while Ca and Mg at upper depths. Under that conditions ESP of soil was decreased due to the applied treatments while increased under the control.

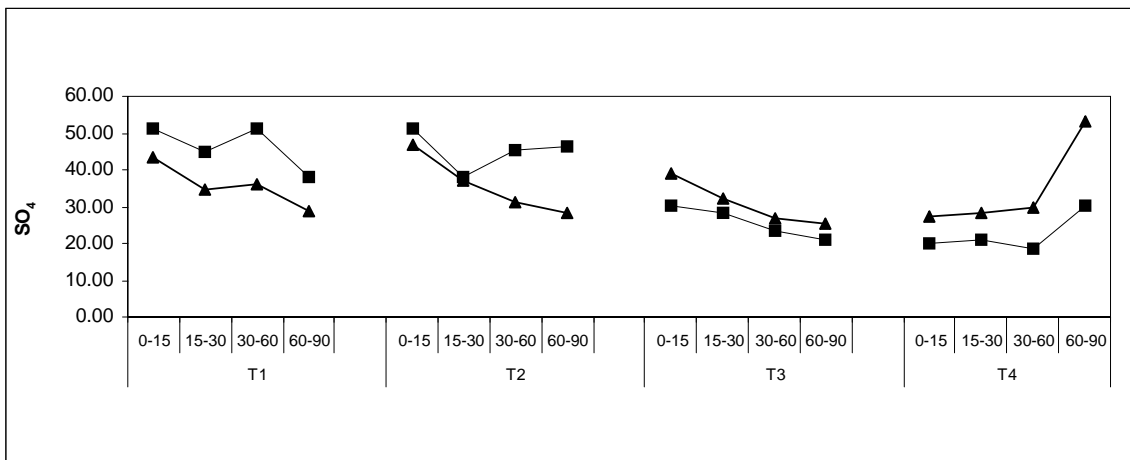
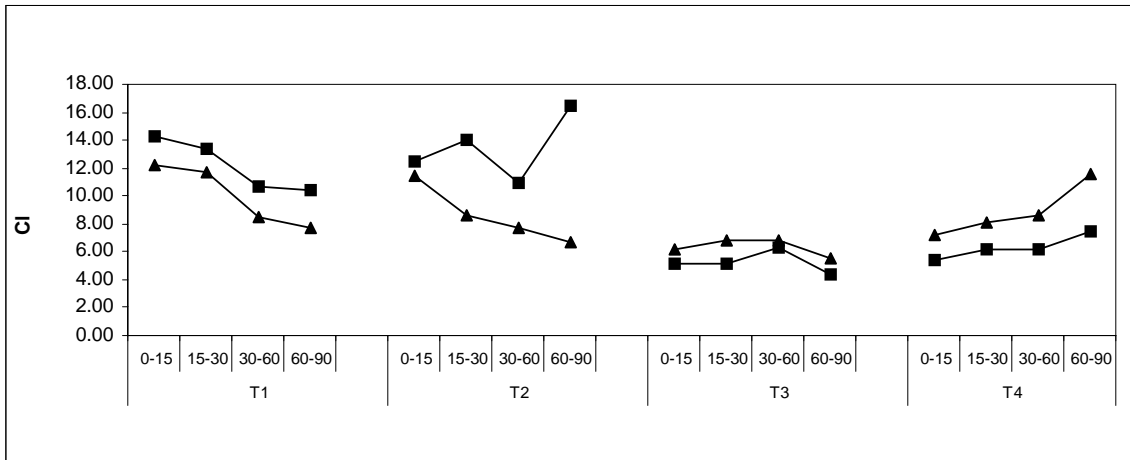
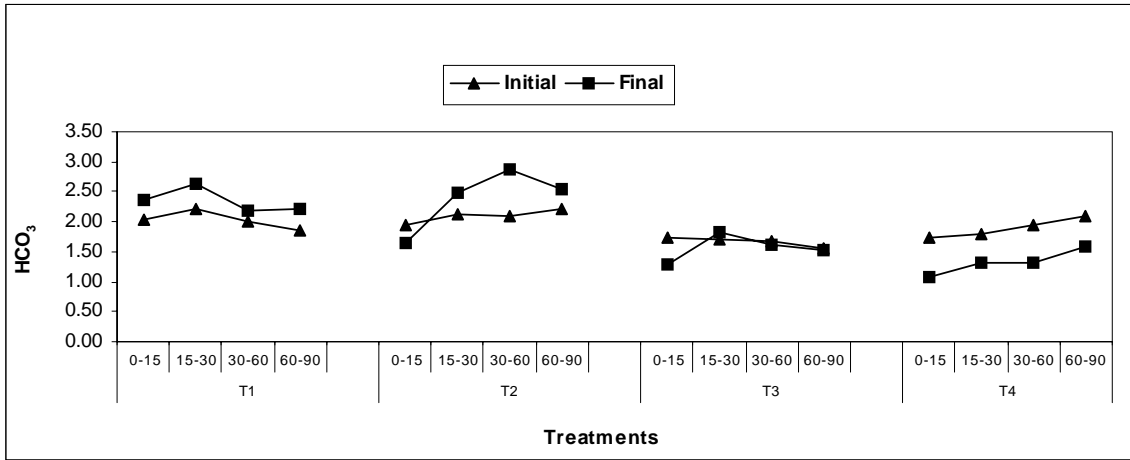
Table 13: Soil Analysis Results Before and After Study

Treatment	Soil Depth (cm)	EC_e ($dS\ m^{-1}$)		pH		ESP	
		before	after	before	after	before	after
T_1 (control)	0-15	3.81	4.49	7.3	7.4	12.21	14.65
	15-30	3.05	4.36	7.4	7.5	11.58	13.00
	30-60	3.71	4.03	7.4	7.5	12.10	12.75
	60-90	3.10	3.63	7.2	7.4	11.15	12.00
T_2 (Minimum Tillage + 75% CU)	0-15	3.70	3.60	7.2	7.1	12.36	12.00
	15-30	3.60	3.45	7.3	7.2	11.50	12.10
	30-60	3.61	3.45	7.4	7.3	12.10	12.40
	60-90	3.80	3.31	7.5	7.4	11.17	12.00
T_3 (Optimum Tillage + 100% CU)	0-15	3.78	3.69	7.4	7.3	11.38	10.00
	15-30	3.91	3.17	7.5	7.3	12.01	10.03
	30-60	3.94	3.03	7.4	7.3	11.14	10.00
	60-90	3.89	3.16	7.3	7.3	11.49	10.06
T_4 (Maximum Tillage + 125% CU)	0-15	3.21	2.04	7.4	7.0	11.39	9.00
	15-30	3.92	3.20	7.3	7.1	12.11	10.34
	30-60	3.34	3.51	7.3	7.1	11.69	10.35
	60-90	4.04	2.74	7.4	7.0	11.31	10.00

5.3.3.2 Crop Yields Response

Evidently, T_4 gave better yields of wheat and cotton (Table 14). Overall there was no eventual variation of wheat yield between the two seasons under all the treatments. However, cotton yield decreased in the second crop season under the treatments. In relative terms, the decline in cotton yield in the second over the first crop season was nearly of the same magnitude under T_1 (43%) and T_2 (45%). The minimum decreased (18%) of cotton yield in the second season was found under T_4 .

Figure 11: Tillage and Irrigation Effects on Movement of Individual Salts under Reclaimed Lands



Continued...

Figure 11 (– Contd.)

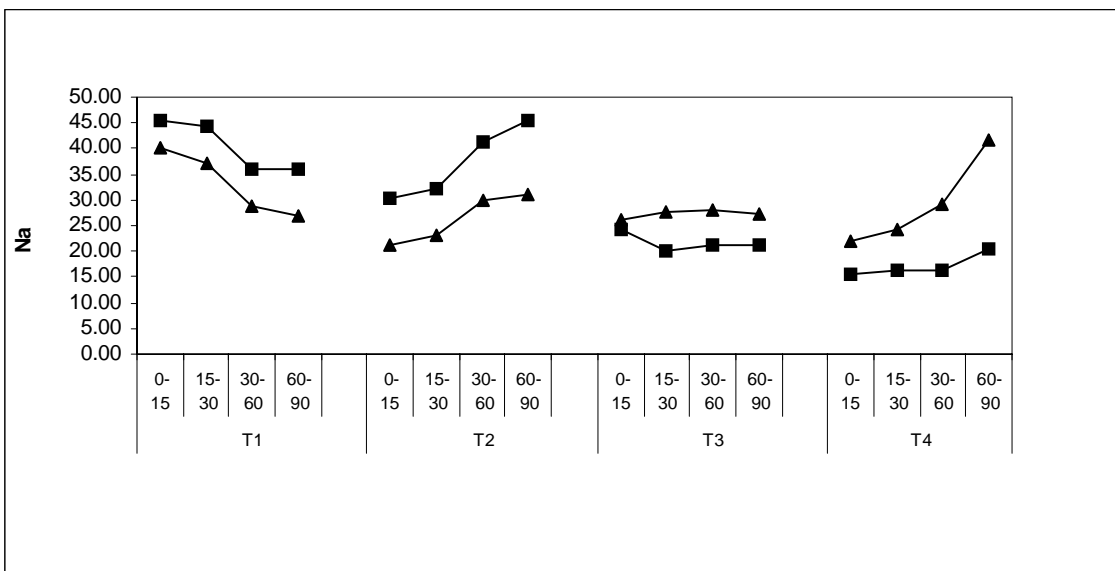
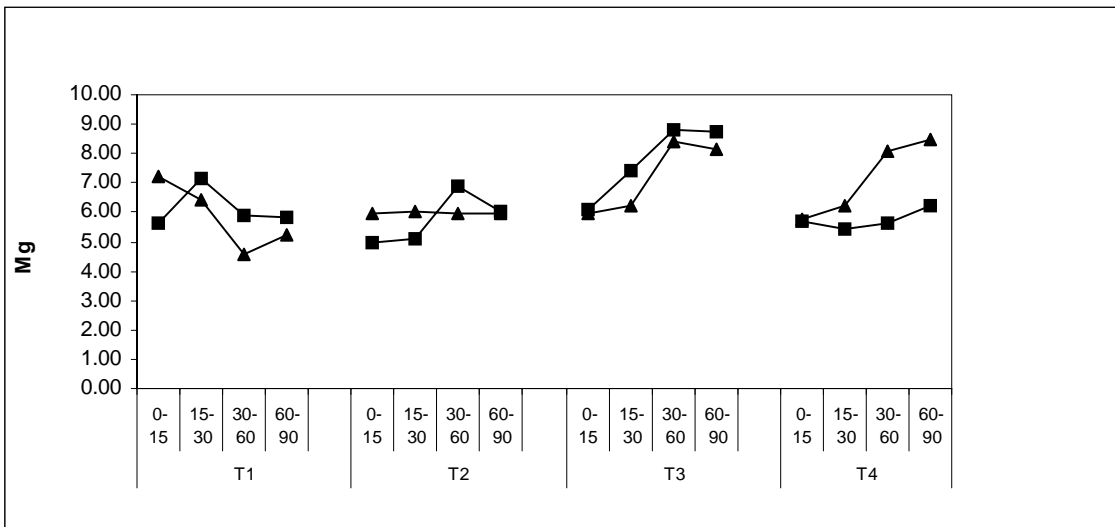
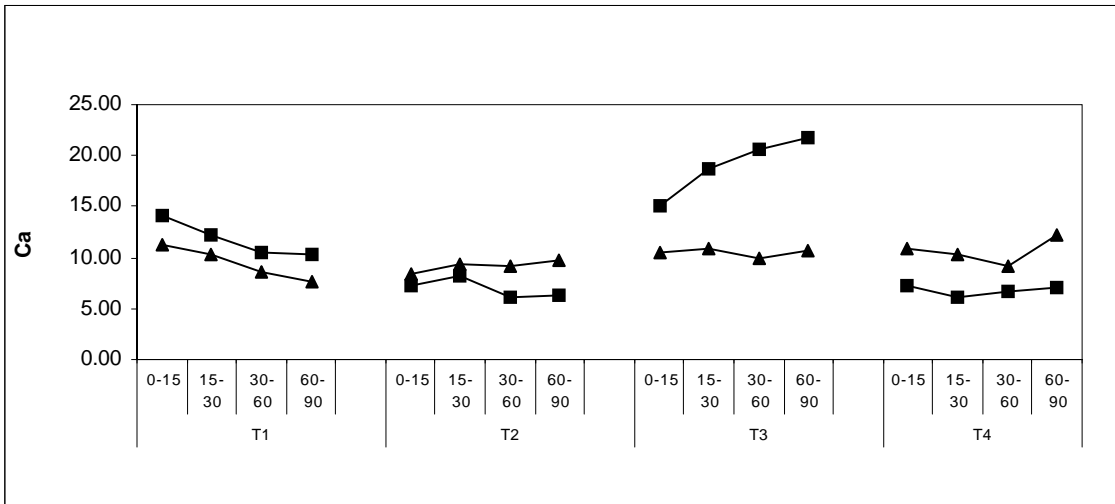


Table 14: *Wheat and Cotton Yields by Treatments*

<i>Treatment</i>	<i>Wheat</i>		<i>Cotton</i>	
	<i>1995-96</i>	<i>1996-97</i>	<i>1996</i>	<i>1997</i>
T ₁ (control)	1.92	2.03	1.31	0.74
T ₂ (Minimum Tillage + 75% CU)	2.05	2.13	1.76	0.96
T ₃ (Average Tillage + 100% CU)	2.22	2.36	1.89	1.23
T ₄ (Maximum Tillage + 125% CU)	2.98	3.16	2.14	1.75

5.4 Irrigation Practices Effect on Soil Salinity

5.4.1 *Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton*

This study was based on three levels of consumptive use of water for wheat and cotton, over three seasons. Accordingly, the treatments applied were: T₁, 75 percent CU (375 mm to wheat and 412 mm to cotton); T₂, 100 percent CU (450 mm to wheat and 550 mm to cotton); and T₃, 125 percent CU (562 mm to wheat and 687 mm to cotton). The results are briefly discussed below:

5.4.1.1 *Effect on Soil Salinity*

Figure 12 indicates that there was only a notable decrease in EC_e of about 23 percent (up to 90 cm soil depth) under T₃. The other two treatments showed decrease of EC_e by 5 and 8 percent, respectively. As apparent, there was no remarkable effect on the soil EC_e, even after three years, on account of the three irrigation levels. The pH of soil also increased in the order of 10, 11 and for T₁, T₂, T₃ respectively. However, soil SAR was increased with high magnitude of 91, 76, 53 percent under T₁, T₂, and T₃, respectively. Likewise, ESP value (average of all depths) also reflected a high increase of 63, 101 and 99 percent under the treatments T₁, T₂, and T₃, respectively

5.4.1.2 *Wheat and Cotton Yields*

Table 15 shows that the yield of wheat had no notable variation by treatments and by crop seasons. There were small increases in the first and the second *Rabi* under T₃ and in the last *Rabi* season under T₂. Overall, there was no difference of wheat yield either amongst the treatments or crop seasons. The yield of wheat in the three *Rabi* seasons did not vary significantly under all the treatments.

The cotton yield also did not show significant variation between the treatments (1.11–1.18 ton/ha), in the first *Kharif* season (1990). The maximum yield (2.53 ton/ha), was under T₂ in the second season. In the third season, cotton yield varies closely from 1.97 ton/ha under T₁ to 2.16 ton/ha under T₃ having 2.14 ton/ha under T₂. As in the first season, there is also no notable variation in yields of cotton between the treatments in the third crop season. There were some improved levels of cotton yields in the second and third *Kharif* seasons against the first crop season.

5.4.1.3 Water Use Efficiency

Table 15 shows that higher WUE was achieved under T₁ during the *Rabi* season (wheat). Obviously, there was a declining trend of WUE from T₁ to T₃ for each *Rabi* season. In case of cotton, the WUE did not reflect a consistency among crop seasons however, by treatments, WUE also showed a declining trend from T₁ to T₃ particularly, in *Kharif* 1990. From the crop yields and WUE results, it may be concluded that the applied treatments of consumptive use of water could not result in significant change in yields and WUE of wheat and cotton.

Table 15: *Crop Yields and Water Use Efficiency*

Description	Treatment		
	75 Percent CU (T ₁)	100 Percent CU (T ₂)	125 Percent CU (T ₃)
Wheat Yield (ton/ha)			
1989-90	2.23	2.31	2.38
1990-91	2.28	2.30	2.60
1991-92	2.90	3.01	2.23
WUE (kg/ha-mm)			
1989-90	6.61	5.13	4.23
1990-91	6.76	5.11	4.62
1991-92	8.60	6.68	3.96
Cotton Yield (ton/ha)			
1990	1.12	1.18	1.11
1991	1.72	2.53	2.23
1992	1.97	2.14	2.16
WUE (kg/ha-mm)			
1990	2.71	2.14	1.61
1991	2.84	4.60	3.24
1992	4.78	3.89	3.14

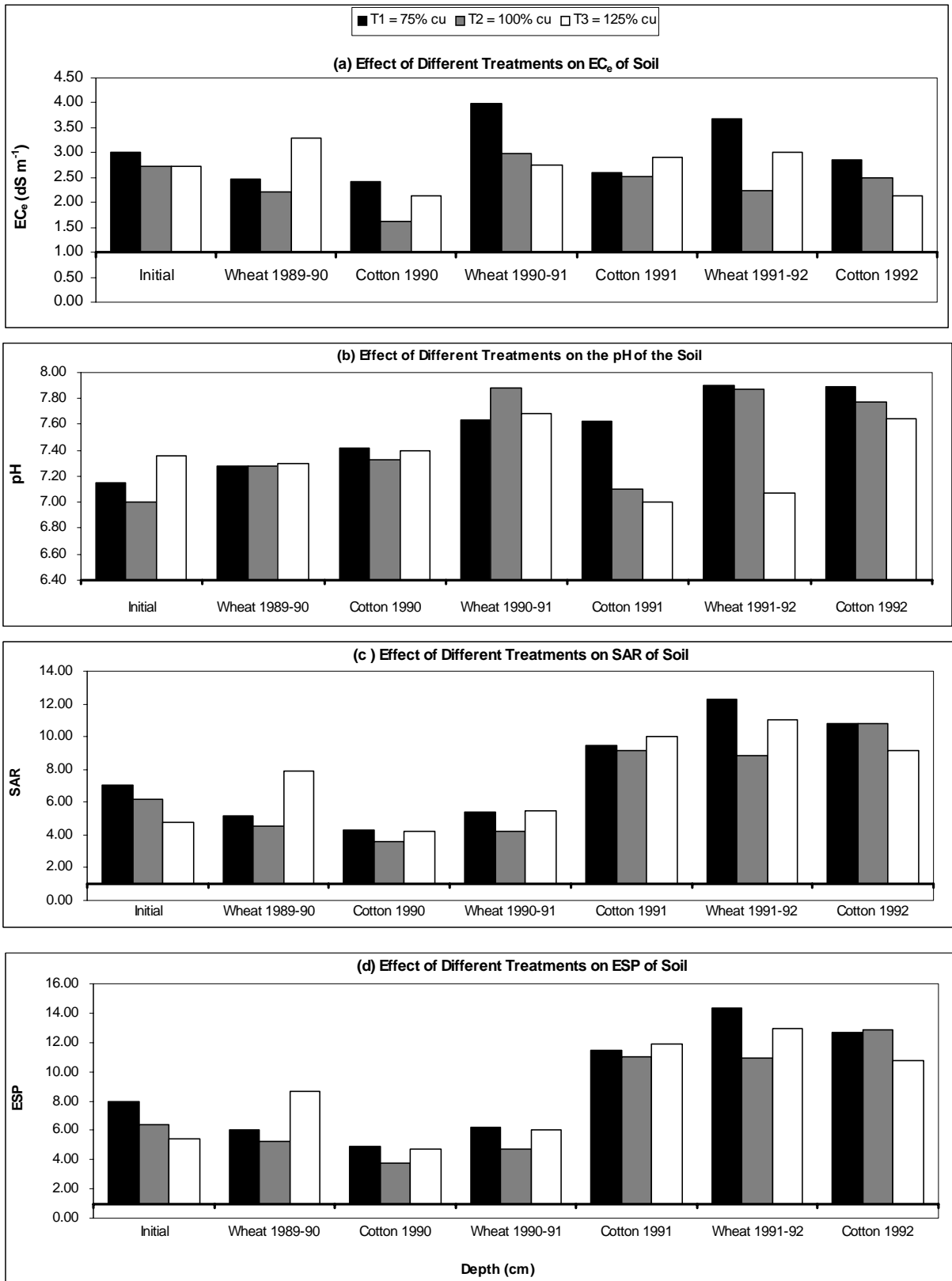


Figure 12: Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton

5.4.2 Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions

Under this study the treatments were: T₁ control for recommended irrigation of 550 mm for cotton and 450 mm for wheat; T₂, T₁ coupled with leaching fraction to reduce the original EC_e to 8 dS m⁻¹ and T₃, T₁ plus leaching fraction to bring down the EC_e to 4 dS m⁻¹. The results are discussed below.

5.4.2.1 Effect on Soil Salinity

Figure 13 reveals that the maximum decrease (70%) of EC_e was achieved under T₃. T₂ decreased the EC_e by 64 percent and the T₁ decreased the EC_e by 63 percent. There appeared no difference between T₁ and T₂ in decreasing EC_e of soil. However, there was a progressive trend of decreased EC_e at the end of each crop season. Though the effect of decreased pH of soil reflected the same order of the treatments as that of decreased EC_e but relatively, reduction of pH showed no wide variation between the treatments *i.e.* 11, 10 and 9 percent under T₃, T₂ and T₁, respectively.

The decrease in SAR was observed at all soil depths. The decrease in SAR was 49, 43 and 42 percent under T₃, T₂ and T₁, respectively. Similarly, ESP decreased by 58 percent under T₁. Dielman (1963) also reported that slightly and moderately saline soils could be reclaimed by irrigating the fields with proper leaching practices.

5.4.2.2 Trend of Crop Yields

Table 16 reveals that there were higher yields of cotton and wheat under the treatment T₃. These higher yields of both the crops were persistent by the respective crop seasons. The cotton yield under T₃ varied from 1.03 ton/ha (*Kharif* 1992) to 1.15 ton/ha (*Kharif* 1994). Similarly, the yield of wheat under T₃ ranged between 1.75 ton/ha (*Rabi* 1992-93) and 3.51 ton/ha (*Rabi* 1994-95). However, the mean values of yield of both the crops showed no statistical significance difference either amongst the treatments or the crop seasons.

Table 16: Crop Yields by Treatment

Description	Treatments		
	T ₁	T ₂	T ₃
<i>(ton/ha)</i>			
Cotton			
<i>Kharif</i> 1992	0.91	0.91	1.03
<i>Kharif</i> 1993	1.03	1.08	1.10
<i>Kharif</i> 1994	1.12	1.12	1.15
Wheat			
<i>Rabi</i> 1992-93	1.40	1.45	1.75
<i>Rabi</i> 1993-94	2.52	2.76	2.88
<i>Rabi</i> 1994-95	3.20	3.39	3.51

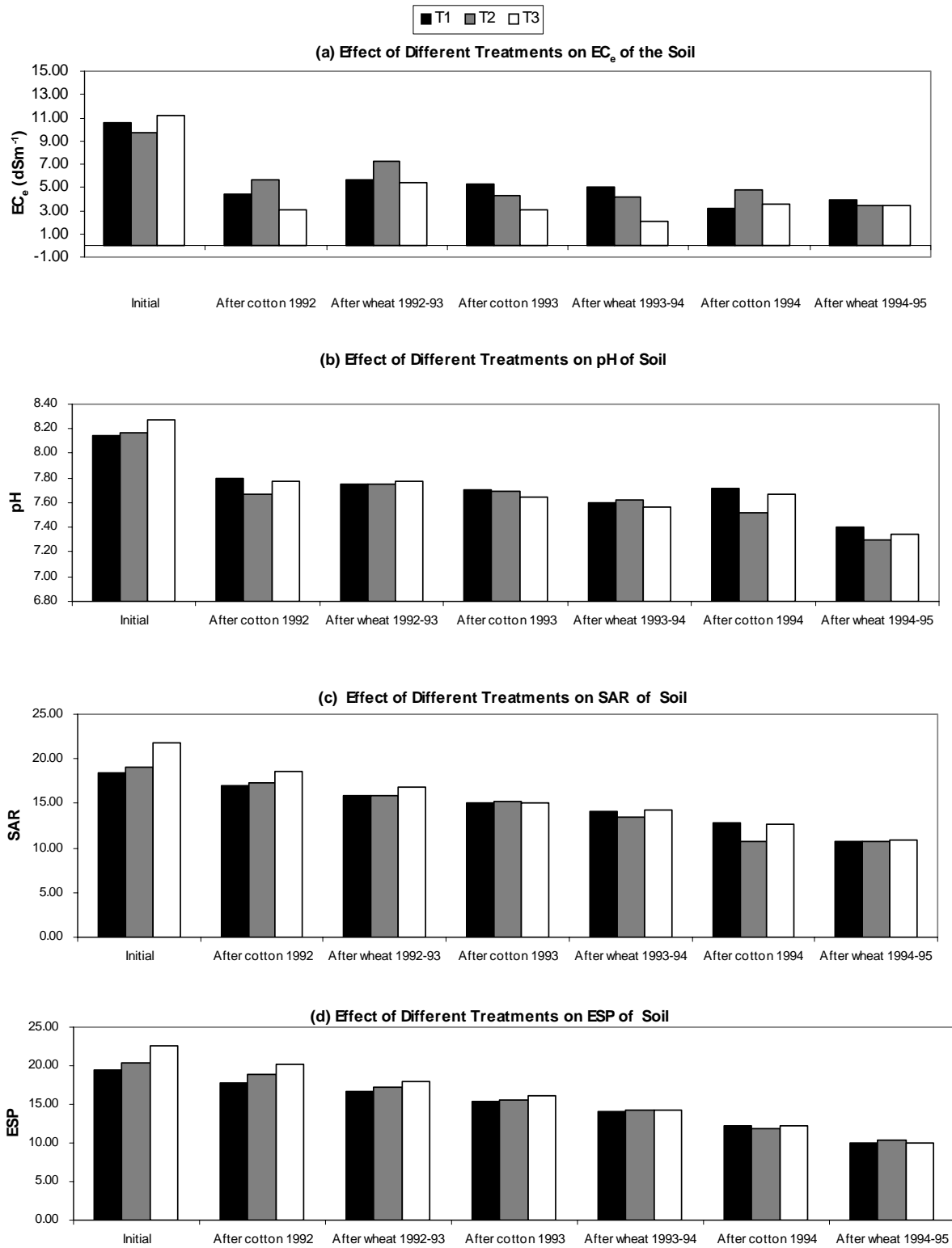


Figure 13: Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions

5.4.3 Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil

This study concentrated on various irrigation and fertilizer levels applied to wheat and cotton. The treatments were defined in terms of water consumptive use and NPK combinations. The water consumptive use levels were I₁ (75%), I₂ (100%) and I₃ (125%). Two NPK levels were F₁ (247-124-0 kg/ha) and F₂ (371-186-72 kg/ha). So, T₁ = I₁F₁, T₂ = I₁F₂, T₃ = I₂F₁, T₄ = I₂F₂, T₅ = I₃F₁ and T₆ = I₃F₂. The results of the study are discussed below:

5.4.3.1 Effects on Soil Salinity

Soil salinity/sodicity as affected by the irrigation and fertilizer levels are shown in Figure 14. At 0-15 cm depth three treatments I₁F₁, I₂F₂ and I₃F₂ resulted in reduction of EC_e by 23, 4 and 5 percent, respectively. The other treatments increased the EC_e at the above said depth by varying magnitude and the maximum increase (74%) of EC_e was found under I₁F₁. The minimum increase (7%) of EC_e was observed at 0-15 cm depth under I₃F₁. The similar trend of change in EC_e was observed under these treatments at the depth of 15-30 cm. At this depth the increase of EC_e under I₁F₁, I₁F₂ and I₃F₁ was 48, 24 and 4 percent, respectively whereas, decrease of EC_e was 6, 4 and 2 percent under I₂F₂, I₃F₂ and I₂F₁, respectively. At 30-60 cm depth, the decrease in EC_e of 7 and 2 percent was observed under I₂F₁ and I₂F₂ respectively. The EC_e value was however, increased under the other four treatments with the maximum of 33 percent (I₁F₂) and the minimum of 3 percent (I₃F₁). At 60-90 cm depth, the treatments of I₂F₁ and I₂F₂ decreased EC_e by only 6 and 3 percent, respectively. It therefore may be concluded that the 100 percent consumptive use of water combined with 247-124-0 and 371-186-72 kg/ha NPK levels may be more effective to maintain the salt balance in the root zone under wheat and cotton cultivation.

At 0-15 cm depth, a decrease of 4 and 2 percent in pH of soil was observed in I₂F₁ and I₂F₂ treatments, respectively. The other treatments caused an increase of varying magnitude at this depth. At the lower depths, though the trend of change in pH was similar but by magnitude it reflected very small or no decrease in pH.

In reducing SAR in 0-15 cm layer I₂F₁ treatment was the most effective giving a relative decrease of 31 percent. The second noted beneficial treatment of I₂F₂ could cause a decrease in SAR by only 3 percent. The other four treatments, tended to increase the SAR, as varying from 4 percent (I₃F₁) to 20 percent (I₁F₂). At 15-30 cm depth, the decrease of SAR was 18 and 6 percent under I₂F₁ and I₂F₂, respectively. The maximum decreases in SAR at the depths of 30-60 cm and 60-90 cm under I₂F₂ treatment (highest levels of CU and NPK) were 11 and 18 percent, respectively. For the lower depths, the maximum increase of SAR was under I₁F₁, accounting for 20 percent at 30-60 cm and 18 percent at 60-90 cm depth. SAR showed similar trend as that of EC_e and pH of soil.

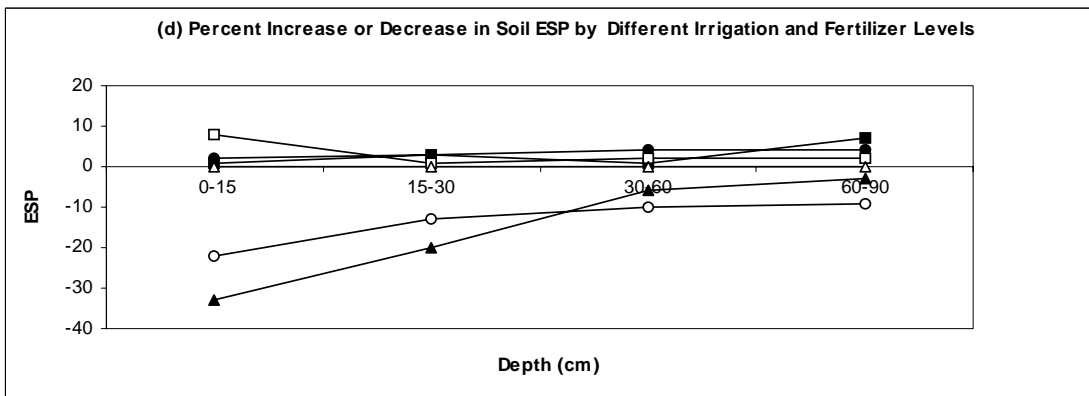
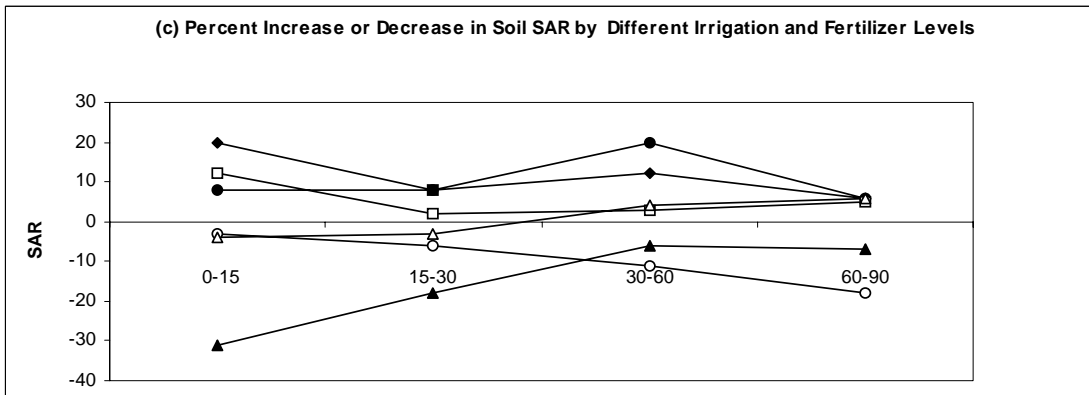
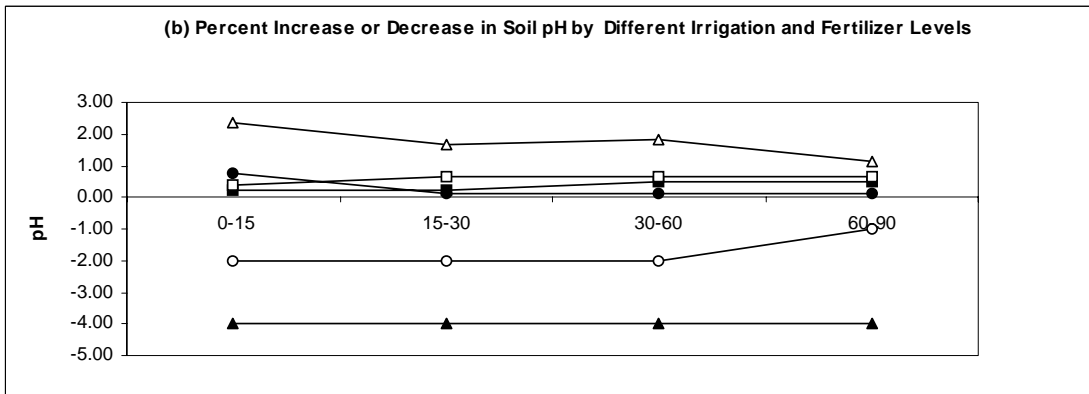
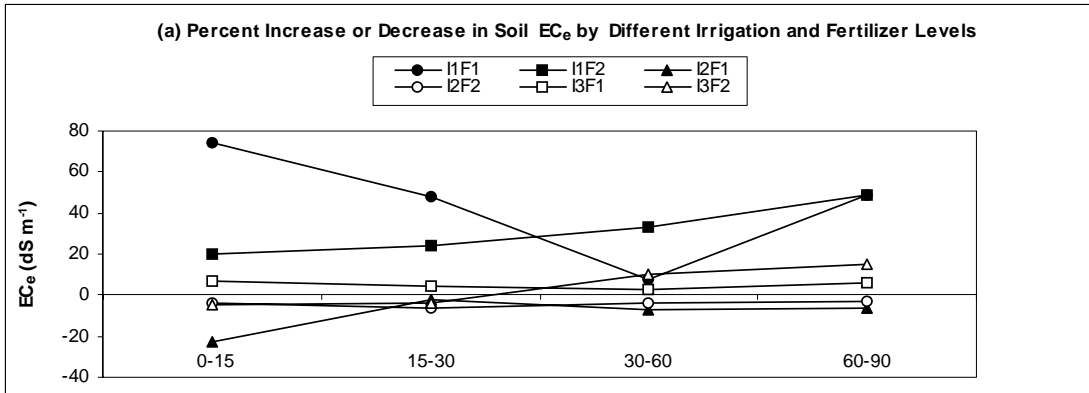


Figure 14: Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil

The maximum decreases under I_2F_1 at 0-15 cm, 15-30 cm, 30-60 cm and 60-90 cm depth were 8, 20, 10 and 9 percent, respectively. Whereas, the increase under other four treatments varied from 8 to 1 percent at 0-15 cm, each 4 to 1 percent at 15-30 cm and 30-60 cm depth and 7 to 2 percent at 60-90 cm depth. Jurinak and Wagenet (1981) stated that in most cases moderate level of soil salinity could be compensated by increased fertilization, so long as the salinity level was not excessively high and the crop was not salt sensitive.

5.4.3.2 Wheat and Cotton Yields Trend

Table 17 reveals that the I_2F_1 and I_2F_2 resulted in higher yield of wheat. These higher yield varied from 1.75 ton/ha (*Rabi* 1995-96 under I_2F_2), to 2.35 ton/ha (*Rabi* 1994-95 under I_2F_1). The difference of mean values of yield by seasons and by treatments was statistically significant at 5% significant level.

In case of cotton, its yield remained comparatively low in the first *Kharif* season (1994) but showed same high yield (0.73 ton/ha) under I_2F_1 treatment. The cotton yield in the other two crop seasons showed its higher yield of 2.25 ton/ha in *Kharif* 1995 and 1.59 ton/ha in *Kharif* 1996 under I_2F_1 . There was no statistical significance of mean yield difference between the treatments but there was significant difference between the crop seasons. Chaudhry *et al.* (1996) observed a significant increase in yield from the treatments of different irrigation and fertilizer levels applied to wheat. Drip (1992) reported the high yield of wheat and cotton using 100 percent CU of water for wheat and cotton with no increase of salts in the soil profiles.

Table 17: *Wheat and Cotton Yields by Treatment and Season*

Crop/Season	Treatments					
	I_1F_1 (T_1)	I_1F_2 (T_2)	I_2F_1 (T_3)	I_2F_2 (T_4)	I_3F_1 (T_5)	I_3F_2 (T_6)
Wheat						
<i>Rabi</i> 1993-94	1.47	1.57	1.97	1.83	1.15	1.23
<i>Rabi</i> 1994-95	1.85	1.78	2.35	2.19	2.01	1.93
<i>Rabi</i> 1995-96	1.49	1.51	1.91	1.75	1.48	1.52
Cotton						
<i>Kharif</i> 1994	0.53	0.54	0.73	0.46	0.45	0.44
<i>Kharif</i> 1995	1.25	1.40	2.25	1.31	1.25	1.07
<i>Kharif</i> 1996	1.04	0.99	1.59	1.03	0.97	0.93

5.5 Saline and Drainage Water Use for Crop Production

5.5.1 Crop Production with Saline Drainage Effluent

By definition four treatments were applied under this study for cotton and wheat crops. These treatments were: T_1 , control (canal water); T_2 , saline drainage water; T_3 , T_2 combined with 15 percent leaching fraction of canal water and T_4 , T_2 plus 20 percent leaching fraction of canal water. The results are discussed below:

5.5.1.1 Effect on Soil Properties

The results of EC_e, pH, SAR and ESP are presented in Table 18. Under T₁ the average decrease in EC_e (based on all depths) was about 7 percent and varied from 2 percent (75-100 cm depth) to 14 percent (0-25 cm depth). Whereas, the other three treatments increased the EC_e with the maximum average of about 87 percent under T₂ and the minimum of about 25 percent under T₃. On the overall, the increase of EC_e was considerably higher beyond 50 cm depth especially at 75-100 cm depth.

The treatment of T₁ resulted in only 1.0 percent reduction of pH. On the contrary, the other treatments increased the pH with the maximum of 9 percent under T₂ and the minimum of 5 percent under T₃. Higher increases of pH were found under T₂ to T₃ at the lower depths of 50-75 cm and 75-100 cm.

Table 18: Effect of Canal and Saline Drainage Water on Soil Properties

Soil Depth (cm)	Prior to Treat- ments	T ₁		T ₂		T ₃		T ₄	
		Final	Percent change	Final	Percent change	Final	Percent change	Final	Percent change
EC_e (dS m⁻¹)									
0-25	3.46	3.05	-11.05	4.86	40.46	3.88	12.17	3.93	13.50
25-50	3.50	3.17	-9.42	5.10	45.71	3.93	12.20	3.97	13.42
50-75	3.26	3.11	-4.60	6.87	110.73	4.01	23.00	4.17	27.91
75-100	2.71	2.65	-2.21	6.85	152.76	4.13	52.37	4.49	65.60
<i>Average</i>	<i>3.23</i>	<i>2.90</i>	<i>-6.85</i>	<i>5.92</i>	<i>87.41</i>	<i>4.01</i>	<i>24.93</i>	<i>4.14</i>	<i>30.10</i>
pH									
0-25	7.27	7.23	-0.55	7.91	9.40	7.48	3.45	7.58	4.28
25-50	7.40	7.31	-1.21	7.93	8.48	7.67	3.64	7.76	4.86
50-75	7.37	7.28	1.22	7.99	9.63	7.75	5.15	7.88	6.91
75-100	7.30	7.21	-1.23	8.05	10.27	7.79	6.71	7.93	8.63
<i>Average</i>	<i>7.33</i>	<i>7.25</i>	<i>-1.05</i>	<i>7.97</i>	<i>9.44</i>	<i>7.67</i>	<i>4.73</i>	<i>7.78</i>	<i>6.17</i>
SAR									
0-25	7.81	7.68	-1.96	9.20	17.70	8.23	5.37	8.36	7.04
25-50	7.71	7.56	-1.94	9.26	20.10	8.09	4.52	9.21	6.48
50-75	8.90	8.46	-4.92	10.64	19.57	9.26	4.04	9.37	5.28
75-100	9.44	8.31	-11.42	11.23	18.90	10.13	7.30	10.28	8.87
<i>Average</i>	<i>8.46</i>	<i>8.00</i>	<i>-5.12</i>	<i>10.22</i>	<i>19.08</i>	<i>8.92</i>	<i>5.40</i>	<i>9.05</i>	<i>6.91</i>
ESP									
0-25	7.78	7.73	-0.64	8.83	13.47	8.13	4.49	8.21	5.52
25-50	8.65	8.57	-0.92	9.67	11.77	9.28	7.28	9.39	8.55
50-75	9.24	9.06	-1.94	10.30	11.44	9.87	6.81	10.01	8.33
75-100	10.63	10.41	-2.06	11.69	9.97	10.96	5.28	11.22	5.55
<i>Average</i>	<i>9.07</i>	<i>8.94</i>	<i>-1.39</i>	<i>9.88</i>	<i>11.66</i>	<i>9.56</i>	<i>5.56</i>	<i>9.70</i>	<i>8.89</i>

In case of SAR, there was a decrease of 5.0 percent in its value under T₁. However, the increase in SAR under the other treatments (T₂ to T₄), varied from 19 percent (T₂) to 5 percent (T₃) with about 7 percent under T₄. The ESP values under T₁ decreased slightly (1.4%). Whereas, the average increase in ESP was the maximum (11.7%) under T₂ followed by 5.6 and 8.9 percent under T₃ and T₄, respectively. Therefore, the exclusive use of saline drainage water for cotton and wheat crops notably aggravated the soil salinity and sodicity.

5.5.1.2 Effect on Crop Yields

Table 19 shows that cotton gave low yield in *Kharif* 1989 irrespective of the amendments. In other two crop seasons however, the high cotton yields were achieved. Obviously, canal water (T₁) produced the higher yield *i.e.* 3.44 and 3.84 ton/ha in the later two *Kharif* seasons. There was no difference of cotton yield between T₂ (saline drainage water) and T₃ (saline water coupled with 15% leaching fraction). The lower yields of 2.85 and 2.77 ton/ha were achieved under the treatment of saline water combined with 20 percent leaching fraction from canal water.

The wheat yield was higher under T₁ *i.e.* 5.30, 4.62 and 5.49 ton/ha, respectively in 1989-90, 1990-91 and 1991-92 *Rabi* seasons. In relation to the other treatments, the wheat yield did not show a persistent trend by the treatments as well as by the crop seasons. The treatments of T₂ and T₃ showed higher yield in the first *Rabi* season (1989-90) while T₄ resulted in the higher yield in the last *Rabi* season (1991-92).

Table 19: Cotton and Wheat Yields by Treatment

Crop/Season	Treatment			
	Canal water (T ₁)	Saline water (T ₂)	Saline water + 15 percent leaching from canal water (T ₃)	Saline water + 20 percent leaching from canal water (T ₄)
Cotton				
<i>Kharif</i> 1989	0.92	0.79	0.79	0.44
<i>Kharif</i> 1990	3.44	3.19	3.19	2.85
<i>Kharif</i> 1991	3.84	3.57	3.57	2.77
Wheat				
<i>Rabi</i> 1989-90	5.30	4.66	4.95	4.17
<i>Rabi</i> 1990-91	4.62	3.10	4.14	4.48
<i>Rabi</i> 1991-92	5.49	4.12	4.68	4.83

5.5.2 Management of Poor Quality Irrigation Water

Under this study the four treatments include: T₁, all canal irrigations; T₂, one irrigation of 75 mm with saline drainage water after 4 weeks of sowing; T₃, the same variable of irrigation but after 7 weeks and T₄ was again with the same variable but after 10 weeks of sowing. The experimental crops were wheat and cotton each over three crop seasons. The results are discussed below:

5.5.2.1 Effect on EC_e of the Soil

Figure 15 indicates that EC_e decreased considerably under T₁ at all depths (0-15 cm to 60-90 cm), in *Rabi* and *Kharif* seasons. In *Rabi* seasons, reduction of EC_e varied from 13.5 to 57.3 percent under T₁ at the lowest depth of soil. Under T₂, EC_e decreased varying from 18.4 to 111.4 percent. In *Kharif* seasons, the decrease of EC_e varied from 20.5 to 34.4 percent under T₁. The other treatments increased the EC_e by varying magnitude. However, the minimum increase in EC_e (1.6 to 67.0%) was under T₃ in *Rabi* seasons and under T₂ in *Kharif* seasons.

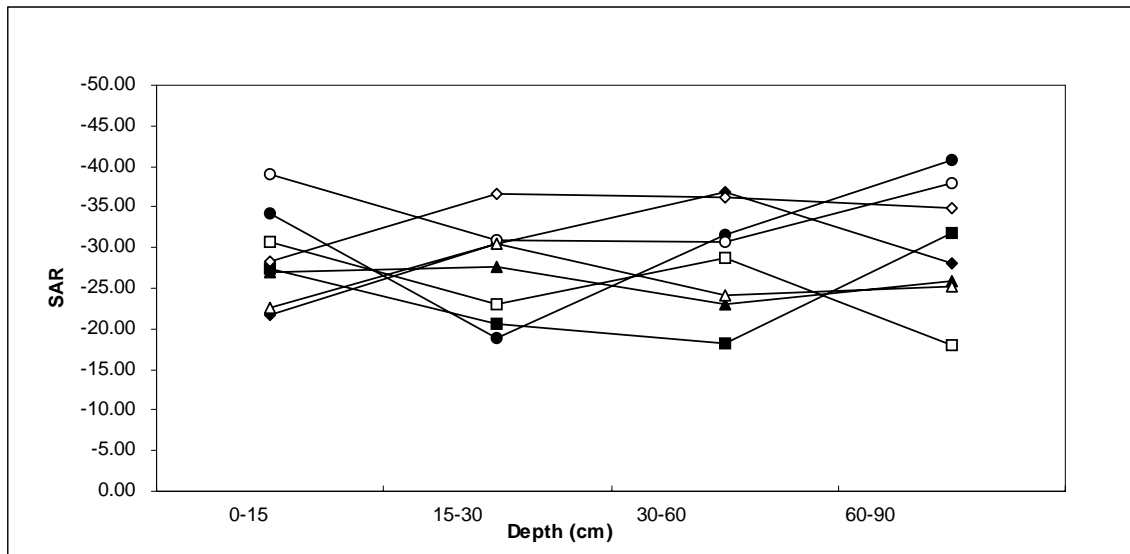
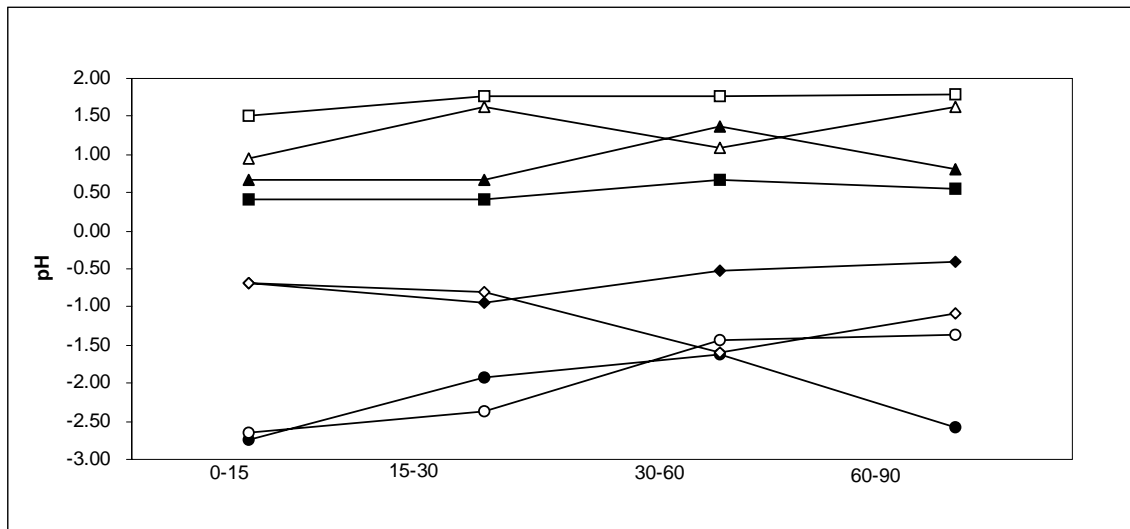
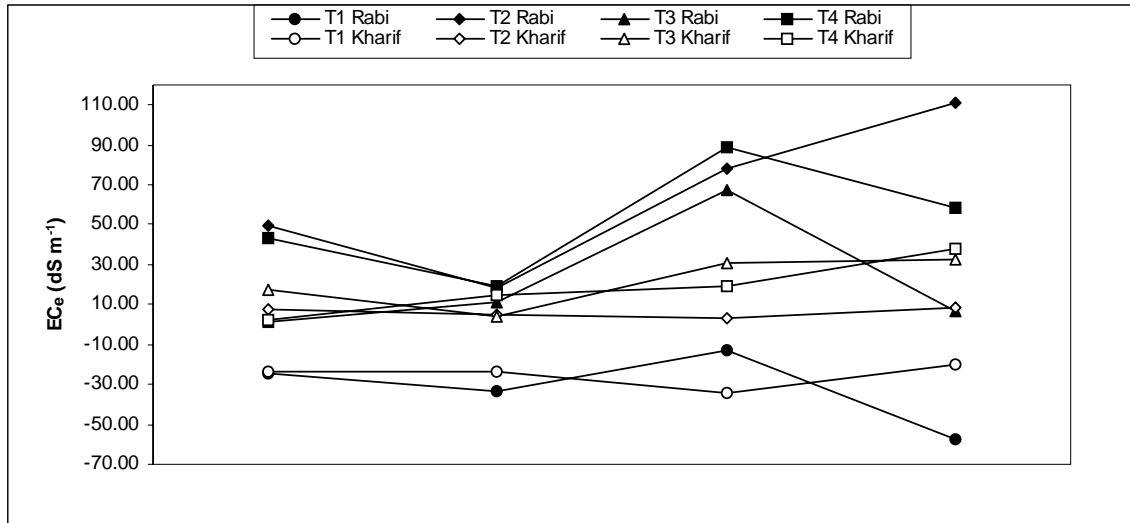


Figure 15: Effect of Different Treatments on Soil Salinity

5.5.2.2 Effect on pH of Soil

In *Rabi* seasons, the pH decreased by 0.4 to 2.7 percent only under T₁ and T₂ at all the soil depth. The other treatments of T₃ and T₄ increased the pH value by 0.4 to 1.4 percent. The similar trend was found in *Kharif* seasons where pH was decreased from 0.7 to 2.6 percent under T₁ and T₂. Under T₃ and T₄, pH value increased by 0.9 to 1.8 percent.

5.5.2.3 Effect on SAR of Soil

The results showed that in *Rabi* seasons, the SAR decreased under all the treatments at each depth. The maximum reduction was 40.9 percent under T₁ at 60-90 cm depth. While the minimum reduction (18.3%) of SAR was under T₄. In *Kharif* seasons, the maximum reduction of SAR was 39.1 percent under T₁ at 0-15 cm depth. The reduction of SAR occurred under all the treatments but with varying magnitude. The effectiveness of the treatments in reducing SAR was projected in the descending order of T₁, T₂, T₃ and T₄, in *Rabi* as well as in *Kharif* seasons. The SAR results conform with those reported by Hussain *et al.* (1990). Somani (1991) also reported that one supplementary irrigation with saline water followed by subsequent canal irrigations prevented the build up of soluble salts concentration in the root zone beyond the permissible limits.

5.5.2.4 Effect on Crop Yields

Table 20 gives the seasonal yields of wheat and cotton by treatments. The yield of wheat was higher under T₁. These higher rates showed increasing trend by crop seasons and varied from 2.21 to 2.69 ton/ha from *Rabi* 1994-95 to 1996-97. The lower yields (1.33 to 1.85 ton/ha) were under the treatment of one irrigation of saline drainage water in addition to the canal irrigations. *Rabi* 1996-97 was the exceptional season projecting the higher yield by treatments.

Cotton yield was higher (1.61 to 2.27 ton/ha) under T₁ while the lower yield were under T₃ (1.20 to 1.44 ton/ha) and T₄ (1.21 to 1.44 ton/ha). The yield of cotton did not reflect any variation between T₂ and T₃ in *Kharif* 1996 and 1997.

Table 20: Crop Yields by Treatment

Crop/Season	Treatment			
	T ₁	T ₂	T ₃	T ₄
(tons/ha)				
Wheat				
<i>Rabi</i> 1994-95	2.21	1.89	1.51	1.33
<i>Rabi</i> 1995-96	2.55	1.96	1.80	1.69
<i>Rabi</i> 1996-97	2.69	2.24	2.16	1.85
Cotton				
<i>Kharif</i> 1995	1.61	1.28	1.20	1.21
<i>Kharif</i> 1996	2.21	1.66	1.44	1.41
<i>Kharif</i> 1997	1.75	1.64	1.44	1.44

5.5.3 Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production

Under this study four treatments were used. T₁ was canal water irrigation, T₂ as saline drainage water, T₃ as mixed irrigation (1:1) and T₄ was alternate irrigation with canal water and saline drainage water. The results are discussed below:

5.5.3.1 Effect on Soil Salinity and Sodicity

Table 21 gives the results regarding EC_e , pH and SAR of soil. The canal irrigation (T_1) decreased the EC_e within a range of 2.2 to 27.1 percent from 0 to 100 cm depth. Under the mixing (1:1) of canal water and saline drainage water, there was a little decrease of EC_e , ranging from 0.4 to 9.6 percent. The saline drainage water (T_2) caused a very high increase in EC_e varying from 88.5 percent to 156.4 percent at 100 cm depth. The other treatment that resulted in the increase of EC_e (27.2% to 38.4%) was the alternate irrigation with saline drainage water and canal water.

The soil pH decreased under the treatments of T_1 and T_3 . The maximum decrease was 5.4 percent (25-50 cm depth) under T_1 and 1.6 percent (50-75 cm depth) under T_3 . Whereas, the other two treatments (T_2 and T_4) resulted in increased pH. This increase was more evident (12.6%) at 0-25 cm depth under T_2 and at 75-100 cm depth (7.3%) under T_4 .

The canal water irrigation showed the maximum reduction (21.6%) in SAR at 75-100 cm depth. The treatment of mixing water (T_3) also resulted in the decrease of SAR by 8.5 percent at 75-100 cm depth. However, the value of SAR showed its maximum increase of 33.5 percent (25-50 cm depth) under T_2 (saline drainage water). The increase in SAR was 20.7 percent at the same depth under the treatment of alternate irrigation.

Table 21: Soil EC_e , pH and SAR Trend under the Treatment

Soil Depth (cm)	Initial	T_1 (Final)	T_2 (Final)	T_3 (Final)	T_4 (Final)
EC_e ($dS\ m^{-1}$)					
0-25	3.05	2.50	5.76	2.88	3.88
25-50	3.17	2.31	6.13	2.93	3.91
50-75	3.11	2.61	6.77	2.81	4.21
75-100	2.71	2.65	6.95	2.70	3.75
pH					
0-25	7.27	7.20	8.19	7.25	7.68
25-50	7.40	7.00	7.63	7.30	7.66
50-75	7.37	7.20	7.88	7.25	7.78
75-100	7.30	7.20	8.00	7.25	7.83
SAR					
0-25	7.91	7.50	10.26	7.63	8.41
25-50	7.72	7.55	10.31	7.99	9.32
50-75	8.90	7.96	11.53	8.56	9.67
75-100	9.45	7.41	11.37	8.65	9.18

5.5.3.2 Effect on Crop Yields

Table 22 reveals that higher yield of wheat were achieved under T_1 . By crop seasons these rates were more or less consistent and varied from 3.64 ton/ha (*Rabi* 1993-94) and 3.81 ton/ha (1994-95) with 3.75 ton/ha in 1992-93. The lower yield of wheat were under T_2 (irrigation with saline drainage water). Among the crop seasons, these rates varied from 2.75 ton/ha (1993-94) to 2.94 ton/ha (1992-93) showing a consistent trend. The wheat yield under T_3 (mixed irrigation) and T_4 (alternate irrigation with canal water and saline drainage water) however, did not reflect a notable variation between them.

The trend of cotton yields by treatment was not different from that of wheat. The canal irrigation gave the higher yield varying from 2.24 ton/ha (*Kharif* 1995) to 2.66 ton/ha (*Kharif* 1994). Eventually, there was no variation in cotton yields between first two *Kharif* seasons. The cotton yield under the treatments of mixed irrigation (T_3) and alternate irrigation with canal water and saline drainage water (T_4) also did not show much variation between them. It is also evident that there was a trend of lower yields of cotton in *Kharif* 1995 than that in the other two *Kharif* seasons.

Table 22: *Yields of Wheat and Cotton as Affected by Various Treatments*

<i>Crop/Season</i>	<i>Treatment</i>			
	T_1	T_2	T_3	T_4
<i>Wheat</i>				
<i>Rabi</i> 1992-93	3.75	2.94	3.40	3.09
<i>Rabi</i> 1993-94	3.64	2.75	3.12	2.99
<i>Rabi</i> 1994-95	3.81	2.84	3.38	3.38
<i>Cotton</i>				
<i>Kharif</i> 1993	2.61	1.56	2.22	1.94
<i>Kharif</i> 1994	2.66	1.77	2.31	2.25
<i>Kharif</i> 1995	2.24	1.44	1.97	1.83

Chapter 6

MAIN FINDINGS

This chapter delineates the salient findings derived from the results on each of completed soil reclamation research studies. The format of the chapter is the same as adopted in general for the present report.

6.1 Soil Reclamation by Organic, Inorganic Material, Physical and Cultural Practices

6.1.1 *Reclamation of Saline-Sodic Soils by Gypsum under Tile Drainage System*

For reclamation of medium textured saline-sodic soil, gypsum was used at different requirement levels. Beseem-rice rotation was practised for three years under canal water irrigation. The main findings in relation to soil status and crop yields are outlined below:

- The gypsum requirement (GR) of 100 percent was found more effective in reducing the soil salinity and sodicity. Based on the average of all depths, EC_e , SAR and ESP were decreased by about 80 percent each while pH by 7 percent only over the study period;
- Rice due to its high water requirement was the better reclamation than berseem during the reclamation process. Its high delta helped in leaching of salts and dissolving gypsum effectively;
- Berseem was also effective in reducing soil salinity/sodicity to an extent with the replication of 50 percent GR; and
- Under 100 percent GR, the higher yield of rice (3.0 ton/ha) in the later two *Kharif* seasons (1990 and 1991) were achieved. GR 75 percent also showed comparable yields (2.9 ton/ha) of rice in the above said crop seasons.

6.1.2 *Comparative Effect of Inorganic, Organic and Biological Reclamation of Saline-Sodic Soils under Tile Drainage*

To reclaim the saline-sodic soil, the amendments including varying GRs, kallar grass and press mud levels were applied to berseem and rice crops. The findings include the following:

- The GR of 50 percent was the most effective amongst the treatments in reclaiming the saline-sodic soil;
- Relatively, 50 percent GR decreased the EC_e , pH and SAR by 85, 17 and 63 percent, respectively after completion of the study;
- As reclamation, press mud and kallar grass were also found effective in reclaiming the studied soils but took more time to reclaim the same soil;
- Rice gave the higher yields of 2.92, 2.89 and 3.01 ton/ha under 100 percent GR, 50 percent GR and press mud at the rate of 50 tonnes per hectare, respectively. Press mud @ 25 tonnes per hectare and other combinations of GR and press mud responded rice yield less than 2.0 ton/ha; and

- Berseem gave maximum yield of 41.4 ton/ha under 50 percent GR and 29.0 ton/ha under 100 percent GR. The remaining treatments resulted in yield varying from 16 to 20 ton/ha.

6.1.3 Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System

The tested cultural practices included the ploughing (number and depth), coupled with levelling and high seed rate for wheat and cotton sown on ridges. Cotton and wheat were the experimental crops each for three respective crop seasons. The findings related to the effects on soil properties and crop yields are given below:

- Deep ploughing (50 cm) coupled with levelling was more effective for reclaiming the soil. This treatment resulted in a considerable reduction of EC_e of soil at all the soil depths. The reduction of EC_e was maximum (49%) at 30-60 cm depth;
- The reduction in pH and SAR was also of higher magnitude under the deep ploughing with levelling at all soil depths. The maximum reduction of pH was 10 percent at upper soil depth. While the maximum reduction in SAR was 33 percent at lower depths;
- The treatment of three additional ploughings over the recommended tillage operations was also found effective in decreasing the salinity and sodicity but at less rate;
- Higher cotton yields were recorded with deep ploughing/levelling followed by sowing of cotton on ridge. Accordingly, cotton highest yield, on an average was 2.6 ton/ha for deep ploughing and a yield of 2.2 ton /ha by sowing cotton on ridge; and
- Average wheat yield was the highest (2.85 ton/ha) under the deep ploughing/levelling. The high wheat seed rate (50 kg/ha) also produced some higher yield (2.25 kg/ha).

6.1.4 Improvement of Salt Affected Lands through Continuous Cropping

The improvement of salt affected land was assessed through continuous cropping with rotations of berseem-sorghum, mustard-cluster beans, barley-sesbania and alfalfa-pearl millet. The recommended inputs for these crops were applied. The findings derived from the results are given below:

- Barley-sesbania crop rotation was the most effective for improving saline soil and increasing organic matter contents;
- The above mentioned crop rotation resulted in decreasing of EC_e of soil at the all depths. Particularly, in the upper layer of the soil, the reduction of EC_e was the maximum (41% over the initial value). The next rotation causing significant reduction (33%) in EC_e , was the berseem-sorghum;
- Green manuring especially of *sesbania* under continuous cropping proved to be highly effective in the reduction of EC_e , pH and ESP; and
- The harvested crops of barley, sorghum and millet did not reflect any consistent trend of yields. Mustard yield however, showed some persistent increase (0.02 to 0.04 ton/ha) by crop seasons. The variation in yields of the experimental crops were probably due to the moderately saline soil and particularly shortage of irrigation water during the study period.

6.2 Biological Reclamation of Saline and Saline-Sodic Soils

6.2.1 *Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodders*

The reclamation of calcareous saline-sodic soil was experimented by cultivation of the fodders twice in the respective crop seasons. The findings are summarized below:

- The fodder crops decreased the soil salinity and sodicity by varying extent. However, amongst them sorghum proved to be the most effective for the biological reclamation. The EC_e was decreased to the maximum level of 56.4 percent by sorghum cultivation. Maize and Sudan grass reduced the EC_e relatively equally, (39.2% and 40.1%). The higher reduction of pH (8.5%) SAR (41.3%) and ESP (45.7%) was also under sorghum cultivation. Maize and kallar grass were the next crops to cause the reduction in EC_e and SAR thus helped reclaimed the soil biologically;
- The yield of maize, sorghum and Sudan grass projected an increasing trend from the first to the second crop in the three *Kharif* seasons (1991 to 1993); and
- The net increase in yield rates of maize, sorghum and Sudan grass was 47, 92 and 53 percent, respectively from each second crop over the first crop.

6.2.2 *Reclamation of Saline-Sodic Soils by Rice Husk*

Different weights of rice husk were applied as calculated from the percentage of weight of 15 cm soil depth. These weights were 272 kg (0.1%), 545 kg (0.2%) and 1090 kg (0.4%). The findings are given below:

- The use of rice husk for soil reclamation was found very productive. The rice husk decreased the soil EC_e , pH and ESP at both the soil depths (0-15 cm and 15-30 cm);
- Amongst the applied weights of rice husk, the maximum weight of 1090 kg caused the highest reduction of EC_e (30-42%), pH (5-6%) and ESP (49%). The magnitude of reduction of these parameters was directly related to the amount of rice husk. The increase in organic matter was the maximum at 0-15 cm depth under the maximum applied weight of rice husk;
- The rice husk increased the organic matter, improved the porosity and water holding capacity of the soil. These variables ultimately helped the leaching down of the soluble salts;
- The yields of cotton and wheat crops were prominently higher in their respective second seasons (*Kharif* 2000 and *Rabi* 2000-2001). The yields of cotton were the highest (720 and 920 kg/ha) with 0.4 percent applied rice husk. Similarly, 0.4 percent applied husk resulted in the highest wheat yield rates (1750 and 1990 kg/ha), in the two *Rabi* seasons; and
- Amongst the remaining treatment levels, the application of 0.2 percent rice husk resulted in the higher yields of cotton (0.68 and 0.86 ton/ha) and wheat (1.15 and 1.69 ton/ha).

6.2.3 Biological Reclamation of Highly Saline-Sodic Soils

The effectiveness of the biological reclamation was experimented with the crop rotations of rice-berseem and Jantar-berseem in addition to kallar grass, against fallow land. The findings are as follows:

- The biological reclamation of saline-sodic soils was more effective by rotational cultivation of rice and berseem crops;
- Rice-berseem rotation resulted in about 82 percent reduction of EC_e in the upper soil layer (0-15 cm) followed by Kallar grass. Jantar-berseem rotation reduced the EC_e at lower depths. The reduction of pH was also high with rice-berseem rotation;
- The ESP was reduced by 42, 46, 34 and 29 percent, respectively at 0-15, 15-30, 30-60 and 60-90 cm depths;
- The yields of rice, Jantar and berseem reflected a progressively increasing trend, by respective crop seasons. The maximum yield rates were achieved in the last seasons of the crops. Accordingly, the yield of rice and jantar was 0.76 and 0.70 ton/ha (*Kharif* 1998), respectively; and
- The high yield of berseem in the last *Rabi* season (1998-99) were 1.32 and 1.10 ton/ha under the two rotations (rice-berseem and Jantar-berseem rotations).

6.2.4 Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage

This study involved: (i) cultivation of dhancha (jantar); rice and berseem; and (ii) continuous leaching without a crop cultivation. The following are the main findings:

- Amongst the methods studied, the rice-berseem crop rotation was found more effective to reclaim the strongly saline soil;
- The rice-berseem rotation decreased the EC_e at all soil depths. The maximum decrease in EC_e was about 35 percent at 0-15 cm depth. Other treatments causing decrease in the EC_e were jantar-berseem (25%) and continuous leaching without crop (24%);
- The reduction in pH was more in the top soil layer under the rotation of jantar-berseem. ESP of soil showed its reduction though under the applied methods at each soil depth but its highest decrease was found at the upper depth under the rotation of rice-berseem; and
- The yield of berseem under the two rotations were 1.0 and 2.0 ton/ha. Rice gave yield of 0.50 ton/ha.

6.2.5 Comparison of Physical and Biological Methods for Reclamation of Fine-Textured Saline Soils

This study involved wheat, cotton, berseem and jantar crops in relation to without and with deep ploughing to assess the comparative effects of physical and biological methods of reclamation. The findings are outlined below:

- The berseem and jantar cultivation with deep ploughing and their green manuring were found more effective in reclaiming the fine-textured soils;

- The deep ploughing for berseem and jantar contributed very effectively to decrease the EC_e in the upper layer (0-15 cm) of the soil;
- The main crops of wheat and cotton cultivation without deep ploughing was the least effective and at the maximum reduction in EC_e was 8.0 percent (30-60 cm depth);
- Wheat and cotton showed comparatively high yields with deep ploughing. Accordingly, the wheat yield varied between 1.62 and 2.78 ton/ha. Similarly, the cotton yield varied from 0.45 to 0.69 ton/ha; and
- Jantar and berseem with deep ploughing also gave high yields varying from 1.28 to 1.48 ton/ha and from 3.45 to 4.12 ton/ha, respectively.

6.3 Management of Reclaimed Lands

6.3.1 *Resalinization of Recently Reclaimed Lands*

Under the management of reclaimed lands, this study concentrated on wheat-cotton rotation after reclaiming the soil with three levels of gypsum requirement. The findings are given below:

- The soil tended to resalinize under the above crop rotation. Nevertheless, soil salinity remained below the threshold levels for these crops;
- The yields of the two crops were directly related to the levels of GR. Furthermore, crop yields were prominently higher in the second year (1992-93) after reclamation of the soil. The maximum yields of wheat and cotton in this year were 4.08 ton/ha and 1.93 ton/ha, respectively; and
- The yield of wheat under 100% GR showed a net increase of about 57 percent over that without gypsum. Similarly, cotton yield showed the relative increase of about 43 percent.

6.3.2 *Soil and Crop Management under Reclaimed Lands*

This study focused on the management of reclaimed land by sowing crop coupled with the fertilizer applications. Wheat and sorghum were the experimental crops. The findings are given below:

- The sowing of wheat and sorghum during specified time duration (seasonal) and the respective recommended doses of fertilizer helped in maintaining the salt balance in the root zone and achieving improved crop yields;
- The maximum reduction of EC_e was 11.0 percent at 0-15 cm depth on account of seasonal crop sowing and using the recommended doses of fertilizer. Late sowing/high fertilizer doses caused a little decrease in the EC_e . The maximum decrease in pH was about 5 percent at 0-15 cm depth under seasonal crop sowing/recommended fertilizers;
- Wheat yield was slightly higher (2.80 ton/ha) under seasonal crop sowing and with the recommended fertilizer doses. Other sowing periods/fertilizer levels gave low yields of 2.41 ton/ha (early crop/low fertilizer levels) and 2.00 ton/ha (late crop/high fertilizer levels); and
- Sorghum also gave the maximum yield (1.80 ton/ha) under the seasonal crop sowing with recommended fertilizer levels.

6.3.3 Tillage and Irrigation Effect on Movement of Individual Salts under Reclaimed Lands

This study was conducted for wheat and cotton rotation in relation to degrees of tillage operation combined with different levels of water consumptive use on land reclaimed through leaching. The findings are given below:

- The maximum degree of tillage combined with 125 percent consumptive use of water proved effective in maintaining salt balance in the root zone and obtaining high yield;
- The EC_e decreased under all treatments but maximum (21%) under the maximum tillage with 125 percent CU of water. The minimum tillage with 75 percent CU of water decreased the EC_e by 7 percent while under optimum tillage with 100 CU of water, EC_e decreased by 16 percent. On the contrary, there was considerable increase of 21 percent in EC_e on land without any amendment. The pH and ESP showed similar trends as of EC_e ;
- There was more accumulation of salts at all the soil depths under the control condition; and
- The yields of wheat and cotton were high under the treatment of maximum tillage with 125 CU of water. Cotton yield was 2.14 ton/ha in *Kharif* 1996 and 1.75 ton/ha in *Kharif* 1997.

6.4 Irrigation Practices Effect on Soil Salinity

6.4.1 Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton

Under this study, wheat-cotton rotation was experimented in relation to different irrigation levels expressed as water consumptive use of 75, 100 and 125 percent. The main findings are given below:

- The three levels of consumptive use of irrigation did not have notable effects on the soil salinity and the crop yields.
- The yield of wheat varied from 2.23 to 2.90 ton/ha under 75 percent CU, 2.30 to 3.01 ton/ha under 100 percent CU and 2.23 to 2.60 ton/ha under 125 percent CU of water.
- The average yield of cotton over three *Kharif* seasons varied between 1.12 and 1.97 ton/ha under 75 percent CU, between 1.14 and 2.53 ton/ha under 100 percent CU, while between 1.11 and 2.23 ton/ha under water CU of 125 percent.
- The highest water use efficiency of wheat (6.61 to 8.60 kg/ha-mm) was achieved under 75 percent. Whereas in case of cotton, CU of water 75 and 100 percent did not reflect any notable seasonal variation of water use efficiency. However, 125 percent CU of water showed low (1.61 to 3.25 kg/ha-mm) seasonal water use efficiency.

6.4.2 Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions

To reclaim the medium textured saline soil, the recommended irrigation deltas of cotton (55 cm) and wheat (45 cm), were added with estimated leaching fractions firstly to reduce the EC_e of soil to 8 dS m^{-1} and secondly to 4 dS m^{-1} . The findings are summarized below:

- The treatment of recommended levels of irrigation with the leaching fraction of reducing EC_e to 4 dS m^{-1} was more effective to reclaim the medium-textured saline soils;
- The above mentioned treatment resulted in the highest reduction of 70 percent of EC_e . There was also a progressive reduction (64%) of EC_e of soil under the leaching fraction of reducing the original EC_e to 8 dS m^{-1} and irrigation without applying the leaching fraction to the two major crops;
- The trend of reduction of pH, SAR and ESP values was similar to that observed for EC_e of the soil. The maximum decreased values of pH, SAR and ESP under the above said treatment were 11, 49 and 55 percent, respectively; and
- The high yields of cotton and wheat were obtained under the leaching fraction applied to reduce the EC_e to 4 dS m^{-1} coupled with the recommended deltas of irrigation for the crops. Accordingly, cotton yield varied between 1.03 and 1.15 ton/ha.

6.4.3 Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soils

The study concentrated on the irrigation levels (consumptive use of water) in relation to fertilizer NPK nutrients applied to wheat and cotton crops. The findings are given below:

- The 100 percent CU of water (375 mm for wheat and 550 mm for cotton) with 247-124-0 kg/ha NPK and 371-186-72 kg/ha of NPK fertilizers application, respectively showed positive effects on soil salinity/sodicity of moderately saline-sodic soil. There was a better response in terms of crop yields by the treatment of 100 percent CU of water combined with the lower level of NPK fertilizers (247-124-0 kg/ha) as compared to other treatments;
- EC_e of soil decreased (23%) particularly at 0-15 cm depth under 100 percent consumptive use coupled with NPK fertilizers of 247-124-0 kg/ha. The other irrigation treatments were not helpful for reducing the EC_e rather increased it by varying magnitude at various soil depths;
- In case of SAR, 100 percent CU of water with NPK fertilizer of 247-124-0 kg/ha, resulted in its maximum reduction of 31 percent at 0-15 cm depth. While the 100 percent CU of water with NPK fertilizers of 371-186-72 kg/ha caused a decrease of 3 percent only in SAR;
- The yield of wheat was comparatively high under the 100 percent CU of water with 247-124-0 NPK kg/ha fertilizers application. Wheat yield rate varied from 1.91 to 2.35 ton/ha. At the same time, yield rates of wheat achieved under 100 percent CU of water with higher NPK fertilizers (371-186-72 kg/ha) were also higher (1.75 to 2.19 kg/ha) and comparable with that responded by 100 percent CU of water with lower NPK fertilizers level; and
- The trend of cotton yields was the similar to that of wheat. High yield of 0.73 to 2.25 ton/ha were obtained under 100 percent CU of water with lower level of NPK fertilizers.

6.5 Saline and Drainage Water Use for Crop Production

6.5.1 Crop Production with Saline Drainage Water

This study concentrated on use of saline drainage water (EC of 3.0 dS m⁻¹) and its leaching with canal water (EC of 0.4 dS m⁻¹). The main findings are as follows:

- The saline drainage water had serious adverse effects on soil properties and caused considerable decrease of crop yields. However, applying a leaching fraction of 15 percent of canal water, the soluble salts were leached down. The exclusive use of saline water increased the soil EC_e by 87 percent but under 15 percent leaching the EC_e was increased by 25 percent. Saline drainage water resulted in an increase of 9 percent in pH value but with 15 and 20 percent leaching fractions, it was 5 percent each. SAR increased by about 9 percent under saline drainage water use and 5 percent with 15 percent leaching fraction. Similarly, ESP increased by about 12, 5 and 6 percent under saline water, 15 percent leaching and 20 percent leaching fraction, respectively;
- The cotton yield was low during *Kharif* 1989 under all the irrigation waters. However, it was the lowest (0.44 ton/ha) under 20 percent leaching fraction; and
- The wheat yield showed no prominent variation between the treatments of 15 percent leaching (4.14 to 4.95 ton/ha) and 20 percent leaching (4.17 to 4.83 ton/ha), during the three *Rabi* seasons. However, the exclusive use of saline drainage water showed low yield (3.10 to 4.66 ton/ha).

6.5.2 Management of Poor Quality Irrigation Water

One saline water irrigation of 75 mm was tested in relation to the different elapsed times after sowing of wheat and cotton crops, while all other irrigations were applied with canal water. The findings are summarized below:

- The deteriorating effects of high saline water were not evident, when used for one irrigation after four weeks of sowing of wheat and cotton;
- After canal irrigation to wheat, EC_e was decreased when one irrigation of saline water was applied to wheat after 4 weeks of sowing. However, EC_e was increased slightly when one irrigation with saline water was applied to cotton after four weeks of sowing. The soil pH was also decreased under the saline water irrigation after four weeks of sowing of wheat and cotton. The SAR did not reflect any adverse effect under the application of one saline water irrigation at four weeks of sowing; and
- The yields of wheat and cotton were prominently higher with the application of all canal irrigations. The second treatment of one irrigation of saline water after four weeks of sowing also showed the high yield of wheat (1.89 to 2.24 ton/ha) and cotton (1.28 to 1.64 ton/ha). The treatments of one saline water irrigation after 7 weeks and 10 weeks showed no notable variation of yield between them.

6.5.3 Conjunctive Use of Canal Water and Saline Drainage Effluent for Crop Production

The effects on soil salinity and cotton yield were determined in relation to the conjunctive use of canal water and saline drainage water under mixing and alternate irrigation uses. The main findings are given below:

- The exclusive use of saline drainage water had the most adverse effect on soil properties followed by alternate irrigation of canal and drainage water;
- Under the mixed irrigation of canal and saline drainage water, there was a small increase in the EC_e of soil, varying from 0.4 to 9.6 percent. The alternate irrigation with canal and saline drainage water resulted in a considerable increase in EC_e (27 to 38%). The exclusive use of saline drainage water caused a very high increase (88 to 156%) in the EC_e of soil. However, the canal water irrigations decreased the EC_e by 2.2 to 22.1 percent;
- The SAR was decreased by 8.5 percent under mixed irrigation at 75-100 cm depth. Whereas, the alternate irrigation of canal and saline drainage water showed maximum increase of 20.7 percent at 25-50 cm depth. The exclusive use of saline drainage water resulted in a high increase in SAR of 33.5% at 25-50 cm depth of soil. On contrary, canal water decreased the SAR at all depths and maximum decrease was 21.6 percent (75-100 cm depth); and
- Wheat yield was the highest (3.64 to 3.81 ton/ha) under the canal irrigation and the lowest (2.75 to 2.94 ton/ha) under the use of saline drainage water. Wheat under the mixed irrigation from canal and drain water showed high yield (3.12 to 3.40 ton/ha). The alternate irrigation from canal and drainage water showed the yield (2.99 to 3.48 ton/ha) comparable with that under mixed irrigation.

Chapter 7

RECOMMENDATIONS

In the context of reclaiming the salt affected soils and ultimately increasing the irrigated agricultural production on sustainable basis, the research should provide the economically workable methods to reclaim the deteriorated agricultural land. Particularly, in the context of workability and the effective management of saline soils and saline water, the recommended methods and procedures need to be easier and more accessible to practise by the farming community.

The present chapter gives a combined delineation of the recommendations drawn under the deployed methods of soils reclamation and saline water management.

7.1 Soil Reclamation by Organic, Inorganic Materials, Physical and Cultural Practices

- Medium textured moderately saline-sodic soil can be reclaimed by applying 100 percent gypsum requirement for 30 cm soil depth, adopting rice-berseem crop rotation. However, gypsum use should be avoided for reclaiming gypsiferous saline-sodic soils as the same may be achieved through a continuous (three years) rotation of rice-berseem.
- Press mud can be a cost-effective alternative to gypsum for reclaiming saline-sodic soils though it takes more time for soil reclamation.
- Leguminous crops can be cultivated to restore the soil fertility of salt affected land and improve the other related physical conditions.
- The crops such as sesbania, cluster beans and berseem should be cultivated for green manuring during reclamation process.
- Medium textured, well drained and moderately saline soils can be reclaimed through wheat-cotton crop rotation applying the conventional delta of water.
- Deep ploughing, high seed rates for wheat, and sowing of cotton on ridges is recommended for soil reclamation when the water is limited for leaching.
- Bed and furrow method of planting crops should be promulgated particularly in saline areas.

7.2 Biological Reclamation of Saline Sodic Soil

- For reclaiming the calcareous saline-sodic soils, low cost biological reclaims including sorghum, maize and Kallar grass can be used under local conditions.
- The saline land should be kept under continuous cropping and should be kept fallow for long period.
- Rice husk can be used to reduce the salinity and sodicity. The application rates of 0.2 and 0.4 percent of rice husk are quite good for soil reclamation purposes.
- Highly saline-sodic soils can be reclaimed especially through rice-berseem crop rotation. Sesbania and Kallar grass are the alternate.

- Strongly saline soils can also be reclaimed quite effectively by adopting the rice-berseem crop rotation.
- Fine-textured soils can be reclaimed through the cultivation of Jantar and berseem, under deep ploughing and green manuring.
- On lands having less sodicity problem, the preference should be given to biological reclamation as compared to chemical methods.

7.3 Management of Reclaimed Lands

- Resalinization of reclaimed land can be checked, under wheat-cotton rotation, while applying a leaching fraction with the respective recommended irrigation.
- In a reclaimed land, a favourable salt balance in root zone is achievable under an overall management of soil-water-crop *e.g.* wheat sowing at proper time coupled with recommended levels of fertilizer.
- The maximum tillage coupled with a 125% consumptive use of water, under a cotton-wheat rotation can be used and advocated for lands reclaimed recently.

7.4 Irrigation Practices Effect on Soil Salinity

- With the application of 75 percent water consumptive use to wheat prominently, high water saving can be achieved without any notable adverse effect on soil status and crop yields. Leaching of soluble salts to the lower layers of soil can be practised, depending on the availability of irrigation water.
- Reclamation of moderately saline soils of medium textured can be carried out (cotton and wheat crops), through the recommended irrigation levels coupled with a leaching fraction.
- An affective reduction of soil salinity and sodicity in wheat and cotton crops can be achieved through the application of 100 percent water consumptive use combined with 247-124-0 kg/ha of NPK fertilizers.

7.5 Saline and Drainage Water Use for Crop Production

- Saline drainage effluent (EC 3.0 of dS m^{-1}), should not be used for cotton and wheat without adding 15 percent leaching fraction (canal water) as it causes very serious damage to soils.
- Saline water (drainage effluent or tubewell), should not be used for irrigation purposes on saline land, for longer period even under drainage measures. A well defined management strategy for saline water use needs to be drawn under water shortage condition.
- Saline water (EC of 3.0 dS m^{-1}), may be used once for irrigation to wheat and cotton while other requisite irrigations to the crops should be applied from canal water.
- Canal water and saline drainage water in 1:1 may be used when shortage of water is not acute.
- The modes of conjunctive use of canal and saline water, including mixing and alternate irrigation, can be used for wheat and cotton crops supported by other useful practices (bed and furrow planting, *etc.*).

REFERENCES

- Abdullah, M, M. Akram, A.D. Khan and R.H Qureshi (1990). International Water Resource Management by Plants Under Various Root Environmental Stresses with Special References to Kallar Grass. Proceedings of *National Seminar on Water Resources, Development and its Management in Arid Areas*, Organized by PCRWR Quetta, Oct. 6-8, 1990. pp.146-162.
- Abrol, I. P. and D. R. Bhumbla (1979). Crop Response to Different Gypsum Applications in Highly Sodic Soil and Tolerance of Several Crops to Exchangeable Sodium under Field Conditions, *Soil Science Journal*. 127(2): 79-85.
- Ahmad, Ch. N. and N. Ahmad (1987). Increased Crop Production through Conjunctive Use of Surface and Groundwater. Proceedings: *International Symposium on Conjunctive Use of Surface and Ground Water for Agriculture*, held at CWERE, Lahore. pp.429-454.
- Ahmed, R. (1991). Gypsum as Soil Amendment. *Journal of Drainage and Reclamation*, 3(1): 30-35.
- Akhter, J. Waheed R.A, Malik, and Haq, M.I. (1988). Effect of Kallar Grass Growth on Water Transmission Characteristics of Salt Affected Lands Managing Soil Resources. Proceedings of *First National Congress on Soil Science*, Lahore. pp.393-400.
- Ansari, R. and A.N. Khanzada (1995). Biological Amelioration of Saline Soils, Proceedings of National Workshop on *Drainage System Performance in Indus Plain and Future Strategies*, January 28-29, (Vol.II) Drainage and Reclamation Institute of Pakistan, Tando Jam. pp.217-222.
- Arad, N. and P. Gluectern (1981). *Desalinitation - A Review on Technology and Cost Estimates, Salinity in Irrigation and Water Resources*, Marcel, Dekhar, Inc. New York. pp.325-362.
- Aron, I. (1972 a.). *Crop Production in Dry Regions*, Leonard Hill, London. Vol.1. pp.424-429.
- Awan, N.M. (1989). A Review of Waterlogging and Salinity Control Strategy in Pakistan, *Journal of Drainage and Reclamation*, 1(1):8-19.
- Aziz, A. H. (1980). Salt Affected Soils in Afghanistan: International Symposium on *Salt Affected Soils*, Karnal. pp.48-55.
- Bresler, E. (1981). *Irrigation and Soil Salinity, Salinity in Irrigation and Water Resources*, Marcel Dekker, Inc., USA. pp.65-102.
- Chang, M.H. and A.M. Leghari (1995). Biological Reclamation of Saline-Sodic Soils by Sorghum, Maize and Sudan Grass Fodders, *Journal of Drainage and Reclamation*. 7(1&2): 30-36.
- Chaudhary, N. A. and Chaudhary A. R. (1990). Brackish Water Use for Field Crop Production, Proceedings of *ISMR Symposium* held at Islamabad, Nov. 12-14, 1990, Vol.III. pp.17-24.
- Chaudhry, M. R., Chaudhry B.A. and M.S. Rafiq (1990). Brackish Water Effects on Soil Salinity/Sodicity on Yield of Wheat and Sorghum, Proceedings of *ISMR Symposium* held at Islamabad, Nov. 12-14, 1990, Vol.III. pp.7-16.

- Chaudhry, R.A. and B.A. Sabir (1975). *Effect of Different Irrigation Levels on the Growth and Yield of Mexican Wheat*, MONA Publication No.40.
- Chhabra, R. (1996). *Soil Salinity and Water Quality*, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. 284p.
- Department of Agriculture Canada (1982). *Management of Saline Soils*, Publication 1624/E, Ottawa.
- Dhir, R.P, B.K. Shara and N. Singh (1980). Sodic Characteristics of the Highly Saline Water Irrigated Soils and the Importance of Sulphateion, Paper No.8.1, Presented in the *International Symposium on Salt Affected Soils*, held in Karnal, India.
- Dielman, P.J (1979). *East Khairpur Tile Drainage Project*. Revised Plan Report, WAPDA South ILACO.
- Haider, G., G. Hussain and M.S. Tabbasum (1977). Management of Reclaimed Lands. Proceedings of *Water Management in Agriculture*, Exxon Chemical Pak. Ltd. 1(1): 357-363.
- Hameed, A. and M.Q. Channa (1993). Use of Brackish Groundwater for Crop Production. Proceeding of *ISM-R Symposium*, Lahore 11-13. pp.1-12.
- Haroon, V.J.W. (1971). Quality of Irrigation Water, Limits of Use and Production of Long Term Effects, Irrigation and Drainage, Paper 7, Salinity Seminar, Baghdad, FAO, Rome. pp.117-135.
- Hussain, M. A. and M. Asghar (1985). Gypsum as Amendment for Saline-Sodic Lands, Proceedings of *Pakistan Engineering Congress Annual Session 1984-85*.
- Hussain, M. A. and A. Karmat (1989). Management of Saline-Sodic Soils, *Journal of Drainage and Reclamation*, 1(1): 58-67.
- Hussain, M. A. and M. Sadiq (1982). Effect of Fallowing and Cropping on Soil Salinization, *Engineering News*, (27): 122.
- Hussain, T., V. Trimmer and Akram H. (1990). Brackish Water Management Strategies for Crop Production. Proceedings of the *Indo-Pak Workshop on Soil Salinity and Water Management*. pp.369-382.
- Hussain, T.R. K. Aggarwal and K. Dosoky (1993). Leaching Studies in Salt Affected Soils of Iraq, Proceedings of *International Seminar on Water Resources Management*, Univ. of Engg. & Tech. Lahore.
- Indlkar, N. A. and K.J.V. More (1985). Inter Active Effect on Nature of Salinity and Nitrogen on Growth and Nutrient Composition of Sorghum, *India Society of Soil Science*, 33(3): 641-645.
- IWASRI (1987-88). *Register of Current Research on Waterlogging and Salinity*: Report No.4.
- IWASRI (1988). *Abstracts of WAPDA Research Studies on Waterlogging, Salinity and Water Management*, IWASRI Publication No.5, WAPDA, Lahore.
- Javaheri, P. (1975). *Salinity Problem in Iran: The Optimum Use of Water in Agriculture* (CENTO Scientific Programme), Panel Meeting, Report 17, NIAB, Faisalabad.
- Javid, M.A. and M.Q. Channa (1990). Brackish Groundwater for Cotton and Wheat Production in Lower Indus Basin, Proceedings of *ISMR Symposium* held at Islamabad, Nov. 12-14,

1990, (III): 1-6.

- Jerald, E.C.F.E, C. Olsen and L. S. Willardson (1977). Irrigation Water Quality Evaluation, *Journal of Irrigation and Drainage*, ASCE, 2(103): 155-170.
- Jurinak, J.J. and R.J. Wagenet (1981). *Fertilization and Salinity - Salinity in Irrigation and Water Resources*, Marcel Dekker, Inc., USA. pp.103-119.
- Khan, M.A. and M.U. Channa (1988). *Salinity, Fertility Interaction*, International Waterlogging and Salinity Research Institute (IWASRI) Report No.4.
- Kovda, V.A., B. Xaron and R. Shalhevat (1978). *Irrigation, Drainage and Salinity*. An International Source Book-FAO/UNESCO.
- MacDonald, (1965). *Principles and Criteria for Future Development, WAPDA Lower Indus Report*, Vol. 20-22, Hunting Technical Services Ltd., Lahore.
- Maskina, M.S., J.F.Power, J.W. Doran and W.W. Withlem (1993). Residual Effects of No Till Crop Residues on Corn Yield and Nitrogen Uptake. *Soil Science Society of America Journal*, 57(6): 1555-1560.
- Memon, M. I, and M. S. Khan (1995). Salinity Control and Land Reclamation by Physical, Chemical, Cultural and Biological Methods. Proceedings of *National Workshop on Drainage System Performance in Indus Plain and Future Strategies*, Vol.III. pp.32-35.
- MONA (1975 a). *Determination of Relation Between the Irrigation Delta and Fertilizer Rate for Wheat*, MONA, Annual Report 1974-75.
- MONA (1975 b). *Consumptive Use of Major Crops under Optimum Management Conditions*, MONA Annual Report 1974-75.
- More, S.D. and G. U. Malewar (1988). Salt Tolerance Studies in Sorghum and Cotton, *Journal of Mahar Shtra Agriculture University, India* 13(1):13-22.
- Muhammad, S. (1996). Soil Salinity, Sodidity and Waterlogging. *Soil Science*. National Book Foundation, Islamabad. pp.471-505.
- NIAB, (1987). *Biological Methods for Economic Utilization of Salt Affected Lands*. Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad.
- Niazi, M.H.K *et al.* (1990). A Review of Soil Salinity in Pakistan and Future Horizons: Proceedings on *Indo-Pak Workshop on Soil Salinity and Water Management*. pp.119-141.
- Parvez, W.A.R. (1992). *Performance of Maize, Sorghum and Sudan Grass under Moderate Saline Conditions*. M.Sc Thesis Submitted to Sindh Agriculture University, Tando Jam.
- Patrick, B.S. And Lauchii (1990). Growth Response and Mineral Nutrients Relation of Salt Stressed Sorghum, *Crop Science* 19(3): 87-96.
- Qureshi, R. H. (1977). Use of Saline-Sodic Water for Wheat Crop Production, Proceedings of *Water Management Seminar*, Exxon Chemical Pakistan Ltd. II: 329-336.
- Ramzan, M. C., A. Ihsanullah, A. Hamid and M.A. Javaid (1982). *Role of Inorganic and Organic Amendments in Reclamation of Saline-Sodic Soils*, Mona Publication No.124.
- Rauf, A, M. Shah A. Ghafoor and I. Hussain (1990). *Comparison of Biological, Physical and Chemical Reclaiming of Salt Affected Soils with Brackish Groundwater*. Second National Cong, *Soil Science Society of Pakakistan*. pp.35-42.

- Rauf, A., M. Aslam, J. Akhtar, and M.K. Abbasi (1989). Salt Tolerance Studies on Sorghum, *Pakistan Journal of Science*. (24):479-486.
- Rhodes, J.D. (1990). Salt Problems from Increased Irrigation Efficiency. *Advances in Irrigation and Drainage*. pp.427-435.
- Rhodes, J.D. (1992). Quality of Water for Irrigation, *Soil Science*, 113: 273-284.
- Rhodes, J.D. (1998). Evidence of the Potential to Use Saline Water for Irrigation. Proceedings of the *International Seminar on the Reuse of Low Quality Water for Irrigation*. Cario/Aswan. pp.16-21.
- Roy, R. N. and H. Braun (1988). Fertilizer Use and Plant Nutrition to Optimize Production and Economics. Managing Soils Resources. Proceedings of the *First National Congress on Soil Science*, Lahore: pp.161-172.
- Sabir, M.F. (1976). *Cotton Response to Water, Fertilizer and Plant Density in a SCARP Area*, MONA Publication No.45.
- Sadiq, M. (1992). *Review of Reclamation of Salt Affected Soils*, IWASRI Publication No.19.
- Sainberg, I. Keren R and H. Frenkel (1982). Response of Sodic Soil to Gypsum and Calcium Chloride Application. *Soil Science Society of America Journal*. 46(1): 113-117.
- Shakoor, A, M.B. Bhatti and Ch. Zafaruddin (1993). Performance of Different Millet Varieties for Grain and Fodder Production under Rainfed Conditions, *Pakistan Journal of Agricultural Research*, 4(3): 161.
- Shawky, M.E. and G.A. Saber (1992). Soil Salinity Prediction as Affected by Irrigation Water Quality. Proceedings of 5th IDW, Lahore-Pakistan, Vol.II. pp.6-11.
- Tahir, H. and A. Hamid (1978). Reclamation of Saline Sodic Soil by Sulfuric Acid and Rice Husk. Proceedings of the Workshop/Seminar on *Membrane Biophysics and Salt Tolerance in Plants*, University of Agriculture, Faisalabad. pp.97-103.
- Takumi, I. (1992). Some Exotic Fodder Crops for the Sindh, *Modern Agriculture*, 3(29): 4-8.
- Tripathi, B.R., and B. Pal (1980). The Quality of Irrigation Water and its Effect on Soil Characteristics and on the Performance of Wheat. *International Symposium on Salt Affected Soils*, Held In Karnal, India.
- U. S. Salinity Lab. Staff (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Handbook No.60, Washington D.C.
- Verma, K.S. and Abrol I.P. (1980). A Comparative Study of the Effect of Gypsum and Pyrites on Soil, Properties and the Yield of Rice and Wheat Grown on the Highly Sodic Soil. Proceedings of *International Symposium on Salt Affected Soils*, Karnal. pp.330-338.
- Wenberg, R.D. (1990). Drainage for Salinity Management in ISA. *Symposium on Land Drainage for Salinity Control in Arid and Semi-arid Regions*, (3): 55-64.