Research Report-4 2003

SALT AFFECTED SOILS AND THEIR RECLAMATION

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2003

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ISBN 969-8469-10-9

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Acknowledgement

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

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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 reclaiments 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 water-table 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 Bhmbla (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 fallowing 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:

- Resalinazation 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: T_1 = control; T_2 = 100 percent GR; T_3 = 75 percent GR; and T_4 = 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 (T_8), the experimental treatments were: 100 percent GR of the soil (T_1), 50 percent GR, (T_2), kallar grass (T_3), press mud at the rate of 50 ton/ha, (T_4), press-mud at the rate of 25 ton/ha, (T_5), press mud at the rate of 50 ton/ha + 50 percent GR (T_6) and press mud at the rate of 25 ton/ha + 50 percent GR (T_7).

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: T_1 as control; T_2 as three ploughing/leveling, T_3 as deep ploughing/leveling and T_4 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 m^2 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: T_1, berseem followed by sorghum; T_2, mustard followed by cluster beans; T_3, barley followed by sesbania and T_4, 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 alfalfla, 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 m^2 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: T_1, control (without crop); T_2, maize; T_3, sorghum; and T_4 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 (EC 0.45 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 EC 0.4 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 (EC > 15 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: T_1, control (wheat/cotton); T_2, deep ploughing (wheat/ cotton); T_3, berseem/dhancha and T_4, 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: T_1 for the seasonal crop (sowing at proper time), with recommended doses of fertilizer, T_2 for early crop with low doses of fertilizer, T_3 for late crop with high doses of fertilizer and T_1 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/m^2, 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: T_1 as control; T_2 for minimum tillage plus 75 percent consumptive use (CU) of crops; T_3 for optimum tillage plus 100 percent CU and T_4 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: T_1 = 75 percent CU of water; T_2 = 100 percent CU; T_3 = 125 percent CU of water were replicated four times under randomized block design on plot size of 10 x 12 m^2. 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 $T_{1;}$ 450 mm under T_2; and 562 mm under T_3. For cotton, the irrigation water was 412, 550 mm and 687 mm, under T_1, T_2 and T_3 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 (T_1 to T_4). However, 195 cm water of saline drainage was added with 29 cm of canal water under T_3 and 39 cm under T_4. Therefore, the total water applied was 224 cm under T_3 and 234 cm under T_4. 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 T_3 and T_4, respectively. Therefore, the total water applied to wheat was 190 cm and 198 cm under T_3 and T_4, respectively. The leaching fraction of canal water under T_3 and T_4 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: T_1 for canal irrigation, T_2 for one irrigation of 75 mm with saline drainage water at four weeks of sowing, T_3 and T_4 were of the same quantity and quality of saline drainage water as under T_2 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: T_1, canal water irrigation; T_2, saline drainage water use; T_3, mixed irrigation (1:1); and T_4, 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: T_1 as control; T_2, T_3 and T_4 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 gypsiferious 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 (T_2) during the three seasons, as compared to that of control (T_1) 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.

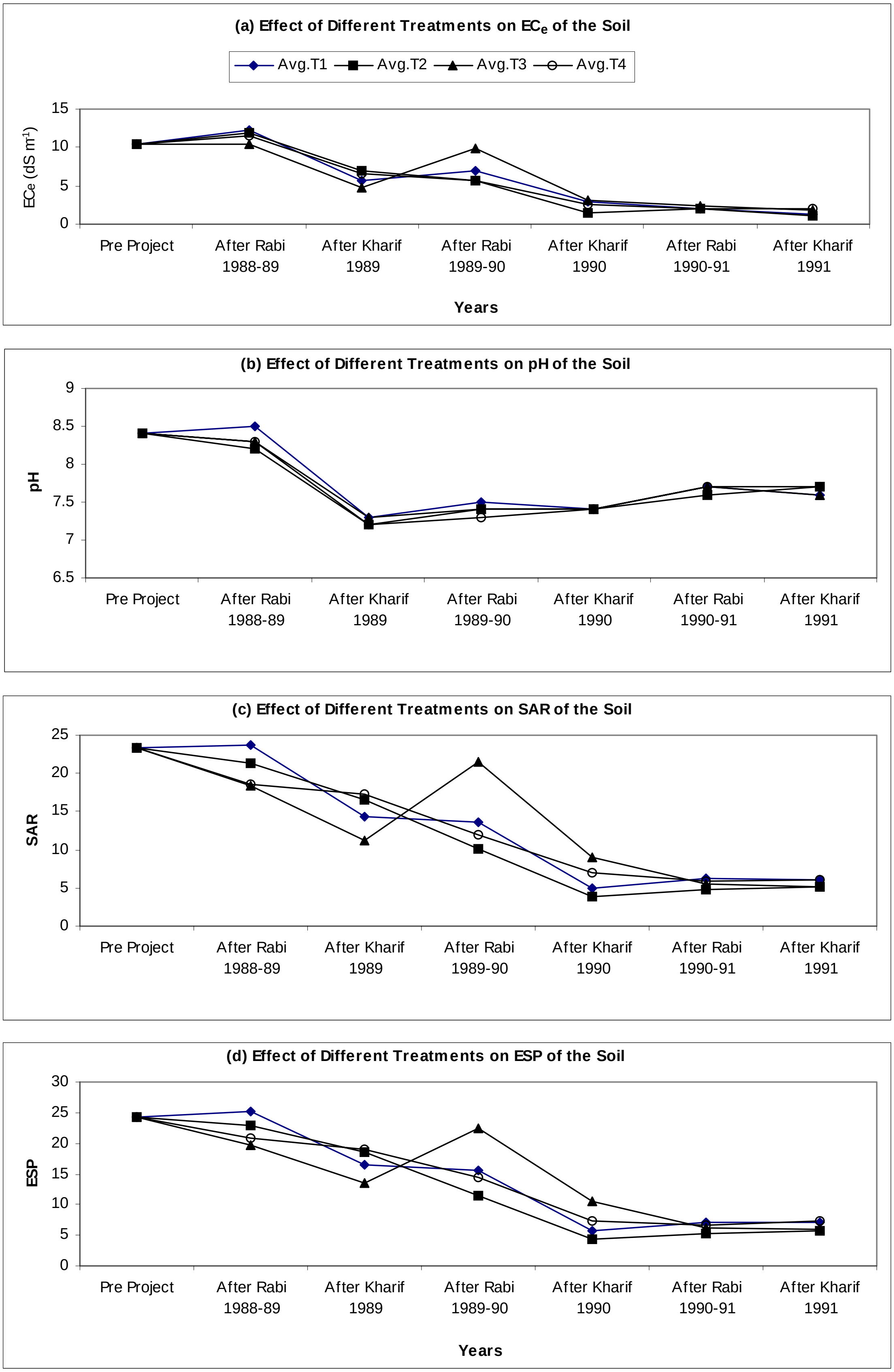


Figure 1: *Reclamation of Saline-Sodic Soil by Gypsum under Tile Drainage System*

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 extant 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*

(ton/ha)

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*

(ton/ha)

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).

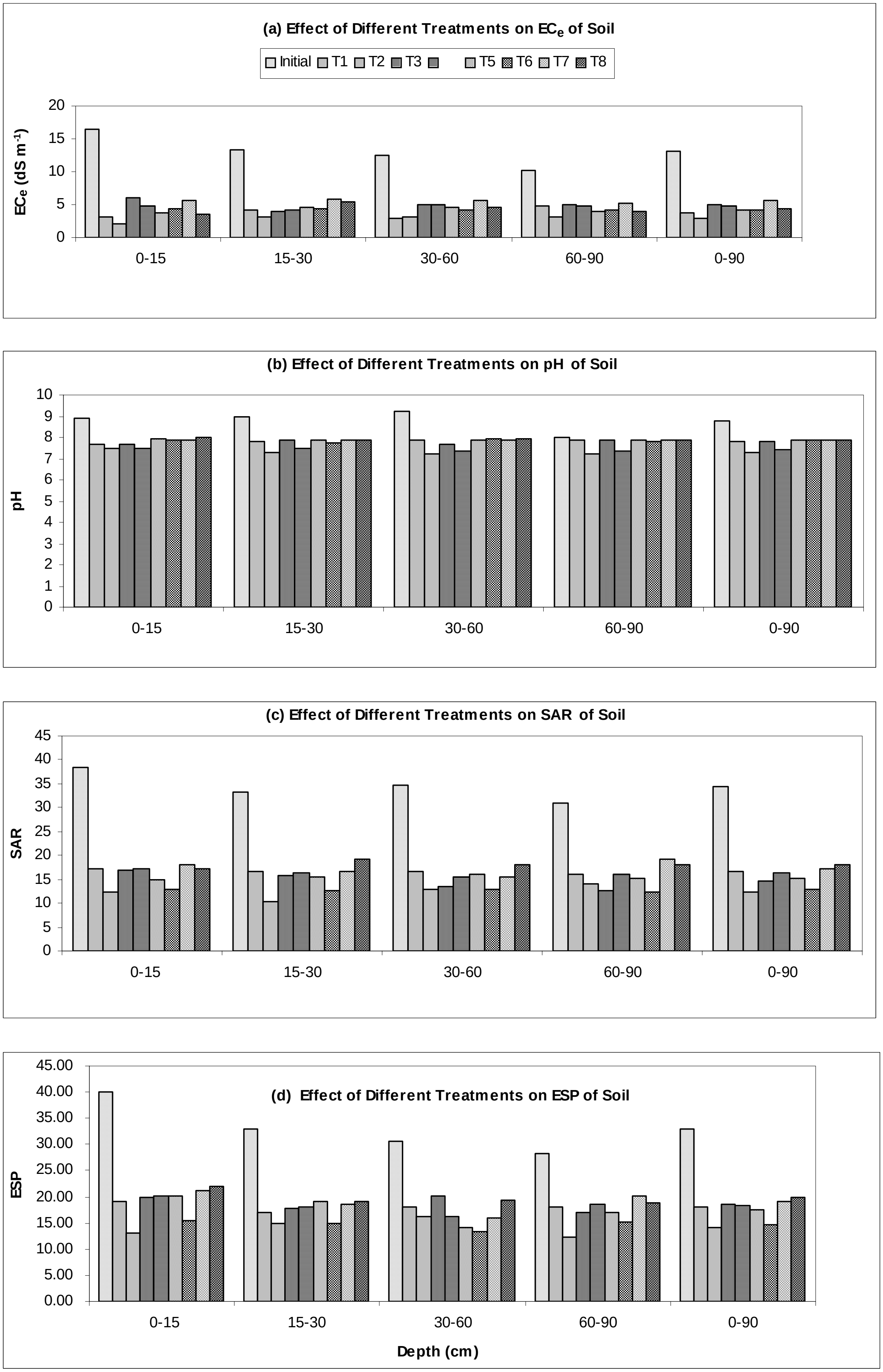


Figure 2: *Comparative Effect of Organic, Inorganic and Biological Reclamation*

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.

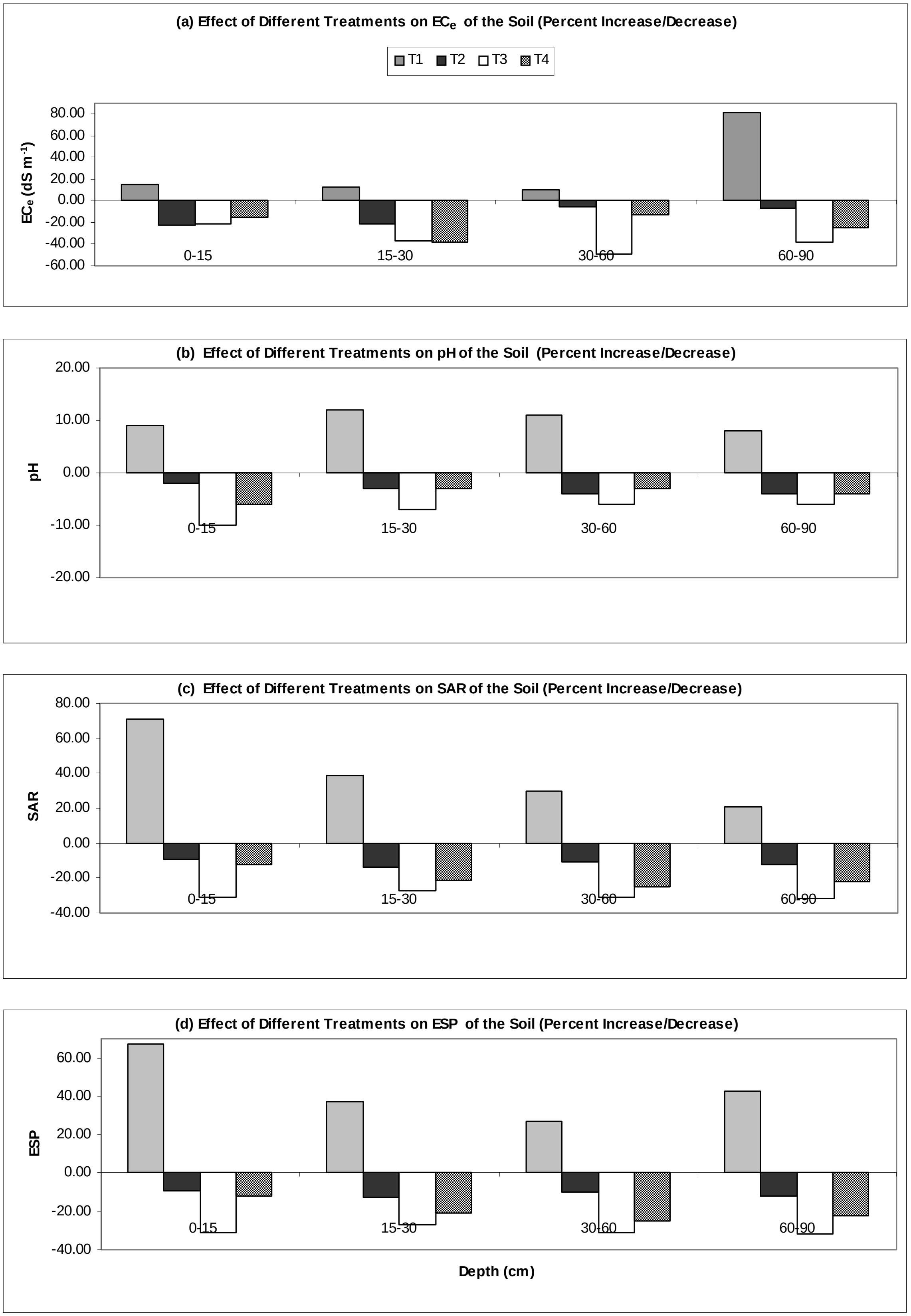


Figure 3: *Reclamation of Saline-Sodic Soils through Cultural Management under Tile Drainage System*

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

(ton/ha)

Treatment	**Cotton**		
	1996	*1997*	*1998*
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
		Wheat	
	1996-97	*1997-98*	*1998-99*
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: T_1, berseem-sorghum, T_2, mustard-cluster beans, T_3, barley-sesbania and T_4, 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 (T_3), resulted in the maximum reduction (40.8%) by EC_e at the soil depth of 0-15 cm. T_1 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, T_3 was found more effective for reducing pH than the other treatments (T_1, T_4 and T_2, in descending order).

The ESP was decreased under all the treatments and its maximum reduction was observed under T_3, at 0-15 cm depth. The other treatments in reducing the ESP were T_1, T_4 and T_2 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 (T_3 followed by T_1), was also prominent.

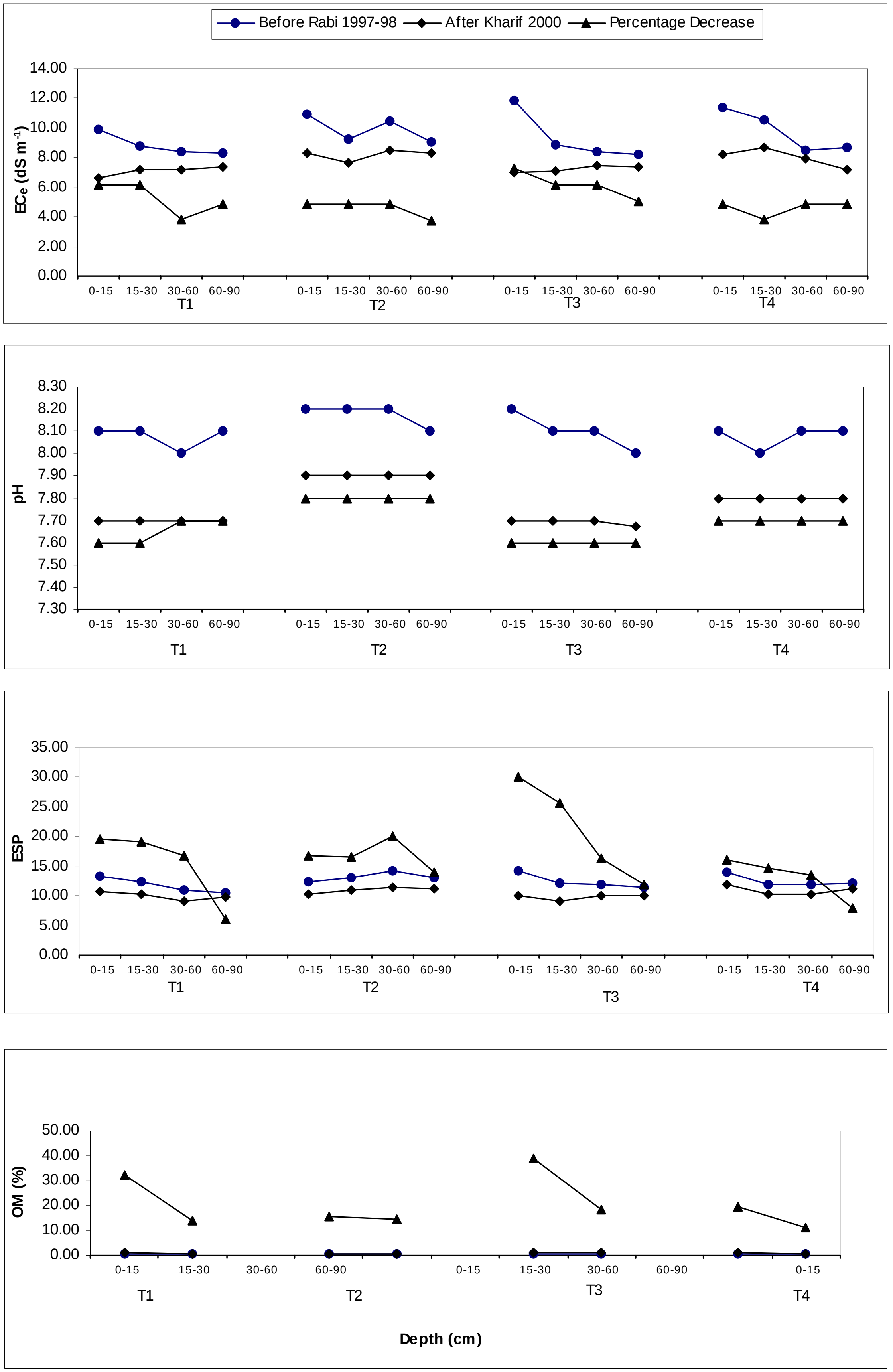


Figure 4: *Improvement of Salt Affected Lands through Continuous Cropping*

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*

(ton/ha)

Crop	*Season*		
Rabi	*1997-98*	*1998-99*	*1999-2000*
Mustard	0.02	0.03	0.04
Barley	0.90	1.47	0.53
Kharif	*1998*	*1999*	*2000*
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: T_1, control (without crop), T_2, T_3 and T_4 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 T_3 (sorghum cultivation). The other treatments of T_2 (maize cultivation) and T_4 (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 T_1 (control).

The pH value showed its higher decrease (8.46%) than that accounted for by T_2 and T_4. The pH of land without crop was increased by 15.14 percent. The maximum reduction in SAR (41.28%) occurred under T_3 (sorghum). The next treatment of T_4 (Sudan grass), showed the SAR reduction by 35.88 percent while under T_2 (maize), the SAR reduction was 9.71 percent. SAR under control condition (T_1) was increased by 14.30 percent. The value of ESP was decreased by 45.66 percent (maximum) under T_3 while T_4 and T_2 resulted in ESP reduction by 37.94 percent and 37.33 percent, respectively. Whereas, ESP under T_1, 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.

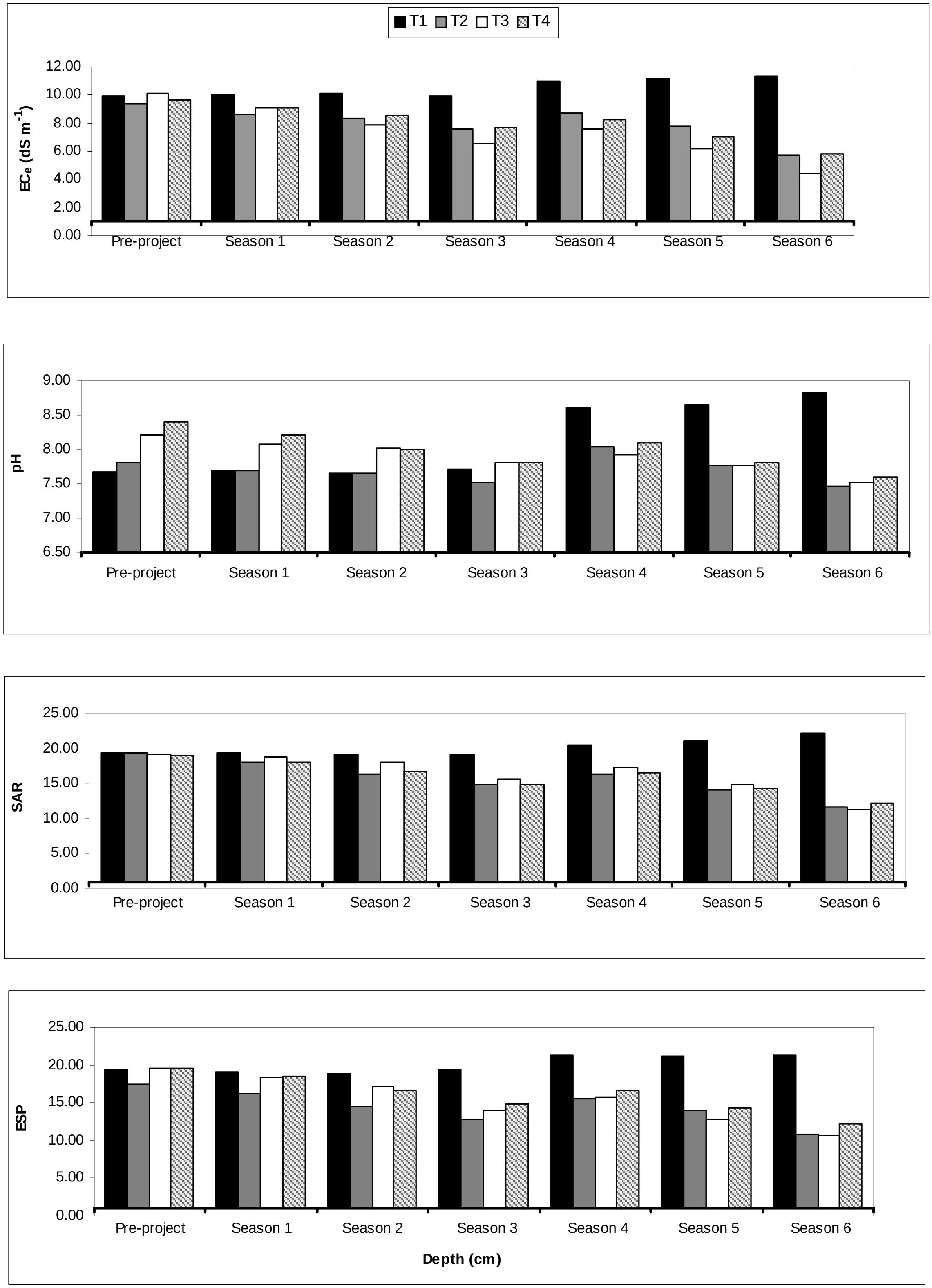


Figure 5: *Biological Reclamation of Calcareous Saline-Sodic Soils by Growing Sorghum, Maize and Sudan Grass Fodder*

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*

(ton/ha)

Crop	*Kharif 1991*		*Kharif 1992*		*Kharif 1993*		*Net Percent Increase (y / x)*
	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, T_1 was without rice husk, T_2 (at 0.1%) *i.e.* 272 kg, T_3 (at 0.2%) *i.e.* 545 kg and T_4 (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 (T_2 to T_4), at both the experimental soil depths of 0-15 and 15-30 cm. Relatively, under T_4 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 T_3 and then under T_2. 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 (T_1). 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 T_4 (maximum application of rice husk), the reduction of ESP was more than 49 percent at both the depths. On the contrary, under the T_1, 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 (T_4), in 0-15 cm layer of soil apparently, the other two treatments of rice husk (T_2 and T_3), the increase in organic matter was of the same order at both the soil layers. However, T_1 (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.

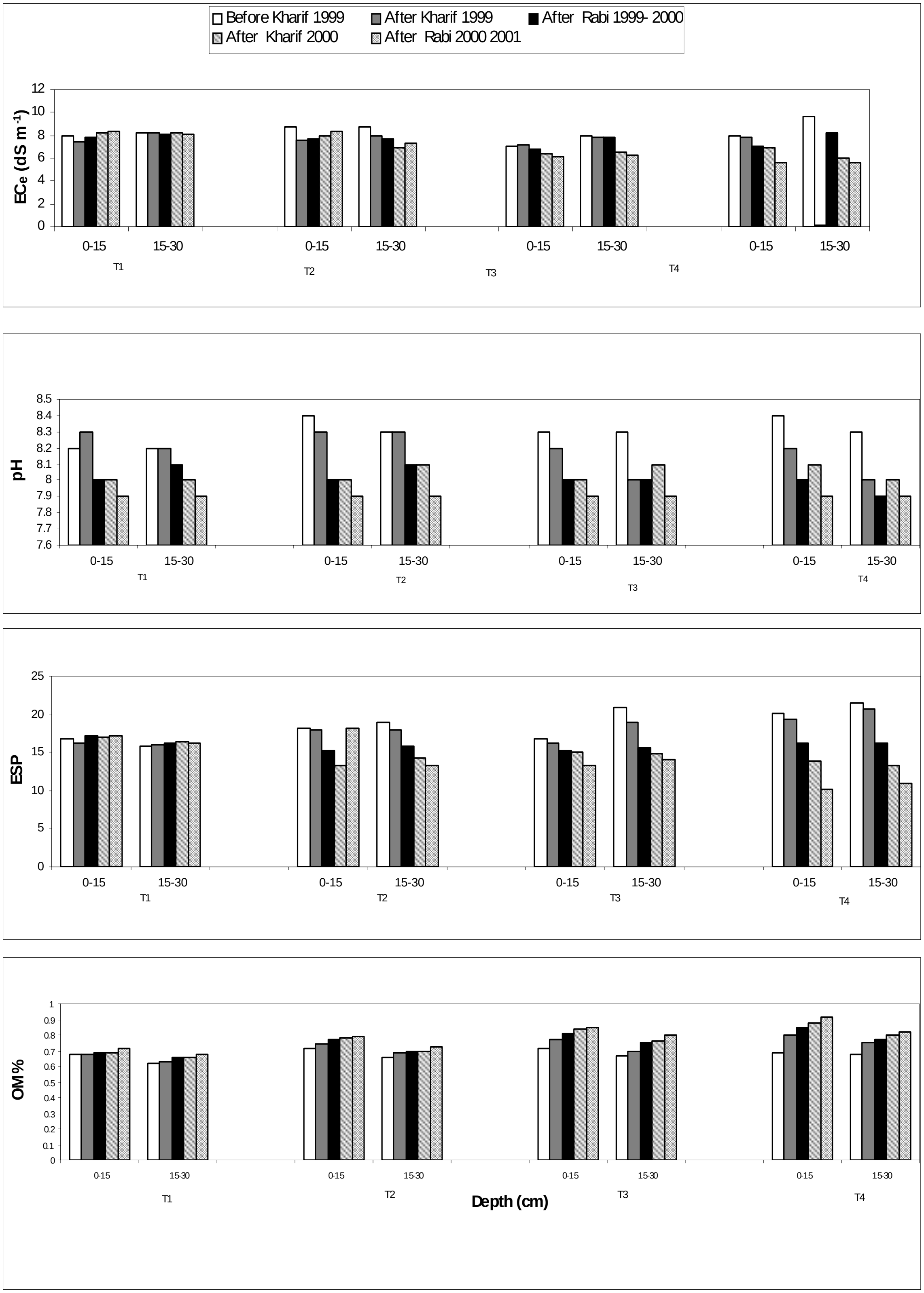


Figure 6: *Reclamation of Saline-Sodic Soils by Rice Husk*

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 T_4 (maximum use of rice husk). Statistically, there was no significant difference of mean yields of the two crops, firstly, between T_1 and T_2 and secondly, between T_3 and T_4. 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*

(ton/ha)

Treatment	*Cotton*		*Wheat*	
	1999	*2000*	*1999-2000*	*2000-2001*
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* (T_1), Jantar in *Kharif* and berseem in *Rabi* (T_2) and Kallar grass (T_3). T_4 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 T_1 (rice-berseem rotation). This decrease was the maximum (81.6%), at 0-15 cm depth where T_3 (Kallar grass) also reduced the EC_e of lower order. The rotation of Jantar-berseem (T_3), 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 T_4 (fallow land). Decrease in pH was more at upper depth (10-15 cm) under T_1 and at lower depths under T_3. This value was however, increased at all depths under T_4, the fallow land.

The ESP under T_1, T_2, T_3, 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 T_4 (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 T_1 (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 T_1 (rice-berseem). The yield of berseem under T_2 (Jantar-berseem), ranged from 0.20 to 1.10 ton/ha between respective three crop seasons.

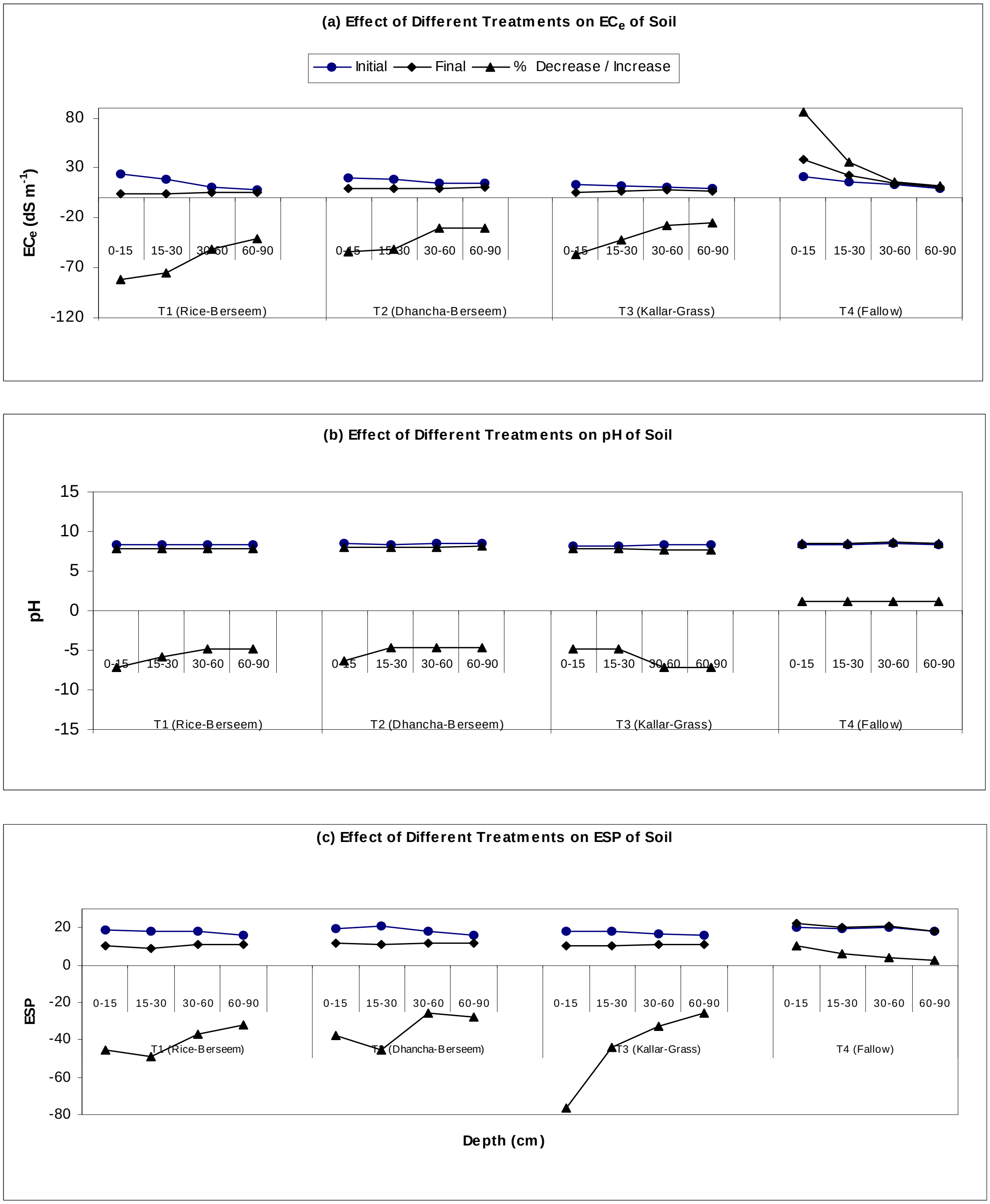


Figure 7: *Biological Reclamation of Highly Saline-Sodic Soils*

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
	Rabi 1996-97	*Rabi 1997-98*	*Rabi 1998-99*
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: T_1 as control (with no crop and no irrigation); T_2 (without crop/continuous leaching); T_3 (dhancha and berseem in *Kharif* and *Rabi*, respectively); and T_4 (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 T_4 (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 T_3 (dhancha-berseem) but more at lower depths (25.4%). T_2 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 T_4 at all the soil depths. However, the maximum reduction of pH was noticed under T_3 (dhancha-berseem rotation), in the top layer of soil. ESP of soil decreased under T_2 to T_4 treatments at all the soil depths and the highest decrease was under T_4 (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 cops are found with crops which are salt tolerant.

Table 8: *Crop Yields by Season*

Season/Crop	*Yield (ton/ha)*
***Rabi* 2000-2001**	
Berseem under T_3	1.00
Berseem under T_4	1.20
***Kharif* 2001**	
Berseem under T_3	1.00
Rice under T_4	0.50

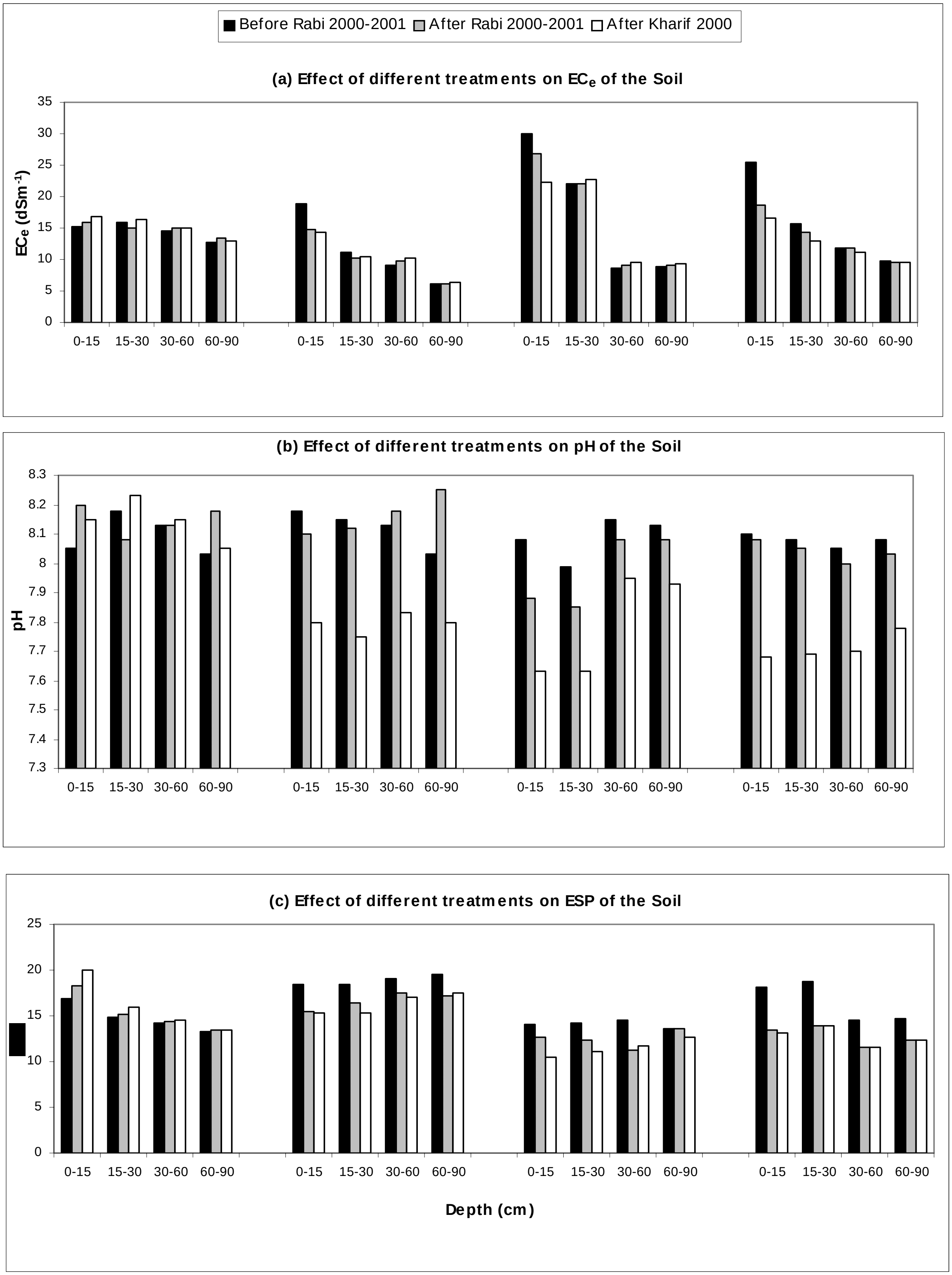


Figure 8: *Reclamation of Strongly Saline Soils by Different Methods under Tile Drainage System*

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: T_1, control (wheat and cotton); T_2, deep ploughing (wheat and cotton); T_3, (berseem and dhancha); and T_4, 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 T_4 and then by T_3 followed by T_2. The treatment T_1 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 T_4 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 T_2 and T_4, 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 T_2 over T_1. Similarly, the yield of wheat increased by 19 to 49 percent under T_2 over T_1.

Table 9: *Crop Yields by Treatment and Season*

(ton/ha)

Treatment	*Kharif*			
	Crop	*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
		Rabi		
		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

[a]Completely green manured. [b]Partly green manured.

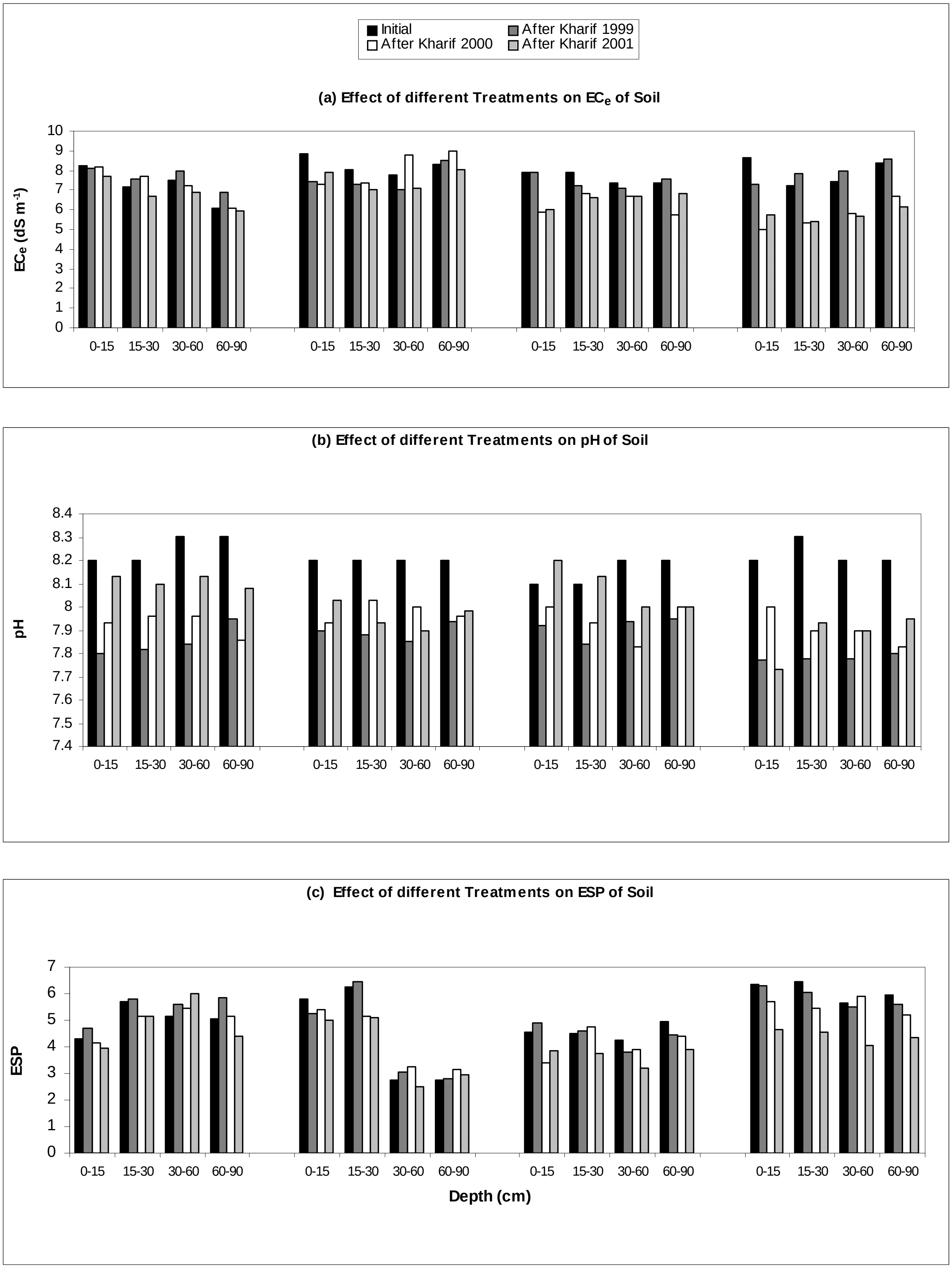


Figure 9: *Comparison of Physical and Biological Methods for Reclamation of Fine Texture Saline Soils*

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 T_2, T_3 and T_4, respectively. The control T_1 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 T_4 (50% GR). By soil depth, this increase varied from 37 percent (60-90 cm) to 132 percent (15-30 cm). On the contrary, under T_1 the EC_e increased from 152 percent (15-30 cm) to 370 percent (30-60 cm depth). Under T_4 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 form 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: T_1, seasonal crop with the recommended fertilizers dose; T_2, early crop with low dose of fertilizer; T_3, late crop with high dose of fertilizers and T_4, 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 T_1 and the maximum reduction of 11.0 percent was found at 0-15 cm depth of soil. T_2 (early crop with less fertilizers) decreased the EC_e by about 7.0 percent (0-15 cm depth). Under T_3 (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.

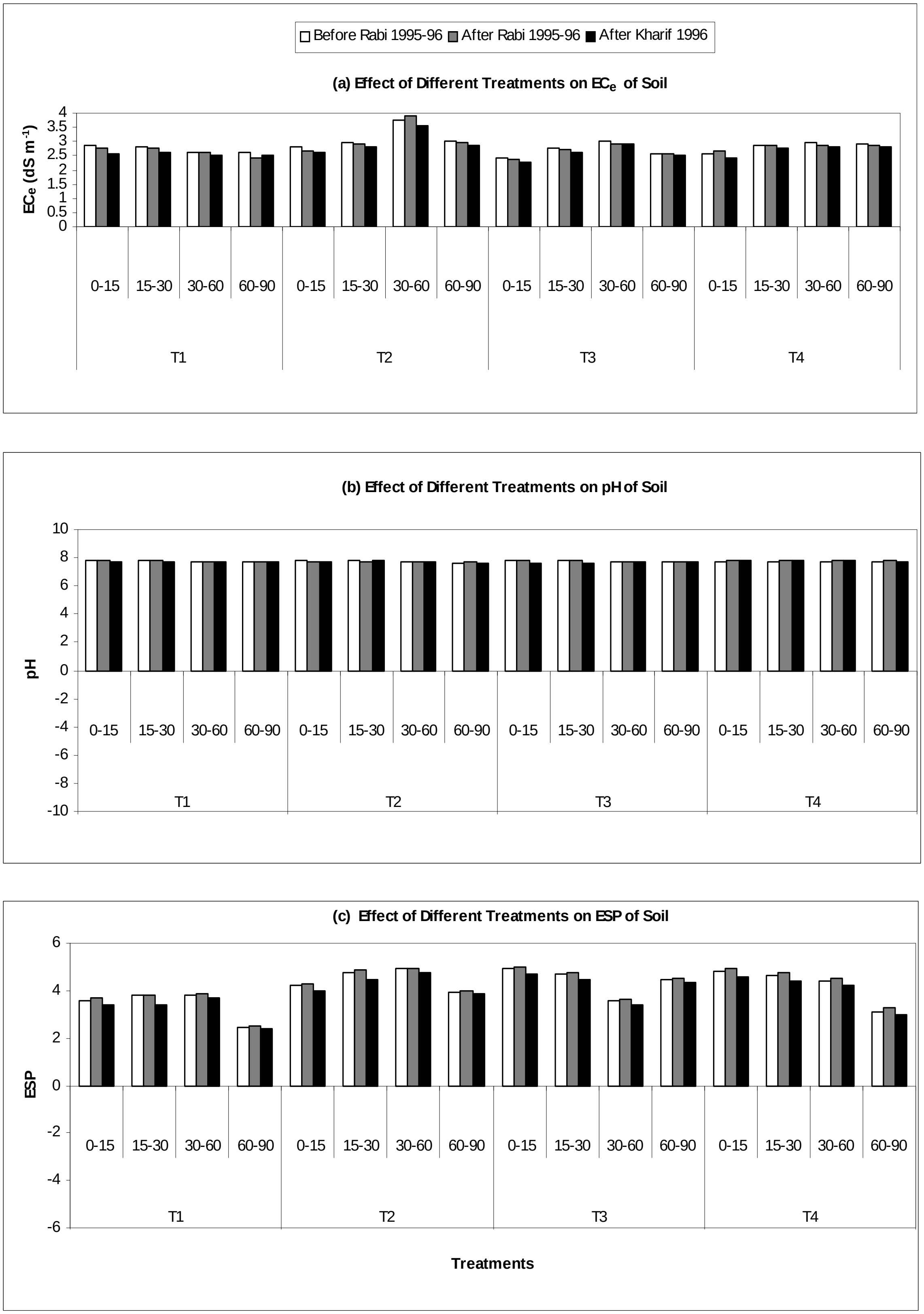


Figure 10: *Soil and Crop Management under Reclaimed Lands*

The value of pH was decreased by different order of magnitude in the upper soil depth. Apparently, T_3 decreased the pH by 2.6 percent equally between the upper tow layers of soil. T_1 and T_2 reduced the pH smaller than that under T_3 at 0-15 and 15-30 cm depths. Under T_4, 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 (T_4), 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 T_1 and T_2 resulted in higher yield of wheat *i.e.* 2.86 and 2.41 ton/ha, respectively. T_3 and T_4 gave equal yield of wheat (2.0 ton/ha). In case of sorghum, its higher yield (1.8 ton/ha) was achieved from T_1. 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*

	Treatments			
Description	*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: T_1, control; T_2, minimum tillage with 75 percent CU; T_3, average tillage with 100 percent CU; and T_4, 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 T_4. 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.

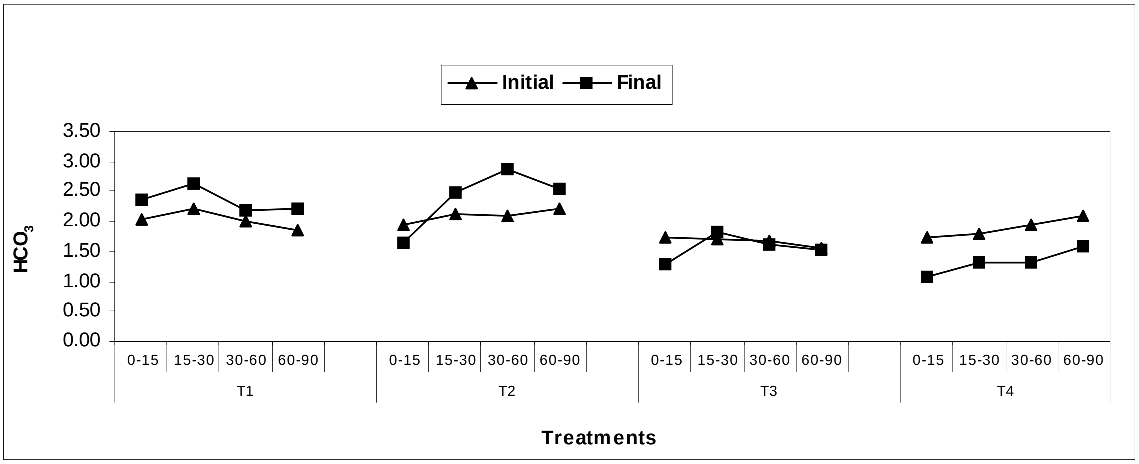
Table 13: *Soil Analysis Results Before and After Study*

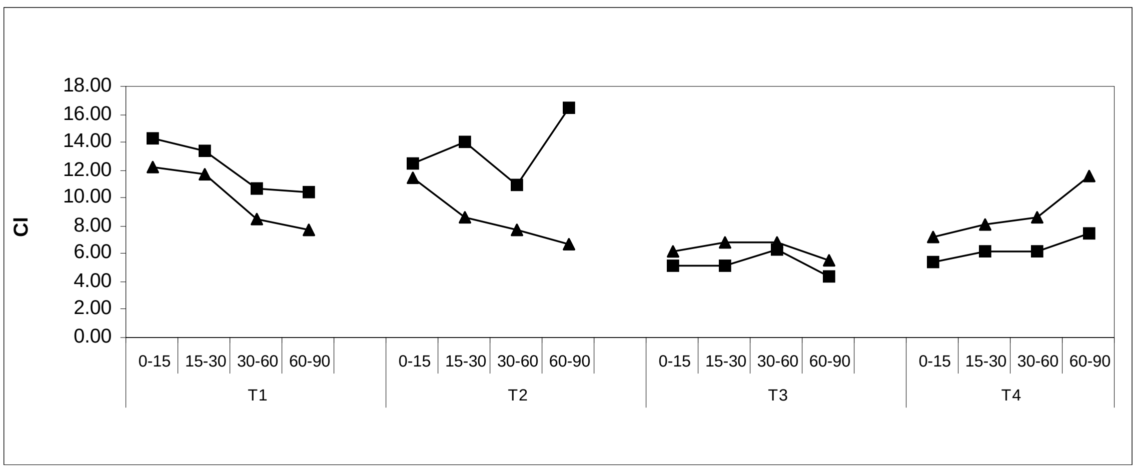
Treatment	*Soil Depth (cm)*	*EC_e (dS m^{-1})*		*pH*		*ESP*	
		before	*after*	*before*	*after*	*before*	*after*
T_1 (control)	0-15	3.81	4.49	7.3	7.4	12.21	14.65
	15-30	3.05	4.36	7.4	7.5	11.58	13.00
	30-60	3.71	4.03	7.4	7.5	12.10	12.75
	60-90	3.10	3.63	7.2	7.4	11.15	12.00
T_2 (Minimum Tillage + 75% CU)	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*





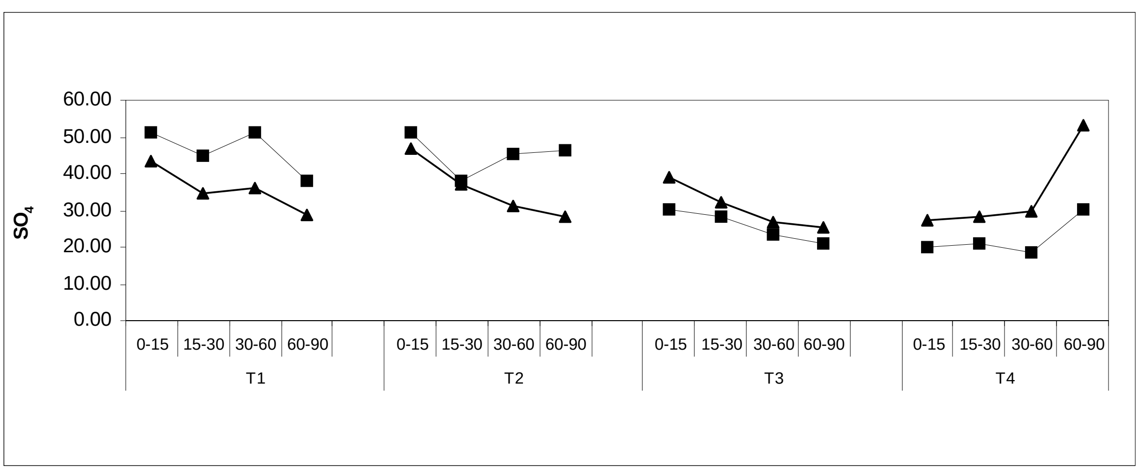


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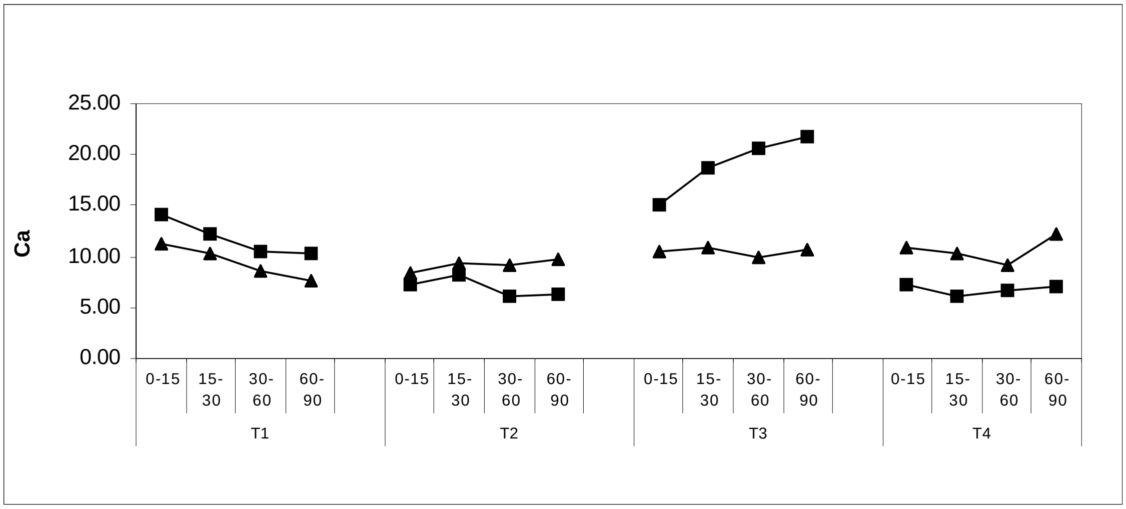
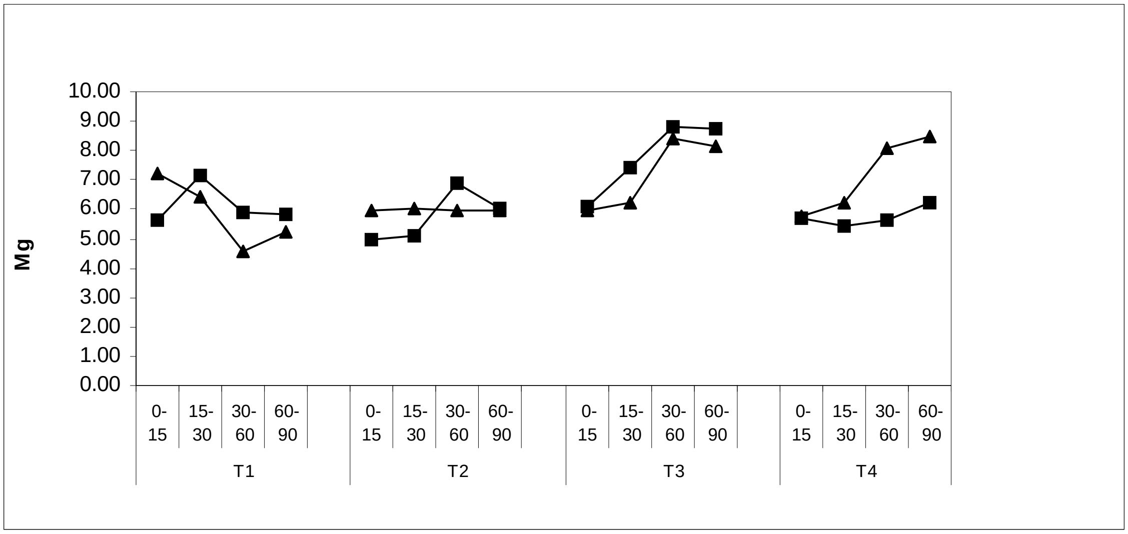
Figure 11 (– *Contd.*)





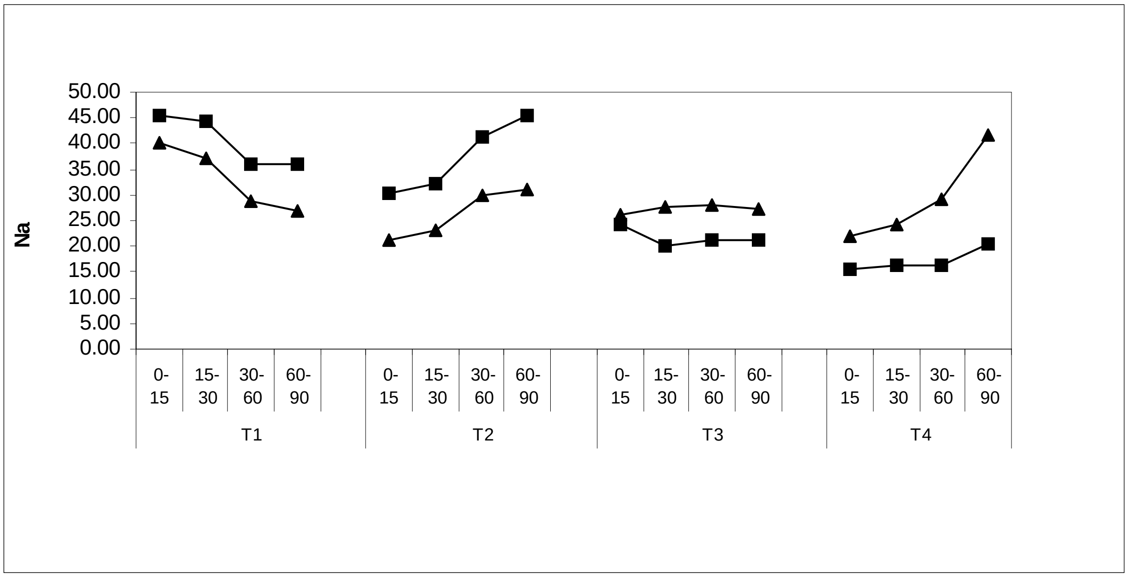


Table 14: *Wheat and Cotton Yields by Treatments*

(ton/ha)

Treatment	*Wheat*		*Cotton*	
	1995-96	*1996-97*	*1996*	*1997*
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: T_1, 75 percent CU (375 mm to wheat and 412 mm to cotton); T_2, 100 percent CU (450 mm to wheat and 550 mm to cotton); and T_3 125 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 T_3. 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 T_1, T_2, T_3 respectively. However, soil SAR was increased with high magnitude of 91, 76, 53 percent under T_1, T_2, and $T_{3,}$ respectively. Likewise, ESP value (average of all depths) also reflected a high increase of 63, 101 and 99 percent under the treatments T_1, T_2, and T_3, 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 T_3 and in the last *Rabi* season under T_2. 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 very 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 T_2 in the second season. In the third season, cotton yield varies closely from 1.97 ton/ha under T_1 to 2.16 ton/ha under T_3 having 2.14 ton/ha under T_2. 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 T_1 during the *Rabi* season (wheat). Obviously, there was a declining trend of WUE from T_1 to T_3 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 T_1 to T_3 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

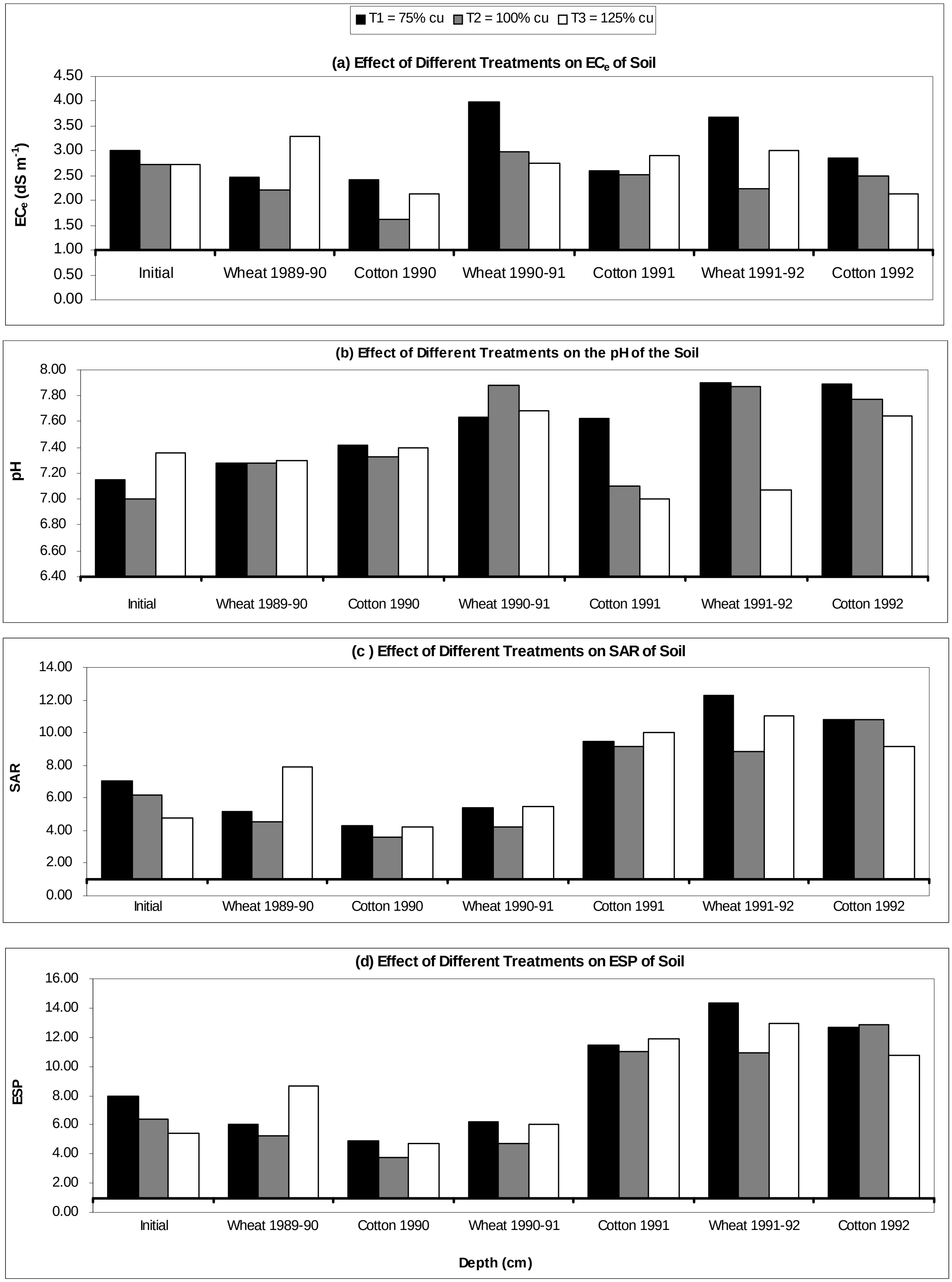


Figure 12: *Effect of Different Irrigation Levels on Soil Salinity and Production of Wheat and Cotton*

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

Under this study the treatments were: T_1 control for recommended irrigation of 550 mm for cotton and 450 mm for wheat; T_2, T_1 coupled with leaching fraction to reduce the original EC_e to 8 dS m^{-1} and T_3, T_1 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 T_3. T_2 decreased the EC_e by 64 percent and the T_1 decreased the EC_e by 63 percent. There appeared no difference between T_1 and T_2 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 T_3, T_2 and T_1, respectively.

The decrease in SAR was observed at all soil depths. The decrease in SAR was 49, 43 and 42 percent under T_3, T_2 and T_1, respectively. Similarly, ESP decreased by 58 percent under T_1. 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 T_3. These higher yields of both the crops were persistent by the respective crop seasons. The cotton yield under T_3 varied from 1.03 ton/ha (*Kharif* 1992) to 1.15 ton/ha (*Kharif* 1994). Similarly, the yield of wheat under T_3 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*

(ton/ha)

Description	*Treatments*		
	T_1	*T_2*	*T_3*
Cotton			
Kharif 1992	0.91	0.91	1.03
Kharif 1993	1.03	1.08	1.10
Kharif f 1994	1.12	1.12	1.15
Wheat			
Rabi 1992-93	1.40	1.45	1.75
Rabi 1993-94	2.52	2.76	2.88
Rabi 1994-95	3.20	3.39	3.51

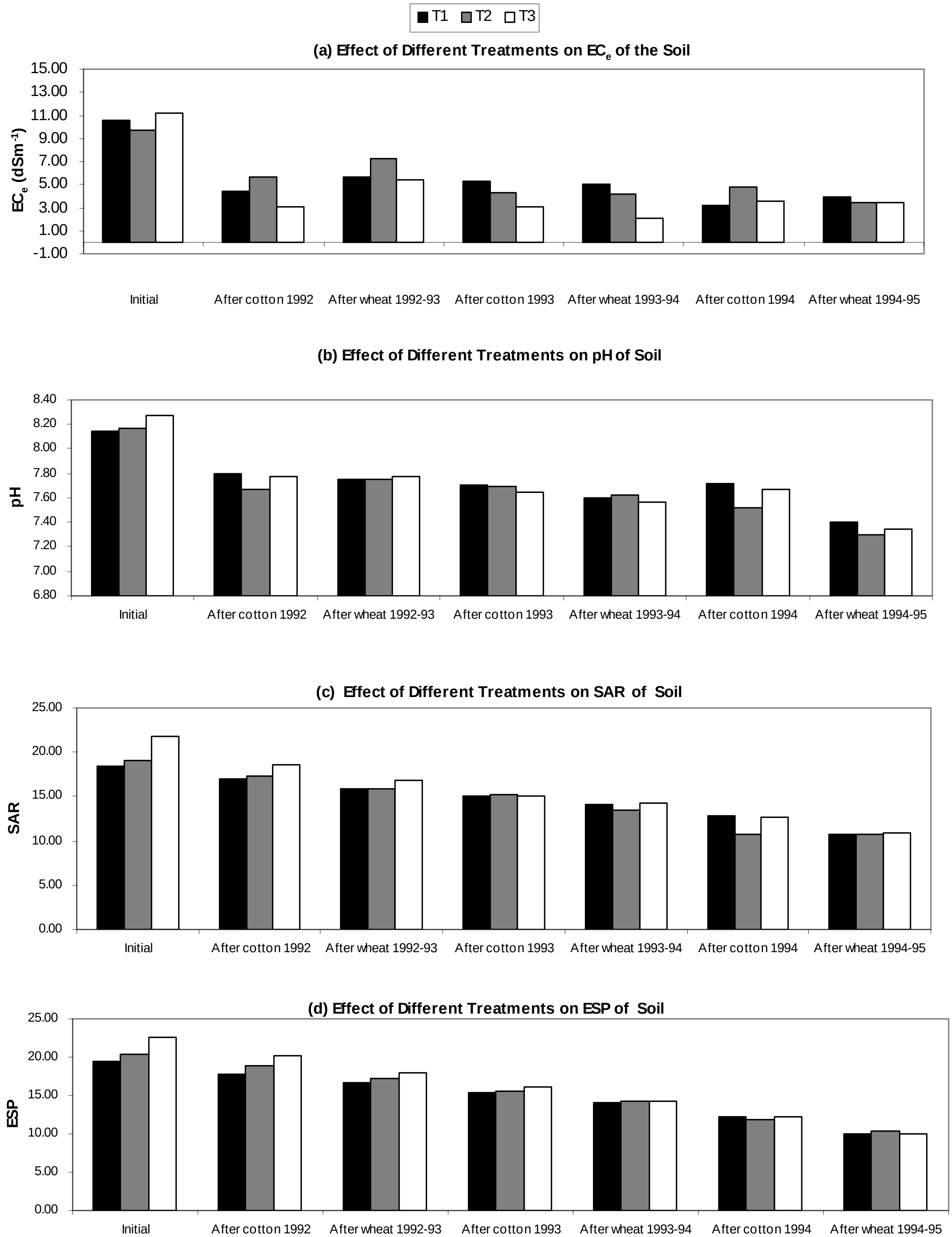


Figure 13: *Reclamation of Medium Textured Saline Soils by Conventional Irrigation under Tile Drainage Conditions*

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 I_1 (75%), I_2 (100%) and I_3 (125%). Two NPK levels were F_1 (247-124-0 kg/ha) and F_2 (371-186-72 kg/ha). So, $T_1 = I_1F_1$, $T_2 = I_1F_2$, $T_3 = I_2F_1$, $T_4 = I_2F_2$, $T_5 = I_3F_1$ and $T_6 = I_3F_2$. 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 I_1F_1, I_2F_2 and I_3 F_2 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 I_1F_1. The minimum increase (7%) of EC_e was observed at 0-15 cm depth under I_3F_1. 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 I_1F_1, I_1F_2 and I_3F_1 was 48, 24 and 4 percent, respectively whereas, decrease of EC_e was 6, 4 and 2 percent under I_2F_2, I_3F_2 and I_2F_1, respectively. At 30-60 cm depth, the decrease in EC_e of 7 and 2 percent was observed under I_2F_1 and I_2F_2 respectively. The EC_e value was however, increased under the other four treatments with the maximum of 33 percent (I_1F_2) and the minimum of 3 percent (I_3F_1). At 60-90 cm depth, the treatments of I_2F_1 and I_2F_2 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 I_2F_1 and I_2F_2 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 I_2F_1 treatment was the most effective giving a relative decrease of 31 percent. The second noted beneficial treatment of I_2F_2 could cause a decrease in SAR by only 3 percent. The other four treatments, tended to increase the SAR, as varying from 4 percent (I_3F_1) to 20 percent (I_1F_2). At 15-30 cm depth, the decrease of SAR was 18 and 6 percent under I_2F_1 and I_2F_2, respectively. The maximum decreases in SAR at the depths of 30-60 cm and 60-90 cm under I_2F_2 treatment (highest levels of CU and NPK) were 11 and 18 percent, respectively. For the lower depths, the maximum increase of SAR was under I_1F_1, 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.

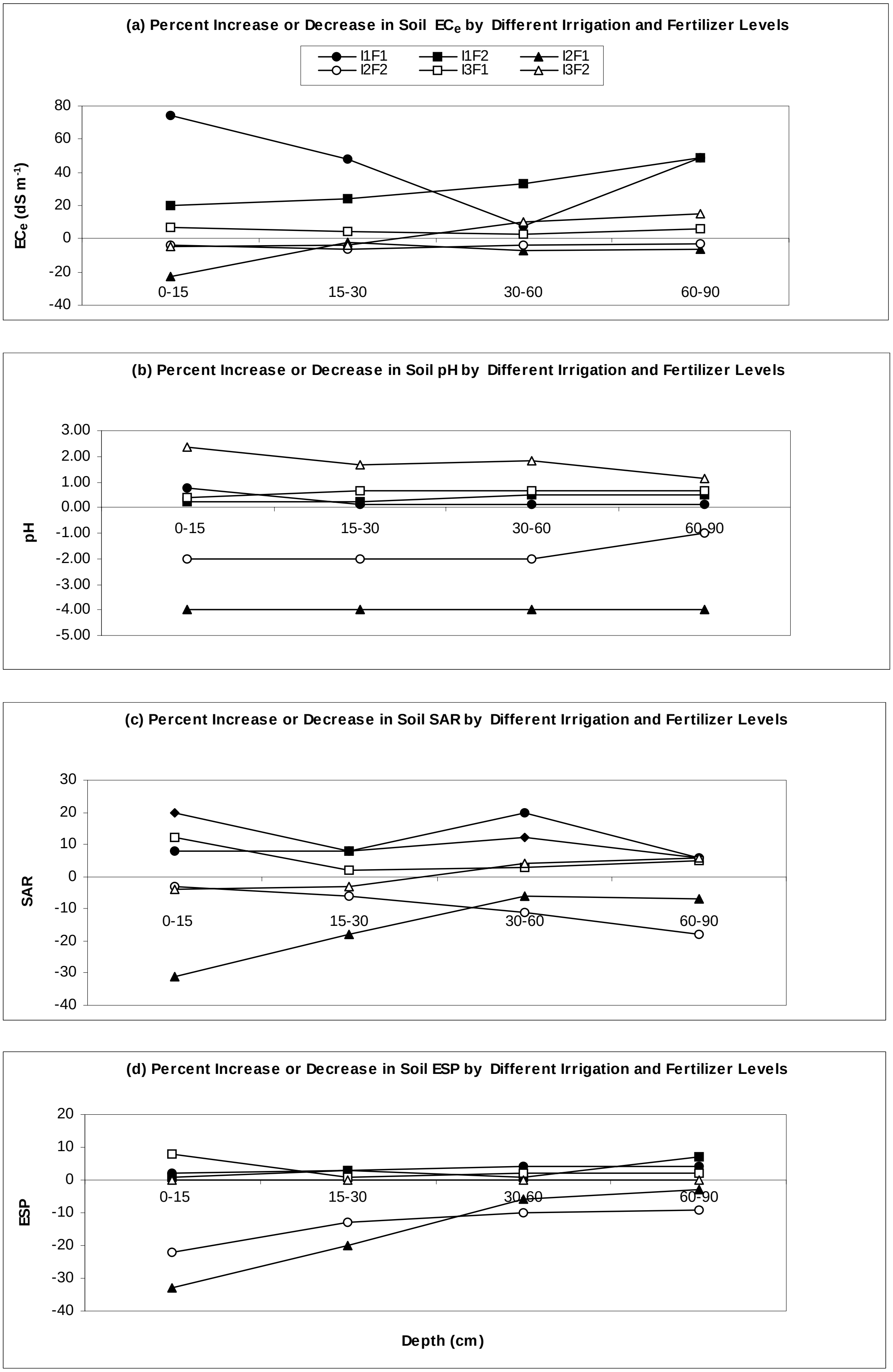


Figure 14: *Irrigation and Fertilizer Interaction in a Moderately Saline-Sodic Soil*

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*

(ton/ha)

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						
Rabi 1993-94	1.47	1.57	1.97	1.83	1.15	1.23
Rabi 1994-95	1.85	1.78	2.35	2.19	2.01	1.93
Rabi 1995-96	1.49	1.51	1.91	1.75	1.48	1.52
Cotton						
Kharif 1994	0.53	0.54	0.73	0.46	0.45	0.44
Kharif 1995	1.25	1.40	2.25	1.31	1.25	1.07
Kharif 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 T_1 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 T_2 and the minimum of about 25 percent under T_3. On the overall, the increase of EC_e was considerably higher beyond 50 cm depth especially at 75-100 cm depth.

The treatment of T_1 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 T_2 and the minimum of 5 percent under T_3. Higher increases of pH were found under T_2 to T_3 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
Average	*3.23*	*2.90*	*-6.85*	*5.92*	*87.41*	*4.01*	*24.93*	*4.14*	*30.10*
				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
Average	*7.33*	*7.25*	*-1.05*	*7.97*	*9.44*	*7.67*	*4.73*	*7.78*	*6.17*
				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
Average	*8.46*	*8.00*	*-5.12*	*10.22*	*19.08*	*8.92*	*5.40*	*9.05*	*6.91*
				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
Average	*9.07*	*8.94*	*-1.39*	*9.88*	*11.66*	*9.56*	*5.56*	*9.70*	*8.89*

In case of SAR, there was a decrease of 5.0 percent in its value under $T_{1.}$ However, the increase in SAR under the other treatments (T_2 to T_4), varied from 19 percent (T_2) to 5 percent (T_3) with about 7 percent under T_3. The ESP values under T_1 decreased slightly (1.4%). Whereas, the average increase in ESP was the maximum (11.7%) under T_2 followed by 5.6 and 8.9 percent under T_3 and T_4, 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 (T_1) 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 T_2 (saline drainage water) and T_3 (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 T_1 *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 T_2 and T_3 showed higher yield in the first *Rabi* season (1989-90) while T_4 resulted in the higher yield in the last *Rabi* season (1991-92).

Table 19: *Cotton and Wheat Yields by Treatment*

(ton/ha)

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				
Kharif 1989	0.92	0.79	0.79	0.44
Kharif 1990	3.44	3.19	3.19	2.85
Kharif 1991	3.84	3.57	3.57	2.77
Wheat				
Rabi 1989-90	5.30	4.66	4.95	4.17
Rabi 1990-91	4.62	3.10	4.14	4.48
Rabi 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: T_1, all canal irrigations; T_2, one irrigation of 75 mm with saline drainage water after 4 weeks of sowing; T_3, the same variable of irrigation but after 7 weeks and T_4 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 T_1 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 T_1 at the lowest depth of soil. Under T_2, 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 T_1. The other treatments increased the EC_e by varying magnitude. However, the minimum increase in EC_e (1.6 to 67.0%) was under T_3 in *Rabi* seasons and under T_2 in *Kharif* seasons.

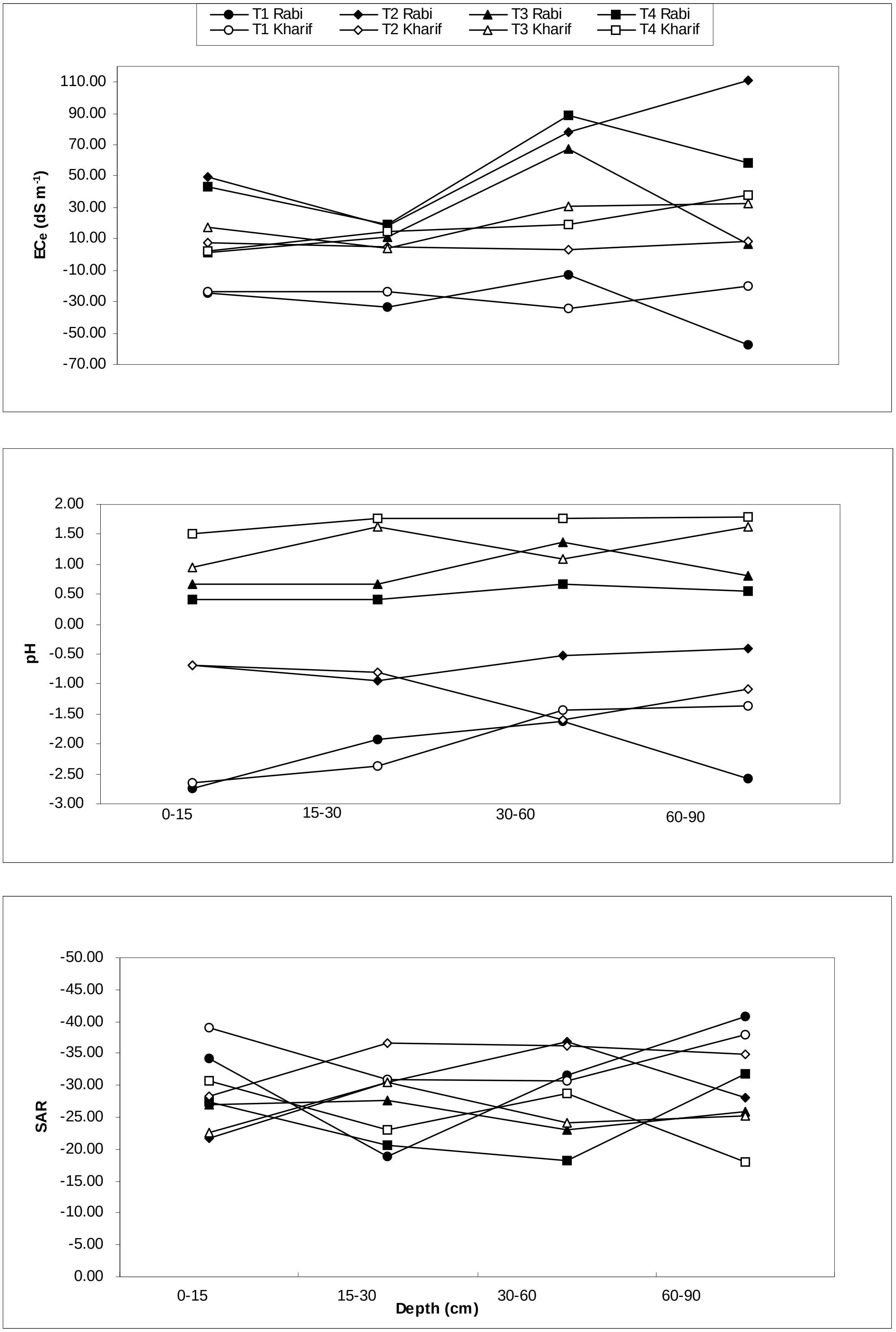


Figure 15: *Effect of Different Treatments on Soil Salinity*

5.5.2.2 *Effect on pH of Soil*

In *Rabi* seasons, the pH decreased by 0.4 to 2.7 percent only under T_1 and T_2 at all the soil depth. The other treatments of T_3 and T_4 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 T_1 and T_2. Under T_3 and T_4, 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 T_1 at 60-90 cm depth. While the minimum reduction (18.3%) of SAR was under T_4. In *Kharif* seasons, the maximum reduction of SAR was 39.1 percent under T_1 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 T_1, T_2, T_3 and T_4, 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 T_1. 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 T_1 while the lower yield were under T_3 (1.20 to 1.44 ton/ha) and T_4 (1.21 to 1.44 ton/ha). The yield of cotton did not reflect any variation between T_2 and T_3 in *Kharif* 1996 and 1997.

Table 20: *Crop Yields by Treatment*

(tons/ha)

Crop/Season	*Treatment*			
	T_1	T_2	T_3	T_4
Wheat				
Rabi 1994-95	2.21	1.89	1.51	1.33
Rabi 1995-96	2.55	1.96	1.80	1.69
Rabi 1996-97	2.69	2.24	2.16	1.85
Cotton				
Kharif 1995	1.61	1.28	1.20	1.21
Kharif 1996	2.21	1.66	1.44	1.41
Kharif 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. T_1 was canal water irrigation, T_2 as saline drainage water, T_3 as mixed irrigation (1:1) and T_4 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*

(ton/ha)

Crop/Season	*Treatment*			
	T_1	T_2	T_3	T_4
Wheat				
Rabi 1992-93	3.75	2.94	3.40	3.09
Rabi 1993-94	3.64	2.75	3.12	2.99
Rabi 1994-95	3.81	2.84	3.38	3.38
Cotton				
Kharif 1993	2.61	1.56	2.22	1.94
Kharif 1994	2.66	1.77	2.31	2.25
Kharif 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 reclaiment 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 reclaiments, 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 *sesbenia* 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 form 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 gypsiferious 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 reclaiments 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*.).

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