MANAGEMENT OF SALT AFFECTED SOILS AND POOR QUALITY WATER IN AGRICULTURE – RESEARCH HIGHLIGHTS OF 25 YEARS IN TAMIL NADU

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FOREWORD

Soil salinization is a global and dynamic problem and is projected to increase in future under climate change scenario. In order to meet the need for more food for the increasing population, the reclamation of problem soils and development of new land resources is becoming imperative. Large areas of land can be made available for cultivation in the arid and semi arid regions provided that irrigation can be made feasible but much of this land has constraint of actual or potential salinity or sodicity. Thus in order to utilize and reutilize salt affected soils, first deleterious conditions of salinity or sodicity has to be corrected and secondly management practices that will prevent their recurrence must be introduced.

Central Soil Salinity Research Institute, Karnal is taking sternous efforts to develop and propagate well tested methods to solve the problems of salt affected soils existing nationwide. All India Coordinated Research Project on "Management of Salt Affected Soils and Use of Saline Water in Agriculture" is under operation at Anbil Dharmalingam Agricultural College & Research Institute, Trichy. Since its inception, the centre has been in the forefront to develop technologies for diagnosis, reclamation and management of salt affected soils and judicious use of poor quality waters.

The technological packages for reclamation of alkali, saline and waterlogged saline soils and sustainable use of saline and alkali waters for irrigation including nutrient management issues are generated from experimental results of Anbil Dharmalingam Agricultural College & Research Institute, Trichirapalli centre of All India Coordinated Research Project on "Management of Salt Affected Soils and Use of Saline Water in Agriculture'. Technologies generated since 1995 are documented in this book.

This compendium would be useful for planners and policy makers to know the extent of losses due to salt-affected soils and helpful to minimize the losses by taking suitable location specific remedial actions.

Dt. 3.10.2022

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FOREWORD

India needs to achieve food grain production of 311 million tonnes by 2030 and 350 million tonnes by 2050 to feed around 1.43 and 1.8 billion people, respectively. It is a huge task and it compels us to use all available land and water resources including marginal lands and marginal waters for food production. The soil salinity and soil sodicity as well as saline and sodic ground water are formed due to chemical degradation of these resources. Such types of soils and ground waters are found in different states of India due to various reasons such as flat topography, excess irrigation, lack of natural drainage, mineralogy, sea water intrusion, etc. The AICRP on "Management of Salt Affected Soils & Use of Saline Water in Agriculture" (SAS&USW) was established on 14 April 1972 at Central Soil Salinity Research Institute, Karnal to address the issues of soil salinity, soil sodicity and poor quality ground waters at national level and reduce the agricultural production losses. A centre of AICRP on SAS&USW at Anbil Dharmalingam Agricultural College and Research Institute (ADAC&RI), Tiruchirappalli under Tamil Nadu Agricultural University (TNAU) was established on 1 January 1995 to address these issues in Kaveri delta in Tamil Nadu. The Tiruchirappalli has a background as Kumaraperumal Farm Science Centre was functioning there from 1977 and Soil Salinity Research Centre (SSRC) from 1980. After merging these centres, in 1992, it was renamed as Anbil Dharrmalingam Agricultural College and Research Institute.

Since the inception, the centre has contributed towards ground water quality survey and initially released groundwater quality map at 1: 2,50,000 scale in 2004 and later on completed intensive survey at 1:50,000 scale for 14 coastal districts for preparation groundwater quality maps for irrigation purpose. The centre has developed technologies for reclamation of sodic soils and sodic water through gypsum and distillery spent wash, conjunctive use of canal and sodic water, agro-forestry on sodic soils and integrated farming system model. The centre has an excellent facility for screening of crops for sodicity tolerance and screened several field crops, fibre crops and vegetables. These technologies of the centre have reached to farmers and state government is supporting the technologies through developmental schemes. The centre has adopted a nearby scheduled caste village for its overall development. The information about all these developments is scattered. On the occasion of XVII Biennial Workshop at Tiruchirappalli, the centre has compiled details of 25 years of research achievements. It is really good publication which will be certainly referred by planners and researchers. I wish every success to centre for its future endeavors.

Date: 6-10-2022

(P.C. Sharma)

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Director of Research

FOREWORD

Soil salinization is projected to increase under changing climatic scenarios viz., rise in sea level and impact on coastal areas, rise in temperatures and increase in evaporation *etc.* Estimates suggest that every year nearly 10 percent of additional area is getting salinized and around 50 percent of the arable land would be salt-affected by 2050. Soil salinity reduces crop yields up to 50 percent and thus making significant area to become uncultivable. Developing salinity tolerant crop varieties, cost effective reclamation procedures and improved nutrient management practices are vital in sustaining crop production under changing climatic conditions.

ICARs All India Coordinated Research Project on "Management of salt affected soils and use of saline water in agriculture" operates with a sole objective of increasing crop production under salinity prone areas. Anbil Dharmalingam Agricultural College and Research Institute, Trichy is one of the key partners in the AICRP-Management of salt affected soils and use of saline water in agriculture since 1995 and pioneering in developing reclamation technologies for salt affected soils and use of poor-quality water in agriculture.

This group has done a commendable job in compiling vast knowledge on various salinity mitigation technologies from AICRP annual reports, research papers and bulletins and thus fulfills the long felt need of the scientists working in this area. This document highlights the extent of salinity, effective mitigation technologies and success stories. All the scientists who contributed for compiling this document are greatly appreciated. This document will greatly benefit the scientific communities, policy makers and development agencies who are interested in management of land and water in saline environment. Ongoing research efforts towards management and reclamation of saline soils would pave way for ensuring food security in the country. I appreciate the Chief scientist of this program and his team of scientists for bringing out the 25 years of research achievements in an impressive book form as a useful reference to the end users.

Date: 07.10.2022

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1. INTRODUCTION

Tamil Nadu state is situated at the South Eastern extremity of the Indian peninsula bounded on the North by Karnataka and Andhra Pradesh, in the East by Bay of Bengal, in the South by Indian Ocean and in the West by Kerala State. It has a coastal line of 922 km and a land boundary of 1200 km.

Tamil Nadu lies between 76°14′and 80°21′E longitude and 8°4′ and 13°54′N latitudes. It has a total geographical area of 13.0 m.ha. The state is divided into four geomorphic zones *viz*. Coastal Plain, Eastern Ghats, Central Plateau and Western Ghats.

Agro-climatic Zones of Tamil Nadu

Based on altitude, annual rainfall and annual PET, Tamil Nadu has been divided into 7 agro-climatic Zones. (Table 1)

Table 1. Agro-climatic Zones of Tamil Nadu

S.No.	Name of the Zone	Altitude(m)	Annual rainfall(mm)	Annual PET(mm)
1.	North Eastern Zone	100-200	1105	1700
2.	North Western Zone	200-600	875	1727
3.	Western Zone	200-600	718	1622
4.	Cauvery delta Zone	100-200	984	1932
5.	Southern Zone	100-600	857	1825
6.	High rainfall Zone	100-200	1420	1516
7.	Hilly Zone	2000 and above	2124	1213

Climate and Rainfall

The climate of Tamil Nadu is basically tropical. The maximum daily temperature rarely exceeds 43°C and the minimum daily temperature seldom falls below 18°C.

The normal distribution of rainfall during different seasons is as follows:

1. South West Monsoon	:	307.6 mm
2. North East Monsoon	:	438.7 mm
3. Winter	:	42.2 mm
4. Summer	:	136.5 mm
Total	:	**925.0 mm**

Fig.1 Land degradation map of TamilNadu

Land Utilisation Pattern in Tamil Nadu

Out of 13.0 m.ha of total geographical area of Tamil Nadu, about 5.8 m.ha (45%) is net area sown followed by 2.1 m.ha (16%) under forest, 1.9 m.ha (15%) under non-agricultural use. The cropping intensity of the state is 121.4 per cent. The total cropped area including area sown more than once is 7.0 m.ha (Fig.1).

Soils of Tamil Nadu

The nine groups of the soil depicted in the soil map of Tamil Nadu are classified into the following four major groups.

1. Alluvial soils (Entisols)
2. Red soils (Inceptisols, Alfisols)
3. Laterite soils (Alfisols, Ultisols) and
4. Black soils (Vertisols)

Salt affected soils of Tamil Nadu

The salt affected soils of Tamil Nadu based upon their geographical distribution have been classified into coastal saline soils and inland saline or sodic soils. The area under these above two categories of salt affected soils is given in Table 2.

Coastal soils of Tamil Nadu

The coastal soils of Tamil Nadu are prevalent all along the coast starting from Chengalpet District in the North to the Kanyakumari District in the South. The coastal area varies between few kilometres to about 30 kilometres, close to the coast, along the low lying areas and estuaries.

Table 2. Salt affected soils of Tamil Nadu

District	Saline (ha)	Alkali (ha)	Saline-alkali (ha)	Total (ha)
1. Chennai	-	-	-	-
2. Thiruvallur	11,036	18,165	52	29,253
3. Kanchipuram	23,224	42,100	259	65,583
4. Vellur	6,650	15,832	-	22,482
5. Thiruvannamalai	2,005	27,068	-	29,073
6. Villupuram	6,653	10,144	298	17,095
7. Cuddalur	7,011	5,050	26	12,087
8. Dharmapuri	4,250	10,540	-	14,790
9. Salem	6,020	10,830	-	16,850
10. Namakkal	14,500	6,380	-	20,880
11. Erode	660	4,400	-	5,060
12. Coimbatore	1,030	1 ,1 05	-	2,135
13. Karur	3,800	2,515	-	6,315
14. Tiruchirapalli	2,715	8,450	-	11 ,165
15. Pudukkattai	1 ,292	18,293	2,879	22,464
16. Perambalur	2,550	8,815	-	11,365
17. Thanjavur	4,183	12,516	3,181	19,880
18. Thiruvarur	11,161	12,956	9,920	34,037
19. Nagapattinam	24,250	21,526	18,133	63,909
20. Dindigul	160	295	-	455
21. Madurai	165	2,590	-	2,755
22. Theni	40	150	-	190
23. Virudhunagar	1,050	720	-	1,770
24. Ramanathapuram	5,318	16,359	321	21,998
25. Sivagangai	250	1 ,140	-	1,390
26. Thuthukudi	7,010	13,710	1 ,334	22,054
27. Thirunelveli	2,502	9,634	832	12,968
28. Kanyakumari	1 ,730	-	-	1 ,730
29. Nilgris	-	-	-	-
Total	**1,51,215**	**2,81,283**	**37,235**	**4,69,733**

Genesis of salt affected soils of Tamil Nadu

Saline soils

The nature of salinity especially in the coastal areas of Tamil Nadu, is due to the presence of chlorides mainly and bicarbonates rarely, of sodium, calcium, potassium and magnesium. In general the development of salinity in the soils is attributable to the following.

1. Chemical weathering of primary minerals
2. Sea effects, inclusive of intrusion of sea water, littoral winds, lateral seepage of sea water and monsoonal tidal waves
3. Low precipitation, meagre leaching and inadequate drainage
4. High water table with poor quality ground water
5. Field to field drainage system in the inland and improper land use.
6. Among the five, the first one is the direct cause of salinity in the inland areas.

Alkali soils

The in-situ formation of alkali soils in the coastal tract of Tamil Nadu is virtually absent and the alkalinity has developed due to the following factors (Special Report No.30, 1982)

1. Inadequate leaching of saline soils whereas salinity is due to the presence of excess NaCl as in the case of Ramanathapuram, Tirunelveli and Kanyakumari districts.
2. The presence of soluble carbonates or bicarbonates in the soil as seen in Thanjavur and Cuddalore districts.
3. Alternate ingress and recession of sea water especially during monsoon periods with deposition of large amounts of Na salts which on hydrolysis produce alkalinity as in the case of coastal swamps of Madurantakam down to Marakanam and Thiruthuraipoondi.
4. Significant rise and fall of high ground water table with $NaHCO_3$ type of water.
5. Subramaniam (1985) reported that the development of sodic and saline conditions in black vertisols was due to the practices of irrigated farming and prevailing shallow water table. He also found that accumulated salts are correlative with the underground water quality.

Quality of Ground Water in Coastal Districts of Tamil Nadu

The ground water quality is either saline, marginally saline or high SAR saline in coastal districts of Tamil Nadu. In Tirunelveli districts alkali or marginally alkali waters are also reported. (Special Report No.30, 1982). Water quality in the unconfined aquifers in Ramanathapuram and Tirunelveli districts of Tamil Nadu is poor due to residual salinity of high SAR in a narrow zone. In the east coast, Cuddalore sandstone carries fresh waters. In the Cuddalore sandstone tertiary formations groundwater even close to the sea is of good quality but sulphated at places due to the presence of lignite (Technical bulletin No.19, 1994).

2. CROP YIELD LOSSES DUE TO SOIL SALINITY/SODICITY PROBLEMS IN TAMIL NADU

Salt affected soils are one of the major land degradation problems in Indian agriculture which adversely affects the productivity of agricultural land. The production and monetary losses information at the state and national level are essential to target the implementation of development programs. For estimation of production losses loss factor were computed for slightly (ECe 4.0-8.0 dSm^{-1}, pH 8.5-9.0, ESP <15) and moderately (ECe 8.1-16.0 dSm^{-1} pH 9.1-9.8, ESP 15-40) affected areas based on the ESP for sodicity ECe for salinity threshold limit and slope of a given crop.

The information on production and monetary losses due to excess amount of salts is very important. Each year, India loses 11.18 million tonnes of farm production from sodic area, which accounted the monetary loss of 150.17 billion. Similarly, country loses annually 5.66 million tonnes of farm production from saline area and accounted the monetary loss of 80.02 billion. Hence, India loses annually 16.84 million tonnes of farm production valued at 230.19 billion due to salt-affected soils as per estimates (Sharma et.al. 2015). With the support of World Bank, European Union and other developmental agencies, India has reclaimed 1.95 M ha of alkali lands. Across states, Punjab has reclaimed largest area (0.79 M ha), followed by Uttar Pradesh (0.73 M ha), Haryana (0.35 M ha) and other states (0.70 M ha) (Sharma et al. 2016b).

Sodic soils covered 18% of salt-affected areas in the peninsular plain and are distributed in Tamil Nadu, Andhra Pradesh and Karnataka states. These are slight (59%), moderate (32%) and strongly (4%) sodic in Ramanathapuram, Cuddalore, Kanchipuram, Tirunelveli, Thanjavur, Pudukottai and Tiruchirapalli districts of Tamil Nadu. Production and monetary losses due to sodicity and salinity were computed for Tamil Nadu. The gross salt affected area in Tamil Nadu is 3, 94,527 Ha, with production loss of 0.147 million tonnes and the production loss percentage is 0.87. The state accounted monetary loss of 1378 million tonnes with monetary loss percentage of 0.60 in the total monetary losses at the national level.

Extent and distribution of salt affected soils in TamilNadu state contributes 13,231 ha of saline soils and 3, 54,784 ha of alkali soil (Mandal *et al* 2010). There are 16 major crops were considered for computation losses in TamilNadu i.e. Paddy, pearl millet, sorghum finger millet, other cereals which include foxtail millet, mustard ,sesame, groundnut, pigeon pea, black gram, green gram, and other pulses which include cowpea, cotton, sugarcane and potato. In Tamil Nadu, district wise cropped area reported under salinity are as follows: in Pudukottai district, cereals 197 ha, oil seeds 41ha, pulses 5 ha, cash crops 14 ha, in Ramanathapuram district, cereals 9032 ha, oil seeds 272 ha, pulses 248 ha, cash crops 54 ha, in Tanjore cereals 2113 ha, oil seeds 196 ha, pulses 259 ha, cash crops 139 ha and in Tirunelvelli district cereals 2045 ha, oil seeds 72 ha, pulses 388 ha, cash crops 158ha. The total cropped area reported in sodic soils under cereals are 3, 00,696 ha, oil seeds 27,979 ha, pulses 29,328 ha and cash crops 21,290 ha.

There is no crop area observed under saline soils of Tiruchirapalli district, hence no production losses due to salinity. The production losses reported for various crops are as follows: cereals 947 tonnes, oilseeds 370 tonnes, pulses 344 tonnes, and cash crops 1 tonne in Tiruchirapalli district due to soil sodicity. Out of which the cropped area under sodic soils of Tiruchirapalli district are cereals 14904 ha, oil seeds 1411 ha, pulses 2235 ha and cash crops 1635 ha. The production losses for cereal crops under sodic soil are 17,191 tonnes with a monetary loss of 14.16 million, oil seeds 673 tonnes with a monetary loss of 5.3 million, pulses 336 tonnes with a monetary loss of 10.52 and cash crops 26,080 tonnes with a monetary loss of 0.03 million. The total monetary loss of Tamil Nadu due to sodicity is 30 million and loss percentage of Tiruchirapalli district alone to state is 0.78. This study would be useful for planners and policy makers to know the extent of losses due to salt-affected soils and helpful to minimize the losses by taking suitable location specific remedial actions.

Mandate

The AICRP on management of salt affected soils and use of saline water in agriculture - Tiruchirapalli Centre is functioning from 1.01.1995 at Anbil Dharmalingam Agricultural College and Research Institute, Navalur Kuttapattu, which is 12 km away from Tiruchirappalli on NH-45. In this location Kumaraperumal Farm Science Centre was functioning from 1977 and Soil Salinity Research Centre (SSRC) was started during 1980.The SSRC was upgraded as Agricultural College and Research Institute of Tamil Nadu Agricultural University during 1992 and named after former Agricultural minister of Tamil Nadu Mr. Anbil Dharmalingam.

The mandate for AICRP on management of salt affected soils and use of saline water in agriculture- Tiruchirappalli centre is as follows:

1. Develop strategies for mitigating the adverse effects of salts on soil and crops.
2. Conjunctive use of poor quality ground waters.
3. Survey of poor quality ground waters and salt affected soils.

3. CHARACTERIZATION AND DELINEATION OF SALT AFFECTED SOILS

An attempt has been made on characterization of sodic soils by using reconnaissance soil survey methods in North Western Zone of Tamil Nadu encompassing the districts of Tiruchirapalli, Dharmapuri, Salem, Krishnagiri and Namakkal. Surface soil samples were collected as per reconnaissance soil survey reports of Dept. of Agriculture and analyzed the soil pH and EC. Based on the analytical report the severity of sodicity problem was quantified.

3.1 Salt affected soil map of Tiruchirapalli District

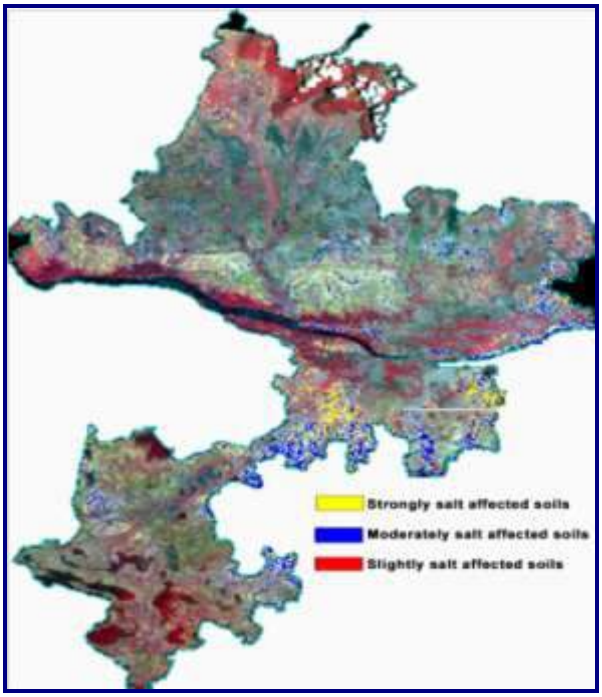


Fig 2. Salt affected soils of Tiruchirappalli district

The salt affected soils map of Tiruchirapalli District was prepared at 1:50,000 scale using remote sensing data and ground truth verification. For delineation of salt affected soils of Tiruchirapalli district, satellite data of IRS 1D L3 of Path/ Row 101/66 (13^{th} Sep. 2002 pass) and 102/66 (2^{nd} June 2002 pass) were used. Both the adjacent scenes were merged to get mosaic of whole Tiruchirapalli district. The satellite data was interpreted in conjunction with SOI toposheets 58J and 58I and district map of Tiruchirapalli district. The toposheet and district map were scanned and used for geo-referencing of satellite data. The satellite data were interpreted using ERDAS imagine 8.5 digital analysis software. The common ground control points (GCP) were selected on both satellite imagery and scanned toposheets and rectification was done using nearest neighbourhood re-sampling technique. The FCC was displayed using bands 432 and assigning RBG to them. Then using the scanned district map of Tiruchirapalli district, boundary was digitized on screen and satellite data of Tiruchirapalli district was extracted. On standard FCC based upon the variation in colour and tone training sets for different types of salt affected soils were identified and spectral signatures were generated and ground truth was collected. During ground truth collection from both profiles and surface soil samples were collected and analysed. By incorporating the ground truth, the satellite data of whole Tiruchirapalli district was classified using supervised classification and maximum likelihood algorithm. The accuracy of the classification made is verified and salt affected soil map of Tiruchirapalli district was prepared (Fig.2).

The image characteristics and extent of area under different types of salt affected soils are as follows:

S.No	Class	Image characteristics	Area (ha)
1.	Slightly salt affected	Pinkish	7,362
2.	Moderately salt affected	Bluish	10,729
3	Strongly salt affected	White	64
		Total	**18,155**

The results revealed that out of the total geographical area of 4,40,412 ha, 7,362 ha are slightly salt affected, 10,729 ha are moderately salt affected and 64 ha are strongly salt affected. The map will be helpful to identify and transfer site specific management technologies for salt affected soils of Tiruchirappalli District.

3.2 Manikandam block

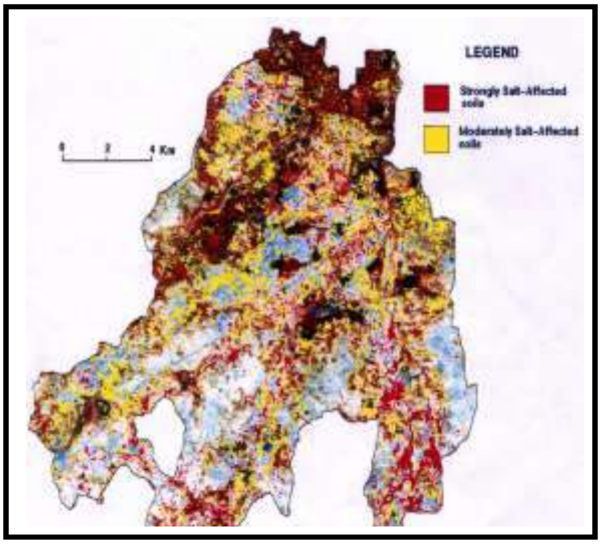


Fig 3. Salt affected soils of Manikandam block of Tiruchirappalli district

The district of Tamil Nadu were delineated using satellite data of IRS 1C LISS III sensor of 20.4.98 pass at 1:50000 scale. The satellite data was analysed on IBM workstation using EASI /PACE image analysis software packages. Based on the available ground truth the training areas were defined on FCC of IRS 1C data for salt affected soils, fallow areas, water bodies, crops, etc., The spectral signatures for the training areas in terms of digital number (DN) and standard deviation were generated (Table 3). The class seperability analysis was carried out and signature for above mentioned were finalised. IRS 1C data was classified using spectral signatures following maximum likelihood algorithm. The statistics for salt affected soils were extracted from the classified data. The salt affected soils were found as patches of varying dimension in the study area. The salt affected soils on standard false colour composite (FCC) print appeared as bright to dull white tone. Based on the total variation two types of salt affected soils were delineated. The data generated from six profile samples during 1997-98 were also made use of for the interpretation.

Out of the 21404 ha of total geographical area of Manikandam block, about 3667 ha are salt affected soils. The area under two types of salt affected soils is 1167 and 2500 ha are strongly and moderately salt affected soils respectively (Fig.3). The pH of the strongly salt affected soils was in the range of 9.2 to 10.3 and EC was 0.10 - 1.8 dSm^{-1} while pH of the moderately salt affected soils was in the range of 8.5 to 9.0 and EC was 0.1 to 1.7 dSm^{-1}. The soil classification as per US Soil Taxonomy for the two types of salt affected soils identified in the satellite imagery is given in Table 4.

Table 3. Spectral signatures of different classes in IRS 1C LISS III data

S.No.	Class	Mean DN values Band 1	Band 2	Band 3
1.	Fallow	136.64	126.92	115.63
2.	Fallow 2	128.60	95.59	93.40
3.	Paddy	102.36	59.65	104.64
4.	Coconut	108.60	68.62	138.07
5.	Water	109.34	71.37	60.75
6.	Town	132.50	103.05	86.62
7.	Sugarcane	100.04	57.03	126.79
8.	Strongly salt affected soils	167.83	142.49	125.70
9.	Moderately salt affected soils	154.64	125.29	114.80

Table 4: Soil Characterisation in two types of salt affects soils observed on satellite imagery

S.No	**Soils and site of Profile**	**Tone on satelite imagery**	**Soil classification (US Soil Taxonomy)**
A.	**Strongly salt affected soils**		
1.	Alathur I(Pirattiyur)	Bright whilte patches	Vertic Haplustalf
2.	Pirattiyur I (Pirattiyur)	Bright white patches	Vertic ustropept
3.	Panjappur I (Panjappur)	Bright white patches	Typic ustropept
4.	Panjappur II (Panjappur)	Bright white patches	Fluventic Rhodustalf

B.	**Moderately salt affected soils**		
1.	Alathur II (Pirattiyur)	Dull white patches	Vertic Natrustatlf
2.	Piratiyur II (Pirattiyur)	Dull white patches	Typic ustropept

4. EVALUATION OF PLANTS FOR SODICITY TOLERANCE

In alkali soils of Tamil Nadu single rice crop is grown during rainy season and the land is kept fallow during dry seasons. Though underground water is available, it is mostly of poor quality like alkali water. Hence field experiments were carried out at Anbil Dharmalingam Agrl. College and Research Institute Farm, Tiruchirapalli from 2000 onwards in field No. A7b to evaluate the sodicity tolerance of different crops and varieties to identify crops suitable for sodic soils cultivation during rainy season and dry season using alkali water.The crops were grown in sodic soils with artificially created ESP gradients and the tolerance limits for different crops and varieties were fixed based on the yields. The main plot consists of four levels of ESP (M1-8.0, M2- 16.0, M3-26.0 and M4-35.0) with four crop varieties under subplot treatment. The subplot treatment comprises of S1- Cereals, S2-Pulses, S3-Oilseeds and S4- fibre crops and first year of the experiment only three rice varieties were tested under this experiment.

The soil of the experimental field is fine mixed calcareous isohyperthemic Vertic Ustropept. The texture is clay loam with pH of 8.5, EC of 0.43 dSm^{-1}, CEC 21 cmol (p^+ kg^{-1}) and ESP of 16.5. The irrigation water is highly alkali with pH of 9.0, EC 1.65 dSm^{-1}, RSC 10.5 and SAR 10.7. Four ESP levels were created by applying calculated quantities of sodium bi-carbonate (to raise the ESP) and gypsum (to reduce the ESP). Crops were grown during three seasons *viz* June to September; September to January and February to May. The details of experiments conducted are furnished in Table 5.

The yield data of all the experiments are given in Table 6. The results revealed that among the coarse grained rice varieties, TRY 1 performed better than CO-43 and TRY (R) 2 (*Rabi 2000*). The yield was high in ESP level 16 (6767 kg ha^{-1}) followed by 35 (6042 kg ha^{-1}). The fine grained rice variety White Ponni performed better than ADT-39 and ADT-45 (*Rabi 2001*). The yields recorded at ESP levels 8, 16 and 26 were on-par (3666, 3500 and 3466 kg ha^{-1}, respectively) but declined at ESP 35. Among the pulses, greengram (var. Pusa Bold) recorded the highest yield of 1200 kg ha^{-1} at ESP 16 but the yield declined drastically above ESP 16 (*Kharif 2001*).

Table 5. Details of Experiments

Expt. No.	Season	Test crop(s) and Varieties	ESP gradients
1.	Rabi (2000)	Rice (TRY 1, CO 43 and TRY (R) 2)	8, 16.5, 35 and 45
2.	Kharif (2001)	Blackgram (T 9 and ADT 5) Greengram (Pusa bold)	8, 16, 26 and 35
3.	Rabi (2001)	Rice (ADT 39, ADT 45, White Ponni)	8, 16, 26 and 35
4.	Kharif (2002)	Bhend (Parbhani kranti) Vegetable cowpea (VBN37) Clusterbean (Pusa Nowbhahar)	8, 16, 26 and 35
5.	Rabi (2002)	Maize(COHM4)	8, 16, 32 and 48

		Sunflower(CO4) Sesame (CO 1)	
6.	Kharif (2003)	Bhendi (Parbhani kranti) Clusterbean (Pusa Nowbhahar) Sesame (CO 1)	8, 16, 32 and 48
7.	Rabi (2003)	Pearlmillet (6 genotypes)	8, 16, 32 and 48
8.	Kharif (2004)	Sunflower (CO 4)	8, 16, 32 and 48

Plate 1. Sunflower (CO4) grown in Alkali soil

The highest pod yield of bhendi (*Kharif 2002*) (12.37 t ha^{-1}) was recorded at an ESP level of 8, which was followed by soil ESP of 16 and 26, which were on par. At soil ESP level of 35, the yield was significantly lower (8.21 t ha^{-1}). Similarly the highest cluster bean yield of 13.11 t ha^{-1} was recorded at soil ESP level of 8 followed by soil ESP levels of 16 and 26. The vegetable cowpea (VBN2) did not perform well at all ESP levels tested. The germination percentage of maize (COH- M4), sunflower (CO4) and sesame (CO 1) grown during *Rabi 2002* ranged from 73 to 91 in soil ESP levels of 8 and 16. At soil ESP levels of 32 and 48 the germination was poor. The highest yields (3130, 2170 and 1050 kg ha^{-1} in maize, sunflower and sesame, respectively) were recorded in soil ESP level of 8 beyond which the yields declined (Table.7)

During *kharif* 2003, the germination percentage of bhendi, cluster bean and sesame ranged from 70 to 85 in soil ESP levels of 8 and 16. At soil ESP levels of 36 and 48 the germination was less than 8 and 6 per cent, respectively. In all the crops, maximum yield was recorded at ESP 8 (7.96, 6.79 and 0.97 t ha^{-1} for bhendi, cluster bean and sesame respectively). The yield of economic produce reduced drastically in the soil ESP levels of 36 and 48. The germination percentage of pearl millet cultivars was 80 to 91 at ESP 8 (*Rabi 2003*). At soil ESP level of 48 the germination was 2 to 12 per cent. In all the cultivars the grain yields declined with increasing soil ESP levels. The cultivars UCC 23 and UCC 17 performed better at higher ESP of 36 (1490 and 1460 kg ha^{-1}, respectively). During *kharif* 2004, the highest sunflower seed yield of 1841 kg ha^{-1} was recorded at ESP 8 which declined to 1420 kg ha^{-1} at ESP 16. There was a drastic reduction in the seed yield beyond ESP 16.

Table 6. Effect of different soil ESP levels on yield of different crops

ESP levels	Pearlmillet grain yield (kg ha^{-1}) (*Rabi 2003*)							Sunflower seed yield (kg ha^{-1}) (*Kharif 2004*)
	CO7	**COHCu 8**	**UCC23**	**UCC17**	**ICMY221**	**PT1890**	**Mean**	
8.0	2240	2250	2750	2050	2240	2290		1841
16.5	1980	2270	2670	1660	1540	1660	2290	1420
36.0	920	810	1490	1460	810	710	1960	278
48.0	320	390	540	410	230	420	1030	73
Mean	**1360**	**1400**	**1860**	**1400**	**1210**	**1270**	**380**	**903**
CD (P=0.05)		**M**	230					51
		V	130					112
		M at V	330					
		V at M	270					

ESP levels		Vegetable yield (t ha-1) (Kharif 2002)		Grain yield (kg ha-1) (Rabi 2002)			Yield (t ha-1) (Kharif 2003)		
	Bhendi (Parbhani kranti)	**Vegetable cowpea (VBN-2)**	**Cluster bean (Pusa Nowbuhar)**	**Maize (Co H M4)**	**Sunflower (Co 4)**	**Sesame (Co 1)**	**Bhendi (Parbhani kranti)**	**Clusterbean (Pusa naubuhar)**	**Sesame (Co 1)**
8.0	12.37	1.50	13.11	3133	2107	1051	7.96	6.79	0.974
16.5	10.38	0.65	11.62	2766	1619	837	6.82	6.05	0.809
35.0	9.99	1.32	10.23	926	218	207	0.39	0.252	0.033
45.0	8.21	1.01	9.79	448	203	138	0.15	0.136	0.006
Mean	**12.37**	**1.50**	**13.11**	**1843**	**1037**	**554**	**3.83**	**3.31**	**0.456**
CD (P=0.05)		**M**	10.38		115		0.11		
		V	0.65		112		0.21		
		M at V	11.62		216		0.36		

		V at M	10.38		223		0.42		

ESP levels	**Rice Grain Yield (kg ha^{-1}) (*Rabi 2000*)**			**Grain yield (kg ha^{-1}) (*Kharif 2001*)**			**Rice Grain Yield (kg ha^{-1}) (*Rabi 2001*)**		
	TRY1	**CO43**	**TRY(R)2**	**Black gram (Var-2)**	**Black gram (ADT-2)**	**Green gram (Pusa bold)**	**ADT-39**	**ADT-45**	**White Ponni**
8.0	5775	6458	3633	12.37	1.50	13.11	3100	2600	3666
16.5	6767	6492	3642	10.38	0.65	11.62	3383	2766	3500
35.0	6042	5033	4108	9.99	1.32	10.23	2491	2508	3466
45.0	5178	4166	3633	8.21	1.01	9.79	2683	2525	3066
Mean	**5941**	**5537**	**3754**	624.0	840.0	867.0	2914	**2600**	**3425**
CD (P=0.05)		**M**	162		42.0		239.0		
		V	143		35.2		135.0		
		M at V	514.4		67.3		324.8		
		V at M	509.8		74.4		270.9		

The contents of N, P, K and Na of rice cultivars were analyzed, their uptake was calculated and the values are furnished in Table 11.

Table 7. Effect of different soil ESP levels on Nutrient uptake

ESP levels	Total N uptake (kg ha^{-1})			Total P uptake (kg ha^{-1})			Total K uptake (kg ha^{-1})		
	ADT39	ADT45	White Ponni	ADT39	ADT45	White Ponni	ADT39	ADT45	White Ponni
8.0	70.8	65.0	96.1	16.4	14.9	18.4	51.8	51.9	65.8
16.0	71.8	72.2	93.6	16.1	14.3	18.3	52.3	57.4	66.4
26.0	58.6	63.4	88.3	13.1	12.9	17.5	45.5	50.1	65.4
35.0	58.7	66.2	84.8	14.3	12.1	17.1	43.4	48.8	61.3
CD (P=0.05)		**M**	3.99		1.39			2.55	
		V	2.54		0.654			2.25	
		M at V	5.74		1.75			4.47	
		V at M	5.07		1.31			4.51	

The edible parts of three vegetables were analysed for sodium and potassium content and their uptake was computed and given in Tables 8. The result revealed that sodium content in edible part of all vegetables increased with increasing levels of ESP. In bhendi the lowest Na content of 0.21 per cent was recorded at soil ESP level of 8 and the highest Na content of 1.09 per cent at soil ESP level of 35. In cluster bean the highest Na content of 0.79 per cent was recorded at soil ESP level of 35 while the lowest Na content of 0.22 per cent was recorded at soil ESP level of 8. The maximum Na uptake of 12.56 kg ha^{-1} was recorded in cluster bean followed by bhendi and vegetable cowpea. In bhendi Na uptake increased with increasing soil ESP level upto 26 which was on par with soil ESP of 35.

Table 8. Effect of different soil ESP levels on Na content (%) and Na uptake (kg ha^{-1}) in edible parts of vegetables

ESP levels	Bhendi		Vegetable Cowpea		Cluster bean		Mean	
	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake
8	0.21	3.57	0.167	0.42	0.223	5.88	**0.199**	**3.29**
16	0.60	8.78	0.497	0.56	0.600	13.93	**0.567**	**7.76**
26	0.99	13.89	0.703	1.56	0.73	15.00	**0.811**	**10.15**
35	1.09	12.52	0.75	1.24	0.787	15.42	**0.876**	**9.73**
Mean	**0.72**	**9.69**	**0.529**	**0.95**	**0.586**	**12.56**		
M S M at S S at M								
CD (P=0.05) Content 0.027 0.009 0.031 0.019								
Uptake 0.88 0.834 1.62 1.67								

The K content of three vegetables tested decreased with increasing ESP levels. The K content ranged from 1.98 to 1.79 percent in bhendi and 1.79 to 1.59 per cent in cluster bean. The highest K uptake of 47.1 kg ha^{-1} was recorded in cluster bean at soil ESP level of 8. In bhendi K uptake decreased from 34.4 kg ha^{-1} to 20.7 kg ha^{-1} at soil ESP levels of 8 and 35, respectively (Table.9).

To assess the sodicity tolerance of crops Na/K ratios in different plant parts were computed and given in Table 14. In all plant parts Na/K ratios were found to increase with increasing level of soil ESP. In edible parts among different ESP levels the ratio ranged from 0.104 to 0.606 for bhendi, 0.107 to 0.535 in vegetable cowpea and 0.124 to 0.493 in cluster bean.

Table 9. Effect of different Soil ESP levels on K content (%) and K uptake (kg ha^{-1}) in edible parts of vegetables

ESP levels	Bhendi		Vegetable Cowpea		Cluster bean		Mean	
	Content	Uptake	Content	Uptake	Content	Uptake	Content	Uptake
8.0	1.983	34.4	1.557	4.0	1.797	47.1	1.779	28.5
16.0	1.887	27.1	1.500	1.7	1.723	40.0	1.703	22.9
26.0	1.853	25.9	1.433	3.2	1.673	34.2	1.653	21.1
35.0	1.797	20.7	1.400	2.4	1.593	31.2	1.597	18.1
Mean	1.880	27.0	1.473	2.80	1.697	38.1		
M S M at S S at M								
CD (P=0.05) Content 0.0096 0.0065 0.0143 0.0131								
Uptake 2.4 2.1 4.2 4.3								

Table 10. Effect of different Soil ESP levels on Na/K ratios in different plant parts of vegetables

ESP levels	Bhendi			Vegetable cowpea			Cluster bean		
	Edible part	Shoot	Root	Edible part	Shoot	Root	Edible part	Shoot	Root
8.0	0.104	0.45	1.52	0.107	0.44	0.63	0.124	0.30	2.1
16.0	0.319	0.49	1.81	0.331	0.54	1.1	0.348	0.39	2.76
26.0	0.538	0.50	1.92	0.490	0.60	1.3	0.438	0.47	3.08
35.0	0.606	0.60	2.36	0.535	0.70	1.42	0.493	0.60	3.3

Wider Na/K ratios were recorded in root when compared shoot and edible parts. Among vegetables, root of cluster bean recorded wider ratio of 3.3 at soil ESP level of 35 whereas narrow ratio was recorded at 8 ESP. The Na/K ratios in roots varied from 1.52 to 2.36 for bhendi, 0.63 to 1.42 in vegetable cowpea and 2.1to 3.3 in cluster bean. The Na/K ratios varied in the order of cluster bean > bhendi > vegetable cowpea. Among different crops tested, the highest Na uptake of 17.7 kg ha^{-1} and 24.1 kg ha^{-1} were recorded by bhendi and clusterbean respectively at soil ESP of 16 (Table 10 & 11). In bhendi and cluster bean, Na uptake decreased drastically at ESP level of 36 and 48. The highest K uptake of 47.9, 54.9 and 49.9 kg ha^{-1} was recorded in bhendi, cluster bean and sesame respectively at soil ESP level of 8 beyond which K uptake decreased with increasing soil ESP level. The K uptake also drastically reduced at higher soil ESP level of 36 and 48.

Table 11. Effect of different Soil ESP levels on total Na and K uptake (kg ha^{-1})

ESP levels	Bhendi		Cluster bean		Sesame		Mean	
	Na	K	Na	K	Na	K	Na	K
8.0	12.2	47.9	19.1	54.9	11.4	49.9	14.2	51.0
16.0	17.7	35.2	24.1	48.5	9.7	39.1	17.2	40.9
36.0	1.4	2.1	0.77	1.36	0.45	1.29	0.87	1.58
48.0	0.61	0.82	1.06	1.33	0.08	0.21	0.58	0.79
Mean	8.0	21.5	11.3	26.5	5.4	22.6		
CD (P=0.05)			M	S	M at S	S at M		
		Na	1.13	0.83	1.7	1.8		
		K	2.53	2.46	4.74	4.93		

The Na/ K ratios were computed for all the vegetables for different plant parts is shoot, root and edible part. In all the plant parts and all crops Na/K ratio increased with increasing ESP levels. Wider Na/K ratios were recorded in root when compared to shoot and edible parts. Among crops tested, root of cluster bean recorded wider ratio of 4.03 at 48 ESP level whereas narrow ratio was recorded at 8 ESP (Table 12). The Na/K ratios in roots indicate the Sodicity tolerance of crop viz., cluster bean> bhendi> sesame.

Table 12. Effect of different Soil ESP levels on Na/K ratios in different plant parts

ESP levels	Bhendi			Cluster bean			Sesame		
	Edible part	Shoot	Root	Edible part	Shoot	Root	Seed	Shoot	Root
8.0	0.10	0.25	1.05	0.13	0.31	1.9	0.13	0.18	0.94
16.0	0.32	0.45	1.56	0.35	0.38	2.84	0.15	0.20	1.02
36.0	0.56	0.52	2.45	0.46	0.50	3.34	0.20	0.24	2.33
48.0	0.63	0.54	2.72	0.51	0.67	4.03	0.21	0.27	3.45

The per cent yield reduction of different crops tested at different soil ESP level is presented in Tables 13 and 14. A soil ESP of 16, maize (CoHM4), Bhendi (Parbhani kranti), cluster bean (Pusa naubuhar), pearlmillet (CO7, UCC 23) recorded the yield reduction 15 %. The soil ESP level of 36 and 48 yield reduction was above 59 % except for pearlmillet cultivars UCC 23 and 17.

The benefit cost ratios were calculated for different crops considering the cost of all inputs and the market price of the economic produce and by-products at the time of harvest and given in Table 15. At 16 soil ESP level pearlmillet variety UCC 23, bhendi (Parbhani kranti), sunflower (CO 4) and sesame (CO1) recorded higher B:C ratios. The pearlmillet varieties UCC 23 and UCC 17 recorded positive benefit cost ratio even at soil ESP level of 36 and these varieties can be recommended as alternate crop after rice crop.

Table 13. Per cent yield reduction of different crops/varieties at different ESP levels

	ESP levels		
Crop/Variety	**16**	**26**	**35**
Rice (TRY 1)	-	10*	24*
Rice (CO43)	-	22	36
Rice (TRY(R)2)	-	-	11***
Black gram (T9)		65*	70*
Black gram (ADT 5)	-	66*	71*
Green gram (Pusa bold)	-	58*	65*
Rice (ADT39)	-	26*	21*
Rice (ADT45)	-	9*	8*
Rice (White ponni)	-	6*	16*
Bhendi (Parbani kranti)	16**	19**	34**
Cluster bean (Pusa nowbuhar)	11**	22**	25**

*- compared to 16 ESP level; ** **-** compared to 8 ESP level; ***- compared to 26 ESP level

Table 14. Per cent yield reduction of different crops at different ESP levels

Crop	**ESP levels**		
	16	**36**	**48**
Maize (COHM4)	12	70	86
Sunflower (CO4)	23	89	90
Sesame (CO1)	20	80	88
Bhendi (Parbhani kranti)	14	90	98
Cluster Bean (Pusa naubuhar)	10	96	97
Sesame (CO1)	16	96	98
Pearlmillet			
CO7	12	59	85
COHCu8	-	62	82
UCC23	3	45	80
UCC17	19	29	79
ICMY221	32	64	89
PT1890	27	69	81

Table 15. Benefit Cost ratios for different crops at different ESP levels

Crop	ESP levels			
	8	16	36	48
Maize	1.60	1.40	-	-
Sunflower	3.40	2.64	-	-
Sesame	3.03	2.41	-	-
Bhendi	3.10	2.70	-	-
Cluster bean	1.80	1.60	-	-
Pearl millet varieties / cultivars				
CO7	2.44	2.16	1.00	-
COHCU 8	2.26	2.39	-	-
UCC 23	3.00	2.90	1.57	-
UCC 17	2.20	1.80	1.59	-
ICMY 221	2.47	1.68	-	-
PT 1870	2.48	1.80	-	-

The yild data of various crops grown during the past four years were plotted against ESP levels to identify the best fitting curve. The second order quadratic polynomial curve was found to be the best fit with highest R^2 values for all the crops. From the second order quadratic polynomial curves, the ESP levels for 10, 25 and 50% yield reductions were predicted and presented in Table 16.

Table 16. Predicted yield reduction of different crops at different ESP levels

Crop	Season	Y_{max}	Predicted ESP levels for yield reduction of		
			10 %	25 %	50 %
Maize	Rabi 2002-03	3133	15	21	29
Sunflower	Kharif 2004	1841	12	16.5	24
Sesame	Kharif 2003	974	14	18	24
Bhendi	Kharif 2003	7967	14	19	24.5
Cluster bean	Kharif 2003	6793	16	19.5	25
Pearl millet varieties / cultivars					
CO7	Rabi 2003-04	2244	15	22	32
COHCU 8	Rabi 2003-05	2245	21	25.5	32
UCC 23	Rabi 2003-06	2748	21	28	37.5
UCC 17	Rabi 2003-07	2053	11	33	43
ICMY 221	Rabi 2003-08	2243	10	14	25
PT 1870	Rabi 2003-09	2289	10	15	25

The results revealed that the 50 per cent yield reduction from the maximum obtained yield was at the lowest ESP level of 24 for sunflower (CO4) and sesamum (CO1), where as for the pearl millet cultivars UCC 23 and UCC 17, the 50 per cent yield reduction was observed at the highest ESP levels of 37.5 and 43, respectively.

Prediction of yield loss from the threshold ESP- Mass Hoffman Equation

The Y_{max}, threshold yield (T_T), threshold sodicity (a) and the slope of per cent yield reduction curve (b) beyond the threshold (a) calculated by fitting the yield data in Mass Hoffman Equation are furnished in Table 17.

Using the Mass Hoffman constants, the per cent yield losses from the yield at threshold ESP (Y_T) of different crops predicted at various ESP levels are furnished in Table 18. Among the crops tested, the yield loss from the yield at Threshold ESP was the lowest (24 per cent at ESP 40) for pearl millet cultivar UCC 17.

Table 17. Threshold ESP, yield at threshold ESP and the slope of yield curve (after threshold ESP) of various crops

Crop	Y_{max} (ESP 8.0)	Y_T at (ESP_T)	a (ESP_T)	B
Maize	3133	2766	16	-2.2401
Sunflower	1841	1420	16	-3.0718
Sesame	974	809	16	-3.2747
Bhendi	7967	6816	16	-3.224
Cluster bean	6793	6047	16	-3.1879
Pearl millet varieties / cultivars				
CO7	2244	1980	16	-2.63
COHCU 8	2245	2266	16	-2.6562
UCC 23	2748	2670	16	-2.4653
UCC 17	2053	1464	36	-5.9825
ICMY 221	2243	2243	8	-2.1091
PT 1870	2289	2289	8	-2.0244

Table 18. Yield loss of various crops at various ESP levels predicted using Mass Hoffman Equation

Crop	Y_T (kg ha^{-1})	ESP levels					
		10	20	30	40	50	60
Maize	2766	-	9	31	54	76	99
Sunflower	1420	-	12	43	74	-	-
Sesame	809	-	13	46	79	-	-
Bhendi	6816	-	13	45	77	-	-
Cluster bean	6047	-	13	45	77	-	-
Pearl millet varieties / cultivars							
CO7	1980	-	11	37	63	89	-
COHCU 8	2266	-	11	37	64	90	-

UCC 23	2670	-	10	35	59	84	-
UCC 17	1464	-	-	-	24	84	-
ICMY 221	2243	4	25	46	67	89	-
PT 1870	2289	4	24	45	65	85	-

Salient Findings

- The coarse grained rice variety TRY 1 and fine grained variety ADT 45 tolerates up to an ESP of 26
- Green gram variety Pusa Bold tolerates an ESP of 16.
- At higher ESP level of 36, pearlmillet cultivar UCC 17 performed better with minimum yield loss.
- Upto an ESP of 16, the other crops *viz.*, Maize (COH M4), Sunflower (CO 4), Sesame (CO 1), Bhendi (Parbhani Kranti), Cluster bean (Pusa Naubuhar) performed better with minimum yield loss.

4.1 Evaluation of Different Sunflower Varieties for Sodicity Tolerance

A field experiment was conducted during July 2006 to September 2006 in split-split plot design with two sunflower varieties *viz.,* TCSH 1 (Hybrid) and CO 4 as test crop to study the effect of micronutrients viz., Zinc and Boron and their combination with and without rubbing of heads during flowering stage on enhancing the grain yield in four ESP levels viz., 9.2 (M1), 16.7 (M2), 24.9 (M3) and 33.2 (M4). This field experiment was conducted by Split-Split plot design (Factor C as a Split Plot on A and B) with four replications and the experimental details are furnished below.

Treatment Details

Factor A ESP levels (4)	**Factor B** Sunflower varieties (2)	**Factor C** Micro-nutrients/Rubbing
1) 9.2	1) CO4	1) $ZnSO_4$ Spray
2) 16.7	2) Hybrid (TCSH1)	2) Boron Spray
3) 24.9		3) Rubbing the flower heads
4) 33.2		4) $ZnSO_4$ + Boron Spray
		5) $ZnSO_4$ + Rubbing
		6) Boron + Rubbing
		7) $ZnSO_4$ + Boron + Rubbing

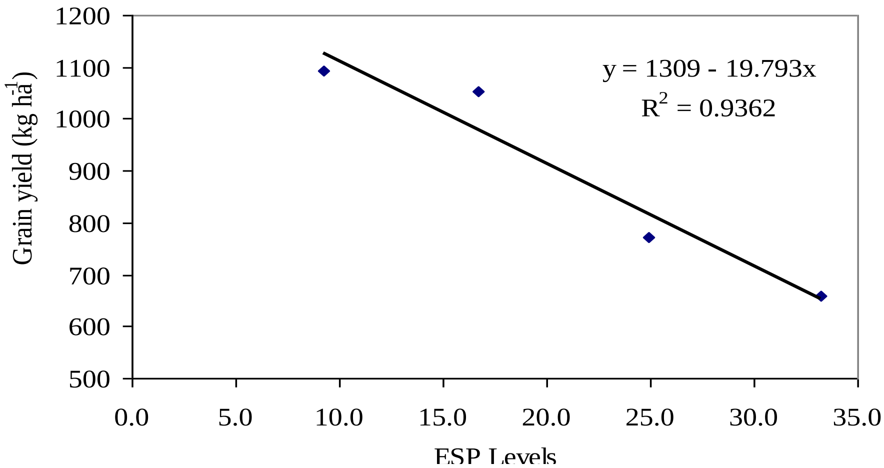
The result on sunflower grain yield is furnished in Table 19. The mean grain yield as influenced by ESP levels is furnished in Figure 4**.** The grain yields at ESP 9.2 and 16.7 were on par (1092 and 1052 kg ha^{-1}) but were significantly higher than ESP levels 24.9 and 33.2. Hybrid sunflower TCSH 1 recorded significantly higher yield (1012 kg ha^{-1}) than Variety CO 4 (775 kg ha^{-1}). In TCSH 1, the highest grain yield of 1273 kg ha^{-1} was recorded at ESP 9.2. The yield declined to 1183 kg ha^{-1} at ESP 16.7. In Variety CO 4, the highest yield of 922 kg ha^{-1} was recorded at ESP 9.2 which was on par with the yield recorded at ESP 16.7 (910 kg ha^{-1}).

Among the micronutrient treatments, the highest mean grain yield and the highest grain yields in TCSH 1 and CO 4 were recorded in the treatment combination of Zn and Boron spray with rubbing of flower heads (1130, 1279 and 981 kg ha^{-1}, respectively. The mean grain yields in Zn + B, Zn with rubbing and B with rubbing were found to be on par but significantly higher than control, Zn alone and B alone treatments. The ESP level at which 50 % of the mean maximum yield got reduced was found to be 38.6.

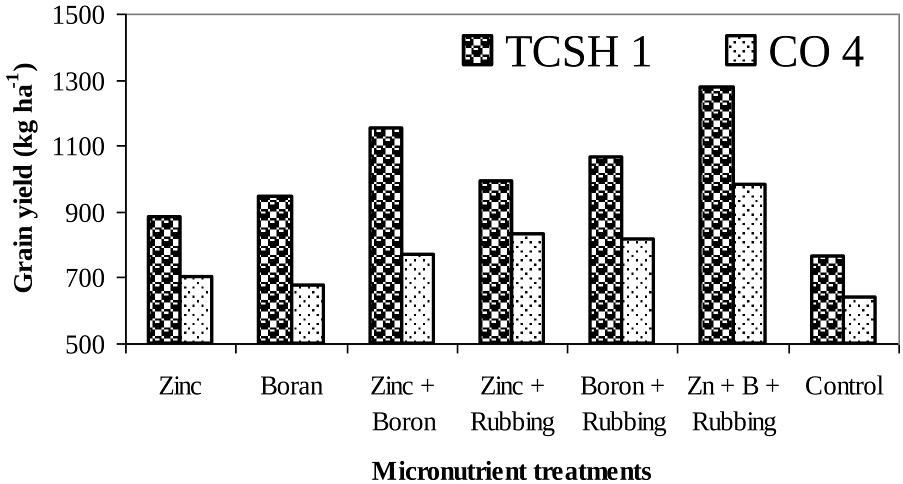
Table 19. Grain yield of sunflower varieties under different ESP levels as influenced by micronutrient and rubbing treatments

Treatments	Hybrid (TCSH 1)					Variety (CO 4)					Mean (ESP Vs. Micronutrients)				
	ESP Levels				Mean (TCSH 1)	ESP Levels				Mean (CO 4)	ESP Levels				Mean (MNS)
	9.2	16.7	24.9	33.2		9.2	16.7	24.9	33.2		9.2	16.7	24.9	33.2	
Zinc	1162	1056	752	562	**883**	881	814	588	533	**704**	988	969	670	547	**793**
Boron	1134	1202	809	640	**946**	891	759	534	526	**677**	947	1046	671	583	**812**
Zinc + Boron	1565	1275	870	910	**1155**	1001	930	610	545	**772**	1247	1138	740	728	**963**
Zinc + Rubbing	1190	1139	884	751	**991**	923	956	842	615	**834**	1073	1031	863	683	**913**
Boron + Rubbing	1289	1208	945	817	**1065**	912	1058	747	557	**818**	1173	1060	846	687	**941**
Zn + B + Rubbing	1612	1370	1203	933	**1279**	1060	1174	862	827	**981**	1393	1215	1032	880	**1130**
Control	961	1029	526	539	**764**	787	679	633	452	**638**	820	908	580	496	**701**
Mean	**1273**	**1183**	**856**	**736**	**1012**	**922**	**910**	**688**	**579**	**775**	**1092**	**1052**	**772**	**658**	**893**

	ESP levels (A)	Varieties (B)	A x B	Micronutrients (C)	A x C	B x C	A x B x C
SEd	28	20	40	32	64	45	90
CD (0.05)	59	42	83	63	NS	89	NS



(a)



(b)

Fig 4: Sunflower grain yield as influenced by (a) Zn, B and rubbing treatments (b) different ESP levels

Mass Hoffman Equation

Y_r (%) = 100% – b (ECe-a)

Where,

Y_r = relative yield in presence of salinity (sodicity)

b = slope of yield reduction curves (% yield loss, per unit increase in salinity (sodicity) beyond the threshold (a).

a = threshold soil salinity (sodicity), after which yield decreases begin.

The Y_{max}, threshold yield (Y_T), threshold sodicity (a) and the slope of per cent yield reduction curve (b) beyond the threshold (a) calculated by fitting the yield data in Mass Hoffman Equation are furnished below.

The yield data were fitted to Mass-Hoffman Equations and the Y_{max}, Y_T, a and b values are furnished in Table 20. The threshold ESP (a) at the deflection point of yield curve was found to be 16.7 for both the varieties. The slope of the per cent yield reduction curve after threshold yield (Y_T) was -2.2805 and -2.1945 for TCSH 1 and CO 4, respectively.

Table 20. Mass-Hoffman equation parameters

Crop	Y_{max} (ESP 9.2)	Y_T at (ESP_T)	a (ESP_T)	b
Mean Yield	1092	1052	16.7	-2.2625
TCSH 1	1273	1183	16.7	-2.2805
CO 4	922	910	16.7	-2.1945

Table 21. Mass-Hoffman equation parameters for sunflower variety CO 4 and hybrid TCSH1

Crop	Y_{max} (ESP 9.2) (kg/ha)	Y_T at ESP_t (kg/ha)	ESP_t	b	ESP at 50% yield reduction
TCSH 1	1273	1183	13.0	-2.1187	34
CO 4	922	910	16.5	-2.1667	37

The threshold ESP_t at the deflection point of yield curve was found to be 13.0 for TCSH1 and 16.5 for CO4 (Table 21). The slopes of the per cent yield reduction curve after threshold yield were -2.1187 and -2.1667 for TCSH 1 and CO4, respectively.

The grain yield, BC Ratio, Na and K uptake and Na/K ratio in different plant part of sunflower (TCSH1 and CO4) at different ESP levels are furnished in Table 22. The highest B:C ratio of 3.1 was obtained at ESP 9.2 in TCSH1 sunflower hybrid. The B:C ratio for TCSH1 hybrid at ESP 24.9 was 2.3 which was equal to the B:C ratio of CO 4 sunflower variety at ESP 9.2. The highest sodium and potassium uptakes were at ESP 9.2. At all the ESP levels, the highest Na to K ratio was found in roots in both the varieties and the ratio increased with increasing ESP levels.

Table 22. Total grain yield, BC ratio, Na and K uptake and Na/K ratio in
1. different plant parts of sunflower (CO4 and TCSH1) at different ESP levels

ESP levels	Seed yield (kg/ha)		B:C ratio		Total Na and K uptake (kg/ha)				Na / K ratio					
					Na		K		TCSH1			CO4		
	TCSH1	CO4	TCSH1	CO4	TCSH1	CO4	TCSH1	CO4	Seed	Shoot	Root	Seed	Shoot	Root
9.2	1612	1174	3.1	2.3	19.7	14.3	146.5	106.7	0.09	0.13	2.21	0.08	0.12	2.15
16.7	1370	1060	2.6	2.0	16.7	12.9	124.5	96.4	0.15	0.16	2.65	0.14	0.14	2.42
24.9	1203	862	2.3	1.7	14.7	10.5	109.4	78.4	0.24	0.17	3.64	0.21	0.14	3.27
33.2	933	827	1.8	1.6	11.4	10.1	84.8	75.2	0.26	0.25	4.54	0.25	0.22	4.19
Mean	1280	981			15.6	12.0	116.3	89.2	0.19	0.18	3.26	0.17	0.16	3.01
SEd	28		-	-	0.51	0.48	1.16	1.06	-	-	-	-	-	-
CD (p=0.05)	59		-	-	1.13	1.05	2.58	2.31	-	-	-	-	-	-

4.2 Evaluation of Different Okra Varieties for Sodicity Tolerance

The second field experiment with three okra varieties were conducted during 2006 and 2007 with split plot design. The main plots have four ESP levels (M_1. 9.8, M_2. 17.3, M_3. 25.5, and M_4. 35.3) and subplot consists of three Okra varieties viz., Parbhani Kranti (S1), Arkha Anamika (S2) and Hybrid No.10 (S3).

Among the okra varieties, hybrid No.10 produced an average yield of 6.79 t /ha which was at par with Arkha Anamika 5.86 t /ha. The highest mean yield was registered at ESP 9.8 (7.56 t/ha) which was reduced to 3.43 t /ha at 35.3 (Table 23).

Table 23. Yield of okra Varieties (t/ha) at Different ESP levels

Cultivars	ESP levels				Mean
	9.8	17.3	25.5	35.3	
Parbani Kranti	6.02	5.51	3.01	2.49	**4.26**
Arkha Anamika	7.22	6.89	5.29	4.03	**5.86**
Hybrid No.10	9.43	8.43	5.53	3.76	**6.79**
Mean	**7.56**	**6.94**	**4.61**	**3.43**	

	Cultivars	ESP levels	Cultivars x ESP Levels
SEd	0.46	0.24	0.42
CD (P=0.05)	1.28	0.54	0.88

The Y_{max}, threshold yield (Y_T), threshold sodicity ESP_t and the slope of per cent yield reduction curve (b) beyond the threshold ESP were calculated by fitting the yield data in Mass Hoffman Equation are furnished in Fig 5, 6, 7 and Table 24.

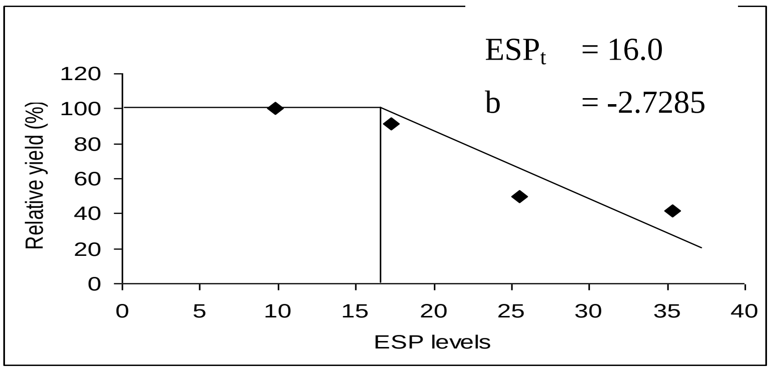


Fig 5. Relative yield of okra variety Parbhani kranti as influenced by ESP levels

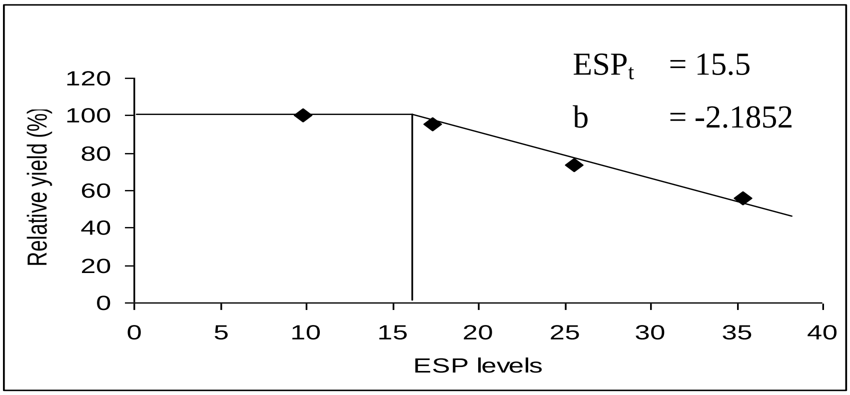


Fig 6: Relative yield of okra variety Parbhani kranti as influenced by ESP levels

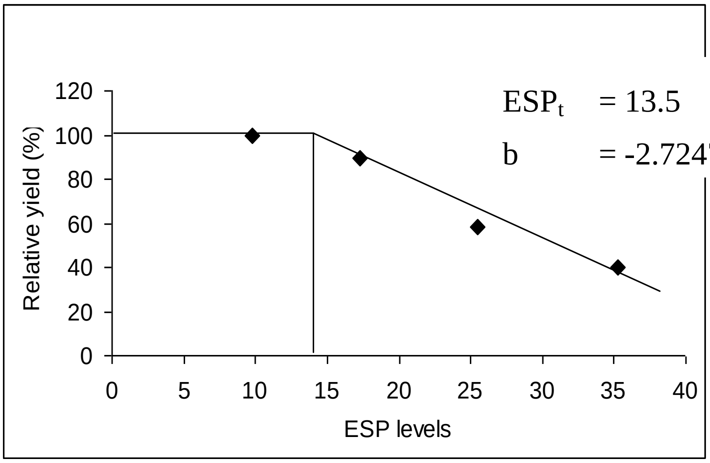


Fig 7: Relative yield of okra variety Parbhani kranti as influenced by ESP levels

Table 24. Mass-Hoffman Equation Parameters for okra Varieties

Varieties	Y_{max} (ESP 9.8)	Y_T at ESPt	ESP$_t$	b	ESP at 50% yield reduction
Parbhani Kranthi	6018	5508	16.0	-2.7285	30.0
Arkha Anamika	7219	6890	15.5	-2.1852	34.0
Hybrid No.10	9428	8433	13.5	-2.7247	31.0

Salient Findings

- The threshold ESP for the sunflower variety CO4 and hybrid TCSH1 were 16.5 and 13.0, respectively.
- The ESP at 50% yield reduction for sunflower variety CO4 and hybrid TCSH1 were 37 and 34, respectively
- The threshold ESP for okra varieties were 13.5, 15.5 and 16 for hybrid No10, Arkha anamika and Parbhani kranti, respectively.
- The ESP at 50% yield reduction for okra varieties were 31, 34 and 30 for hybrid No10, Arkha anamika and Parbhani kranti, respectively

4.3 Evaluation of Different Cotton Varieties and Hybrids for their Tolerance to Sodicity Level

The results from the third year (2014) of the field experiment showed that among the varieties and hybrid tested under different ESP levels, the hybrid(Bt cotton) cotton RCH-20 has performed better and recorded higher yield (2954 kg ha^{-1}) at all ESP level compared to varieties (Table 25). However, the same hybrid the seed cotton yield was significantly reduced as the ESP level increases from 9.6 to 38. With regards to soil pH at different ESP levels the soil pH values were increased as the ESP levels increased at post harvest soil and this might be due to irrigation with water alkali water during the crop growth period. Over all finding from the past three years the hybrid cotton has performed better in seed cotton yield compared to varieties at different ESP levels. The data on Na/K ratio in cotton hybrids and varieties showed that, the hybrid cotton RCH-20 recorded the lowest ratio than the varieties Surabhi and SVPR-2. It indicates that the under different sodicity levels the hybrid cotton excluded the Na uptake in the plant system than K compared to varieties. That is why the hybrid cotton performed better in term of yield and other biometric parameters than the varieties (Table.26).

Table 25. Seed Cotton yield under different ESP levels (kg ha^{-1})

Treatments (ESP levels)	Seed Cotton yield (kg ha^{-1})			
	Cotton variety / Hybrid*			
	S1 (Surabhi)	S2 (RCH-20)*	S3 (SVPR-2)	Mean
M1 (9.6)	2030	2954	1931	2300
M2 (18.5)	1461	2106	1464	1677
M3 (29)	1294	1333	1273	1300
M4 (38)	931	1234	843	1002
Mean	1429	1906	1377	
CD (p = 0.05)	**M**	**S**	**M at S**	**S at M**
	121.67	91.04	191.65	182.07

Table 26. Na/K ratio in cotton crop under different ESP levels

Treatments (ESP levels)	Na/K ratio			
	Cotton variety / Hybrid*			
	S1 (Surabhi)	S2 (RCH-20)*	S3 (SVPR-2)	Mean
M1 (9.6)	1.01	0.73	1.14	0.96
M2 (18.5)	1.17	0.80	1.23	1.06
M3 (29)	1.25	0.89	1.33	1.15
M4 (38)	1.35	0.95	1.46	1.25
Mean	1.19	0.84	1.29	

4.4 Evaluation of Different Sorghum Varieties for their Tolerance to Sodicity Level

A field experiment was conducted to assess the effect of different Exchangeable Sodium Percentage (ESP) levels of soil on growth and yield of sorghum varieties and to fix optimum sodicity tolerance limits of sorghum varieties based on the performance under different soil sodicity levels. This experiment was continuous and permanent one, so far different crops were tested for their tolerance to sodicity. In existing experimental field, based on the ESP existed in the different main plots, the sodium bicarbonate was applied to main plots and mixed thoroughly with the soil to create different gradient ESP levels viz., 8, 16, 24, 32, 40 and 48 were artificially. Further, the ESP 8 and 16 were created through application of gypsum and leaching with good quality water. The experimental plot was thoroughly ploughed individually to bring optimum soil tilt and the ridges and furrows were formed and seeds of sorghum varieties viz. K12, Co30, Local –Red and Local – Irungu (Black) were sown on 08.02.2019 with a spacing of 45x15 cm.

Table 27. Effect of graded levels of Exchangeable Sodium Percent (ESP) on Grain yield (Kg/ha) of sorghum cultivars

ESP level/varieties	S1 – K12	S2 – Co 30	S3 – Red local	S4 – Irungu local	Mean
M1 – 8	1024.7	1433.7	625.3	459.3	885.8
M2 – 16	827.0	1162.0	593.0	331.7	728.4
M3 – 24	660.3	944.7	419.3	242.7	566.8
M4 – 32	392.3	855.3	360.0	235.3	460.7
M5 – 40	102.7	201.0	140.7	87.7	133.0
M6 – 48	55.7	166.3	54.0	26.3	75.6
Mean	510.4	793.8	365.4	230.5	
		SED		**CD(0.05)**	
M		11.72		26.11	
S		11.72		23.77	
M at S		27.49		56.75	
S at M		28.71		58.23	

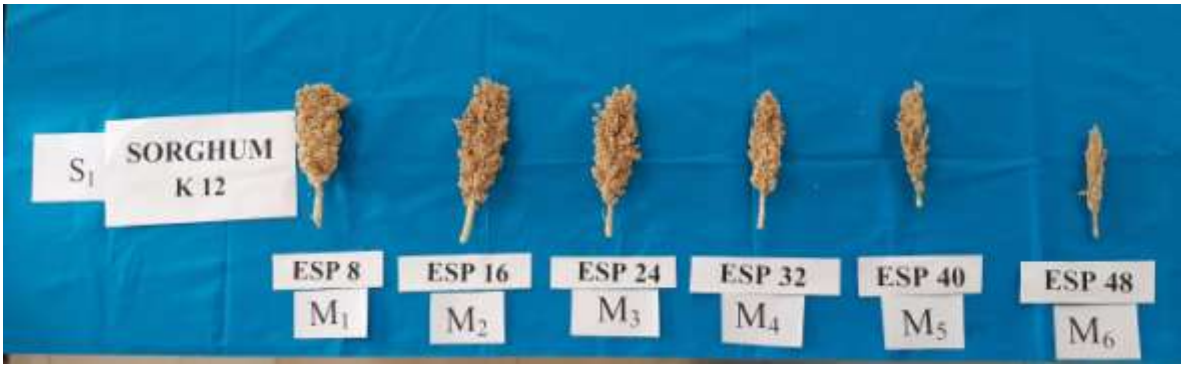
Table 28. Effect of graded levels of Exchangeable Sodium Percent (ESP) on Halum yield (Kg/ha) of sorghum cultivars

ESP level/varieties	S1 – K12	S2 – Co 30	S3 – Red local	S4 – Irungu local	Mean
M1 – 8	1540.3	915.7	1120.7	1749.7	1331.6
M2 – 16	1392.7	856.3	961.0	1654.3	1216.1
M3 – 24	1344.7	816.7	818.7	1607.7	1146.9
M4 – 32	1002.0	791.7	635.0	1377.3	951.5
M5 – 40	733.0	568.3	489.3	1031.3	705.5
M6 – 48	388.7	479.3	425.0	865.7	539.7

Mean	1066.9	738.0	741.6	1381.0	

	SED	**CD(0.05)**
M	28.65	63.85
S	15.54	31.51
M at S	43.67	92.34
S at M	38.06	77.19

The results revealed that the interaction of ESP and Cultivars, the highest grain yield of 1433.7 kg per ha was recorded by Co 30 at 8 ESP level (Table 27). The lowest grain yield of 26.3 kg per ha recorded by Irungu local at 48 ESP level. However, 50 per cent grain yield was recorded in the cultivars viz., Co 30, Red local and Irungu local at the ESP of 32 per cent whereas in the cultivar K12 recorded 50 per cent yield at 24 ESP level which is clearly indicated that the cultivars Co 30, Red local and Irungu local could be grown in the sodic soil having the ESP up to 32 per cent whereas the cultivar K12 can be recommended to the sodic soil having the ESP level up to 24 per cent. The results of haulm yield revealed that the 50 per cent haulm yield was recorded in the cultivars viz., Red local and K12 at the ESP of 32 per cent whereas, Co 30 and Irungu local recorded 50 per cent yield at 48 and 40 ESP level respectively (Table 28). The haulm yield results clearly indicated that the cultivars Co 30, though it recorded the lowest haulm yield, it tolerance to 48 ESP while obtaining 50 per cent of maximum possible haulm yield. Although, the Irungu local recorded the lowest grain yield, it recorded the highest haulm yield among the cultivar which could suitably recommended for cultivation as fodder crop in the sodic soil up to 40 per cent ESP level (Plates 2 & 3).



Plates 2 and 3 Ear head of sorghum varieties under different ESP levels

4.5 Evaluation of Different Onion Varieties for their Tolerance to Sodicity Level

A field experiment was conducted to assess the effect of different Exchangeable Sodium Percentage (ESP) levels of soil on growth and yield of onion and to fix optimum sodicity tolerance limits of onion based on the performance under different soil sodicity levels. This experiment was continuous and permanent one, so far different crops were tested for their tolerance to sodicity. In existing experimental field, based on the ESP existed in the different main plots, the sodium bicarbonate was applied to main plots and mixed thoroughly with the soil to create different gradient ESP levels viz., 8, 16, 24, 32, 40 and 48 were artificially. Further, the ESP 8 and 16 were created through application of gypsum and leaching with good quality water. The experimental plot was thoroughly ploughed individually to bring optimum soil tilt and the ridges and furrows were formed and onion bulb of local variety and seedlings of Co 5 were planted with a spacing of 45x10 cm with the application of fertilizers viz., 60:60:60 kg N, P_2O_5 and K_2O (50% of N at basal and remaining 50% at 30 DAS). The experiment was carried out with five levels of ESP in main plot and two onion variety in strip plot design with four replications. The results revealed that among the different levels of ESP, the bulb yield was declined with increased ESP levels from 8. However, more than 50 per cent yield could be achieved up to 24 ESP level. Among the varieties Co 5 (seed) and local (Bulb), the performance of Co 5 was superior over local. The highest onion bulb yield of 14206 and 16213kg per hectare was recorded in local (onion bulb) and Co5 (seed) varieties respectively (Table 29). Similar trend with respect to the individual bulb weight per plant was also recorded. Hence, it is concluded that the onion can be grown in sodic soil up to the ESP level of 24 where the 50 per cent of yield.

Table 29. Effect of Graded Levels of Sodicity on Bulb Yield of Onion

Treatments ESP levels	Bulb wt.(g/plant)		Mean	Bulb Yield (kg/ha)		Mean
	V1-Onion bulb	V2 –Onion seed (Co5)		V1-Onion bulb	V2 –Onion seed (Co5)	
8	71.2	82.3	76.8	14206	16213	15209
16	54.4	68.7	61.6	10845	13642	12243
24	46.6	51.4	49.0	9286	10219	9752
32	24.6	35.7	30.2	4845	7089	5967
40	10.2	15.4	12.8	1944	3026	2485
48	9.8	10.3	10.1	1887	1966	1926
Mean	**36.13**	**43.97**		**7169**	**8692**	
	SED	CD		SED	CD	
ESP levels	1.45	3.08		311.8	664.5	
Varity	0.014	0.042		2.38	7.57	
ESP at Var	4.87	10.25		961.4	2049.2	
Varity at ESP	3.81	8.23		494.6	1054.6	

5. CROP NUTRIENT MANAGEMENT UNDER SALT AFFECTED SOILS

5.1 Effect of Levels of N and Organic Materials/ Green Manures on the Performance of Rice under Sodic Soil Conditions

The investigations were carried out to study the effect of different levels of N and organic materials/ green manures on the performance of rice and soil properties under sodic soil conditions.

The treatment combinations of application of 75 % RDN through Urea with four different types of organic manures namely daincha (5 t/ha), subabul (5 t/ha), FYM (15 t/ha) and Rice husk ash (5 t/ha) were on par statistically as for as the yield (Fig 8 & 9) was considered with application of 100 % RDN or 125 % RDN alone.

The treatment combination of 75 % N through urea and organic manures recorded higher N recovery (ANR) and lowered the soil pH and improved the organic carbon content and soil available N (Table 30). Further, the addition of organics like FYM, daincha, subabul and rice husk ash reduced the soil pH considerably. So also the status of organic carbon has become improved concurrently.

Interestingly, percentage of the ANR (Apparent nitrogen recovery) got increased up to 27.2 % in the field applied with 50 kg N/ha. The definite improvement in the effect of organics was observed at the third year field experiment (Table 31 & 32).

Salient Findings

Addition of urea @ 112.5 kg N/ha with organics like daincha or subabul or FYM or rice husk ash @ 5 t/ha, 15 t /ha and 5 t /ha respectively will result in higher grain yield and also improves soil fertility and apparent N recovery.

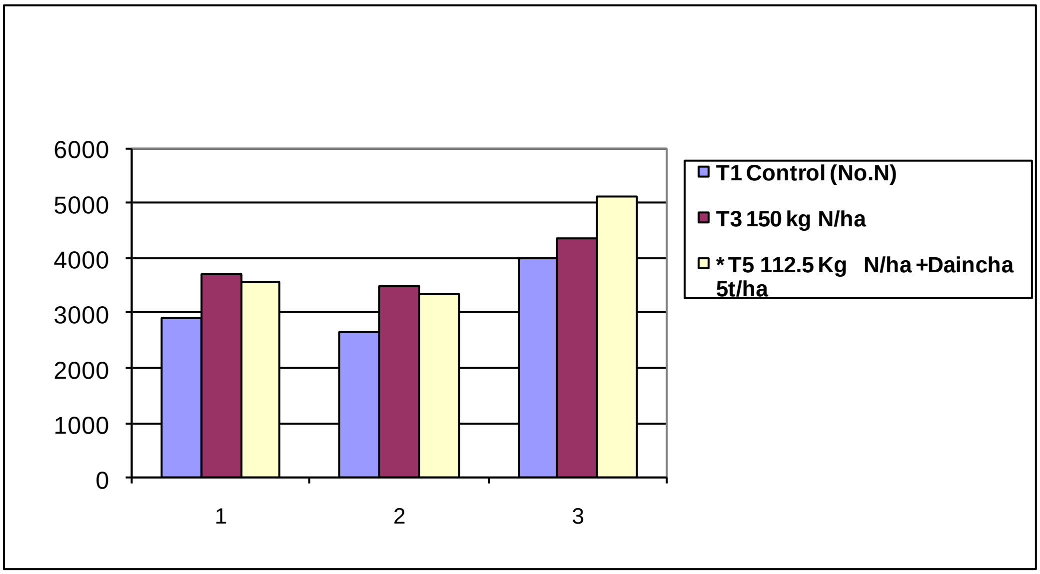


Fig. 8 Effect of organic amendment on rice yield (kg/ha) during 1995-98 (Rabi season)

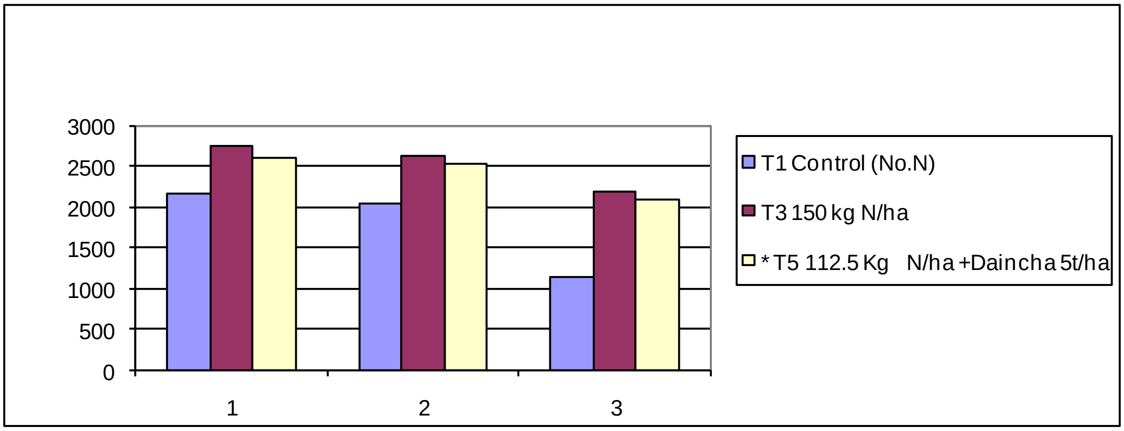


Fig 9 Effect of organic amendments on rice yield (kg/ha) during 1995-98 (summer)

Table 30. Effect of Nitrogen Management with organics on soil pH and EC in a sodic soil

Treatments	pH						EC (dS/m)					
	Rabi 95-96	Summer 95-96	Rabi 96-97	Summer 96-97	Rabi 97-98	Summer 97-98	Rabi 95-96	Summer 95-96	Rabi 96-97	Summer 96-97	Rabi 97-98	Summer 97-98
T_1Control	8.7	8.6	8.6	8.5	9.1	9.0	0.22	0.20	022	0.20	0.22	0.24
T_2 75 Kg N ha^{-1}	8.6	8.5	8.6	8.6	9.0	9.1	0.16	0.15	0.16	0.16	0.16	0.17
T_3 150 Kg N ha^{-1}	8.5	8.4	8.4	8.4	8.9	8.9	0.18	0.16	0.18	0.16	0.19	0.18
T_4 187.5 Kg N ha^{-1}	8.4	8.2	8.4	8.4	8.9	8.9	0.16	0.14	0.16	0.15	0.18	0.18
* T_5 112.5 Kg N ha^{-1} + Daincha 5t ha^{-1}	803	8.2	8.4	8.3	8.5	8.4	0.16	0.14	0.16	0.14	0.18	0.19
* T_6 112.5 Kg N ha^{-1} + Subabul 5t ha^{-1}	8.5	8.4	8.4	8.2	8.7	8.6	0.18	0.16	0.18	0.16	0.18	0.20
* T_7 112.5 kg N ha^{-1} + FYM 15t ha^{-1}	8.7	8.6	8.3	8.2	8.6	8.5	0.18	0.16	0.18	0.17	0.19	0.19
* T_8 112.5Kg N ha^{-1} + RHA 5t ha^{-1}	8.7	8.5	8.4	8.3	8.6	8.6	0.18	0.15	0.18	0.16	0.18	0.19
*T_9 75Kg N ha^{-1} + Daincha 5t ha^{-1}	8.5	8.4	8.5	8.4	8.7	8.4	0.15	0.14	0.15	0.14	0.15	0.15
* T_{10} 75kg N ha^{-1} + Subabul 5t ha^{-1}	8.4	8.3	8.5	8.4	8.9	8.5	0.17	0.16	0.17	0.16	0.17	0.18
* T_{11} 75Kg N ha^{-1} + FYM 15t ha^{-1}	8.4	8.4	8.5	8.4	8.9	8.5	0.22	0.20	0.20	0.20	0.21	0.21
* T_{12} 75Kg N ha^{-1} + RHA 5t ha^{-1}	8.8	8.6	8.4	8.4	8.9	8.8	0.16	0.15	0.16	0.15	0.18	0.17
SED CD (5%)	0.11 0.22	0.11 0.22	0.1 0.25	0.12 0.25	0.07 0.14	0.11 0.22	0.03 0.07	0.03 0.07	0.03 0.07	0.03 0.07	NS	NS

*Organics were applied only for Rabi crops

Table 31. Effect of Nitrogen Management with organics on organic carbon content and available nitrogen content of sodic soil

Treatments	Organic carbon (%)						Available Nitrogen (kg/Ha)					
	Rabi 95-96	Summer 95-96	Rabi 96-97	Summer 96-97	Rabi 97-98	Summer 97-98	Rabi 95-96	Summer 95-96	Rabi 96-97	Summer 96-97	Rabi 97-98	Summer 97-98
T_1Control	0.52	0.56	0.47	0.45	0.39	0.40	157	179	149	133	151	154
T_2 75 Kg N ha^{-1}	0.56	0.59	0.47	0.46	0.45	0.47	174	180	180	152	165	166
T_3 150 Kg N ha^{-1}	0.59	0.59	0.49	0.46	0.45	0.48	172	182	183	158	164	165
T_4 187.5 Kg N ha^{-1}	0.57	0.59	0.50	0.47	0.46	0.48	171	182	184	163	204	196
* T_5 112.5 Kg N ha^{-1} + Daincha 5t/ha	0.53	0.60	0.56	0.57	0.59	0.54	149	213	117	173	192	194
* T_6 112.5 Kg N ha^{-1} + Subabul 5t/ha	0.49	0.59	0.55	0.51	0.51	0.52	156	227	173	163	169	166
* T_7 112.5 kg N ha^{-1} + FYM 15t/ha	0.50	0.63	0.57	0.59	0.57	0.58	152	220	161	183	187	194
* T_8 112.5Kg N ha^{-1} + RHA 5t/ha	0.51	0.67	0.53	0.52	0.52	0.54	158	208	171	156	171	172
*T_9 75Kg N ha^{-1} + Daincha 5t/ha	0.47	0.60	0.56	0.52	0.53	0.55	172	225	178	163	169	170
* T_{10} 75kg N ha^{-1} + Subabul 5t/ha	0.51	0.60	0.55	0.52	0.51	0.53	174	225	167	156	168	168
* T_{11} 75Kg N ha^{-1} + FYM 15t/ha	0.49	0.65	0.54	0.51	0.52	0.53	175	217	169	168	161	168
* T_{12} 75Kg N ha^{-1} + RHA 5t/ha	0.49	0.70	0.55	0.49	0.50	0.53	188	213	165	158	164	165
SED	0.02	0.02	0.02	0.02	0.03	0.01	7.0	4.6	3.9	5.0	12.0	3.6
CD (5%)	0.05	0.05	0.04	0.04	0.05	0.03	15.0	9.6	8.1	10.0	26.0	7.5

*Organics were applied only for rabi crop

Table 32. Effect of Nitrogen management with organics on apparent N recovery in sodic soil

Treatments	Apparent N % recovery					
	95-96	95-96	96-97	96-97	97-98	97-98
T_1Control	-	-	-	-	-	-
T_2 75 Kg N ha^{-1}	13	17	14.7	8.0	22.6	30.4
T_3 150 Kg N ha^{-1}	12	9	12	6	1103	28.6
T_4 187.5 Kg N ha^{-1}	12	9	11.7	5.3	19.7	-
* T_5 112.5 Kg N ha^{-1} + Daincha 5t/ha	9	11	13.6	12.4	27.2	20.8
* T_6 112.5 Kg N ha^{-1} + Subabul 5t/ha	10	12	15.7	6.2	16.0	25.6
* T_7 112.5 kg N ha^{-1} + FYM 15t/ha	9	9	11.1	12.4	18.7	40.2
* T_8 112.5Kg N ha^{-1} + RHA 5t/ha	11	14	17.1	5.3	18.9	28.1
*T_9 75Kg N ha^{-1} + Daincha 5t/ha	10	19	19	9.3	23.2	60.7
* T_{10} 75kg N ha^{-1} + Subabul 5t/ha	11	16	17.8	8.0	21.1	57.4
* T_{11} 75Kg N ha^{-1} + FYM 15t/ha	11	21	10.0	13.3	14	55.4
* T_{12} 75Kg N ha^{-1} + RHA 5t/ha	11	19	22.4	6.7	22.4	45.2
SED	-	-	-	-	-	-
CD (5%)	-	-	-	-	-	-

*** Organics were applied only for rabi crop**

5.2 Site Specific Nutrient Management for rice in salt affected soils of Tamil Nadu

The IRRI sponsored Mega Project on Reversing Trends on Declining Productivity (RTDP), has proved beyond doubt that in irrigated cropping system, long term declines in grain yield at constant fertilizer application had been noted in normal soils of Cauvery Delta Zone (Cessman *et al.* 1995). The factors which have partially contributed to the yield decline includes:

1. Decrease in availability of native soil N and in spite of regular application of N fertilizer and maintained or increased levels of total soil N.
2. Decreased efficiency of applied N fertilizers
3. Lower capacity of N uptake by new rice varieties than by older varieties
4. Deficiencies of nutrients other than NPK.

Thus the causes of yield decline or declining productivity are complex and still fully not understood. Hence to study the factor productivity or partial factor productivity which contributes to the yield decline in unreclaimed or reclaimed alkali soils this project was undertaken with on station experiment and on farm trials in farmer's holdings in nearby Manikandam block of Trichy District with the following objectives

1. To find out indigenous nutrient supply (INS, IPS and IKS) using on farm field trials (OFT) through missing nutrient technique (N, PK, NP, NK and NPK) along with farmers fertilizer practice (FFP) with and without amendments like gypsum or spent wash used for reclamation of alkali soils.

2. To find out the nutrient use efficiencies in salt affected soils reclaimed with different amendments like gypsum or spent wash.
    a. Total factor productivity (TFP)
    b. Partial factor productivity (PFP)
    c. Agronomic efficiency (AE)
    d. Physiological efficiency
    e. Recovery efficiency
    f. Internal use efficiency
3. To develop and validate Site Specific Nutrient Management (SSNM) technology for intensive irrigated rice based cropping system in reclaimed salt affected soils.

Two on station experiments in ADAC&RI Farm and three on farm experiments in Manikandam block of Tiruchirappalli district were laid out during Samba 2002 (October 2002- February 2003). The initial soil characteristics and rice varieties tested were as follows.

Table 33. Yield gap of rice (t ha^{-1}) between NPK and FFP at different locations

S.No	Location	Rice Variety	Amendments used	Initial soil characteristics		
				pH	EC (dS/m-1)	ESP
1	ADAC&RI Farm	ADT39	Gypsum	8.3	1.1	16.0
2	ADAC&RI Farm	TRY1	Distillery spentwash	8.9	1.1	21.4
3	M.C.Chinnadurai Poongudi	Andhra Ponni	---	8.4	0.48	---
4	Mr.Rangasamy Poongudi	Ponni	---	9.1	0.63	---
5	Mr.Veeramuthu Poongudi	Ponni	---	8.2	0.30	---

In all the sites, nutrient omission plots were created (N, PK, NK, NP, NPK) with two replications and it was compared with farmers practice (FFP). Nitrogen was applied in four splits at 25 % each at basal, 21, 42 and 63 DAT. The full dose of P and $ZnSO_4$ @ 40 kg /ha were applied as basal. The K was applied 50% as basal and 50% with II top dressing of N. At harvest, grain and straw yield were recorded in 5m^2 test plot. The grain and straw yield were also computed by harvesting 20 hills and recording plant height, panicle length, 1000-grain weight, straw and grain yield. The initial moisture content of grain and straw were recorded and yield was computed to 14% moisture. The rice grain yields recorded in different locations are given in Table 33.

In gypsum reclaimed alkali soils, farmer's fertilizers practice (FFP) of applying 200 kg N ha^{-1}recorded highest rice grain yield of 6110 kg ha^{-1}. This was followed by application of NPK (150:50:50 kg ha^{-1}), SPAD based N management (105 kg N ha^{-1}), NK and NP applied plots which were on par. In distillery spent wash reclaimed alkali soil, absolute control (-F) recorded a rice grain yield of 6566 kg ha^{-1}while NPK recorded 7113 kg ha^{-1} of rice grain yield. The farmers practice (FFP) with 187.5 kg Nha^{-1} application recorded rice grain yield of 6652 kg ha^{-1} while N management with SPAD with 105 kg N ha^{-1} recorded the highest rice grain yield of 8062 kg ha^{-1} which was 21% and 23% higher than farmers practice and absolute control (-F) respectively (Table 34).

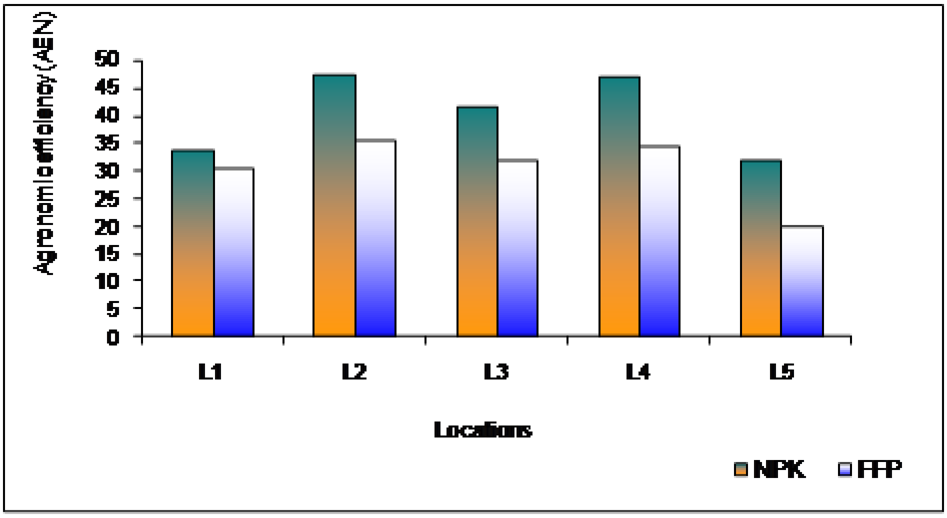
Table 34. Rice Yield in Nutrient Omission Plots at Different Locations

S.No	Treat-Ment	Location				
		ADAC&RI Gypsum	ADAC&RI Spentwash	Mr.Chinnadurai Poongudi	Mr.Rangasamy Poongudi	Mr.Veeramuthu Poongudi
1	-F (control)	1459	6566	3910	4660	2745
2	PK	1407	6208	4020	4760	2855
3	NK	4999	7261	5520	5995	4210
4	NP	4969	6925	5810	5950	4210
5	NPK	5103	7113	6250	7070	4780
6	FFP	6110	6652	6040	6510	3800
7	SPAD	5051	8062	-	-	-
				Location	Treatment	L X T
	CD (0.05)	460	-	598	846	1466

Of the three OFT, in two location rice grain yields in NPK @ 150: 50:50 kg ha^{-1} appplied plots were on par with farmers fertilizer practice (FFP) of applying 25% extra N applied plots (187.5: 50:50 NPK kg ha^{-1}). In third location (Mr. V. Veeramuthu) recommended NPK recorded significantly higher yield than FFP. For all the five location, agronomic efficiency of N (AEN –kg grain / kg of N applied) were worked out and given in Table 35 and Fig 10. In recommended NPK (150: 50: 50 kg ha^{-1}) applied plots recorded higher AEN than FFP, which varied between 31.9 to 47.4 and 20.3 to 35.5 (kg grain/ kg of N applied), respectively. In SPAD based N management the AEN were 48.1 and 76.8 kg grain/ kg of N applied in gypsum and spentwash applied alkali soils, respectively.

Table 35. Agronomic Efficiency (kg grain/ kg of N applied) for Different Locations

Treatment	ADAC&RI Gypsum	ADAC&RI Spentwash	Mr.Chinnadurai Poongudi	Mr.Rangasamy Poongudi	Mr.Veeramuthu Poongudi
NPK	34.0	47.4	41.7	47.1	31.9
FFP	30.6	35.5	32.2	34.7	20.3
SPAD	48.1	76.8	-	-	-



L1 -ADAC&RI,Gypsum L2 -ADAC&RI,Spentwash
L3 -Mr.Chinnadurai, Poongudi L4 -Mr.Rangasamy,Poongudi

Fig. 10 Agronomic efficiency for Nitrogen in different locations

On-Station and on- Farm Field Trials on SSNM for Rice in Salt Affected Soils of Tamil Nadu

a. On-Station Experiment

The On-station experiment is being conducted in Anbil Dharmalingam Agricultural College and Research Institute (ADAC & RI) farm, Tiruchirappalli district, Tamil Nadu to study the long term effect of nutrient omission plots on Indigenous nutrient supply *viz.*, indigenous nitrogen supply (INS), indigenous phosphorus supply (IPS) and indigenous potassium supply (IKS). The gradient crop with fodder sorghum (CO 27) was raised during July – August 2004. The soil is sandy clay loam in texture with pH of 8.6, EC 0.27 dSm^{-1}, and ESP of 16. Taxonomically the soils of experimental field belong to fine, mixed, calcareous isohyperthemic Vertic Ustropept.

b. On-farm Experiments (2004-05)

The contact farmers (24 Nos) were identified with the help of Agricultural Development Officer, Manikandam block of Tiruchirappalli district for conducting OFT within a radius of 25 km around AD Agricultural College and Research Institute (ADAC & RI), Tiruchirappalli. Of these, 15 farmers were selected for on - farm trials. The Manikandam block of Tiruchirappalli district of Tamil Nadu lies between 10°35′ to 10°56′ N Latitudes and 78°5′ to 78°54′E Longitudes. The location map of the study area is given in Fig.11. The total geographical area of Manikandam block is 21,044 ha in which about 5000 ha^{-1} of sodic soils are prevalent. The lithology of the study area broadly comprises of granitic gneiss and charnockites. In the study block the slope gradient is gentle ie. less than

3 per cent. Koraiyar acts as a natural drainage and other small streams are Ariyaru and Kattaru. The climate of the study area is semi-arid, sub tropical and monsoonal type. Out of the mean rainfall of 870 mm, 46 per cent is received during north east monsoon (October to December). The maximum temperature ranges between 28°C and 38°C reaching the maximum in the months of April and May. The minimum temperature ranges between 18°C to 27°C reaching the minimum in the months of November and December. The evaporation rate ranges between 5 and 12 mm day^{-1} and it is high in the months of June and July. The mean wind velocity ranges between 6.0 km hr^{-1} and 15 km hr^{-1} and it is high during June and July. Rice is the main crop, Rice-Rice followed by brinjal/sesame are the main cropping system with sugarcane and coconut plantation in small areas. The Manikandam block is irrigated by High Level Kattalai canal and Uyyakondan canal fed by Cauvery.

The initial soil characteristics of the 15 on farm sites are given in Table 36. Among the 15 sites, three sites were without reclamation, nine sites were reclaimed by gypsum @ 50% GR ha^{-1} and three sites were reclaimed by distillery spent wash @ 3.75 lakh liters ha^{-1}. Gypsum and distillery spentwash were applied on three days and one month before transplanting respectively. The treatments consisted of nutrient omission plots viz., (-) F (T_1), PK (T_2), NK (T_3), NP (T_4), NPK (T_5), SSNM (T_6) and it was compared with Farmers Fertilizer Practice (FFP) which was laid out in RBD with two replications. In most of the locations rice BPT 5204 (Andhra Ponni) variety was used as test crop. As per the treatments N was applied in four splits, full dose of P as basal and K in two splits were applied. For SSNM treatment, N was applied based on Leaf colour chart (LCC) values monitored from 14 DAT onwards and N was applied @ 30 kg N ha^{-1} whenever LCC values ≤ 3.0. The full dose of P @ 50 kg P_2O_5 as basal and 50 kg K_2O in 2 splits were applied. In all the treatments Zinc sulphate @ 40 kg ha^{-1} as basal and *Pseudomonas fluorescence* @2.5 kg ha^{-1} on 30 DAT were applied. Except SSNM treatment, Nitrogen was applied in four splits at 25 % each at basal, 21, 42 and 63 DAT.

Fig.11. Location map of on-farm experimental sites in Manikandam block, Tiruchirapalli district

The full dose of P and $ZnSO_4$ @ 40 kg ha^{-1} were applied as basal. The K was applied 50% as basal and 50% with II top dressing of N. At harvest, grain and straw yield were recorded in $5m^2$ test plot. The grain and straw yield were also computed by harvesting 20 hills and plant height, panicle length, 1000 grain weight were also recorded. The initial moisture content of grain and straw were recorded and yield was computed to 14% moisture content and different use efficiencies were worked out.

Table 36. Initial soil characteristics of on farm sites

S.No	Name of the farmers and location	pH	EC ds/m	ESP	Amendment and quantity	Test Crop/ Cultivar
1	P.Krishnasamy Poongudi	8.70	0.54	19.8	No amendment	Rice ASD 19
2	V.Balamurugan, Aravagudi	8.63	0.61	21.1	No amendment	Rice CO 43
3	J.Manivel Aravagudi	8.65	0.15	20.5	No amendment	Rice ASD 19
4	A.Natarajan Aravagudi	8.75	0.72	33.3	Gypsum @ 4.13 t ha^{-1}	Rice BPT 5204
5	M.Chinnadurai, Aravagudi	8.33	1.65	31.3	Gypsum @ 10.70 t ha^{-1}	Rice BPT 5204
6	K.Jambulingam Aravagudi	8.64	0.65	21.2	Gypsum @ 4.82 t ha^{-1}	Rice ASD 19
7	T. Mani Essanappatti	9.09	0.30	30.8	Gypsum 11.01 t ha^{-1}	Rice BPT 5204
8	A.Maria Luiees			-	Gypsum@	Rice

	N.Kuttappattu	8.15	0.15		1.76 t ha-1	BPT 5204
9	A.Arumairaj N.Kuttappattu	8.32	0.15	11.0	Gypsum @ 3.13 t ha-1	Rice BPT 5204
10	A.Arokiasamy N.Kuttappattu	8.25	0.42	11.4	Gypsum@ 1.25 t ha-1	Rice BPT 5204
11	K.Veerappan Essanaipatti	8.96	0.20	23.5	Gypsum @ 6.20 t ha-1	Rice BPT 5204
12	S.Adaikkalasamy Navalur Kuttappattu	8.80	0.52	27.4	Gypsum @ 4.81 t ha-1	Rice CO 43
13	P.Veeramuthu Aravagudi	8.37	1.55	28.9	DSW @ 5 lakh lit ha-1	Rice BPT 5204
14	U.Thavasi Mela Paganur	8.91	0.19	-	DSW @ 5 lakh liters ha-1	Rice CO 43
15	T.Karuppaiya, Mela Paganur	8.92	0.23	-	DSW @ 5 lakh liters ha-1	Rice ASD19

a. On - Station Experiment (2004-05)

The effect of nutrient omission plots on rice grain yield is given in Table 37. Among the different amendments, distillery spent wash (DSW) recorded the highest grain yield of 6.74 t ha^{-1} followed by gypsum @ 50% GR, which is on par with control (M_1) Among the nutrient omission plots, application of 100% recommended NPK recorded the highest grain yield of 6.97 tha^{-1} which was on par with N alone (T_6) followed by NP (T_5). The –F plot (T_1) recorded the lowest grain yield of 4.96 t ha^{-1} which is on par with PK. There was significant interaction between amendments and nutrient omission plots. The distillery spent wash (DSW) reclaimed alkali soil with application of 100% recommended NPK recorded the highest grain yield of 7.14 t ha^{-1}.

Table 37. Effect of different amendments and Nutrient omission plots on rice grain yield (t ha^{-1})

Omission plots / **Amendments**	**-F**	**PK**	**NK**	**NP**	NPK	**N alone**	**Mean**
Control	4.14	4.09	6.25	6.46	6.78	6.74	**5.74**
Gypsum	4.31	4.42	6.10	6.80	6.99	7.04	**5.94**
DSW	6.43	6.63	6.71	6.73	7.14	6.83	**6.74**
Mean	**4.96**	**5.04**	**6.35**	**6.66**	**6.97**	**6.87**	

		SEd		**CD(p=0.05)**		
	M	0.118		0.328		
	T	0.104		0.213		
	M at T	0.203		0.465		
	Tat M	0.181		0.370		

b. On-farm Experiment (2004-05)

The effect of different N management practices *viz*., recommended NPK, SSNM (N through LCC) and Farmer's fertilizers practice (FFP) (N @ 187.5 kg Nha^{-1}) on rice grain yield is given in Table 37.

The different amendments were used for reclamation of alkali soils in different locations. The rice grain yield ranged from 4.43 to 7.49; 4.86 to 7.65 and 5.95 to 7.69 t ha^{-1} in control, Gypsum @ 50% GR and DSW reclaimed alkali soils respectively. The yield gap between recommended NPK and FFP is given in Table 39. The yield gap varied between 0.06 and 0.88; 0.04 and 1.95 and 1.36 to 1.72 t ha^{-1} in control, Gypsum @ 50% GR and DSW applied sites. The mean effect of different amendments and N management practices on rice grain yield is given in Fig.13. Among the different amendments, mean grain yield was highest in DSW reclaimed alkali soils followed by gypsum @50 GR and no amendments applied sites. Among the different nitrogen management practices, application of recommended N recorded the highest grain yield followed by SSNM (LCC based N) and farmers fertilizers practice (FFP).

Efficiency Factors

The different efficiency factors *viz*., total factor productivity (TFP), partial factor productivity for nitrogen (PFP_N) and Agronomic use efficiency for nitrogen (AE_N) were computed for different locations and given in Table 38.

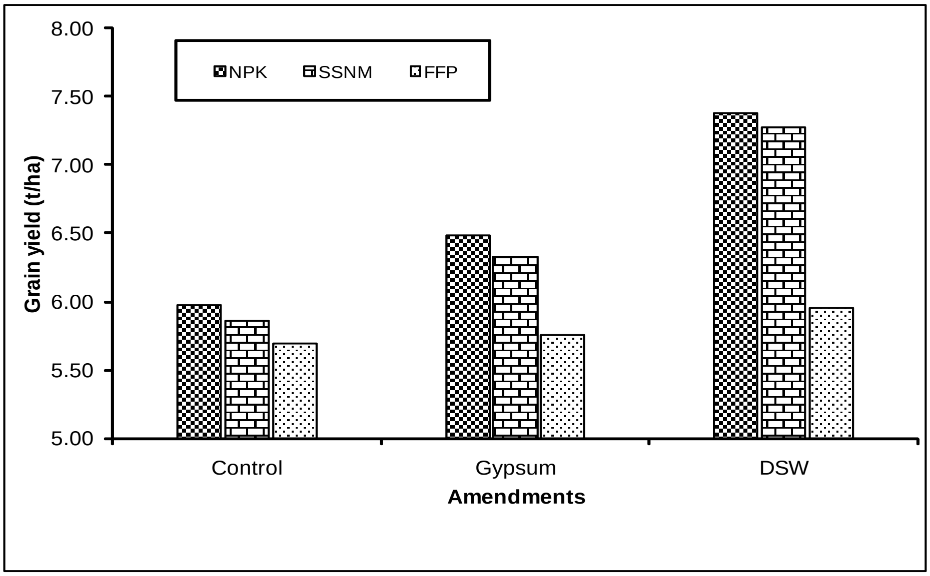


Fig.12. Effect of different N management practices on rice grain yield in onfarm trials

The total factor productivity (TFP), PFP_N and AE_N were highest in SSNM (LCC based N) treatment followed by NPK and FFP recorded the least. Among the different amendments, TFP ranged from 15.41to 39.42 kg grain/ kg of nutrient applied; PFP_N ranged from 23.63 to 83.21kg grain/kg of N applied and AE_N ranged from 1.13 to 23.45 kg grain increased / kg of N applied in no amendments applied sites. The range of TFP, PFP_N and

AE_N is 17.73 to 40.40; 27.19 to 107.74 and 2.09 to 23.45 respectively in gypsum @ 50% GR reclaimed alkali soils.

In all the 15 locations, the highest TFP and PFP_N values of 43.01 and 114.69 were recorded in SSNM (LCC based N) while lowest TFP and PFP_N values of 15.41 and 23.63 were observed in FFP plots. The highest AE_N of 23.45 was recorded in SSNM (LCC based N) in gypsum reclaimed alkali soils while the lowest AE_N of 1.13 was observed in un-reclaimed soils. The PFP for phosphorus varied between 106.3 to 143.9, 102.4 to 152.9 and 143.3 to 153.8 kg grain / kg of P in no amendment, gypsum @ 50 GR and DSW applied sites, respectively. In general PEP for phosphorus is higher in RDN and SSNM treatments than FFP. Almost similar trend was followed for PFP for K. The agronomic efficiency for P varied between 5.17 to 31.75, 1.95 to 69.61 and 0.02 to 20.3 kg grain increase / kg of P applied in no amendment, gypsum @ 50 GR and DSW applied sites, respectively. The AE_K varied between 8.49 to 30.65, 0.7 to 14.9 and 10.4 to 22.2 kg grain increase / kg of K applied in no amendment, gypsum @ 50 GR and DSW applied sites, respectively.

Table 38. Effect of different amendments and nutrient management practices on rice grain yield, TFP, PFP_N, PFP_P and PFP_K; AE_N, AE_P and AE_K - on-farm trials

L.No	Name of the farmers and location	Treatment	Grain yield (t ha^{-1})	Efficiency factors						
				TFP	PFP_N	PFP_P	PFP_K	AE_N	AE_P	AE_K
I. Control (No reclamation) 1-3 Locations: (3 sites)										
1	P.Krishnasamy Poongudi	1. NPK	5.42	21.68	36.13	108.39	108.39	3.52	7.77	-
		2. SSNM	5.03	22.85	41.90	100.55	100.55	1.13	-	-
		3. FFP	5.53	19.23	29.48	110.56	110.56	3.39	9.94	-
2	V.Balamurugan, Aravagudi	1. NPK	7.20	28.79	47.99	143.97	143.97	11.18	25.93	24.83
		2. SSNM	7.49	39.42	83.21	149.79	149.79	21.86	31.75	30.65
		3. FFP	7.14	24.83	38.07	142.76	142.76	8.62	24.72	23.62
3	J.Manivel Aravagudi	1. NPK	5.32	21.26	35.43	106.29	106.29	11.64	5.17	13.75
		2. SSNM	5.05	22.96	42.10	101.03	101.03	12.36	-	8.49
		3. FFP	4.43	15.41	23.63	88.61	88.61	4.60	-	-
II. Gypsum @ 50 % Grreclaimed soil 4-12 locations: (9 sites)										
4	A.Natarajan Aravagudi	1. NPK	5.58	22.33	37.22	111.67	111.67	9.58	-	3.13
		2. SSNM	5.97	27.14	49.76	119.42	119.42	15.20	-	10.88
		3. FFP	5.54	19.26	29.53	110.74	110.74	7.42	-	2.20
5	M.Chinnadurai, Aravagudi	1. NPK	5.63	22.53	37.55	112.64	112.64	9.78	6.66	0.70
		2. SSNM	5.17	27.22	57.47	103.45	103.45	11.20	-	-
		3. FFP	5.27	18.34	28.13	105.48	105.48	5.92	-	-
6	K.Jambulingam Aravagudi	1. NPK	6.99	27.97	46.62	139.85	139.85	9.33	16.83	10.09
		2. SSNM	6.85	36.06	76.12	137.02	137.02	13.99	14.00	7.26
		3. FFP	6.09	21.17	32.47	121.75	121.75	2.64	-	-
7	T. Mani Essanappatti	1. NPK	6.90	27.62	46.03	138.08	138.08	9.88	-	-
		2. SSNM	7.36	38.72	81.74	174.13	174.13	21.50	5.03	4.49
		3. FFP	5.81	20.22	31.01	116.28	116.28	2.09	-	-

8	A.Maria Luiees N.Kuttappattu	1. NPK	6.72	26.88	44.80	134.41	134.41	11.09	26.15	14.91
		2. SSNM	6.46	40.40	107.7	129.29	129.29	23.45	21.03	9.79
		3. FFP	6.22	21.66	33.21	124.54	124.54	6.24	16.28	5.04
9	A.Arumairaj N.Kuttappattu	1. NPK	7.65	30.58	50.96	152.89	152.89	12.91	16.55	5.33
		2. SSNM	7.63	34.67	63.55	152.53	152.53	15.98	16.19	4.97
		3. FFP	6.92	24.05	36.88	138.29	138.29	6.43	1.95	-
10	A.Arokiasamy N.Kuttappattu	1. NPK	5.12	20.47	34.12	102.37	102.37	4.29	-	-
		2. SSNM	4.86	30.36	80.92	97.16	97.16	6.38	-	-
		3. FFP	5.09	17.73	27.19	101.96	101.96	3.32	-	-
11	K.Veerappan Essanaipatti	1. NPK	6.76	27.02	45.04	135.12	135.12	11.68	25.14	13.58
		2.SSNM *	-	-	-	-	-	-	-	-
		3. FFP	5.80	20.19	30.95	116.08	116.08	4.26	6.10	-
12	S.Adaikalasamy N. Kuttappattu	1. NPK	7.06	28.25	47.08	141.25	141.25	13.92	69.61	9.99
		2.SSNM*	-	-	-	-	-	-	-	-
		3. FFP	5.11	17.78	27.27	102.26	102.26	0.74	30.62	-
III.Distillery spentwash reclaimed soil 12-15 Locations: (3 sites)										
13	P.Veeramuthu Aravagudi	1. NPK	7.17	28.66	47.77	143.32	143.32	2.73	0.02	-
		2. SSNM	6.88	43.01	114.7	137.63	137.63	2.08	-	-
		3. FFP *	-	-	-	-	-	-	-	-
14	U.Thavasi Mela Paganur	1. NPK	7.31	29.25	48.75	146.26	146.26	12.62	20.30	22.18
		2.SSNM *	-	-	-	-	-	-	-	-
		3. FFP	5.95	20.70	31.74	119.02	119.02	-	-	-
15	T.Karuppaiya, Mela Paganur	1. NPK	7.69	30.77	51.28	153.83	153.83	12.59	19.79	10.49
		2. SSNM	7.68	40.47	85.43	153.78	153.78	20.95	19.74	10.44
		3. FFP	5.96	20.76	31.83	119.36	119.36	-	-	-
			L	T	LxT					
	SEd		0.89	0.44	1.53					
	CD (P = 0.05)		1.94	0.89	3.04					

* Not included for statistical analysis

Table 39. Yield gap of rice (t ha-1) between NPK and FFP at different locations

Location No.	Name of the farmers and location	Treatments			
		NPK	SSNM	FFP	Yield gap
I. Control (No reclamation) 1-3 Locations: (3 sites)					
1	P.Krishnasamy Poongudi	5.42	5.03	5.53	-
2	V.Balamurugan, Aravagudi	7.20	7.49	7.14	0.06
3	J.Manivel Aravagudi	5.31	5.05	4.43	0.88
II.Gypsum @ 50% GR reclaimed soil 4-12 Locations: (9 sites)					
4	A.Natarajan Aravagudi	5.58	5.97	5.54	0.04
5	M.Chinnadurai, Aravagudi	5.63	5.17	5.27	0.36
6	K.Jambulingam Aravagudi	6.99	6.85	6.09	0.90
7	T. Mani Essanappatti	6.90	7.36	5.81	1.09
8	A.Maria Luiees N.Kuttappattu	6.72	6.46	6.23	0.49
9	A.Arumairaj N.Kuttappattu	7.64	7.63	6.91	0.73
10	A.Arokiasamy N.Kuttappattu	5.12	4.86	5.10	0.02
11	K.Veerappan Essanaipatti	6.76	-	5.80	0.96
12	S.Adaikkalasamy N.Kuttappattu	7.06	-	5.11	1.95
III. Distillery spentwash reclaimed soil 12-15 Locations: (3 sites)					
13	P.Veeramuthu Aravagudi	7.17	6.88	-	-
14	U.Thavasi Mela Paganur	7.31	-	5.95	1.36
15	T.Karuppaiya, Mela Paganur	7.69	7.68	5.97	1.72

Validation of SSNM for rice in salt affected soils of Tamil Nadu

The Site Specific Nutrient Management (SSNM) is an approach for feeding rice with nutrients as and when needed. With the SSNM approach, fertilizers are applied to meet the deficit between rice demand for nutrients and the indigenous nutrient supply of nutrients from soils and organic inputs for a targeted yield of rice. Hence, to know the indigenous nutrient supply from reclaimed alkali soils of Trichy district, one on - station experiment at AD. Agricultural College and Research Institute farm and 15 on farm trials in Manikandam block of Tiruchirappalli districts were laid during samba season with commonly used amendments for reclamation of sodic soils *viz.*, gypsum and distillery spentwash (DSW).

During 2006-07, one on-station trial and 10 on-farm trials were conducted to validate the SSNM package developed from the 25 on farm trials and two on-station trials conducted during 2004-05 and 2005-06. The on-station experiment was conducted in the Institute farm from September 2006 to February 2007 with rice variety BPT 5204 (Table.40).

Table 40. Effect of different amendments on Indigenous nutrient supply (kg/ ha) (on station)

Amendments	INS	IPS	IKS
No amendment	91	19	104
Gypsum	86	13	88
DSW	93	17	101

Table 41. Effect of different amendments and nutrient Omission on rice grain yield (kg/ ha) – On station 2006-07

Amendments	
No amendment	5.98
Gypsum	5.98
DSW	6.41
SEd	0.05
CD (P=0.05)	0.14
Nutrient omission	
(-)F	5.01
PK	5.32
NK	6.44
NP	6.53
NPK	6.96
N alone	6.57
SEd	1.02
CD (P=0.05)	2.08

Table 42. Effect of different amendments on Nutrient use efficiencies of rice (On station)

Amendment	PFP_N	PFP_P / PFP_K	AE_N	AE_P	AE_K	RE_N	RE_P	RE_K
No amendment	47.1	141.4	15.3	8.1	10.2	0.27	0.05	0.03
Gypsum	45.5	136.6	11.6	13.6	4.4	0.31	0.23	0.49
DSW	45.5	136.4	4.7	6.3	8.3	0.32	0.41	0.41

Table 43. Effect of amendments and nutrient omission on total N, P and Kuptake (kg/ha) by rice (on station)

Amendment	Nutrient uptake (kg/ ha)			Nutrient requirement (kg t^{-1})		
	N	P	K	N	P	K
No amendment	110	17	90	18.5	2.8	14.9
Gypsum	108	15	88	19.4	2.7	15.9
DSW	125	18	104	20.8	2.7	17.3

Table 44. Nutrient limiting yield (kg/ ha) and fertilizer N, P_2O_5 and K_2O requirement (kg/ ha) of rice as per SSNM approach

Amendment	Mean Nutrient limiting yield (kg/ ha)			Mean fertilizer requirement*		
	N	P	K	N	P_2O_5	K_2O
No amendment	4.77	6.66	6.56	80	Nil	Nil
Gypsum	5.09	6.15	6.61	78	25	Nil
DSW	6.11	6.50	6.41	Nil	25	Nil

* For a yield target of 6 kg/ ha

Grain yield

The effect of different amendments and nutrient management practices on grain yield of rice during validation of SSNM package is given in Table 41. In both gypsum and DSW reclaimed sites, SSNM package recorded the highest mean grain yield of 6.2 and 61 kg/ ha followed by FFP which recorded the yield of 5.8 and 57 kg/ ha (Table.41). The lowest mean grain yield was recorded with no amendment plot.

Table 45. Nutrient limiting yield (kg/ ha) and fertilizer N, P_2O_5 and K_2O requirement (kg ha^{-1}) of rice as per SSNM approach

Amendment	Mean N limiting yield		Mean fertilizer N requirement	
No amendment	4.49	5.24	152	138
Gypsum	4.84	3.76	112	219
DSW	5.66	5.02	30	134
SEd	0.29	0.25		
CD (P=0.05)	0.58	0.51		
	Mean P limiting yield		**Mean fertilizer P_2O_5 requirement**	

No amendment	5.20	5.50	30	25
Gypsum	5.82	4.63	25	30
DSW	6.72	5.94	25	25
SEd	0.29	0.25		
CD (P=0.05)	0.58	0.51		
	Mean K limiting yield		**Mean fertilizer K_2O requirement**	
No amendment	5.23	5.16	70	75
Gypsum	5.96	4.74	66	74
DSW	6.85	5.33	Nil	75
SEd	0.29	0.25		
CD (P=0.05)	0.58	0.51		

Validation of SSNM package developed

The developed SSNM package was test verified during the *samba* season (September - February) of 2006-07 in the ten on farm sites and it was compared with targeted yield of 6 kg/ ha to validate SSNM practice. Among the ten sites, yield target of 6 kg/ ha were recorded in 6 sites, while it was lesser by 10% in 2 sites and 25% in 2 sites (Table 42 to 47)

Table 46. Effect of different amendments and nutrient management practices on grain yield (kg/ ha) of rice during validation of SSNM

Amendments	**Grain yield (kg/ ha)**								
	RDN			**SSNM**			**FFP**		
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**
No amendment	3.7	6.4	4.9	3.5	6.3	4.8	3.3	6.0	4.7
Gypsum	4.6	5.8	5.4	5.8	6.4	6.2	5.3	6.4	5.8
DSW	4.0	6.4	5.3	6.0	6.4	6.1	5.0	6.2	5.7
Mean			5.20			5.70			5.4

Table 47. Validation of SSNM Technology

Sl. No	**Farmers name**	**Targeted yield (kg/ ha)**	**Actual yield (kg/ ha)**	**% yield loss or gain**
No amendment				
1.	Narayanasamy	6.0	4.47	-25.5
2.	Seethapathy	6.0	3.52	-41.3
3.	Rangasamy	6.0	6.33	5.5
Gypsum				
4.	Chinnadurai	6.0	6.47	7.8
5.	Deiveegarajan	6.0	6.27	4.5
6.	Mani	6.0	5.89	-1.8

Distillery spentwash				
7.	Thavasi	6.0	6.37	6.2
8.	T.Karuppiah	6.0	6.45	7.5
9.	Pachaikutti	6.0	5.57	-7.2
10	Karuppiah	6.0	6.04	0.7

Salient Findings

- Reclamation of alkali soil with gypsum of Distillery Spent Wash (DSW) increased the indigenous N supply. The amendments did not have profound influence on indigenous P supply while reclamation of alkali soil with gypsum decreased indigenous K supply and that by DSW increased the same.
- The total N, P and K uptake by rice increased with reclamation of alkali soil either with gypsum or DSW. Similarly, the N, P and K requirement to produce one tonne of rice also increased with reclamation.
- In OFT, the mean fertilizer N requirement for a yield target of 6 kg/ ha was 162 and 137 kg/ ha under no amendment and gypsum reclamation. But for DSW reclaimed alkali soils, the mean nutrient requirement was 30 and 134 kg N ha during I and II year of reclamation, respectively. Hence, DSW, apart from soil reclamation also adds organic matter and potassium and saves N in first year of reclamation.
- For a yield target of 6 kg/ ha in both years, mean P requirement as per SSNM approach varied between 25 to 35 kg P_2O_5 ha irrespective of the amendment used.
- In on farm trials, the fertilizer K requirement varied between 66 to 76 kg K_2O ha for a yield target of 60 kg/ ha irrespective of the amendments, which is higher than the general recommendations.

6. INTEGRATED FARMING SYSTEM SUITABLE FOR PROBLEM SOIL AREAS OF TAMIL NADU

The objective of the experiment is to increase the income and employment generation of salt affected area. For this purpose, 0.80 ha of land was taken up, out of which 0.40 ha of land has been allotted exclusively for paddy cropping alone wherein daincha and rice will be cultivated. In the other 0.40 ha of land, cropping is done along with poultry and fisheries components.

Components

I. **Crop:** Rice -0.36 ha

II. **Fisheries :**

Fish pond area : 0.04 ha

i) Silver carp/catla (surface feeder) (40%) : 390 nos.
ii) Rohu (column feeder)(20%) : 520 nos.
iii) Mirgal/Common carp (Bottom feeder) : 130 nos.
iv) Grass carp (Grass Feeder) : 260 nos.

III. **Poultry**: To meet the feed requirement of fish fingerlings and to generate additional income, 20 layers of Babcock birds were reared in IFS program.

IV. **Control:**

Normal Crop Rotation followed by the farmer (0.40 ha)

Daincha (July-Aug)	Rice(TRY 1) (Sep-Jan)	Fallow (Feb-Jun)	0.4 ha

In the IFS program under crop component 0.30 ha of land was cultivated with paddy crop (TRY 1). The details on cost of cultivation and income generated are presented in the following table (Table 48).

Table 48. Crop Component (0.30 ha)

Details	Quantity	Cost
Seed	20 kg @ Rs. 20/ kg	**Rs. 400**
Land Preparation including nursery		**Rs. 1500**
Planting	15 labours @ Rs. 166 per labour	**Rs. 2500**
Inter cultural operation	Two weedings	**Rs.3500**
Fertilizer cost	Urea 100 kg @ Rs.268 / 50 kg = 536 Super 150 kg @Rs. 381 / 50kg = 1143 MOP 50 kg @ Rs.840 / 50 kg = 840 $ZnSO_4$ 10 kg @ Rs 30/ kg = 300	**Rs. 2819**
Foliar spray	Cost Rs 1000	**Rs.1000**
Harvest		**Rs. 2000**
Total expenditure		**Rs 13719**

The total cultivation expenditure for 0.30 ha of paddy crop was Rs. 13,719.00 and the total income generated from the sale of grains and straw were Rs. 28,258.00. A net profit of Rs. 10,539.00 was obtained for the cultivation of 0.30 ha of paddy crop.

The fisheries (Four types of fish of 300 numbers) and poultry (layer birds 20 numbers) components of IFS was laid out in 0.10 ha of land. The fisheries component incurred a total expenditure of Rs. 7600.00 (Table 48) and the poultry component incurred a total expenditure of Rs. 12,000.00 (Table 66). Both the fisheries and poultry component consumed a capital investment of Rs. 24,000.00 (Table 49).

Table 49. Fisheries

Details	Quantity	Cost
Cost of fingerlings	1200 @ Rs. 1 / each	**Rs. 1200**
Transport		**Rs. 800**
Cost of fish feed		**Rs. 5600**
Total expenditure		**Rs. 7600**

Table 50. Poultry Component

Details	Quantity	Cost
Cost of birds	40 nos.	**Rs. 4800**
Feed material	300 Kg @ 1200 / 50 kg bag	**Rs. 7200**
Total		**Rs. 12000**

Table 51. Cost on Capital Investment

Fish Pond digging Charge	:	Rs. 60,000
Poultry shed	:	Rs. 30,000
Total	:	Rs. 90,000
Cost on capital investment for 1^{st} yr	:	Rs. 15,000
Interest on capital (1 %) 1st	:	Rs. 9,000
Total	:	**Rs. 24,000**

The net profit from IFS components of crop (0.30 ha), fisheries and poultry (0.10 ha) are tabulated in the following table (Table 50, 51). An overall profit of Rs. 1, 16, 328.00 was obtained from all three components of IFS program and the fisheries and poultry component yielded a profit of 80% and 13 % respectively. The highest net return of > 4 times was obtained from fisheries component among the IFS components.

Table 52. Net profit from IFS Components

Component	Income	Expenditure	Profit
Cropping (0.36 ha)	28,258	13719	10,539
Fisheries	1,15,360	7,600	1,07,760
Poultry	29029	12,000	17,029
Cost on capital investment		24,000	
Net profit	**1,71,647**	**57,319**	**1,35,328**

The following table (Table 52) illustrates the net profit which can be obtained from a pure crop component program for 0.40 ha. In comparison with a pure crop program for 0.40 ha (Table 53), the IFS program (0.30 ha for crop and 0.10 ha for poultry and fisheries) has yielded high net returns and BC ratio of 2.36 which is 1.33 higher than the crop alone program.

Table 53. Economics of the Pure cropping system (0.40 ha)

Details	Quantity	Cost (Rs.)
Seed	20 kg @ Rs. 20/ kg	**400**
Land Preparation including nursery		**2,500**
Planting	20 labours @ 166	**3,320**
Inter cultural operation	Two weedings	**4,000**
Fertiliser cost	Urea 150 kg @ Rs.268 / 50 kg = 804 Super 200 kg @Rs. 381 / 50kg = 1524 MOP 50 kg @ Rs.840 / 50 kg = 840 $ZnSO_4$ 10 kg @ Rs 30/ kg = 300	**3,468**
Foliar spray	Rs 1000	**1,200**
Harvest		**2,500**
Total expenditure		**17,388**

Income		
Paddy grain yield	:	2,521 kg
Income from grains (2521 x Rs. 11)	:	Rs. 27,731
Income from Straw	:	Rs. 7,500
Total Income from cropping	:	**Rs. 35,231**
Net profit from Cropping		
Total income	:	Rs. 35,231
Expenditure	:	Rs.17,388
Net profit	:	**Rs. 17,843**

Table 54. Comparison of IFS with pure cropping

Components	Profit	Cost	B/C ratio
IFS Components (0.4 ha)	Rs. 1,35,328	Rs. 57,319	2.36
Pure cropping (0.4 ha)	Rs. 17,843	Rs. 17,388	1.03

Therefore, it is always recommended to adopt IFS program in problem soil area to increase the income of all types of farmers (small, marginal and big) and the government can subsidize the capital investment cost in establishing the fisheries and poultry component Table. 54). For this year, 2013-14, in the crop component TRY 3 paddy seedlings were transplanted in field no. 5A to the extent of 0.10 ha on 26.09.13. In the fish and poultry component, pond was allowed to stabilize for one month after adding calcium carbonate. Later water was let into the pond and fish fingerlings were released on 11.10.13 and 25.10.13. Totally 1800 fish fingerlings were released, comprising of Catla - 525, Roghu – 700, Mirgal – 200, and Grass carp – 375. On 30.10.13 twenty numbers of Babcock egg laying birds were released in the cage inside the pond.

Plate 4. Project Coordinator visit to IFS model at ADAC&RI, Trichy

7. RECLAMATION AND MANAGEMENT OF ALKALI/SODIC SOILS

7.1 Evaluating the reclamation efficiency of different sources of Gypsum for Sodic Soil Management

A Field experiment was conducted during *kharif* 2020 to assess the reclamation efficiency of different sources of Gypsum in sodic soil as an alternate to mineral gypsum. Mineral gypsum, phospho gypsum and marine gypsum were used for the study. All the gypsum sources were used @ 50 percent GR based on soil test value. The experimental data reveals that, maximum exchangeable Ca and exchangeable Ca were recorded in marine gypsum applied filed followed by mineral gypsum and phospho gypsum. Lowest exchangeable Calcium, Magnesium recorded in control. Regarding exchangeable Na, Lowest Exchangeable Sodium was recorded in marine gypsum applied filed followed by mineral gypsum and phospho gypsum. Highest Exchangeable Sodium was recorded in control. Maximum Exchangeable potassium was recorded in in marine gypsum applied filed followed by mineral gypsum and phosphor gypsum (Table. 55). However, T_4 and T_2 were statistically on par with each other. Lowest Exchangeable potassium was recorded in T_1.

Table 55. Effect of different sources of Gypsum on exchangeable Ca, Mg, Na and K (c mol ($p^{+)}$ kg $^{-1}$) content of sodic soils.

Treatment	*Kharif* 2020				*Rabi* 2020-21			
	Ca	**Mg**	**Na**	**K**	**Ca**	**Mg**	**Na**	**K**
T1: Control	7.67	3.78	6.03	0.21	7.40	3.40	6.17	0.20
T2: Mineral Gypsum (50 % GR)	11.81	4.67	2.79	0.34	11.49	4.54	2.95	0.29
T3: Phospho Gypsum (50 % GR)	10.74	4.49	3.25	0.29	10.25	4.37	3.22	0.23
T4: Marine Gypsum (50 % GR)	12.80	5.33	2.51	0.37	12.31	4.86	2.61	0.31
SEd	0.084	0.064	0.073	0.018	0.037	0.044	0.045	0.011
CD(0.05)	0.18	0.14	0.16	0.04	0.08	0.09	0.09	0.02

Table 56. Effect of different sources of Gypsum on pH, EC (dSm^{-1}) and ESP of sodic soil

Treatment	*Kharif* 2020			*Rabi* 2020-21		
	pH	**EC**	**ESP**	**pH**	**EC**	**ESP**
T1: Control	9.37	0.43	34.09	9.50	0.45	35.96
T2: Mineral Gypsum (50 % GR)	8.66	0.50	14.21	8.70	0.54	15.29
T3: Phospho Gypsum (50 % GR)	8.89	0.54	17.30	9.01	0.58	17.81
T4: Marine Gypsum (50 % GR)	8.52	0.46	11.95	8.67	0.50	13.00
SEd	0.052	0.012	0.299	0.046	0.017	0.181
CD(0.05)	0.11	0.03	0.65	0.10	0.04	0.39

The highest pH was recorded in control followed by phosphor gypsum and mineral gypsum. Lowest pH was recorded in marine gypsum applied field. With respect to EC, the highest data was recorded in phosphor gypsum followed by mineral gypsum and marine gypsum. The lowest EC was recorded in T_1. The experimental data also revealed that lowest Exchangeable Sodium Percentage (ESP) was recorded in marine gypsum applied filed followed by mineral gypsum and phospho gypsum. Highest ESP was recorded in control (Table 56).

Table 57. Effect of different sources of Gypsum on Grain and Straw yield (kg/ha) of rice in sodic soils

Treatment	*Kharif* 2020		*Rabi* 2020-21	
	Grain yield	**Straw yield**	**Grain yield**	**Straw yield**
T1: Control	2802	4063	2980	4060
T2: Mineral Gypsum (50 % GR)	4218	5788	5681	7416
T3: Phospho Gypsum (50 % GR)	4020	5642	5415	7314
T4: Marine Gypsum (50 % GR)	4511	5916	6367	8017
SEd	56.0	100.2	57.1	212.8
CD(0.05)	122	218	124	463

The experimental data revealed that, maximum grain yield was recorded in marine gypsum applied filed followed by mineral gypsum and phospho gypsum (Table 57). Lowest grain yield recorded in control. Regarding the straw yield, maximum data was recorded in marine gypsum applied filed followed by mineral gypsum and phospho gypsum. However, T4, T2 and T2, T3 are statistically on par with each other. Lowest straw yield was recorded in T1.

7.2 Reclamation of Sodic Vertisols in Conjunction with Soil and Water Conservation Practices Under Rainfed Conditions

Field experiments were conducted for four years from 1995-96 to 1998-99 at Anbil Dharmalingam Agricultural College and Research Institute, Tiruchirapalli, to assess the effect of rain water conservation measures in sodic clay soils on the reclamation by adopting raised and sunken bed system, to find out the suitable spacing for raised and sunken beds under rainfed conditions for better crop production and soil water conservation and to find out the suitable mulches for prolonged water conservation during cropping season in plough layer soil.These experiments were conducted in different fields each year. The soil properties of the experimental fields are given below (Table 58).

Table 58. Initial soil properties of experimental field

S. No.	Properties	1995-96	1996-97	1997-98	1998-99
1.	pH	9.60	9.15	9.45	9.05
2.	EC (dsm^{-1})	0.235	0.310	0.331	0.212
3.	ESP	15.9	19.5	21.9	16.2
4.	Available N (Kg ha^{-1})	161	195	186	173
5.	Available P (Kg ha^{-1})	5.8	8.2	7.2	7.6
6.	Available K (Kg ha^{-1})	236	241	250	246
7.	Field capacity (%)	23.5	25.6	24.8	23.1
8.	Permanent wilting point (%)	12.6	13.2	13.1	12.2

The experiment plots were randomized based on split -plot design with three replications. The main plot treatments (bed size) imposed were check (Conventional method-Flat bed no channel), 135/30 cm, 270/30 cm and 405/30 cm. The sub- plot treatments were Check, Pressmud @ 12.5 t/ha, FYM @ 12.5 t/ha, Coirpith @ 12.5 t/ha and Rice husk ash @ 12.5 t/ha. The test crop was sunflower (Var.Co.2). After application of gypsum uniformly to all the plots, beds were formed. Fertilizers were applied uniformly to all the plots @ 40:20:20 Kg NPK/ha. The various organic wastes were super imposed and the seeds were sown. All other cultural practices were carried out as per the recommendation given in the crop production guide. Initial and post harvest soil samples were collected and analysed for pH, Ec, ESP and available N, P and K. The soil samples (0-30 cm depth) were collected and estimated gravimetrically.

During the third year of experiment (1997-98) seed germination and seedling establishment were good. There was a heavy and continuous rain from 14th October 1997 onwards, and during that period plants were at vegetative and flowering stages. Due to this heavy rainfall the field was under waterlogged condition for a long period. Most of the plants withered and dried completely, hence the trial could not be continued. To obtain concurrent results, the result was continued for the fourth year.

Results of Experiments

i. Soil Moisture Content (1995-96)

The data on soil moisture content indicated that check plot recorded soil moisture below critical limit 3 times, while it was only twice in 405/30 cm, 135/30 and 270/30 cm beds. In sub-plot treatments, application of pressmud and coirpith recorded soil moisture below the critical limit twice while it was thrice in all the treatments.

1996-97

In the main plot treatments, check plot and 405/30 cm plot recorded soil moisture below critical limit twice whereas in 135/30 cm and 270/30 cm it was only one time. In sub-plot treatments, check plot and plot receiving rice husk ash recorded moisture content below critical limit twice while it was only once in all other treatments.

1998-99

In the main plot treatments, 405/30 cm plot and 270/30 cm plot recorded soil moisture content below critical level twice whereas other treatments recorded three times. In sub-plot treatments FYM and coirpith applied plots recorded soil moisture content above critical limit at all the stages except maturity. Check plot and rice husk ash applied plot had soil moisture content below critical limit at four stages.

ii. Soil pH

1995-96

Among the main plot treatments, the pH in the surface soil was reduced from 9.7 to 9.1 in 135/30 cm bed which was followed by 270/30 cm bed. In sub-plot treatments application of pressmud reduced the pH from 9.7 to 9.1 which was followed by coirpith application (Table 59).

1996-97

Both main and sub-plot treatments did not significantly influence the pH in both surface and sub surface soils. However, the largest reduction of 0.85 and 0.73 units in surface and sub-surface soils respectively was observed in pressmud applied plots.

1998-99

Both main and sub plot treatments did not significantly influence the pH in surface and subsurface soils. However more reduction in pH was observed in pressmud and rice husk ash applied plots in surface soil and in FYM applied plots in subsurface soil.

Table 59. Effect of raised beds and organic amendments on Soil pH and EC

Treatments	1995-96		1996-97		1998-99		1995-96		1996-97		1998-99	
Main Plot	**pH**						**EC (dSm^{-1})**					
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
M1 Check	9.3	9.1	8.5	8.7	8.9	8.8	0.31	0.28	0.21	0.27	0.15	0.18
M2 135/30cm	9.1	9.1	8.5	8.7	8.7	8.7	0.31	0.32	0.21	0.27	0.15	0.17
M3 270/30cm	9.2	9.1	8.4	8.6	8.8	8.8	0.31	0.30	0.21	0.27	0.15	0.17
M4 405/30cm	9.2	9.1	8.5	8.7	8.8	8.7	0.31	0.31	0.21	0.27	0.15	0.17
Sub-plot												
S1 Check	9.5	9.3	8.8	8.9	9.0	8.9	0.31	0.29	0.23	0.29	0.18	0.20
S2 Pressmud	9.1	9.1	8.3	8.5	8.7	8.8	0.31	0.31	0.18	0.24	0.14	0.18
S3 FYM	9.2	9.1	8.4	8.6	8.8	8.6	0.32	0.31	0.20	0.26	0.15	0.18
S4 Coir Pith	9.2	9.3	8.6	8.7	8.8	8.7	0.30	0.29	0.23	0.29	0.18	0.20
S5 Rice husk ash	9.3	9.2	8.5	8.7	8.7	8.8	0.31	0.30	0.22	0.28	0.17	0.19
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	0.02	0.02	0.02	NS

iii. Soil EC (1995-96)

In both surface and sub surface soils there was not much variation in EC due to the treatments. However, a little reduction of EC was found in the soil sample collected at postharvest stage compared to initial soil.

1996-97

The main plot treatments did not considerably affect the EC of soil in both the depths. But the organic amendments applied have a considerable influence in reduction of soil EC. In both soil depths, the pressmud application greatly reduced the EC (reduction 0.09 and 0.1 dsm^{-1} in surface and sub-surface soils, respectively) and it was on par with FYM applied plot where the EC reduction was 0.07 and 0.09 dsm^{-1} in surface and sub-surface soils respectively.

1998-99

Main plot treatments did not influence EC of soil markedly. But the organic amendments applied had a significant effect in reducing EC in surface layer. Pressmud applied plot recorded low EC in both layers. However reduction was not significant at 15-30cm depth with regard to sub plot treatments.

iv. Availability of N, P, and K in post-harvest soil
1995-96

The effect of raised beds on the availability of N, P and K at post harvest stage was non-significant. In sub-plot treatments, application of organics amendments had a significant effect only on available P and K. With respect to available P, incorporation of pressmud recorded significantly highest value and it was on par with FYM application. With respect to available K application of rice husk ash registered significantly highest values and this was comparable with coir pith application (Table.60).

1996-97

With respect to soil available N, only sub-plot treatments had a considerable influence. FYM application recorded significantly, the highest available N (233 kg/ha) which was followed by pressmud application (222 kg/ha). Different bed sizes did not significantly influence the soil available P. But in sub-plot treatments, FYM applied plots registered significantly the highest available P (15 kg/ha). Though the influence of main and sub-plot treatments on available K was statistically non-significant, rice husk ash applied plot recorded the highest soil available K (265 kg/ha).

1998-99

The effect of raised beds on the availability of N, P and K at post harvest stage was non-significant. In sub plot treatments application of organic amendments had a significant effect on available N, P and K. With regard to N and P, FYM applied plot recorded higher post harvest availability but comparable with pressmud applied plots. In case of K, post harvest availability was high in rice husk ash applied plot. However it was comparable with other organic amendments.

Table 60. Effect of raised bed and organic amendments on available N, P & K (kg ha^{-1})

Treatments	Available N			Available P			Available K		
	95-96	96-97	98-99	95-96	96-97	98-99	95-96	96-97	98-99
Main Plot									
Check	177	204	198	7.3	12.0	9.1	253	250	254
135/30cm	186	220	210	9.2	12.0	9.8	261	254	262
270/30cm	190	226	215	9.3	13.0	10.4	263	258	258
405/30cm	176	215	221	8.1	11.0	11.0	256	250	264
CD (5%)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub-plot									
Check	169	209	179	7.1	9.0	8.6	250	245	251
Pressmud	172	222	210	9.4	14.0	12.8	251	248	264
FYM	176	233	227	8.3	15.0	13.6	249	253	261
Coir Pith	170	210	198	7.2	11.0	10.3	252	253	268
RHA	173	211	192	7.2	11.0	10.2	261	265	271
CD (5%)	NS	9.3	11.1	2.1	0.6	1.3	8.4	NS	6.9

v. Sunflower seed yield (1995-96)

The sunflower seed yield data showed that among the main plot treatments 405/30 cm bed recorded significantly highest seed yield(922 kg/ha) and it was on par with 270/30cm and 135/30cm beds., The check plot produced. The lowest seed yield of 697 kg/ha. In the sub-plot treatments application of FYM recorded significantly the highest seed yield (826 kg/ha) and it was comparable with all other organic amendments applied. The check plot produced the lowest seed yield of 706 kg/ha (Table 61).

1996-97

Both main and sub-plot treatments had a significant influence on seed yield. Among the different beds, 270/30cm bed produced significantly the highest seed yield (742 kg/ha) and it was superior to all other treatments. This treatment recorded 23.5% higher yield than the check plot which produced the lowest yield of 601 kg/ha. In sub-plot treatments, application of FYM recorded significantly the highest seed yield of 694 kg/ha and it was closely followed by pressmud applied plot which recorded 690 kg/ha. The yield increment was 11.6% and 10.9% in FYM and pressmud applied plots, respectively over control.

Table 61. Effect of raised beds and organic amendments on sunflower seed yield (kg ha^{-1})

Treatments	1995-96	1996-97	1998-99
Main Plot			
Check	697	601	787
135/30cm	812	632	932
270/30cm	846	742	1024
405/30cm	922	652	1081
CD (5%)	121	22.0	113
Sub-plot			
Check	706	622	817
Pressmud	818	690	995
FYM	826	694	1039
Coir Pith	805	646	947
RHA	815	633	983
CD (5%)	35.5	23.0	44.7

1998-99

Both the main plot and sub plot treatments had significant effect on sunflower seed grain yield. Among the raised beds, the bed with a size of 405/30 cm recorded the highest seed yield of 1082 kg/ha followed by 270/30cm. The check plot produced the lowest seed yield. Among the sub plot treatments, FYM applied plots recorded the highest seed yield of 1039 kg/ha followed by pressmud applied plots. Check plot produced the lowest seed yield.

Salient Findings

Field experiments were conducted for four years (1995-99). The results of the first year (95-96) indicated that raised bed with 405cm/30cm size produced significantly highest sunflower seed yield and it was comparable with 270/30cm and 135/30cm beds. Among the organic amendments, application of FYM (12.5 t/ha) gave significantly the highest seed yield of sunflower which was on par with all other organic amendments applied.

During second year (96-97), bed size of 270/30cm produced significantly the highest seed yield of sunflower and it was superior to all other treatments. In sub-plot treatments, application of FYM produced the highest seed yield of sunflower and it was comparable only with pressmud applied plot. During third year, the trial was abandoned due to heavy and continuous rain and subsequent failure of the sunflower crop.

During the fourth year (1998-99), 405/30cm raised bed produced significantly higher seed yield and it was comparable with 270/30cm bed size. Among the organic amendments, application of FYM @ 12.5 t/ha produced the highest seed yield and it was comparable with application of pressmud (12.5 t/ha).

Plate 5. Press mud application

8. SURVEY AND CHARACTERISATION OF GROUND WATER QUALITY

8.1. Ground Water Quality Map of Tamil Nadu from Existing Data Base

The total geographical area of Tamil Nadu is 13 M. ha of which net area sown and irrigated area is 5.46 and 2.97 M ha respectively. Among the different sources of irrigation, well irrigation contributes 54.7 per cent followed by canal irrigation (26.6%) and tank irrigation (18.3%). Among the 29 districts of Tamil Nadu, well irrigation is the dominant source in Thiruvannamalai (97.9%), Salem (93.5%), Vellore (92.5%) and Perambalur districts (92.3%).

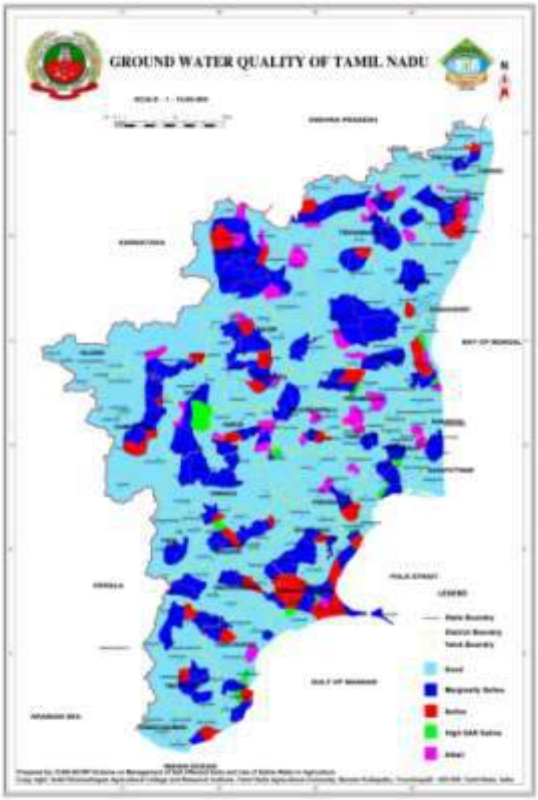


Fig 13: Ground water quality map of Tamil Nadu

Hence survey was made to assess the suitability of underground water. The groundwater quality map of Tamil Nadu was prepared with database available with AICRP on use of saline water (1043 samples), Tiruchirappalli centre, State Ground and Surface Water Resource Data Centre (2109 samples), Chennai and Soil Testing Laboratories of Government of Tamil Nadu (2966 samples). The above database covered the whole of Tamil Nadu and was classified as per criteria developed by AICRP on use of saline water.

The water quality map of Tamil Nadu was prepared in 1:250,000 scale. The results indicate that 73.2% of water samples were found to be of good quality, 21.1% moderately saline and 5.7% were saline. As the EC increased the cationic and anionic composition including B and NO_3 increased. Among the water samples, 92 % of samples were found to be non-alkaline and 8 % were alkaline (Fig. 13). As the RSC increased, Ca and Mg content decreased while Na and CO_3 content increased. With increase in RSC the F content increased while NO_3 content decreased.

8.2 Ground Water Quality Inland Districts of Tamil Nadu

8.2.1. Tiruchirapalli district

The Tiruchirapalli district with an area of 4, 40,412 ha has been subdivided in to eight taluks comprising 483 revenue villages. The talukwise distribution of different classes of irrigation water is given in Table 62 (Fig 14). Of the 597 water samples collected from Tiruchirapalli district, 365 (61%) are good. 90 (15%) marginally saline, 53 (8.8%) saline, 15 (2.5%) high SAR saline, 27 (4.5%) marginally alkali, 41 (6.8%) alkali and 6 (1%) highly alkali.

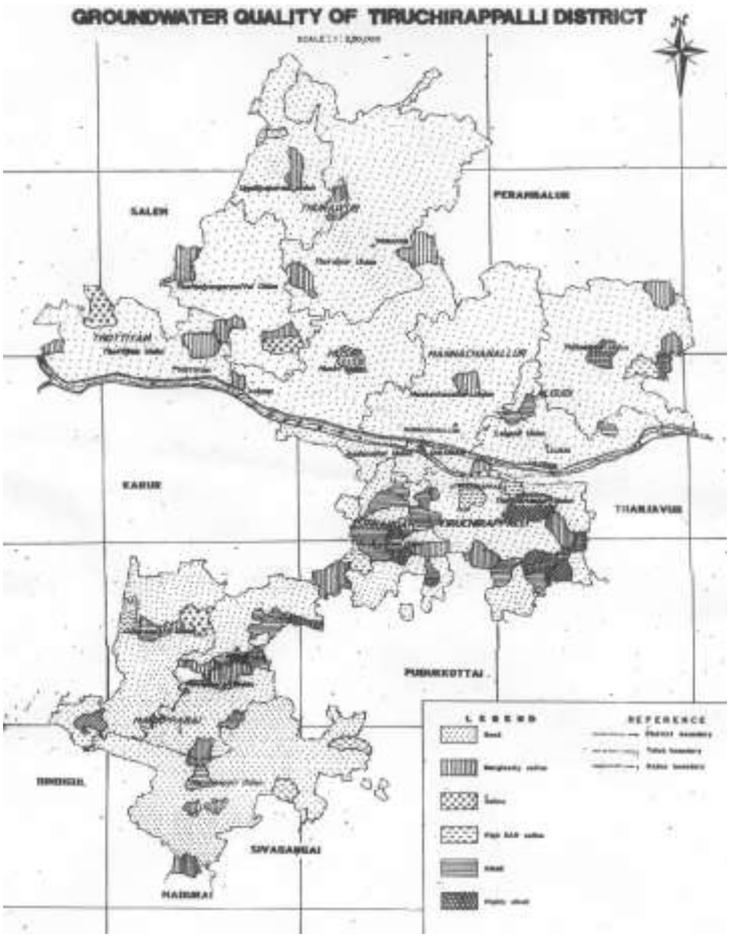


Fig 14: Ground water quality of Tiruchirappalli district

Table 62. Quality of irrigation waters of Tiruchirappalli district, Tamil Nadu

S.No	Taluk	Total	Good	MS	S	HSS	MA	A	HA
Tiruchirappalli district									
1	Tiruchy	94	46	23	6	4	4	10	1
2	Manapparai	160	94	20	3	5	15	18	5
3	Thottiyam	46	1	7	37	1	-	-	-
4	Srirangam	155	128	10	-	4	5	8	-
5	Manachanallur	8	6	2	-	-	-	-	-
6	Thuraiyur	50	27	16	6	1	-	-	-
7	Lalkudi	55	37	9	1	-	3	5	-
8	Musiri	29	26	3	-	-	-	-	-
	Subtotal	597	365 (61)	90 (15)	53 (8.8)	15 (2.5)	27 (4.5)	41 (6.8)	6 (1)

8.2.2 Perambalur District

Among the total samples (680) collected from Perambalur district, the distribution of good, Marginally saline, saline, high SAR saline, marginally alkaline, alkaline and alkaline were 52.4,26.8, 3.2, 0.88, 10.4 and 5.88 per cent respectively. Perambalur District has four Blocks viz., Perambalur, Veppanthattai, Veppur and Alathur Block. Among the four blocks, the distribution of good quality samples were the highest in Perambalur Block (69.2%) and the lowest in Alathur (37.1 %) Block (Table 63). The occurrence of marginally saline water (13.3 to 42.8 %) was prevalent in all the Blocks. The saline waters were prevalent in Alathur (8.5 %) and Veppur (2.5 %) Blocks, while the occurrence of alkali waters were reported in Veppanthattai (15 %) and Alathur (2.5 %). The marginally saline (13.3 to 42.8 %) and marginally alkali (2.5 to 25 %) waters are prevalent in almost all the blocks. High SAR saline water was reported in Alathur Block only (2.8 %). Among the total samples (680) collected from Perambalur district, the distribution of good, marginally saline, saline, high SAR saline, marginally alkaline, alkaline and alkaline were 52.4, 26.8, 3.2, 0.88, 10.4 and 5.88 per cent, respectively as given in Fig. 15.

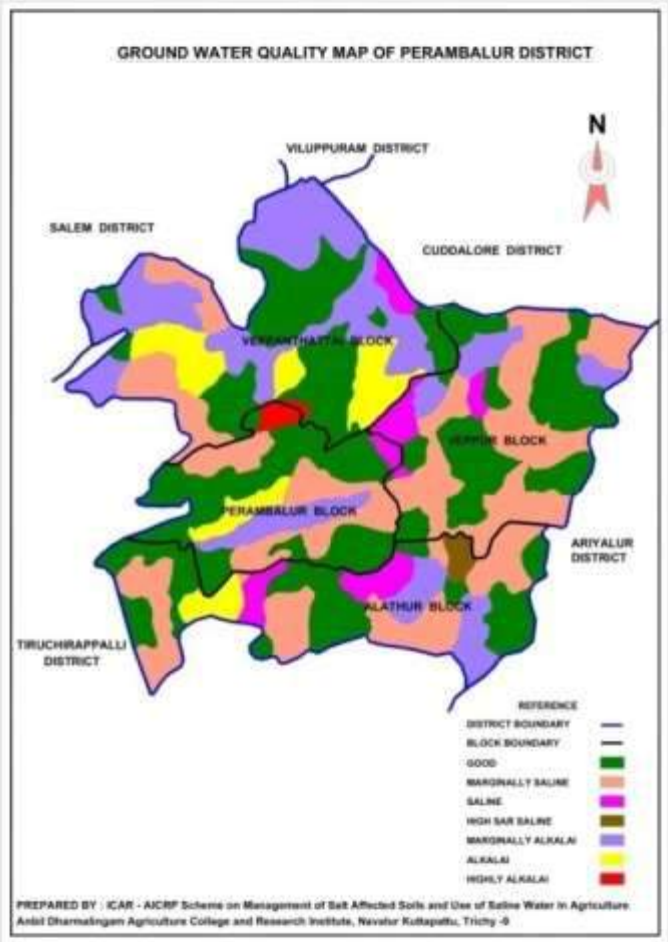


Fig 15. Ground water quality of Perambalur District

Table 63. Ground water quality of Perambalur District

S. No.	Block	No. of Samples	Distribution %						
			Good	MS	Saline	HSS	MA	Alkali	HA
1	Perambbalur	132	69.2	18.2	-	-	12.6	-	--
2	Veppanthattai	147	46.6	13.3	-	-	25.0	15	-
3	Veppur	210	64.1	30.7	2.5	-	2.5	-	--
4	Alathur	191	37.1	42.8	8.5	2.8	5.7	2.8	--
Average			**52.4**	**26.8**	**3.2**	**0.88**	**10.4**	**5.88**	**-**

8.2.3. Ariyalur District

To characterize the qround water quality of Ariyalur district 835 samples were collected from each panchayat villages of Ariyalur district. Among the total samples collected from Ariyalur district, 67.8 % is coming under good quality, 6.35 is marginally saline, 19.9 % is marginally alkaline, 3.54 % is alkaline, and 2.04 % is saline (Fig. 16). Ariyalur District has six Blocks viz., Ariyalur, Thirumanur, Andimadam, Jayankondam, T.Palur and Senthurai. Among the six blocks, the distribution of good quality samples were the highest in Andimadam Block (73.4 %) and the lowest in Jayankondam (56.5 %) Block. The occurrence of marginally Alkali water (8.72 to 30.4 %) was prevalent in all the Blocks. Marginally saline water is prevalent in Ariyalur (8.72 %), Thirumanur (15.4 %), Jayankondam (8.7 %) and Senthurai (4.17 %) Blocks. The saline waters were prevalent in Ariyalur (3.49 %), Thirumanur (3.36 %) and Senthurai (5 %) blocks, while the occurrence of alkali waters were reported in Ariyalur (2.91 %), Thirumanur (3.36 %), Jayankondam (4.35), T.Palur (3.65 %) and Senthurai (8.33 %) Blocks. Highly alkali water was reported only in Ariyalur Block (2.33 %) (Table 64).

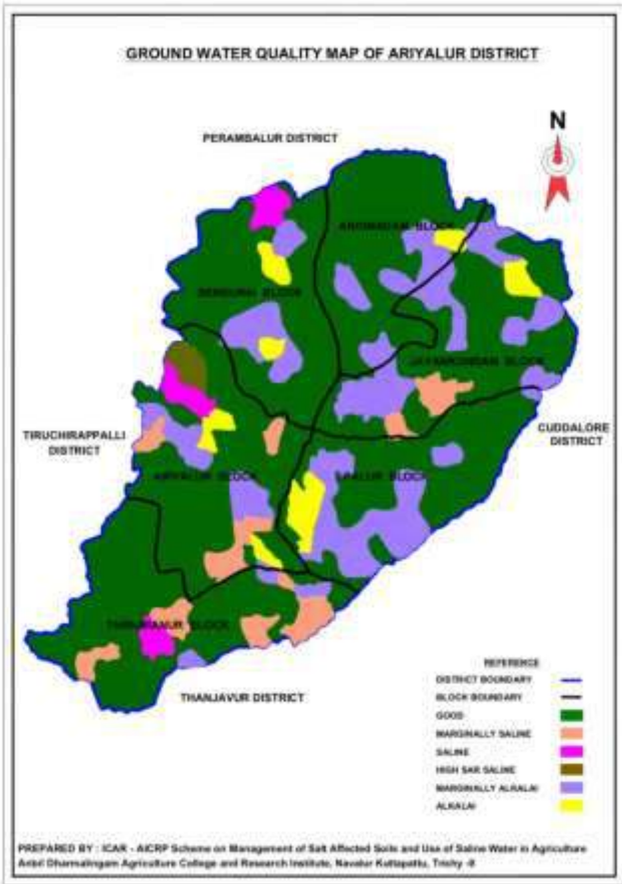


Fig 16: Ground water quality of Ariyalur District

Table 64. Water quality distribution (%) in Ariyalur district.

S.No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	**Ariyalur**	172	68.0	8.72	3.49	-	14.53	2.91	2.33
2	**Thirumanur**	149	69.13	15.4	3.36	-	8.72	3.36	-
3	**Andimadam**	142	73.4	-	-	-	24.6	-	-
4	**Jayankondam**	115	56.5	8.70	-	-	30.4	4.35	-
5	**T.Palur**	137	68.6	-	-	-	27.7	3.65	-
6	**Senthurai**	120	65.8	4.17	5.00	-	16.7	8.33	-
	Total /average	835	67.8	6.35	2.04	-	19.9	3.54	0.48

8.2.4. Namakkal District

To characterize the ground water quality of Namakkal District 1668 water samples (open and bore wells) were collected from different parts of Namakkal district. Among the total samples collected from Namakkal district, 62.3 % is coming under good quality, 27.1 is marginally saline, 6.5 % is marginally alkaline, 1.9 % is alkaline, and 8.5 % is saline.

Namakkal District has 15 Blocks viz., Erumaipatti, Mohanur, Paramathi, Kabilamalai, Namakkal, Sendamangalam, Puduchatram, Namagiripet, Tiruchengodu, Pallipalayam, Kolli hills, Vennandur, Mallasamutram, Elachipalayam and Rasipuram. Among the 15 blocks, the distribution of good quality samples were the highest in Kolli hills Block (85.8 %) and the lowest in Rasipuram (32.5 %) Block (Table 65). The occurrence of marginally saline water (5.90 to 48.7 %) was prevalent in all the Blocks. Marginally alkali water is prevalent in Erumaipatti (9.5 %), Mohanur (8.6 %), Paramathi (4.3 %), Kabilamalai (5.3 %), Puduchatram (10.5 %), Pallipalayam (5.9 %) and Rasipuram (13.3 %) blocks. Saline water was found in almost all the blocks (2.9 to 35.9 %) except Namagiripet, Kolli hills and Rasipuram blocks. Marginally alkali water was found in Erumaipatti (9.5%), Mohanur (8.6%), Paramathi (4.3%), Kabilamalai (5.3%), Puduchatram (10.5%), Pallipalayam (5.9%) and Rasipuram (13.3%) blocks. Alkali water was prevalent in Erumaipatti (2.9%), Paramathi (5.1%), Namagiripet (10.7%), Pallipalayam (4.7%) and Rasipuram (8.5%) blocks. Highly alkali and high SAR saline waters were not found in any part of the district.

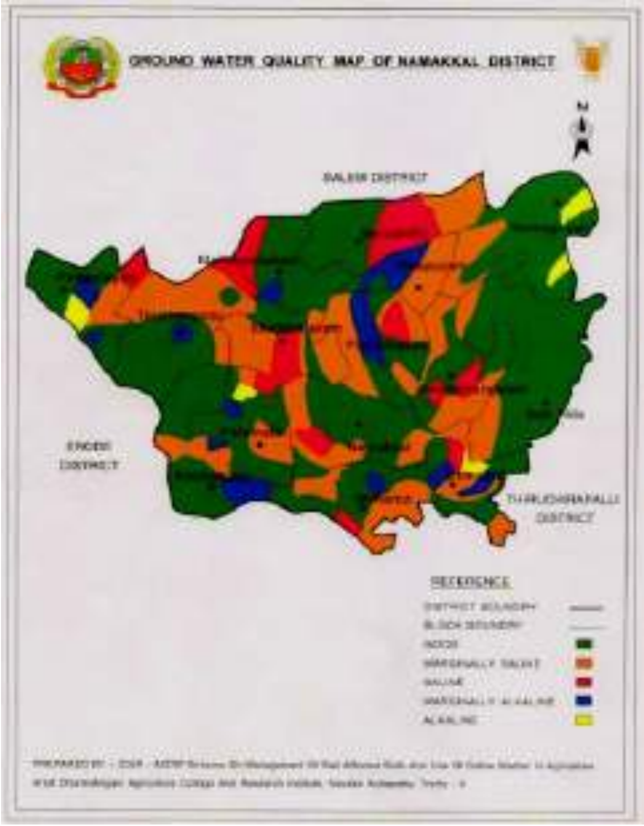


Fig 17. Ground water quality of Namakkal District

Table 65. Water quality distribution (%) in Namakkal district.

S.No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Erumaipatti	136	56.6	27.9	2.9	-	9.5	2.9	-
2	Mohanur	104	73	14.4	3.8	-	8.6		-
3	Paramathi	116	70.6	15.5	4.3	-	4.3	5.1	-
4	Kabilamalai	94	65.9	23.4	5.3	-	5.3	-	-
5	Namakkal	157	64.9	31.8	3.18	-	-	-	-
6	Sendamangalam	76	60.5	22.3	17.1	-	-	-	-
7	Puduchatram	123	32.5	48.7	8.13	-	10.5	-	-
8	Namagiripet	84	83.3	5.9	-	-	-	10.7	-
9	Tiruchengodu	153	46.4	47.7	5.8	-	-		-
10	Pallipalayam	84	61.9	22.6	5.9	-	5.9	4.7	-
11	Kolli hills	99	85.8	14.1	-	-	-	-	-
12	Vennandur	89	62.9	11.2	35.9	-	-	-	-
13	Mallasamudram	111	58.5	12.6	28.8	-	-	-	-
14	Elachipalayam	137	43.7	43.0	13.1	-	-	-	-
15	Rasipuram	105	32.3	45.7	-	-	13.3	8.5	-
	Total /average	1668	62.3	27.1	8.5	-	6.5	1.9	-

9. INTENSIVE INVESTIGATIONS ON GROUND WATER QUALITY COASTAL DISTRICTS OF TAMIL NADU

9.1. Kanyakumari District

Kanyakumari District has 8 blocks viz., Thovalai block, Kuruthencode block, Munchirai block, Thiruvattar block, Kiliiiyur block, Thucklay (Kozhipulai) block, Agastheeswaram block and Rajakamangalam block. Among the 8 blocks, the distribution of 100 % good quality ground water were observed in Thucklay block followed by Rajakkamangalm (89.7%), Agastheeswaram (80.0 %), Munchirai (81.25 %) and Thiruvattar blocks (80.95 %) (Table 66). The good quality water was absent in Thovalai block and almost 73.68 % of ground water samples were saline water. Marginally saline water is also seen in Thovalai block (26.32%), Thiruvarttar block (28.57 %), Munchirai (18.75 %) and Killiyur block (16.66 %). High SAR saline water was found in Agastheeswaram (15%) and Rajakamangalam block only (10.3%). Alkali water was almost absent in all the blocks. Out of the total samples collected from Kanyakumari district, 73.02% is coming under good quality, 12.57 % is marginally saline, 14.81% is saline water and 3.16 % is under high SAR saline categories Fig. 18.

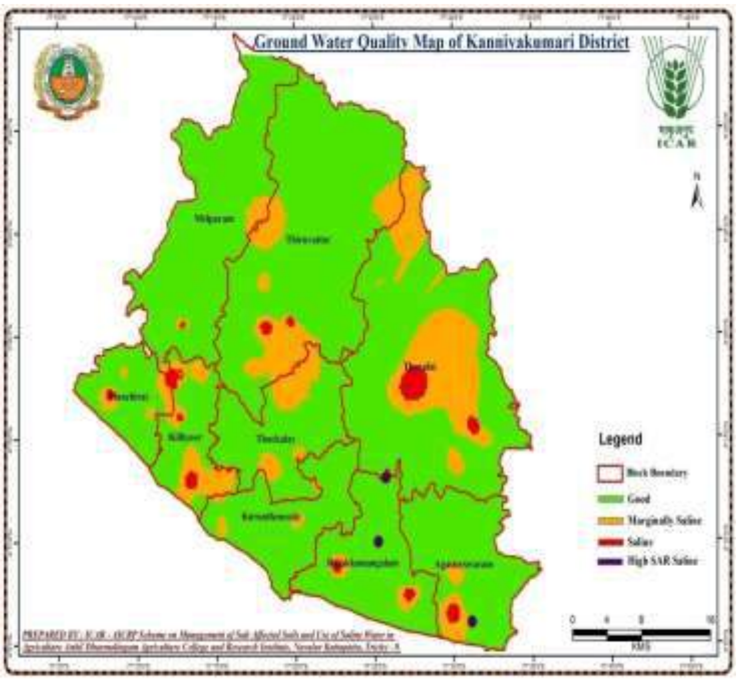


Fig 18. Ground water quality of Kanayakumari District

Table 66. Distribution of water samples in different water quality ratingstion (%) of Kanyakumari district

S.No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Agastheeswaram	20	80.0	5.00	-	15.0	-	-	-
2.	Rajakamangalam	39	89.7	-	-	10.3	-	-	-
3.	Thucklay (Kozhipulai)	39	100.0	-	-	-	-	-	-
4.	Killiyur	42	78.57	16.66	4.76	-	-	-	-
5.	Thiruvattar	21	80.95	28.57	19.05	-	-	-	-
6.	Munchirai	16	81.25	18.75	-	-	-	-	-
7.	Kuruthencode	19	73.7	5.26	21.05	-	-	-	-
8.	Thovalai	19	-	26.32	73.68	-	-	-	
	Total	215	-	-	-	-	-	-	
	Average		**73.02**	**12.57**	**14.81**	**3.16**	**-**	**-**	**-**

9.2. Tirunelveli District

A study was undertaken to assess the groundwater quality in Tirunelveli district by collecting 130 groundwater samples using GPS and analyzed for pH, EC, anions etc. The investigation revealed that groundwater samples with respect to pH and EC ranged from 6.5 to 8.5 and 0.54 to 44.50 dS m^{-1}. Residual Sodium Carbonate (RSC) varied from nil to19.6 meL^{-1} and Sodium Adsorption Ratio (SAR) ranged from 0.34 to 69.12. According to CSSRI, Karnal water quality classification, 57 per cent of groundwater found under good quality, (18%) Marginally saline, (4%) Saline, (11%) Marginally alkali, (8%) Alkali, (1%) High-SAR saline and (1%), High alkali (Table 67). Among the different blocks investigated, the highest percentage of samples with good quality was found in Kalakkadu and Pappakudi (100%), Ambasamudram (87.5%), Cheranmahadevi and Alangulam (80%) and Nanguneri (70%). Similarly, the poor quality water *viz.,* High SAR saline from Radhapuram block (4%), Saline from Palayamkottai (20%), Marginal saline from Kadayanallur (60%), High alkali from Valliyur (11%), Alkali from Palayamkottai and Keezhapavur (40%), Marginally alkali from Kadayanallur (40%) were recorded. Among the different blocks of Tirunelveli district, Radhapuram (75%) and Valliyur (55.55%) recorded the high level of possible seawater intrusion. Out of the total samples collected from Tirunelveli district 57 per cent of groundwater found under good quality, (18%) Marginally saline, (4%) Saline, (11%) Marginally alkali, (8%) Alkali, (1%) High-SAR saline and (1%) High alkali (Fig 19 & 20).

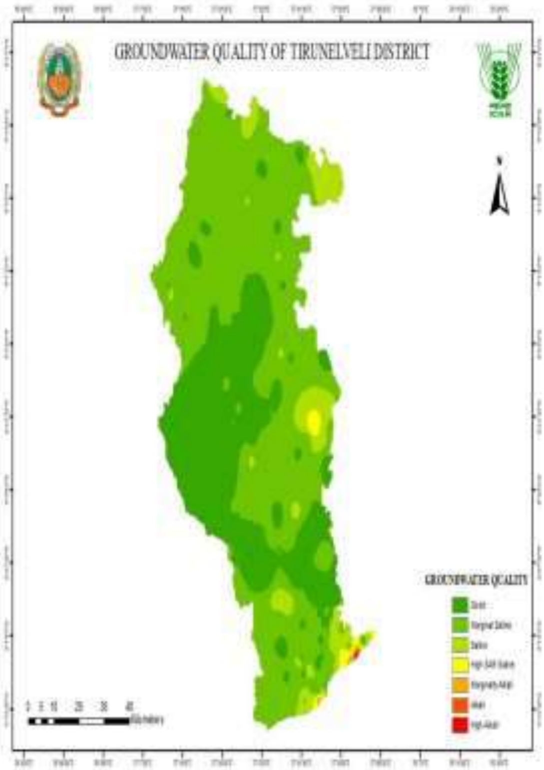


Fig 19. Ground water quality of Tirunelveli District

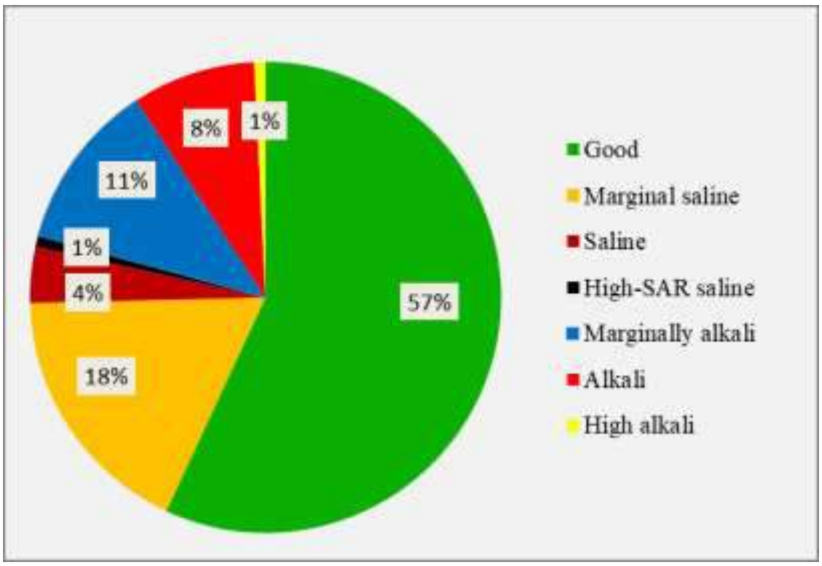


Fig 20. Percent distribution of Ground water quality of Tirunelveli District

Table 67. Water quality distribution (%) in Tirunelveli district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Palayamkottai	5	20		20		20	40	
2.	Cheranmahadevi	5	80	20					
3.	Nanguneri	10	70				20	10	
4.	Radhapuram	24	49.9	16.6	8.3	4.1	20.8		
5.	Valliyur	9	55.5	22.2			11.1		11.1
6.	Kalakkadu	6	100						
7.	Ambasamudram	8	87.5					12.5	
8.	Tenkasi	5	60	20				20	
9	Shencottai	5	60	40					
10.	Kadayanallur	5		60			40		
11.	Vasudevanallur	7	42.84	42.84	14.28				
12.	Sankarankoil	6	66.64	16.66				16.66	
13.	Keezhapavur	5	20	20			20	40	
14.	Kadayam	4	50				25	25	
15.	Pappakudi	4	100						
16.	Alangulam	5	80	20					
17.	Melaneelithanallur	5	60	20			20		
18.	Kuruvikulam	6	33.32	16.66	16.66		16.66	16.66	
19.	Manur	6	49.98	33.32				16.66	
	Average	**130**	**57**	**18**	**4**	**1**	**11**	**8**	**1**

9.3. Thoothukudi District

A study was undertaken to assess the groundwater quality in Thoothukudi district by collecting 151 groundwater samples using GPS and analyzed for pH, EC, etc. The investigation revealed that groundwater samples with respect to pH and EC ranged from 6.84 to 8.87 and 0.13 to 11.90 dS m^{-1}. Residual Sodium Carbonate (RSC) varied from Nil to 18.00 meq L^{-1} and Sodium Adsorption Ratio (SAR) ranged from 0 to 37.02. According to CSSRI, Karnal water quality classification, only 51 per cent of groundwater found under good quality, (21%) marginally saline, (13%) saline, (3%) marginally alkaline, (2%) alkaline, (7%) high SAR saline and (3%) high alkaline (Table 68 & Fig 21). Among the different blocks investigated, the highest percentage of a samples with good quality found in Ottapidaram (92%),Karunkulam (82%), Srivaikundam (75%), Alwarthirunagari (72%), Tiruchendur (59%), Vilathikulam (57%),Kayathar (50%), and Similarly, the poor-quality water viz., High SAR saline from Vilathikulam block (43%), Saline from Sathankulkam (44%), Marginal Saline from Kovilpatti (44%), High Alkali from Thoothukudi (10%), Alkali from Thoothukudi (20%). Among the different blocks of Thoothukudi district, Udangudi (46.15 %), Kovilpatti (40%), Srivaikuntam (37.5 %) and Sathankulam (37.5 %) recorded the possibility of seawater intrusion.

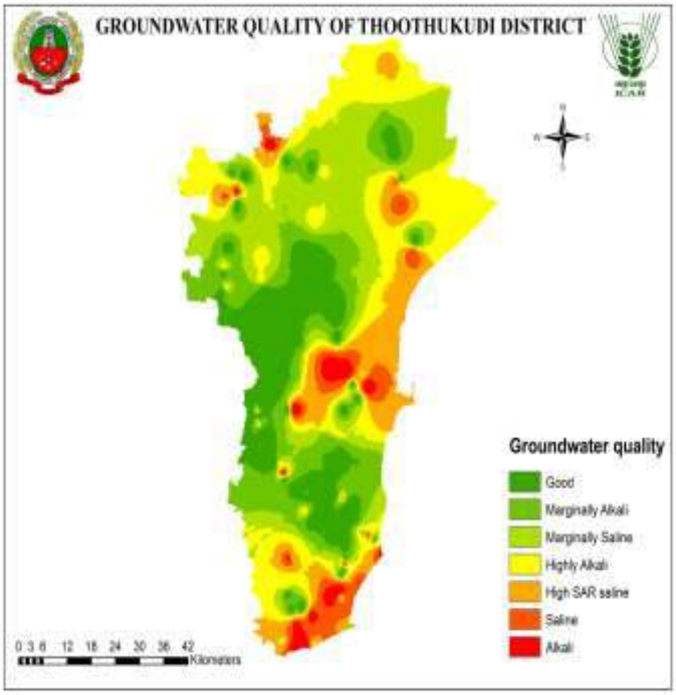


Fig 21. Ground water quality of Thoothukudi District

Table 68. Water Quality Distribution (%) in Thoothukudi District

S.No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	V.Pudur	5	-	60	-	-	20	-	20
2	Vilathikulam	7	57.1	-	-	42.9	-	-	-
3	Kovilpatti	16	37.5	43.7	18.8	-	-	-	-
4	Kayathar	10	50	40	10	-	-	-	-
5	Karunkulam	22	81.8	18.2	-	-	-	-	-
6	Ottapidaram	13	92.3	7.7	-	-	-	-	-
7	Thoothukudi	10	30	10	30	-	-	20	10
8	Srivaikuntam	8	75	12.5	12.5	-	-	-	-
9	Alwarthirunagari	14	71.4	14.2	-	-	7.2	-	7.2
10	Thiruchendur	17	58.9	11.7	5.9	17.6	5.9	-	-
11	Udangudi	13	46.1	7.7	30.8	15.4	-	-	-
12	Sathankulam	16	18.8	31.2	43.8	6.2	-	-	-
	Average	**151**	**51**	**21**	**13**	**7**	**3**	**2**	**3**

9.4. Ramanathapuram

Out of the total samples collected in Ramanthapuram district, 10% is characterized under good quality, 10 % is marginally saline, 4 % is saline, 1 % is marginally alkaline, 10 % is alkaline, 46 % high SAR saline and 19 % high alkaline (Table 69 & Fig. 22). The distribution of water samples in different water quality classes reveals that the samples of good quality underground irrigation water was found in almost all the Mudukalathurblocks (25%), Mandapam (20%), Nainarkovil (20%), Kamuthi (20%)Tirupullani (10%), Tiruvadanai (7.6%), and Kadaladi (7.1%).

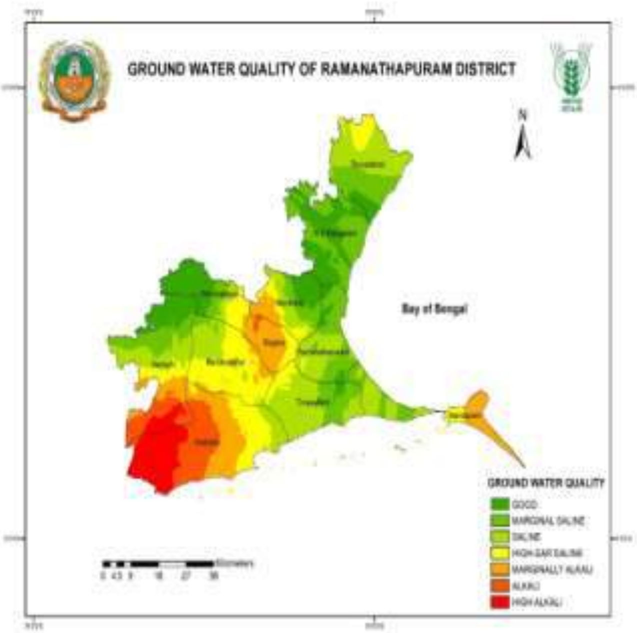


Fig 22 Ground water quality of Ramanathapuram District

Table 69. Water quality distribution (%) in Ramanathapuram district

S.No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Ramanathapuram	12		16.6		33.3			50
2.	Paramakkudi	10		10		10		10	70
3.	Kamuthi	10	20	30		20		20	10
4.	Kadaladi	14	7.1			71.4	7.1		14.2
5.	Tirupullani	10	10	20		70			
6.	Nainarkovil	10	20	20	10	50			
7.	Mandapam	15	20			33.3		33.3	13.3
8.	Mudukalathur	8	25	12.5	12.5	50			
9	Bogalur	8				62.5		12.5	25
10.	Tiruvadanai	13	7.6	7.6	7.6	46.1		15.3	15.3
11.	R.S Mangalam	6			16.6	50		16.6	16.6
	Average	116	10	10	4	46	1	10	19

9.5. Pudukottai District

Pudukkottai district has 13 blocks in Pudukkottai district like Annavasal, Arimalam, Kunnandarkoil, Ponnamaravathi, Pudukkottai, Thirumayam, Viralimalai, Aranthangi, Avudaiyarkoil, Gandarvakottai, Karambakudi, Manalmelkudi, Thiruvarankulam. In which Manalmelkudi, Avudaiyarkoil blocks are comes under coastal line. The location of study area is presented in the Fig. 23. High temperature throughout the year. The temperature ranges from 15.50 to 43.00. The hottest months are April to June, and the coldest months are November to January. Generally, a dry and hot climate prevails in this District. The normal annual rainfall of Pudukkottai district is 910 mm. During Northeast monsoons this district receives the highest rainfall of 427 mm followed by, Southwest monsoon with 340 mm of rainfall. The summer and winter rainfalls are 91 mm and 52 mm, respectively. Out of the total samples collected in Pudukkottai district 45 per cent of groundwater were found as good quality and its remaining samples were found in different categories of water quality *viz.*, Marginally saline (12%), Saline (1%), High-SAR saline (4%), Marginally alkali (14%), Alkali (14%) and High alkali (10%) Table 70.

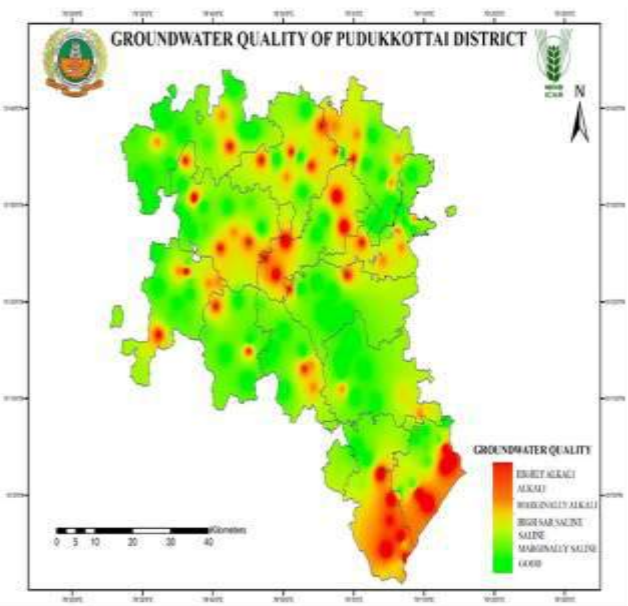


Fig 23. Ground water quality of Pudukottai District

Table 70. Water quality distribution (%) in Pudukkottai district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Viralimalai	16	62.50	19.00			12.50	6.25	
2.	Annavasal	14	50.00	14.00			7.00	22.00	7.00
3.	Ponnamaravathi	14	28.60	35.00			21.50	7.00	7.00
4.	Avadaiyurkovil	15	13.00		6.70	33.0	7.00	7.00	33.00

5.	Manamelkudi	14	21.50	36.00		7.0			35.00
6.	Arantangi	11	55.00	10.00		18.2	18.00		
7.	Thirumayam	8	50.00	25.00				25.00	
8.	Arimalam	9	55.00	11.00			22.00	11.11	
9.	Thiruvarankulam	8	75.00					25.00	
10.	Pudukkottai	8	25.00				12.50	12.50	50
11.	Kunnandarkovil	11	45.00				10.00	45.45	
12.	Gandarvakottai	11	55.00				36.40	10.00	
13.	Karambakudi	10	50.00				40.00	10.00	
	Average	149	45	12	1	4	14	14	10

9.6. Thanjavur

Thanjavur District has 14 Blocks *viz.,* Ammapettai, Budalur, Kumpakonam, Mathukur, Orathanadu, Papanasam, Peravurani, Pattukottai, Sethubavasathiram, Thanjavur, Thiruppanadal, Thiruvaiyaru, Thiruvidaimarudur and Thiruvonam. Out of the total samples collected in Tanjore district, 84.2 % is coming under good quality, 2.19 % is marginally saline, 9.3 % is marginally alkaline, 3.6 % is alkaline, 0.46 % is saline and 0.25 % high SAR saline (Table 71 & Fig. 24). 100 % good quality water was observed in Thiruppanadal and Thiruvonam blocks. More than 90 % water samples collected from Mathukur, Orathanadu, Papanasam, Peravurani, and Thiruvidaimarudur blocks coming under the category of good quality. Marginally saline water was observed in Ammapettai (10 %), Pattukottai (6.66 %), Sethubavasathiram (15.4 %) and Thanjavur (4.54 %) blocks. Saline water was observed in Ammapettai (93.3 %) block only. High SAR saline water was present in Budalur block only. Marginally alkali water was found in some blocks (3.7 to 28.0 %) except Ammapettai, Orathanadu, Sethubasathiram, Thirupananthal, Thiruvidaimarudur and Thiruvonam blocks. Alkali water was found in Ammapettai (3.33%), Budalur (3%) , Kumpakonam (5.71), Orathanadu (8.51), Pattukottai (6.66 %), Sethubavasathiram (2.56 %), Thiruvaiyaru (12 %) and Thiruvidaimarudur (8.51 %) Blocks. Highly alkali water was not found in any part of the district.

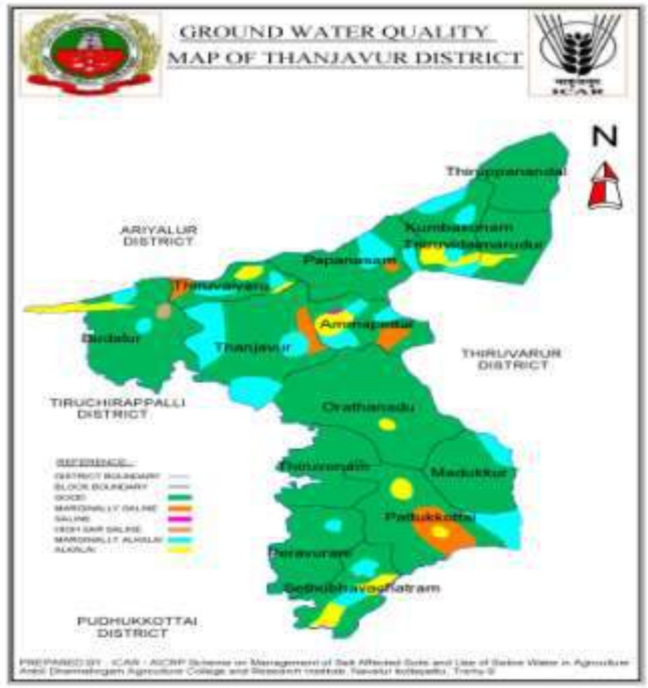


Fig 24. Ground water quality of Thanjavur District

Table 71. Water quality distribution (%) in Thanjavur district

S.No	Block	**No.of samples**	**Good**	**MS**	**Saline**	**HSS**	**MA**	**Alkali**	**HA**
1	Ammapettai	30	83.3	-	3.33	-	10	3.33	-
2	Budalur	20	60	-	-	5	20	15	-
3	Kumpakonam	35	77.14	-	-	-	17.14	5.71	-
4	Mathukur	24	91.6	-	-	-	8.33	-	-
5	Orathanadu	33	97.0	-	-	-	-	3.0	-
6	Papanasam	27	96.29	-	-	-	3.70	-	-
7	Peravurani	32	93.7	-	-	-	6.3	-	--
8	Pattukottai	15	73.33	6.66	-	-	13.3	6.66	-
9	Sethubavasathiram	39	82.05	15.38	-	-		2.56	-
10	Thanjavur	22	81.8	4.54	-	-	13.63	-	-
11	Thiruppanadal	36	100		-	-	-	-	-
12	Thiruvaiyaru	25	56	4	-	-	28	12	-
13	Thiruvidaimarudur	47	91.48	-	-	-	-	8.51	-
14	Thiruvonam	27	100	-	-	-	-	-	-
	Total /average	**412**	**84.2**	**2.19**	**0.46**	**0.25**	**9.3**	**3.6**	-

9.7 Thiruvarur

Thiruvarur District has 10 Blocks viz., Koradacheri, Kottur, Kudavasal, Mannarkudi, Muttupt, Nidamangalam, Nannilam, Thiruthuraipundi, Thiruvarur and Valangaiman. Out of the total samples collected in Thiruvarur district, 83.2% is coming under good quality, 9.93 % is marginally saline, 3.72% is marginally alkaline, 1.24% is alkaline, 0.62% high SAR saline and 1.24 % highly alkaline (Table 72). Among the 10 blocks, the distribution of good quality samples were the highest in Thiruthuraipundi (100%) and the lowest in Nannilam (53.3%) Block. The occurrence of marginally saline water (5.6 to 19.0%) was prevalent in all the Blocks, Marginally alkali water is prevalent in Kudavasal (10%) Nannilam (26.7%) and Valangaiman (4.8%). Alkali water was prevalent in Nannilam (13.3%) and highly alkali was found in Koradacheri (5.5%) and Kudavasal (10%) block. High SAR saline water was found in Valangaiman block only (4.8%) (Fig. 25)

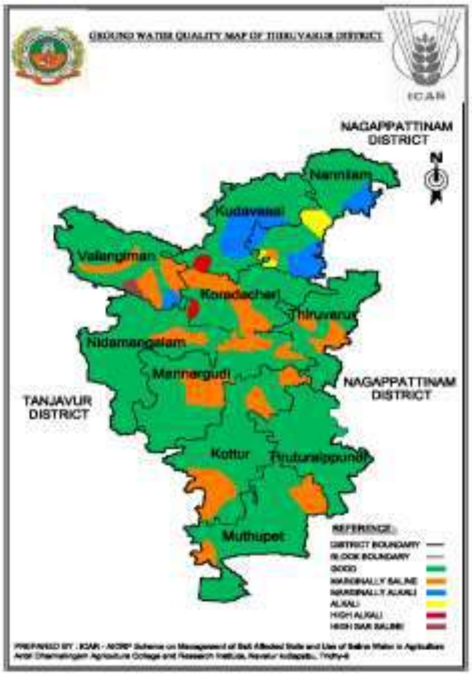


Fig 25: Ground water quality of Thiruvarur District

Table 72. Water quality distribution (%) in Thiruvarur district

S.No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Koratacheri	18	77.8	16.7					5.5
2	Kottur	22	90.9	9.1					
3	Kudavasal	10	80				10		10
4	Mannarkudi	16	81.2	18.8					
5	Muttupet	18	94.4	5.6					
6	Nannilam	15	53.3	6.7			26.7	13.3	

7	Nidamangalam	11	90.9	9.1					
8	Thiruthuraipundi	21	100						
9	Thiruvarur	9	88.9	11.1					
10	Valangaiman	21	71.4	19.0		4.8	4.8		
	Total	161	83.2	9.93		0.62	3.72	1.24	1.24

9.8. Nagapattinam District

Nagapattinam District has 11 Blocks viz., Keelaiyur, Kilvelur, Kollidam, Kuttalam, Mayiladuthurai, Nagapattinam, Sembanar Koil, Sirkazhi, Thirumarugal, Talanayar and Vedaranniyam. Out of the total samples collected in Nagapattinam district, 72.6 % is characterized under good quality, 12.7 % is marginally saline, 7.8 % is saline, 2.9 % is marginally alkaline, 2.9 % is alkaline, and 0.4 % high SAR saline (Table 73 & Fig. 26). More than 90 % water samples collected from Kuttalam and Mayiladuthurai blocks coming were good quality water. Nagapattinam and Vedaranniyam blocks have less than 50 per cent good quality waters. Marginally saline water was observed in almost all the blocks except Kuttalam and Mayiladuthurai. The distribution of marginally saline water were 9.09 % in Sembanarkoil, 9.0 % in Sirkazhi, 16.7 % in Kollidam , 18.2 % in Thirumarumarugal, 18.5 % in Kilvelur, 25 % in Keelaiyur, 38.5 % in Thalanayar and 17.6 % in Vedaranniyam Blocks. The distribution of saline water was 4.54 % in Sembanar Koil, 9% in Sirkazhi, 0.09 % in Thirumarugal, 44.4 % in Nagapattinam, 6.25 % in Keelaiyur, 7.69 in Talanayar and 7.8 % in Vedaranniyam Block. Small quantity of marginally alkali and alkali water was distributed in almost all the blocks. High SAR Saline water was present only in Kilvelur Block.

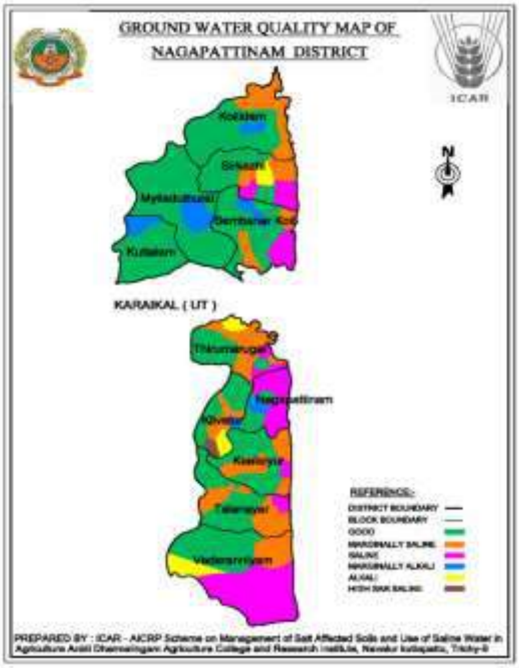


Fig 26: Ground water quality of Nagapattinam District

Table 73. Water quality distribution (%) Nagapattinam district

S. No	Block	No.of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Keelaiyur	16	68.7	25	6.25	-	-	-	-
2.	Kilvelur	27	66.66	18.51	-	3.70	3.70	7.40	-
3.	Kollidam	18	77.8	16.66	-	-	5.55	-	-
4.	Kuttalam	36	97.22	-	-	-	2.77	-	-
5.	Mayiladuthurai	14	92.85	-	4.54	-	7.14	-	-
6.	Nagapattinam	9	33.3	-	44.4	-	11.1	11.1	-
7.	Semmanar kovil	22	81.8	9.09	4.54	-	4.54	-	-
8.	Sirkazhi	22	77.2	9.0	9.0	-	-	4.54	-
9.	Talanayar	13	53.8	38.5	7.69	-	-	-	-
10.	Thirumarugal	11	63.63	18.18	9.09	-	-	9.09	-
11	Vedaranniyam	17	41.1	17.6	35.2	-	-	5.88	-
	Average	**205**	**72.6**	**12.7**	**7.8**	**0.4**	**2.9**	**2.9**	**-**

9.9. Cuddalore

Out of the total ground water samples collected from Cuddalore district, 69.9 per cent is coming under good quality, 16.27 per cent is marginally saline, 9 per cent is saline water, 0.8 per cent is marginally alkali and 3.4 per cent is under high alkali categories (Table 74 & Fig 27). Hence, around 70 percent of the ground water resources can only be made available for irrigation purpose, the remaining are under threat. The maximum EC, SAR and RSC was recorded in Kumaratchi block followed by in Parangipettai block of Cuddalore district since these blocks are situated nearby coastal areas (10 km from sea shore). The nitrate content of the ground water samples of coastal blocks were all in safer side (<2.5meq/l) except in few places exceeding 2.5meq/l. The fluoride content in all blocks of Cuddalore district was found to be safe.

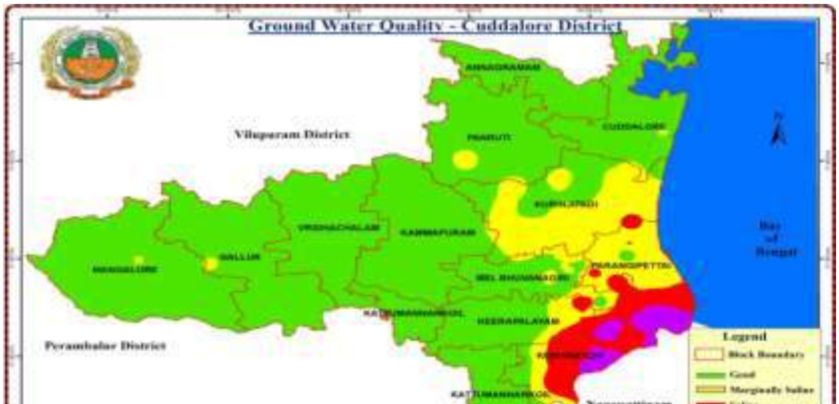


Fig 27. Ground water quality of Cuddalore District

Table 74. Percentage distribution of ground water samples in different EC ,RSC,SAR classes of different blocks of Cuddalore district

S.NO	Blocks	No. of samples collected	Good	Marginally saline	Saline	High SAR saline	Marginally alkali	Alkali	High alkali
1.	Panruti block	11	90.9	9.1	-	-	-	-	-
2.	Cuddalore block	25	92	4	-	-	4	-	-
3.	Annagramam block	12	100	-	-	-	--	-	-
4.	Parangipettai block	13		39	38.5	-	7	-	15.4
5.	Kurinchipadi block	16	6.3	93.7	-	-	-	-	-
6.	Bhuvanagiri block	14	50	35.7	14.3	-	-	-	-
7.	Keerapalayam block	10	90	10	-	-	-	-	-
8.	Kattumannarkoil block	10	100	-	-	-	-	-	-
9.	Kumarachi block	10	-	-	70	-	-	-	30
10.	Kammapuram block	10	100	-	-	-	-	-	-
11.	Virudhachalam block	10	100	-	-	-	-	-	-
12.	Nallur block	10	90	10	-	-	-	-	-
13.	Mangaloor block	10	90	10	-	-	-	-	-
	Total	161				-	-	-	-
	Average		69.9%	16.27%	9%	-	-	-	3.4%

9.10. Villupuram District

A study was undertaken to assess the groundwater quality in Villupuram district by collecting 143 groundwater samples using GPS and analyzed for pH, EC, etc. The investigation revealed that groundwater samples with respect to pH ranged from 7.0 to 8.4 with mean of 7.7 and EC ranged from 0.27 to 4.35 dSm^{-1} with mean of 1.14 dSm^{-1}, respectively. Residual Sodium Carbonate (RSC) varied from nil to 11.10 meq L^{-1} and Sodium Absorption Ratio (SAR) ranged from 0.26 to 20.31 with a mean SAR of 0.93. In the coastal blocks surveyed, the frequency of good quality water was more in Marakkanam block based on the CSSRI, Karnal water quality classification. The Vanur blocks have the highest alkalinity (75%) and the lowest alkalinity was found in Marakkanam block (63.63%). Based on the results of this investigation, only 9.09 per cent of samples were of good quality, Viluppuram district of the coastal blocks. Alkali accounted for 69.3% among all samples, with 12.87 per cent (marginal Alkali), 8.71 per cent (marginal saline) and 4.54 per cent (marginal saline) following closely behind (high SAR saline) Table 75 & Fig. 28. The largest percentage of alkali water samples were found in Vanur. In the Marakkanam blocks, there was an equal percentage of good water, marginal saline, high SAR saline and marginal alkali. 95.455 per cent of samples in Viluppuram district's coastline blocks had varying salinity levels, which could be related to the district's wide coastal line and the district's prolonged drought.

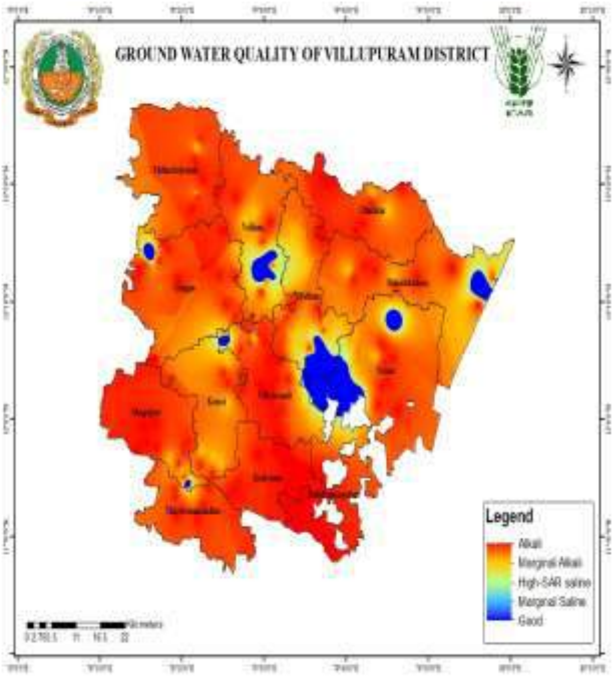


Fig 28. Ground water quality of Villupuram District

Table 75. Water quality distribution (%) in Villupuram district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1.	Mailam	12	25.0	-	-	-	41.7	33.3	-
2.	Vallam	16	18.8	-	-	-	18.8	62.5	-
3.	Melmalayanur	10	-	-	-	-	20.0	80.0	-
4.	Gingee	14	7.1	-	-	-	-	64.3	-
5.	Vikkravandi	13	-	-	-	-	7.7	92.3	-
6.	Kanai	13	7.7	-	-	-	46.2	46.2	-
7.	Mugaiyur	13	-	7.7		-	15.4	76.9	-
8.	Thiruvennainallur	08	-	-	-	-	12.5	87.5	-
9	Marakkanam	11	-	9.1	-	9.1	18.2	63.6	-
10.	Vanur	12	-	8.3	-	-	16.7	75.0	-
11.	Olakkur	10	-	-	-	-	20.0	80.0	-

12.	Koliyanur	05	-	-	-	-	-	100.0	-
13.	Kandamangalam	06	-	-	-	-	-	100.0	-
	Average	**143**	**6**	**2**	**-**	**1**	**18**	**73**	**-**

9.11 Chengalpet

Based on the investigation, out of 250 samples collected in Chengalpattu district alkali accounted for 45% followed by marginal alkali (31%), 16% of samples comes under the good quality and 4% of samples comes under the marginal saline and Highly alkali each (Table 76 & Fig 29). Chengalpattu district have high amount of alkali water. The risk of sodium (Alkali) substituting for calcium ($Ca^{2+)}$) and magnesium ($Mg^{2+)}$) in the soil through the cation exchange process damages the soil structure, namely permeability, which eventually affects the physical qualities of the soil and lowers crop output (Islam and Shamsad, 2009).

The distribution of water samples in different water quality classes in Chengalpattu district reveals that most of the samples come under the alkaline category. In this St.ThomasMount account for 80% followed by Madhuranthagam (53%), Thiruporur (46%), Thirukalukundram (42%). Chithamur and Acharambakkam block have 41 % alkali water followed by Lathur (40%) and Kattankolathur (38%). Next to alkali marginally alkali accounts for 46% in Lathur followed by Thirukalukundram, Thiruporur (36%). Chithamur accounts 33% of marginally alkali water followed by Madhuranthagam (28%), Kattankolathur (22%), Acharambakkam (18%) and St.thomas mount (13%). The highly alkali water quality category also present in Chengalpattu district. In Acharambakkam 18% of samples comes under highly alkali followed by Kattankolathur (9 %) and Chithamur (7%). 3% of groundwater samples comes under highly alkali in Thirukalukundram and Madhuranthgam block. This alkaline nature is may be due to the blocks near to the coastal line and prolong drought.

The marginal saline accounts 7% in Chithamur block followed by Thirukalukundram, Kattankolathur (6%). 5% of water present in Acharambakkam block. Lathur and Thiruporur block has 3% of marginal saline water.

Even though the Chengalpattu district have a high amount of alkali water it also has good quality water. The highest amount of good quality present in Kattankolathur (25%) followed by Acharambakkam (18%),Chithamur (17%), Madhuranthgam (16%), Thiruporur (15%), Thirukalukundram (13%), Lathur (11%) and St.thomas mount (7%). This good water may be due to some villages far away from the coastal line and maybe it receives good rain water.

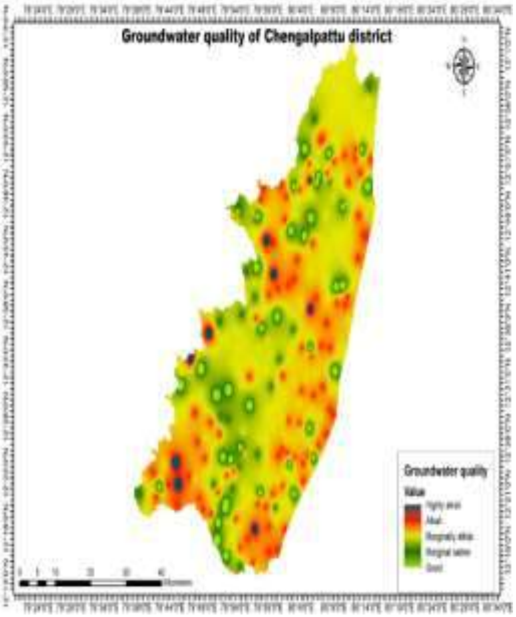


Fig 29. Ground water quality of Chengalpattu District

Table 76. Water quality distribution (%) in Chengalpattu district

S. No	Block	No. of samples	Good	MS	Saline	HSS	MA	Alkali	HA
1	Chithamur	42	17	7	-	-	33	41	7
2	Lathur	37	11	3	-	-	46	40	-
3	Thirukalukundram	31	13	6	-	-	36	42	3
4	Thiruporur	39	15	3	-	-	36	46	-
5	St. Thomas Mount	15	7	-	-	-	13	80	-
6	Kattankolathur	32	25	6	-	-	22	38	9
7	Madhuranthagam	32	16	-	-	-	28	53	3
8	Acharambakkam	22	18	5	-	-	18	41	18
	Total (%)	Total -250	16	4	-	-	31	45	4

9.12 Thiruvallur

A study was undertaken to assess the groundwater quality and seawater intrusion for different blocks in Tiruvallur district by collecting 166 groundwater samples using GPS representing the various block *viz.,* Ellapuram(10), Gummidipoondi(18), Kadambathur(10), Minjur(25), Pallipattu(10), Poonamallee(8), Poondi(10), Puzhal(7), R.K.Pet(11), Sholavaram(11), Tiruvallur(15), Tirutani(11), Thiruvelangadu(10), Villivakkam(10) in which Puzhal, Minjur and Gummidipoondi comes under coastal line.The samples were analysed for pH, EC, cations *viz.,* Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} and anions *viz.,* CO_3^{2-}, HCO_3^{-}, Cl^{-}, SO_4^{2-} by adopting standard procedures. Thematic maps were prepared using ArcGIS software 10.1. The investigation revealed that ground water samples with respect to pH and EC ranged from 7.35 to 8.86 and 0.16 to 4.48 dSm^{-1}. Sodium Adsorption Ratio (SAR) ranged from 0.22 to 14.4 and Residual Sodium Carbonate (RSC) varied from 4.4 to 18.2 meq-1 L^{-1}. The concentration of cations *viz.,* calcium, magnesium, sodium and potassium ranged from 1.00 to 14.4 meqL^{-1}, nil to 10 meq L^{-1}, and 0.55 to 25.717 meq L^{-1} and 0.05 to 2.105 meq L^{-1}, respectively. The anions *viz.,* carbonate, bicarbonate, chloride and sulphate in the ground water samples ranged from 2.0 to 8.0 meq $L^{-1}$and 2.0 to 20.0 meq L^{-1}, 0.6 to 22.1 meq L^{-1}, and 0.05 to 2.209 meq L^{-1}, respectively.

According to CSSRI, Karnal water quality classification 73 percent of ground water were found as good quality, whereas the remaining samples were found in different categories of water quality *viz.,* marginally saline (1 per cent), marginally alkali (14 per cent), Alkali (10 per cent) and High alkali (2 percent) Fig. 30). According to the water quality index, in the Tiruvallur district, 15 per cent of groundwater is excellent quality and 85 per cent of groundwater is good quality, making it suitable for drinking.

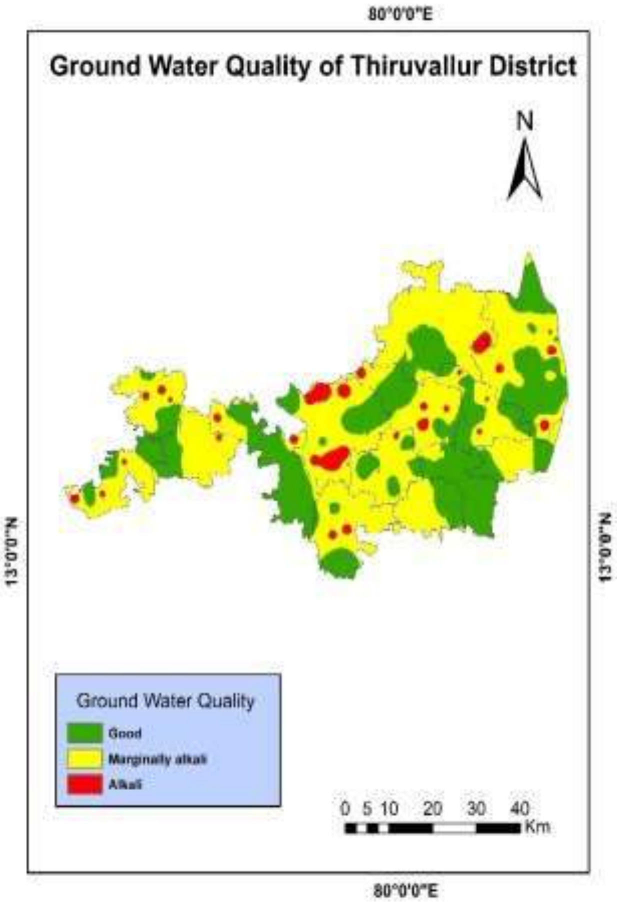


Fig 30: Ground water quality map of Tiruvallur district

10. MANAGEMENT OF POOR QUALITY WATER

The investigations were carried to study the effect of different irrigation schedules through drip on the yield and water use efficiency of sugarcane, to evaluate the performance of different types of emitters, to standardize the emitter suitable for sodic water irrigation and to study the economics of the drip system over conventional system of irrigation.

10.1. Scheduling Irrigation with Alkali Water for Sugarcane under Sodic Soil Condition using Drip Irrigation

The experiment plots were randomized based on strip -plot design with five replications. The main plot treatments (irrigation) imposed were drip irrigation at 100% PE (paired row system), drip irrigation at 80% PE (paired row system), drip irrigation at 60% PE (paired row system) and Surface irrigation (Ridges and furrows at 80 cm interval). The sub- plot treatments were Gypsum application at 50% GR and without gypsum. The test crop was sugarcane (CoSi 95071).

The first crop of sugarcane (CoSi 95071) was planted during June 1999 and harvested during first week of May 2000 and the ratoon crop was harvested during May 2001. The irrigation water used was 'highly alkali' (pH, EC, RSC and SAR were 8.8, 2.2 dSm^{-1}, 12.5 $meql.^{-1}$ and 18.2 respectively). The drip irrigation was given continuously as per the irrigation treatments proposed in the project. The uniformity coefficient was 91 per cent which ensured the uniform distribution of irrigation water .The biometric observations such as number of tillers, number of millable cane, cane height and cane yield were recorded. Sugarcane samples were also collected and analysed for quality parameters like brix, polority, purity and CCS (Table. 77).

In both plant and ratoon canes, irrigation and gypsum treatments had significant influence on the number of millable cane. However, drip irrigation at 100 % PE and 80 % PE were comparable in increasing the number of millable cane over conventional furrow irrigation. The results showed that application of gypsum and drip irrigation with 80 % PE recorded the maximum height of 280 cm and 237 cm respectively.

Effect of irrigation treatments on cane yield is given in tables 90 and 91. Among them, drip irrigation with 80% PE registered significantly the highest cane yield of 102.96 and 98.84 t/ha respectively for plant and ratoon crops. This was followed by the farmer's practice and drip irrigation with 100 % PE (Table. 78). Among the sub plot treatments higher cane yield was obtained with gypsum application @ 50% GR. Apart from the increase in yield, there was water saving due to drip irrigation. The quantity of water used in different treatments during 1999-2000 was as follows:

Treatment	Amount of water given in mm	Water saving in per cent
100 per cent PE (drip)	1447	3.53
80 per cent PE (drip)	1158	22.80
60 per cent PE (drip)	868	42.13
Control	1500	-

The commercial cane sugar content analysed for the cane samples from various treatments showed that the highest sugar content was obtained through drip irrigation at 80 % PE with gypsum application.

Table 77. Effect of irrigation and gypsum on Cane yield (t/ha) (1999-2000)

Treatments	S1	S2	M-mean
M1	99.28	95.64	97.46
M2	107.40	98.52	102.96
M3	96.58	91.10	93.84
M4	99.52	93.78	96.65
S-mean	100.70	94.76	

	SED	CD
M at S	2.56	5.58
S at M	NS	NS

Table 78. Effect of irrigation and gypsum on Cane yield (t/ha) (2000-2001)

Treatments	S1	S2	M-mean
M1	96.02	83.07	89.55
M2	98.84	94.98	96.91
M3	80.06	74.25	77.16
M4	90.07	81.51	85.79
S-mean	91.25	83.45	

	SED	CD
M at S	3.54	7.71
S at M	NS	NS

10.2 Fertigation to Sugarcane under Drip Irrigation Using Ameliorated Alkali Water

This experiment was continuation of earlier conducted experiment on scheduling of irrigation to sugarcane under drip irrigation. The best performing treatment *viz.*, drip irrigation at 80%PE with soil application of gypsum @ 50%GR which was followed by drip irrigation of ameliorated alkali water (pH 9.0, EC 1.78 dSm^{-1}, and RSC 11.4) by gypsum bed and distillery spentwash (DSW) with following objectives

1. To study the efficacy of gypsum and distillery spentwash for ameliorating alkali water

2. To study the effect of fertigation of N and K to sugarcane through drip system using ameliorated alkali water
3. To study salt and nutrient distribution in wetting front of drip irrigation

Treatments

Main plot (Water treatment)

M_1 : Drip irrigation with gypsum bed treated water

M_2 : Drip irrigation with spent wash treated water

M_3 : Drip irrigation with untreated alkali water

M_4 : Farmer's practice (furrow irrigation)

Sub-plot (Soil treatment)

S_1 : Soil application of gypsum @ 50% GR

S_2 : No gypsum

Design : Split plot

Replications : Four

Year	Main /Ratoon crop	Sugarcane variety	Date of Planting	Date of harvest
2003	Main	CoSi 95071	February 2003	January 2004
2004	Ratoon	CoSi95071	February 2004	January 2005
2005	Main	CoSi95071	June 2005	May 2006

Crop variety - Sugarcane: (CoSi 95071)

Drip layout

To reduce the initial drip irrigation cost, double row planting with paired row planting system of sugarcane was followed. In each row the sugarcane sets were planted in two lines with 30 cm spacing. Thus one drip lateral can serve four lines of sugarcane sets. The population per running meter in the drip system and conventional planting system was maintained at eight sets per meter. The drip system was designed and laid out before the planting in alkali soils of ADAC&RI farm with initial soil pH of 9.0 and EC 0.27 dSm^{-1}.

The gypsum bed was fabricated using the 200 litre capacity drum and a mild steel rod stand. The inlet of the irrigation water is provided below the stand and the irrigation water was treated during its upward movement by the gypsum bed provided in powder form kept within a gunny bag over the stand. This treated water is being collected in a storage tank from which the water is pumped into drip system through the filter. During the second main crop (2005-2006), the gypsum bed treatment structure (1000 litres) was erected with RCC rings, but the mechanism of water treatment in the gypsum bed was the same. Similarly, the spent wash is mixed with irrigation water in a ratio of 1:250 through the fertigation unit to treat the alkali water. The drip irrigation is being operated thrice in a week. The duration in each drip irrigation is estimated based of the average evaporation rate, stage of the crop (accounted in terms of Kc value). The recommended quantities of N (

275 kg/ha) and K (112.5 kg/ha) as urea and muriate of potash were given in 12 equal splits through the drip system once in 15 days starting from 15th day of planting. The full dose of P as super phosphate was applied as basal.

In the farmer's method, the sets were planted in ridges and furrow system with 80 cm interval and fertilizer N and K was applied in three splits at 30^{th}, 60^{th}, 90^{th} days after planting. The soil samples were collected from different locations at 0-15 cm and 15- 30 cm depth *viz.,* just below the emitter, midpoint between the emitters, 22.5 cm and 45 cm distance perpendicular to the direction of laterals around the emitters for laboratory analysis. In the same position all tubes were installed to determine soil moisture using soil moisture probe.

Amelioration of Alkali Water

The changes in irrigation water quality by gypsum bed treated water and distillery spent wash treated water is given in the Table 79. The gypsum bed treatment of water could neutralize the RSC from 11.4 to 5.0 meq L^{-1}. The injection of DSW to drip system at 1:250 could reduce the pH of irrigation water from 9.0 to 6.8 with complete neutralization of RSC and with slight increase of electrical conductivity from 1.78 to 2.5 dSm^{-1}.

Table 79. Changes in Quality of Ameliorated Alkali Water

Sl. No	Treatment	pH	EC (dSm^{-1})	RSC
1	Alkali water (untreated)	9.0	1.78	11.4
2	Gypsum bed treated water	8.4	1.76	5.0
3	Distillery spent wash treated water (1:250)	6.8	2.50	Nil

Soil Moisture Distribution and Salinity

The soil moisture distribution recorded at tillering and grand growth stages of 2003 main sugarcane crop are given in Table 80 and 81, respectively. After 24 hours of irrigation, furrow irrigated plot recorded higher moisture than drip irrigation. With respect to soil pH, gypsum applied plot recorded lower soil pH than no gypsum plots. Of the distance studied, forward and backward points along the lateral at 37.5 cm from the emitter recorded the higher pH. Though the soil EC was less than 1.0 dSm^{-1} the surface sample recorded higher soil EC than subsurface sample. Similarly lateral distance both left and right recorded higher EC values, which indicated accumulation of salts in the periphery of wetting zone around the emitter.

Effect of Ameliorated Alkali Water on Soil Properties

The effect of ameliorated alkali water and soil application of gypsum on soil pH, EC and ESP is given in Table 82. The analysis of soil sample taken after the harvest of crops indicates that the increase in the EC from 0.27 dSm^{-1} to 0.57 dSm^{-1} but slight increase of soil pH from 9 to 9.2 was recorded. The increase of soil ESP from 16 to upto 9.7 was noticed which is very significant indication of build-up of soil ESP, particularly in the plot irrigated with alkali water. From the results it is observed that the EC and ESP build-up with respect to the distance from the emitter.

Table 80. Soil moisture, salinity and pH around the emitter at tillering stage

Distance from emitter (cm)	Moisture (%)		Soil pH		Soil EC(dSm^{-1})	
	Gypsum	No gypsum	Gypsum	No gypsum	Gypsum	No gypsum
C-15	12.5	16.9	8.8	9.0	0.36	0.28
C-30	11.8	11.1	8.8	9.0	0.25	0.27
F-15	12.1	12.9	9.1	9.1	0.23	0.29
F-30	7.1	12.7	8.9	9.1	0.28	0.29
B -15	9.0	11.3	8.8	8.9	0.50	0.25
B –30	8.7	9.4	8.8	9.1	0.3	0.32
L -22.5/15	11.4	12.4	8.9	8.9	0.59	0.41
L –22.5/30	9.8	9.8	8.7	8.8	0.39	0.67
L – 45/15	7.8	7.8	8.6	8.8	0.81	0.91
L – 45/30	9.3	10.1	8.8	9.0	0.88	0.56
R -22.5/15	10.4	11.6	8.5	9.1	0.7	0.36
R –22.5/30	10.2	16.3	8.7	8.9	0.61	0.32
R – 45/15	10.0	10.5	8.41	8.9	1.03	0.60
R – 45/30	9.4	10.8	8.4	8.8	0.80	0.67
Furrow /15	14.1	14.4	9.0	9.1	0.21	0.27
Furrow /30	11.3	16.6	8.1	8.9	0.19	0.22

C – Just below emitter at 15 and 30 cm depth

F – Forward distance (37.5 cm) at 15 and 30 cm depth

B- Backward distance (37.5 cm) at 15 and 30 cm depth

L – Left of emitter (22.5 cm and 45 cm distance) at 15 and 30 cm depth

Table 81. Soil moisture distribution around the emitter at Grand growth stage of sugarcane

Distance from emitter (cm)	Moisture (%)	
	Gypsum	No gypsum
C-15	15.9	15.0
C-30	10.3	9.6
F-15	14.6	14.2
F-30	13.7	13.2
B –15	14.1	14.0
B –30	11.9	11.3
L -22.5/15	14.2	14.6
L –22.5/30	10.8	10.3
L – 45/15	12.8	12.2

L – 45/30	12.8	12.9
R -22.5/15	13.4	13.0
R –22.5/30	13.1	12.6
R – 45/15	12.7	13.0
R – 45/30	12.6	12.8
Furrow /15	16.5	15.6
Furrow /30	13.0	13.5

C – Just below emitter at 15 and 30 cm depth

F – Forward distance (37.5 cm) at 15 and 30 cm depth

B- Backward distance (37.5 cm) at 15 and 30 cm depth

L – Left of emitter (22.5 cm and 45 cm distance) at 15 and 30 cm depth

R – Right of emitter (22.5 cm and 45 cm distance) at 15 and 30 cm depth

Table 82. Effect of drip irrigation using ameliorated alkali Water on the pH, EC and ESP of post-harvest soil

	2003						2004					
Treatments	**pH**		**EC (dSm^{-1})**		**ESP**		**pH**		**EC(dSm^{-1})**		**ESP**	
M_1	8.8		0.43		16.2		9.0		0.50		17.0	
M_2	8.8		0.50		15.6		9.0		0.43		18.0	
M_3	9.1		0.57		19.7		9.2		0.36		19.4	
S_1	8.8		0.56		15.5		8.9		0.47		16.6	
S_2	12.0		0.44		18.9		9.2		0.39		19.7	
L_1	9.0		0.29		17.0		9.2		0.39		16.9	
L_2	9.1		0.27		17.1		9.2		0.39		18.2	
L_3	9.0		0.34		17.5		9.2		0.44		18.7	
L_4	8.9		0.76		16.6		9.1		0.50		20.0	
L_5	8.9		0.70		16.5		8.9		0.37		18.0	
L_6	8.9		0.34		18.6		9.1		0.50		18.4	
L_7	8.6		0.68		17.1		8.8		0.45		16.9	
	SE.d	CD (p=0.05)	SE.d	CD (p=0.05)	SE.d	CD (p=0.05)	SE.d	CD (p=0.05)	SE.d	CD (p=0.05)	SE.d	CD (p=0.05)
M	0.01	0.02	0.01	0.03	0.09	1.8	0.01	0.02	0.01	0.02	0.08	0.16
L	0.01	0.02	0.02	0.03	1.00	2.0	0.01	0.02	0.01	0.02	0.09	0.17

Cane Yield

Amelioration of alkali water with gypsum bed and DSW treatments and soil application of gypsum have shown significant effect during 2003-2004 (main crop) (Table 83). In the ratoon crop, the treatment of irrigation water with gypsum bed and DSW were on-par, but in both seasons, the highest sugarcane yield was recorded in the gypsum bed treatment. Drip irrigation with alkali water and farmer's practice were on-par and recorded the lowest cane yield. Apart from the yield of cane, the yield attributes like number of tillers, cane height and girth were also observed and analyzed. The highest number of tillers, cane height and girth were recorded in the gypsum bed water treatment with soil application of gypsum. Cane juice quality was also recorded and commercial cane sugar yield was computed (Table 83).

Table 83. Effect of drip irrigation using ameliorated alkali water on yield of sugarcane

Treatments	2003 (main)	2004 (ratoon)
Gypsum application @ 50% GR	79.2	104.9
No Gypsum	63.4	98.4
SE.d	**4.00**	**3.91**
CD (p=0.05)	**9.04**	**8.85**
Gypsum bed	91.5	110.2
Spent wash	70.9	108.6
Untreated	61.9	92.2
Furrow irrigation	60.8	95.5
SE.d	**0.91**	**2.46**
CD (p=0.05)	**1.99**	**5.37**

Salient findings

- Drip irrigating to sugarcane at 80% PE (paired row system) with gypsum at 50% GR recorded the highest average cane yield of 104.9 t ha^{-1}.
- Drip irrigation to sugarcane saved irrigation water up to 29.5% as compared to furrow irrigation.
- Drip irrigation with gypsum bed treated water in combination with soil application of gypsum @ 50% GR recorded the highest average cane yield of 113.4 t ha^{-1}
- Drip irrigation with gypsum bed treated water in combination with soil application of gypsum @ 50% GR reduced the soil pH and ESP.

10.3 Drip Irrigation to Vegetables in Alkali Soil using Amended Alkali Water

To study the efficacy of ameliorated alkali water and drip irrigation system on vegetable crop, an experiment was carried out during 2009-2010 and 2010-2011. The main plot treatments includes alkali water treatment viz., Drip irrigation with gypsum bed treated water, Drip irrigation with spent wash treated water, Drip irrigation with untreated alkali water and furrow irrigation. The sub plot treatments includes Soil application of gypsum @ 50% GR and control (without gypsum)

The results of the experiments showed that soil application of gypsum @ 50 % GR significantly increased the yield of both Okra (12.6 % in 2009 – 10 and 12.8 % in 2010-11) and cluster bean (22.1 % in 2009 – 10 and 20.9 % in 2010-11) Table 84. Among the irrigation treatments, drip irrigation of spent wash treated water recorded the highest yield in Okra and drip irrigation of gypsum bed treated water recorded highest yield in cluster bean crop.

Table 84. Effect of Drip Irrigation of Ameliorated Alkali Water on Yield of Okra

Treatments	2009-10			2010-11		
	Gyp. @ 50 % GR	No Gyp.	Mean	Gyp. @ 50 % GR	No Gyp.	Mean
Drip with gypsum bed	11.26	10.42	10.84	9.40	8.60	9.00
Drip with spent wash	11.98	10.9	11.44	10.30	9.60	9.95
Drip without treanment	10.2	8.8	9.50	8.60	7.30	7.95
Furrow irrigation	8.89	7.42	8.16	7.80	6.50	7.15
Mean	10.58	9.39		9.03	8.00	8.51

CD	M	S	M x S	S x M	M	S	M x S	S x M
p= (0.05)	0.48	0.41	0.90	0.82	0.56	0.48	1.04	0.95

The interaction effect showed that soil application of gypsum @ 50 % GR along with drip irrigation of spent wash treated water recorded the highest Okra yield which was on par with soil application of gypsum @ 50 % GR along with drip irrigation of gypsum bed treated water. In case of cluster bean, soil application of gypsum @ 50 % GR along with drip irrigation of gypsum bed treated water recorded the highest yield which was on par with soil application of gypsum @ 50 % GR along with drip irrigation of spent wash treated water. The lowest yield was recorded in the treatment without soil application of gypsum along with furrow irrigation of untreated alkali water both in Okra and cluster bean (Table 85).

Table 85: Effect of drip irrigation of ameliorated alkali water on yield of Cluster bean

Treatments	**2009-10**			**2010-11**		
	Gyp. @ 50 % GR	No Gyp.	**Mean**	Gyp. @ 50 % GR	No Gyp.	**Mean**
Drip with gypsum bed	6.72	5.38	6.05	6.16	5.21	5.69
Drip with spent wash	6.21	5.02	5.62	5.86	5.33	5.60
Drip without treatment	5.41	4.76	5.09	5.01	4.21	4.61

Furrow irrigation	4.89	3.86	4.38	4.72	3.25	3.99
Mean	5.81	4.76		5.44	4.50	4.97

CD	M	S	M x S	S x M	M	S	M x S	S x M
p= (0.05)	0.32	0.29	0.59	0.51	0.26	0.23	0.48	0.41

The pH, EC and ESP of the initial soil was 8.61, 0.46 dSm^{-1} and 26.1 percent, respectively (Table 86 & 87). Both alkali water treatment (gypsum bed / spent wash) and soil application of gypsum significantly reduced the pH of the post-harvest soil. However, soil application of gypsum @ 50 % GR significantly reduced the pH of the post-harvest soil below 8.5 from the initial level of 8.61. With regards to interaction effect, furrow irrigation (farmer's practice) without gypsum recorded the highest soil pH (8.71 in Okra field and 8.72 in Cluster bean field) followed by drip irrigation of untreated alkali water without gypsum .

The imposement of treatments *viz.,* soil application of gypsum, treatment of alkali water by gypsum / spent wash did not significantly changed the EC of post-harvest soil (Table 86).

With regards to ESP, furrow irrigation with untreated alkali water recorded the highest ESP followed by drip irrigation with untreated alkali water (Table 87 & 88). Soil application of gypsum @ 50 % GR significantly reduced the ESP of post-harvest soil to 12.9 and 13.1 respectively in Okra and cluster bean fields, respectively from the initial level of 26.1. The interaction effect showed that furrow irrigation of untreated alkali water with no gypsum recorded the highest ESP, while soil application of gypsum with gypsum bed treated drip irrigation recorded the lowest ESP (Table 88).

Table 86. Effect of drip irrigation using ameliorated alkali water on the pH of post harvest soil (2010-11)

Treatments	Okra			**Cluster bean**		
	S1	**S2**	**Mean**	**S1**	**S2**	**Mean**
M_1	8.31	8.52	8.42	8.34	8.56	8.45
M_2	8.3	8.56	8.43	8.3	8.58	8.44
M_3	8.45	8.62	8.54	8.48	8.64	8.56
M_4	8.51	8.65	8.58	8.5	8.68	8.59
Mean	8.39	8.59		8.41	8.62	

CD	M	S	M x S	S x M	M	S	M x S	S x M
p= (0.05)	0.36	0.32	0.56	0.48	0.32	0.28	0.48	0.42

Table 87. Effect of drip irrigation using ameliorated alkali water on the EC (dSm^{-1}) of post-harvest soil (2010-11)

Treatments	Okra				Cluster bean			
	S1	**S2**	**Mean**		**S1**	**S2**	**Mean**	
M_1	0.51	0.47	0.49		0.52	0.46	0.49	
M_2	0.52	0.49	0.51		0.5	0.5	0.50	
M_3	0.48	0.45	0.47		0.47	0.46	0.47	
M_4	0.5	0.48	0.49		0.52	0.49	0.51	
Mean	0.50	0.47			0.50	0.48		
CD	M	S	M x S	S x M	M	S	M x S	S x M
p= (0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 88. Effect of drip irrigation using ameliorated alkali water on the ESP (%) of Post-harvest soil (2010-11)

Treatments	Okra				**Cluster bean**			
	S1	**S2**	**Mean**		**S1**	**S2**	**Mean**	
M_1	13.00	21.40	17.20		13.5	22	17.75	
M_2	13.60	22.80	18.20		13.8	23.1	18.45	
M_3	14.20	26.00	20.10		14.4	26.6	20.50	
M_4	16.20	27.20	21.70		15.8	28	21.90	
Mean	14.25	24.35			14.38	24.93		
CD	M	S	M x S	S x M	M	S	M x S	S x M
p= (0.05)	0.86	0.72	1.20	1.31	0.70	0.81	1.12	1.18

10.3.1 Pressurized Irrigation Methods for Vegetable Crops in Sodic Soils

Field experiment was conducted during 2016-17 and 2017-18 at Anbil Dharmalingam Agricultural College and Research Institute, Trichirappalli on assessing the effect of drip, sprinkler and furrow irrigation methods on vegetable crops under sodic soil. The experiment consists of various irrigation methods in main plots *viz.,* drip, sprinkler and furrow irrigation, and four vegetable crops in sub plots viz., cluster bean, bhendi, vegetable cowpea and onion.

Treatment Details

Main Plot (Irrigation methods)

I_1 : Drip irrigation

I_2 : Sprinkler irrigation

I_3 : Farmers method (Furrow irrigation)

Sub- plot (Crops)

C_1 : Cluster bean (var: PUSA Naubahar)

C_2 : Bhendi (COBhH-4)

C_3 : Vegetable cowpea (var: PKM 1)

C_4 : Onion (CO-5)

Replication : 3
Design : Split- plot design
Date of sowing: 08.07.2016

The results during 2016-17 showed that drip and sprinkle irrigation were more effective and efficient than furrow irrigation for increasing the yield of vegetable crops cultivated under sodic soil condition. The highest yield of 4120, 5160, 9264 and 4019 kg ha^{-1} was recorded in cluster bean, bhendi, vegetable cowpea and onion, respectively under drip irrigation system (Table 89). The yield increase in vegetables under drip irrigation over furrow irrigation was 43% in cluster bean, 34% in bhendi, 71% in vegetable cowpea and 49% in onion respectively. During 2017-18, The results showed that drip and sprinkle irrigation were more effective and efficient than furrow irrigation for increasing the yield of vegetable crops cultivated under sodic soil condition. The maximum yield of 3895, 4820, 7980 and 3785 kg ha^{-1} was recorded in cluster bean, bhendi, vegetable cowpea and onion, respectively under drip irrigation system. The yield increase in vegetables under drip irrigation over furrow irrigation was 38% in cluster bean, 28% in bhendi, 40% in vegetable cowpea and 28% in onion. Therefore, it is recommended the drip irrigation method for vegetable crops cultivation under sodic soil environment to a sustainable use of water resources with improved efficiency.

Table 89. Effect of irrigation methods on yield of vegetables (kg ha^{-1})

Treatments	Cluster bean	Bhendi	Vegetable cowpea	Onion
Drip irrigation	4120	5160	9264	4019
Sprinkler irrigation	3715	4582	7910	3490
Flood irrigation	2880	3856	5426	2692
Mean	3572	4533	7533	3400
CD (P=0.05)	I	C	I at C	C at I
	120	333	511	580

Plate 6. View of experimental field on pressurized irrigation for vegetables

10.4 Drip Irrigation to Cotton in Alkali Soils using Ameliorated Alkali Water

Field experiment was conducted during 2016-17 at Anbil Dharmalingam Agricultural College and Research Institute, Trichirappalli to study the efficacy of irrigation with ameliorated alkali water using gypsum bed and distillery spentwash through drip system on cotton BG II hybrid RCH – 20 under sodic soil. The experiment consists of drip irrigation of different ameliorated water in main plots *viz.* gypsum bed treated water, spentwash treated water and untreated alkali water, and reclamation of sodic soil in sub plots viz., reclamation through gypsum @ 50% GR, reclamation through one time application of raw distillery spentwash @ 5 lakh liters ha^{-1} and unamended sodic soil.

Treatment details

Main plot : Water treatment (3)

M_1 : Drip irrigation with gypsum bed treated water

M_2 : Drip irrigation with spent wash treated water

M_3 : Drip irrigation with untreated alkali water

Sub-plot : Soil treatment (3)

S_1 : Soil application of gypsum @ 50% GR

S_2 : One time application of DSW @ 5 lakh liters ha^{-1}

S_3 : No amendments

Design : Strip- plot design

Replications : Four

Crop : Cotton

Hybrid : RCH 20

Spacing : 90 x 60 cm

The pH of alkali irrigation water is 8.96, and EC and RSC of alkali irrigation water are 1.62 dS m^{-1} and 7.6 meq L^{-1} Table 103. Amelioration of alkali water through distillery spentwash injection to drip system at 1:250 ratio could reduce the pH of irrigation water from 8.96 to 6.95 with complete neutralization of RSC. Gypsum bed amelioration reduced the irrigation water pH from 8.96 to 8.20 and RSC from 7.6 to 3.4 meq L^{-1}. The results showed that irrigation with gypsum bed treated alkali water with reclamation of soil through one time application of DSW @ 5 lakh liters ha^{-1} recorded the highest seed cotton yield of 3014 kg ha^{-1} and the lowest of 1410 kg ha^{-1} was recorded in the untreated alkali water irrigated through drip system at unamended soil Table 90. Ameliorating alkali water through gypsum bed recorded the highest seed cotton yield of 2581 kg ha^{-1} followed by the treatment of irrigation water with DSW which is 2423 kg ha^{-1}. Drip irrigation with alkali water recorded the lowest seed cotton yield of 1880 kg ha^{-1}. Therefore, it is recommended that the drip irrigation with gypsum bed treated alkali water along with sodic soil reclamation using distillery spentwash @ 5 lakh litres ha^{-1} for enhancing cotton productivity in sodic soil with a sustainable use of alkali water (Table 91 & 92).

Table 90. Changes in quality of ameliorated alkali water

Sl. No.	Treatment	pH	EC (dS/m)	RSC
1	Alkali water (untreated)	8.96	1.62	7.6
2	Gypsum bed treated water	8.20	1.80	3.4
3	Distillery spent wash treated water (1:250)	6.95	1.92	Nil

Table 91. Effect of drip irrigation using ameliorated alkali water on seed cotton yield and yield attributes

Treatments	No. of bolls /plant				Seed cotton yield (kg/ha)			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_1	37.1	42.0	19.2	32.8	2780	3014	1948	2581
M_2	35.7	38.6	18.1	30.8	2608	2882	1780	2423
M_3	19.9	20.6	17.6	19.4	2070	2160	1410	1880
Mean	30.9	33.7	18.3	27.6	2486	2685	1713	2295
CD	M	S	M at S	S at M	M	S	M at S	S at M
(p= 0.05)	2.08	2.51	4.19	4.39	156.0	188.0	313.9	329.6

Table 92. Effect of drip irrigation using ameliorated alkali water on pH, EC and ESP of post-harvest soil

Treatments	pH				EC (dS m^{-1})				ESP			
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean
M_1	7.78	7.50	8.75	8.01	0.60	1.04	0.48	0.71	14.8	12.7	23.2	16.9
M_2	7.65	7.40	8.70	7.92	0.76	1.09	0.54	0.80	14.2	11.8	22.6	16.2
M_3	7.90	7.65	8.84	8.13	0.52	0.96	0.45	0.64	15.5	13.3	23.5	17.4
Mean	7.78	7.52	8.76	8.02	0.63	1.03	0.49	0.72	14.8	12.6	23.1	16.8
CD	M	S	M at S	S at M	M	S	M at S	S at M	M	S	M at S	S at M
(p= 0.05)	0.09	0.11	NS	NS	0.04	0.05	NS	NS	0.32	0.39	0.64	0.68

The analysis of soil sample taken after the harvest of crops indicates that the increase in the EC from 0.44 dSm^{-1} to 0.72 dSm^{-1} but slight decrease in soil pH from 8.9 to 8.02 was recorded Table 105. The increase of soil ESP from 16.2 to upto 17.4 was noticed which is significant indication of buildup of soil ESP, particularly in the plot irrigated with untreated alkali water and unamended sodic soil.

Plates 7. General view of field experiment with cotton with Ameliorated alkali water and amendments

10.5 Effect of Conjunctive Use of Canal and Sodic Water on Rice based Cropping Systems

In new Kattalai canal command area of Cauvery, Tamil Nadu, water is released for irrigation only for one season (September-January) and only when there is 90 feet depth of water in the Stanley Reservoir (Mettur dam). Though underground water is available in this part, it is mostly alkali in nature. Hence to study the effect of utilizing this alkali water in the absence of canal water or when the availability is limited. This project was initiated from 1999 with the following Objectives

1. To find out the effect of conjunctive use of canal and sodic water on crop and soil characteristics.
2. To explore the possibility of raising a crop after rice with sodic water.
3. To find out suitable rice based cropping system for sodic soil in Tiruchirapalli district.

Treatment details

Main plot (Irrigation)

M_1 : Irrigating all the crops with sodic water

M_2 : Irrigating rice with canal water and others with sodic water

M_3 : Irrigation rice with 1:1 canal and sodic water and other crops with sodic water

M_4 : Irrigating rice with 1:2 canal and sodic water and other crops with sodic water

Sub plots – (Cropping systems)

S_1 : Daincha-rice-Fallow

S_2 : Daincha-rice-green gram

S_3 : Daincha-rice-sunflower

S_4 : Daincha-rice-cotton

Design **:** Strip plot design

Replication **:** Three

This experiment was initiated during October 1999 at ADAC&RI farm with pH, EC and ESP of 7.8, 0.13 dSm^{-1} and 15.8 respectively. Experiments are conducted for four year from 1999 to evolve a suitable cropping system for alkali soils using canal water for rice and underground alkali water for followup crops. The details of experiments conducted are as follows.

S.No	Year/season	Test crop	Followup crops
1	*Rabi*1999	Rice (TRY 1)	Greengram, sunflower, mesta
2	*Rabi* 2000	Rice (TRY 1)	Greengram, sunflower, mesta
3	*Rabi* 2001	Rice (TRY 1)	Greengram, sunflower, mesta
4	*Rabi* 2002	Rice (TRY-1)	Greengram, Sunflower, cotton

The yield of main crop (rice) and follow up crop were recorded and rice equivalent yield was computed by using the following formula.

$$\text{Rice equivalent yield} = \frac{\text{Yield of follow up crops x Price of the crop}}{\text{Price of rice}}$$

The irrigation water use and its quality it is given in the Table 93.

Table 93. Quality of canal and well irrigation water

Source	pH	EC (dS/m)	SAR	RSC	Class
Canal	7.5	0.5	1.2	1.2	Good
Well	8.4	1.9	16.5	11.8	Highly alkali

10.5.1 Effect of Conjunctive use of Canal and Sodic Water on Rice Grain Yield

The effect of conjunctive use of canal and sodic water on rice grain yield over four year is given in Table 94. In all the four year, irrigating rice with canal water and follow up crop with alkali water recorded the higher rice grain yield while irrigating both the crops with alkali water recorded the least. But the per cent yield reduction between the above two treatments which was 8.3 per cent during first year increased to 15.8, 24.9 and 21.0 per cent with progress of time. In all the years conjunctive use treatments recorded significantly lower yield than best performing treatments.

Table 94. Effect of Conjunctive use of Canal and Sodic Water on Rice Grain Yield

Irrigation Treatments		Rice grain yield (kg ha)			
Rice	**Follow up crop**	**1999**	**2000**	**2001**	**2002**
AW	AW	5297	4661	3924	4539
CW	AW	5777	5540	5226	5763
1CW:1AW	AW	5569	5384	4243	5355
1CW:2AW	AW	5549	5143	4106	4963
CD (p=0.05)		169.0	40.2	211.0	222.5

Plate 8. Overview of experimental field

10.5.2 Effect of Conjunctive use of Canal and Sodic Water on Seed Yield of Green Gram and Rice Equivalent Yields of Follow Up Crops (kg ha^{-1})

The effect of conjunctive use of canal and sodic water on seed yield of green gram for three years is given in Table 95. In all the years, the highest green gram seed yield was recorded in the conjunctive application of canal water for rice crop and irrigating second crop with alkali water which was followed by irrigating rice crop with canal water and alkali water @ 1:1 ratio and follow crop with alkali water. The lowest green gram seed yield was recorded under irrigating both crops with alkali water.

The yield of follow up crops of (2003) last sequence of this experiment, *viz.,* green gram, sunflower and cotton were computed as rice equivalent yield and given in Table 96. In all the follow-up crops maximum rice equivalent yield (REY) was obtained in conjunctive use of canal water for rice and alkali water for follow up crop treatment and continuous use of alkali water for both the crops recorded the lowest REY. Among the crops, REY was higher in green gram followed by cotton and least for sunflower.

Table 95. Effect of conjunctive use of canal and alkali water on seed yield greengram (kg ha^{-1})

Irrigation Treatments		**Greengram (kg ha^{-1})**		
Rice	Follow up crop	1999	2000	2003
AW	AW	334	398	429
CW	AW	597	757	965
1CW:1AW	AW	443	656	726
1CW:2AW	AW	422	571	657

Table 96. Effect of conjunctive use of canal and alkali water on rice equivalent yields of follow up crops (kg ha^{-1})

Irrigation Treatments		Greengram	Sunflower	Cotton
Rice	Followup crop			
AW	AW	1716 **(429)**	513 **(308)**	1503 **(451)**
CW	AW	3860 **(965)**	711 **(427)**	2793 **(838)**
1CW:1AW	AW	2904 **(726)**	648 **(389)**	1993 **(598)**
1CW:2AW	AW	2628 **(657)**	587 **(352)**	1877 **(563)**

Values in parenthesis indicate the actual yield of follow up crops.

10.5.3 Effect of Conjunctive use of Canal and Alkali Water on Soil pH, EC (dSm^{-1}) and ESP

Effect of conjunctive use of canal and alkali water on pH and EC of post harvest soil sample taken after second season and first year of experimentation is given in Table 110. The irrigation treatments had significant influence on soil pH. Continuous irrigation with sodic water (M1) resulted in significantly increased the soil pH from 7.8 to 9.2 in four years period. Irrigating rice with canal water alone or in conjunction with alkali water at 1:1 or 2:1 ratio and subsequent follow up crop with alkali water recorded soil pH of 8.4, 8.7 and 9.1 respectively. Irrigation with sodic water did not have much effect on soil EC as the soils of experimental site are non-saline and the water used in the experiment was highly alkali in nature.

Among the irrigation treatments, irrigating both rice and follow up crop with alkali water recorded the highest sodicity buildup of 34.1 and 39.3 after second and fourth year of experimentation. But irrigating rice with canal water and follow up crops with alkali water recorded marginal increase in soil ESP of 14.7 and 17.6 after second and fourth year of experimentation. The conjunctive use of 1:1 and 1:2 canal: well water for rice and alkali water for followup crops recorded sodicity buildup of in between range (Table 97).

Table 97. Effect of conjunctive use of canal and alkali water on pH, EC and ESP of post-harvest soil sample

Treatment		pH		EC dSm^{-1}		ESP	
Rice	Follow up crop	2002	2004	2002	2004	2002	2004
AW	AW	9.2	9.2	0.69	0.51	34.1	39.3
CW	AW	8.2	8.4	0.58	0.14	14.7	17.6
1CW:1AW	AW	8.7	8.7	0.60	0.19	22.0	25.6
1CW:2AW	AW	9.1	9.1	0.64	0.27	28.3	33.8
CD (p=0.05)		0.05	0.08	0.03	0.07	0.39	0.95

Conjunctive use of Canal and Amended Alkali Water in Rice-Greengram Cropping Systems

Field experiment was conducted from 2006 to 2008 to minimize sodicity buildup by finding a suitable amending technique for sustained use of alkali water irrigated alone or in conjunctive mode in rice- green gram cropping system. With the following objectives.

(i) To find out the effect of conjunctive use of canal and alkali water on crop and soil characteristics.
(ii) To find out a suitable amending technique for sustained use of alkali water in rice-green gram cropping system.

Treatment Details

Main plot : Irrigation methods

M_1 : Irrigating both the crops (Rice – Green gram) with alkali water
M_2 : Irrigating rice with canal water and green gram with alkali water
M_3 : Irrigating rice with canal water and alkali water in 1:1 ratio (cyclic mode) and green gram with alkali water

Subplot : Amendments

S_1 : No amendment
S_2 : Soil application of Distillery spent wash (DSW)
S_3 : Soil application of Gypsum @ 50%GR
S_4 : Amending alkali water with Distillery spent wash (DSW)
S_5 : Amending the alkali water with Gypsum

Design : Strip plot
Replications : Three

Field experiments were conducted during 2006-2008 at ADAC&RI, farm with alkali soil of pH 9.0 and ESP 16.0. Paddy variety TRY 1 was grown during rabi season and greengram variety VBN (GG) 2 during summer season. The quality of irrigation water used in the experiment and soil properties of the main treatment plots are given below. (Table 98 & 99)

Table 98. Quality of Irrigation Water used in the Experiment

Source	EC dS/m)	SAR	RSC
Canal	0.5	1.2	1.2
Alkali	1.6	7.2	6.7
Alkali water treated with distillery spent wash (DSW)	1.9	7.6	7.6
Alkali water treated with gypsum bed technique	1.5	6.5	2.2

Table 99. Soil properties of main treatment plots

Main treatment plots	pH	ESP
Canal	8.4	17.6
Alkali	9.2	39.3
Canal:Alkali in 1:1 ratio	8.7	25.6

The gypsum bed was designed using RCC rings of 3 feet diameter and one feet height. Totally four RCC rings were used to achieve the structural dimension of 4 feet height and 3 feet diameter. The structure is closed in the bottom having inlet (2 inch size) in the bottom ring and outlet in the upper most ring, so as to enable the water coming from the PVC conveyance pipes in the farmers' holdings to pass through the gypsum beds. Powdered gypsum was placed in cloth bags over the iron mesh provided in between the third and fourth ring. Soil application of distillery spent wash @ 5 lakhs litres per ha was carried out one month before start of the experiment and gypsum application was made before last puddling. 1:500 dilution of DSW with alkali water was found to be sufficient to neutralize the RSC value.

10.5.4 Effect of Conjunctive Mode and Amending Techniques on Rice Grain Yield

The rice grain yield influenced by the treatment studied was given in Table 100. Irrigation with canal water recorded rice grain yield of 5.80 t/ha during the fourth year of experiment (2006-07) which was significantly higher than conjunctive use of alkali water in 1:1 ratio. Use of alkali water recorded the lowest grain yield of 4.36 t/ha, which was 24.8 per cent lower than irrigation with canal water. Among the different amendments amending alkali water with gypsum bed recorded significantly higher rice grain yield of 5.72 t/ha which was on par with soil application of gypsum @ 50% GR (5.54 t/ha). No amendment resulted in lowest grain yield of 4.28 t/ha. During the fifth year of the experiment (2007-08) also, canal water irrigation for rice recorded the highest grain yield of 5.93 t/ha followed by CW:AW in 1:1 ratio (5.54t/ha). Among the water treatment methods amending alkali water with gypsum bed recorded the highest grain yield of 5.86 t/ha which was on par with soil application of gypsum @ 50% GR (5.67 t/ha).

10.5.5 Effect of Conjunctive Mode and Amending Techniques on Greengram Yield

The greengram yield influenced by the treatment studied was given in Table 100. Conjunctive use of canal water for rice and alkali water for green gram recorded the highest green gram yield of 0.62 t/ha and 0.69 t/ha during the fourth and fifth year of the experiment respectively (Table 3.1). Among the amendment, amending alkali water with gypsum recorded the maximum green gram yield of 0.64 t/ha and 0.71 t/ha during 2006-07 and 2007-08 which was comparable with soil application of gypsum @ 50% GR.

10.5.6 Effect of Conjunctive mode and Amending Techniques on Post-harvest Soil pH and ESP

The effect of conjunctive use of water and amending techniques on post-harvest soil pH and ESP are given in Table 101. Post-harvest analysis of soil samples revealed that the highest soil pH of 8.98 and 8.64 and soil ESP built up of 29.0 and 25.8 were in continuous use of alkali water for both rice and green gram during the year 2006-07 and 2007-08, respectively. Among the different amending methods, soil application of DSW recorded the lowest pH of 8.48 and 8.36 during the year 2006-07 and 2007-08 respectively. In respect of ESP values soil application of gypsum @ 50% GR recorded the lower soil ESP 18.0 and 17.1 in the year2006-07 and 2007-08, respectively.

Table 100. Grain yield of rice and green gram influenced by conjunctive mode and amending techniques (t/ha)

Irrigation treatment	2006-07 (Rice)						2007-08 (Rice)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1	3.56	4.45	4.62	4.38	4.80	4.36	3.68	4.58	4.75	4.51	4.93	4.49
M_2	4.70	5.59	6.20	5.78	6.35	5.80	4.83	6.12	6.34	5.89	6.49	5.93
M_3	4.58	5.40	5.79	5.28	6.02	5.42	4.71	5.53	5.91	5.41	6.16	5.54
Mean	4.28	5.28	5.54	5.15	5.72		4.41	5.41	5.67	5.27	5.86	
	M	S	MxS	SxM			M	S	MxS	SxM		
CD 5%	0.20	0.24	0.40	0.42			0.20	0.25	0.40	0.48		

Irrigation treatment	2006-07 (Green gram)						2007-08 (Green gram)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1	0.19	0.43	0.49	0.38	0.46	0.39	0.24	0.48	0.54	0.43	0.51	0.44
M_2	0.32	0.67	0.69	0.64	0.77	0.62	0.37	0.74	0.78	0.70	0.86	0.69
M_3	0.24	0.60	0.63	0.59	0.69	0.55	0.29	0.66	0.69	0.64	0.75	0.61
Mean	0.25	0.57	0.60	0.53	0.64		0.30	0.63	0.67	0.59	0.71	
	M	S	MxS	SxM			M	S	MxS	SxM		
CD 5%	0.02	0.05	0.04	0.09			0.03	0.05	0.06	0.10		

M_1 : Irrigating both the crops (Rice-Green gram) with alkali water, M_2 : Irrigating rice with canal water and green gram with alkali water, M_3 : Irrigating rice with canal and alkali water in 1:1 ratio (Cyclic mode) and green gram with alkali water.

S_1 : No amendment, S_2 : Soil application of DSW, S_3 : Soil application of Gypsum @ 50% GR, S_4 : Treating the alkali water with DSW, S_5 : Treating the alkali water with Gypsum.

Table 101. Effect of conjunctive mode and amending techniques on soil pH and ESP

Irrigation treatment	2006-07 (Soil pH)						2007-08 (Soil pH)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1	9.06	8.98	8.63	9.22	9.01	8.98	8.86	8.52	8.27	8.98	8.59	8.64
M_2	8.61	7.82	8.75	8.50	8.66	8.47	8.25	8.21	8.48	8.25	8.43	8.32
M_3	8.67	8.65	8.86	8.73	8.74	8.73	8.42	8.36	8.48	8.47	8.47	8.44
Mean	8.80	8.48	8.75	8.82	8.78		8.51	8.36	8.41	8.57	8.50	
	M	S	MxS	SxM			M	S	MxS	SxM		
CD 5%	0.05	0.11	0.18	0.20			0.12	0.20	0.30	0.38		

Irrigation treatment	2006-07 (Soil ESP)						2007-08 (Soil ESP)					
	S_1	S_2	S_3	S_4	S_5	Mean	S_1	S_2	S_3	S_4	S_5	Mean
M_1	36.2	21.9	20.7	35.4	30.8	29.0	32.9	20.6	18.5	30.0	26.9	25.8
M_2	18.5	15.7	16.2	14.6	22.2	17.4	18.5	16.3	16.0	15.5	15.8	16.4
M_3	20.8	20.8	17.2	18.9	24.0	20.4	20.6	19.4	16.8	16.1	16.0	17.8
Mean	25.7	19.5	18.0	23.0	25.19		24.0	18.8	17.1	20.5	19.6	
	M	S	MxS	SxM			M	S	MxS	SxM		
CD 5%	1.77	2.81	4.68	4.87			4.23	2.31	3.89	4.12		

M_1 : Irrigating both the crops (Rice-Green gram) with alkali water, M_2 : Irrigating rice with canal water and green gram with alkali water, M_3 : Irrigating rice with canal and alkali water in 1:1 ratio (Cyclic mode) and green gram with alkali water.

S_1 : No amendment, S_2 : Soil application of DSW, S_3 : Soil application of Gypsum @ 50% GR, S_4 : Treating the alkali water with DSW, S_5 : Treating the alkali water with Gypsum.

10.5.7 Conjunctive Use of Canal and Alkali Water in Rice-Vegetable Cropping Systems

Field experiment was initiated in 2008 and continued up to 2013 to study the conjunctive use of canal and alkali water with different rice planting methods and to find out a profitable vegetable crop grown after rice in alkali soil.

Treatment details

Main plot : Irrigation mode (3)

M_1 : Irrigating both rice and vegetables with alkali water

M_2 : Irrigating rice with canal water and vegetables with alkali water

M_3 : Irrigating rice with canal water and alkali water in 1:1 ratio (cyclic) and Vegetables with alkali water.

Sub plot : Planting method (4)

S_1 : Conventional planting (Random)

S_2 : Line planting

S_3 : Square planting (SRI)

S_4 : Machine planting

The main plots after rice harvest was divided into 7 subplots and the treatments were imposed as under.

Sub plot : Vegetable crops (7)

S_1 : Bhendi
S_2 : Cluster bean
S_3 : Baby corn*
S_4 : Cucumber*
S_5 : Brinjal
S_6 : Tomato*
S_7 : Amaranthus*

*crops were eliminated due to the poor performance and Vegetable cow pea was included during subsequent years

Sub plot : Vegetable crops (4)

S_1 : Okra or Bhendi
S_2 : Brinjal
S_3 : Clusterbeans
S_4 : Vegetable cowpea
Design : Strip plot
Replications: Three

Field experiments were conducted during 2008-2013(five year) at ADAC&RI farm with alkali soil (pH – 8.7, EC – 0.21 dS/m, ESP – 25.0). Rice was grown during rabi (October – January) and vegetables during summer period (March – June). The quality of the irrigation water used in the study is given below. **(**Table 102)

Table 102. Quality of Irrigation Water Used in the Experiment

Source	EC (dS/m)	SAR	RSC	Class
Canal	0.6	1.3	1.4	Good
Alkali	1.8	8.2	6.9	Alkali

Effect of Conjunctive Mode and Planting Methods on Rice Grain Yield

The rice grain yield influenced by the treatment studied was given in Fig. 31 and Fig. 32. Significant differences were observed for irrigation treatments and method of planting. Regarding the irrigation treatments, canal water irrigation for rice recorded the maximum yield of 5.77, 6.21, 6.5, 5.9 and 6.3 t/ha during 2008-2009, 2009-2010 2010-2011, 2011-2012 and 2012-2013 respectively, followed by cyclic irrigation of canal water and alkali water in 1:1 ratio. Lowest yield was recorded in alkali water irrigation. In respect of method of planting, adopting square planting registered the maximum rice grain yield of 5.82, 6.03, 6.15, 5.48 and 5.85 t/ha, during 2008-2009 2009-2010, 2010-2011,2011-2012 and 2012-2013 respectively, followed by line planting. In both years highest yield of 6.41 t/ha and 6.76 t/ha was recorded with canal water irrigation adopted with square planting followed by canal water irrigation with line planting. Mixing mode of canal water and alkali water (1:1) with square planting recorded 23.0% and 34.9 % more yield than the alkali water irrigation with conventional planting.

Effect of Conjunctive Mode on Vegetable Yield

Among the different vegetable crops grown during summer after the harvest of rice crop, brinjal registered the highest yield of 25.3, 22.8 23.6, 20.2 and 16.8 t/ha with the use of canal water irrigation to rice and alkali water to vegetables during 2008-2009, 2009-2010, 2010-2011, 2011-2012 and 2012-2013, respectively. (Table 103)

Effect of Conjunctive Mode on Post-harvest Soil pH, EC and ESP

The effect of conjunctive use of water and amending techniques on post-harvest soil pH, EC and ESP are given in Table 104. Post-harvest analysis of soil samples revealed that the highest mean soil pH of 9.0 and EC of 0.25 and soil ESP built up of 33.6 % were in continuous use of alkali water for both rice and vegetables at end of fifth years (2012-2013). Different method of planting and cultivation of different vegetables as follow up crop had no significant effect on soil properties at harvest stage.

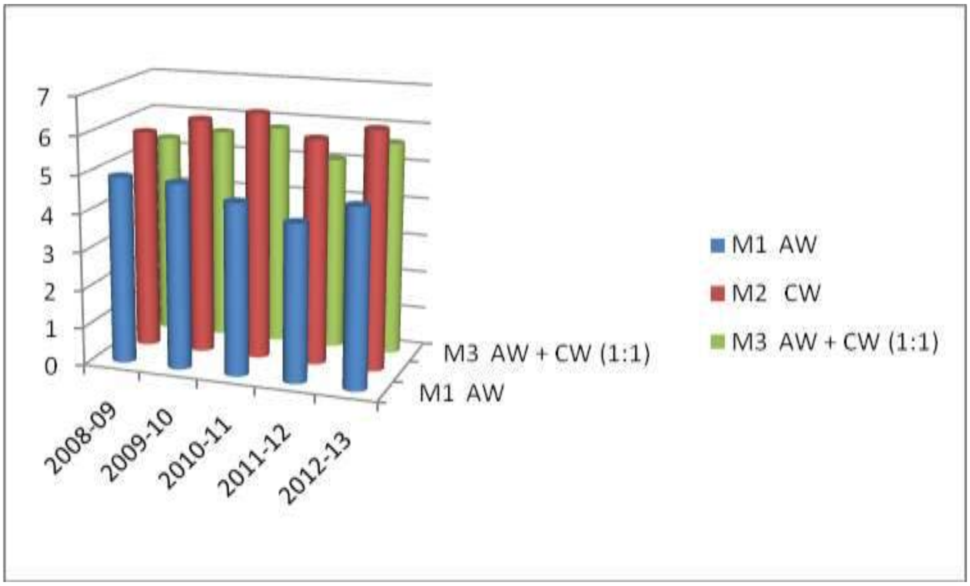


Fig 31 Grain yield of rice with methods of Irrigation

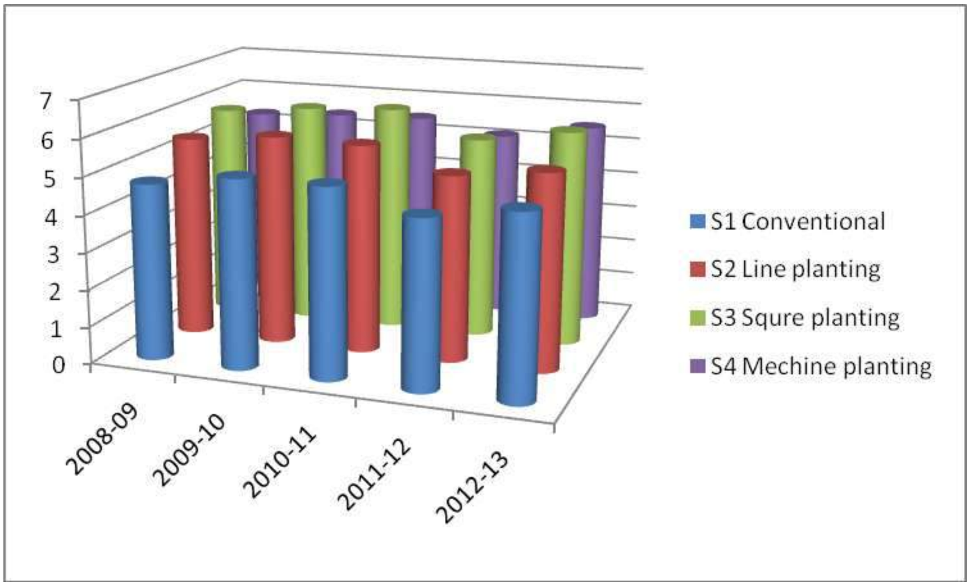


Fig 32. Grain yield of rice with methods of planting

Table 103: Effect of irrigation treatment and method of planting on yield of Vegetables during 2008-13

Treatment	Crop	Yield t/ha				
		2008-09	2009-10	2010-11	2011-12	2012-13
M_1S_1	AW + Okra	6.591	6.12	5.65	5.16	4.21
M_1S_2	CW + Okra	8.246	8.65	9.25	8.65	7.26
M_1S_3	CW & AW + Okra	7.013	7.8	7.01	6.81	5.86
M_1S_4	AW + Brinjal	20.419	18.1	16.18	12.8	10.6
M_1S_5	CW + Brinjal	25.316	22.8	23.6	20.2	16.8
M_1S_6	CW & AW + Brinjal	23.984	20.3	21.6	15.6	14.4
M_1S_7	AW + Cluster bean	4.537	4.16	4.02	4.26	3.85
$M_2 S_1$	CW + Cluster bean	6.124	6.56	7.14	7.94	6.61
$M_2 S_2$	CW & AW + Cluster bean	5.206	5.72	6.15	6.46	5.18
$M^2 S_3$	AW + Vegetable cowpea	-	3.36	3.30	3.12	3.01
$M_2 S_4$	CW + Vegetable cowpea	-	4.64	4.75	4.21	3.86
$M_2 S_5$	CW &AW + Vegetable cowpea	-	4.15	4.36	3.89	3.52
CD	Okra		0.52	0.41	0.32	0.26
(p=0.05)	Brinjal		1.2	1.6	1.24	1.36
	Cluster bean		0.21	0.26	0.21	0.18
	Vegetable cowpea		0.16	0.12	0.15	0.13

AW= Alkali Water, CW= Canal Water, CW&AW=Canal Water & Alkali Water (Cyclic mode)

Salient Findings

- During shortage or limited supply of canal water, conjunctive use of canal and alkali water in 1:1 cyclic mode for rice and alkali water alone for greengram or vegetables can be recommended for alkaline environment of Cauvery irrigation command area.
- For amending alkali water gypsum bed method proved to be superior.
- Continuous use of alkali water for rice and greengram or vegetables resulted in yield decline of 25% in rice and 37% in greengram and 20% in brinjal with increased ESP of 25-34.
- Greengram (Pusa bold or VBN(GG) 2) or brinjal (Co2) can be recommended as follow-up after rice with alkali water irrigation for higher profitability.
- The change in chemical properties of soil viz., pH and ESP due to use of canal + alkali water was observed to be better than use of alkali water alone for both crops.

Table 104: Effect of conjunctive mode and method of planting on post-harvest soil properties at the end of fifth year (2012-13)

Irrigation Treatment	Method of planting														
	Soil pH					Soil EC (dSm^{-1})					Soil ESP				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	9.0	9.16	9.15	9.06	9.09	0.25	0.23	0.26	0.26	0.25	33.6	33.8	32.8	34.0	33.6
M_2	8.51	8.52	8.50	8.49	8.51	0.16	0.18	0.16	0.17	0.17	19.5	18.8	19.9	20.2	19.6
M_3	8.71	8.65	8.72	8.70	8.70	0.20	0.21	0.20	0.21	0.21	26.2	25.8	27.6	26.7	26.6
Mean	8.74	8.78	8.79	8.75		0.20	0.21	0.21	0.21		26.4	26.1	26.8	27.0	
CD (P=0.05)	M	S	M at S	S at M		M	S	M at S	S at M		M	S	M at S	S at M	
	0.28	NS	NS	NS		0.01	NS	NS	NS		1.2	NS	NS	NS	

10.5.8 Management of Sodic Soil under Different Irrigation Scenarios in Rice Based Cropping System in the Cauvery Delta Zone of Tamil Nadu

The experiment was initiated on 18.08.2015 at F.No. A4b. ADAC&RI, Trichy. The treatments viz., Factor A ,: Irrigation scenarios (4) I_1: Canal water alone, I_2: Canal water: Alkali water (1:1 cyclic mode), I_3: Canal + Alkali water combined (50+50 %) per irrigation, I_4: Alkali water alone and Factor B: Soil amendments (4) S_1: Control, S_2: Green / green leaf manuring @ 6.25 t/ha, S_3: Distillery spent wash @ 5 lakh litres / ha, S_4: Gypsum 50 % GR + Green manuring with Daincha @ 6.25 t/ha were imposed as per the treatment schedule. The results reveals that, among the irrigation management practices, application of alkali water alone (I_4) recorded a grain yield of 5049 kg ha^{-1} (Table 105). The other treatments *viz.,* I_3: Application of canal water + Alkali water (50+50), I_2: application of canal and alkali water as 1:1 cyclic mode and I_1: application of Canal water alone recorded with a grain yield of 5622, 5496 and 5905 kg ha^{-1}, respectively. Among the soil amendments, the treatment S_3, application of distillery spent wash @ 5 lakh litres ha^{-1} recorded a highest yield of 5940 kg ha^{-1} followed by S_4; application of gypsum 50% GR + green manuring @ 6.25 kg ha^{-1}, S_2: green manuring @ 6.25 t ha^{-1} and S_1: control with a respective grain yield of 5731, 5432 and 4968 kg ha^{-1} (Table 106). With respect to the interaction effect between irrigation water and soil amendments, the treatment combination I_1S_3: application of canal water irrigation combined with application of distillery spent wash @ 5 lakh litres ha^{-1} resulted significantly higher grain yield of 6460 kg ha^{-1}. (Table 107 & 108)

Table 105. Effect of irrigation scenario and soil amendments on grain yield of Rice (kg ha^{-1})

Treatment (**I:** Irrigation / **S:** Soil amendment	**S_1**: (Farmers practice)	**S_2**: Green manuring @6.25 t ha^{-1}	**S_3**: Distillery spent wash @ 5 lakh lit ha^{-1}	**S_4**: Gypsum 50%GR+ Green manuring	**Mean**
I_1: Canal water (CW)	5292	5684	6460	6183	**5905**
I_2: 1CW:1AW(Cyclic)	5078	5362	5824	5718	**5496**
I_3: CW+AW(50+50)	5237	5512	6005	5733	**5622**
I_4: Alkali water (AW)	4267	5172	5470	5288	**5049**
Mean	**4968**	**5432**	**5940**	**5731**	
		SED	**CD(0.05)**		
	I	63	128		
	S	63	128		
	IxS	125	256		

Table 106. Effect of irrigation scenario and soil amendments on straw yield of rice (kg ha^{-1})

Treatment (**I:** Irrigation / **S:** Soil amendment	**S$_1$**: (Farmers practice)	**S$_2$**: Green manuring @6.25 t ha^{-1}	**S$_3$**: Distillery spent wash @ 5 lakh lit ha^{-1}	**S$_4$**: Gypsum 50%GR+ Green manuring	**Mean**
I$_1$: Canal water (CW)	6734	7234	9296	8102	**7842**
I$_2$: 1CW:1AW(Cyclic)	6463	6890	8381	7278	**7253**
I$_3$: CW+AW(50+50)	6631	6948	8563	7339	**7370**
I$_4$: Alkali water (AW)	5430	6582	7871	6730	**6653**
Mean	**6315**	**6914**	**8528**	**7362**	

	SED	**CD(0.05)**
I	88	180
S	88	180
IxS	176	360

Table 107. Effect of irrigation water and soil amendments on % yield increase over control

Treatment (**I:** Irrigation / **S:** Soil amendment	**S$_1$**: (Farmers practice)	**S$_2$**: Green manuring @6.25 t ha^{-1}	**S$_3$**: Distillery spent wash @ 5 lakh lit ha^{-1}	**S$_4$**: Gypsum 50%GR+ Green manuring	**Mean**
I$_1$: Canal water (CW)	24.0	33.2	51.4	44.9	38.4
I$_2$: 1CW:1AW(Cyclic)	19.0	25.7	36.5	34.0	28.8
I$_3$: CW+AW(50+50)	22.7	29.2	40.7	34.4	31.75
I$_4$: Alkali water (AW)	-	21.2	28.2	23.9	24.4
Mean	21.9	27.3	39.2	34.3	

Table 108. Effect of irrigation scenario and soil amendments on BC ratio

Treatment (**I:** Irrigation / **S:** Soil amendment)	**S$_1$**: (Farmers practice)	**S$_2$**: Green manuring @6.25 t ha^{-1}	**S$_3$**: Distillery spent wash @ 5 lakh lit ha^{-1}	**S$_4$**: Gypsum 50%GR+ Green manuring	**Mean**
I$_1$: Canal water (CW)	2.32	2.24	2.57	2.44	2.39
I$_2$: 1CW:1AW(Cyclic)	2.22	2.12	2.32	2.25	2.23
I$_3$: CW+AW(50+50)	2.29	2.17	2.39	2.26	2.28
I$_4$: Alkali water (AW)	1.87	2.04	2.18	2.09	2.05
Mean	2.18	2.14	2.37	2.26	

The post-harvest soil analysis revealed that pH declined from 9.16 in control to 8.95, 8.37 and 8.45 due to GM (M_2), DSW (S_3) and GYP+GM (S_4) application, respectively. Maximum reduction in soil pH was recorded in DSW applied plots. Significant reductions in the soil exchangeable sodium percentage are noted due to application of amendments. Lowest ESP (13.3) was recorded in the DSW applied treatments and highest (26.3) was recorded in the control. Decrease in the ESP of 4.6, 13.0 and 10.3 was observed on account of application of GM, DSW and Gypsum + GM over the control, respectively (Table 109 & 110).

Table 109. Effect of irrigation water and soil amendments on post-harvest soil pH

Treatment (I: Irrigation / S: Soil amendment)	S_1: (Farmers practice)	S_2: Green manuring @6.25 t ha^{-1}	S_3: Distillery spent wash @ 5 lakh lit ha^{-1}	S_4: Gypsum 50%GR+ Green manuring	Mean
I_1: Canal water (CW)	9.12	8.90	8.32	8.43	8.69
I_2: 1CW:1AW(Cyclic)	9.18	8.96	8.38	8.46	8.75
I_3: CW+AW(50+50)	9.17	8.95	8.39	8.45	8.74
I_4: Alkali water (AW)	9.20	8.98	8.41	8.48	8.77
Mean	9.16	8.95	8.37	8.45	

	SED	CD (0.05)
I	0.09	NS
S	0.09	0.18
IxS	0.18	NS

Table 110. Effect of irrigation water and soil amendments on ESP of post-harvest soil

Treatment (I: Irrigation / S: Soil amendment	S_1: (Farmers practice)	S_2: Green manuring @6.25 t ha^{-1}	S_3: Distillery spent wash @ 5 lakh lit ha^{-1}	S_4: Gypsum 50%GR+ Green manuring	Mean
I_1: Canal water (CW)	25.7	21.2	12.7	15.2	18.7
I_2: 1CW:1AW(Cyclic)	26.3	21.9	13.3	15.8	19.3
I_3: CW+AW(50+50)	26.3	21.2	14.0	15.9	19.7
I_4: Alkali water (AW)	26.9	22.4	14.1	16.9	20.1
Mean	26.3	21.7	13.8	16.0	
	I	S	I x S		
SED	0.75	0.75	1.49		
CD (0.05)	NS	1.4	NS		

10.6 Long Term Effects of Distillery Effluent on Soil Properties and Yield of Sugarcane

Long term field experiment initiated during 2002 at EID Parry (I) Ltd., cane farm, Edayanvelli was continued for 10th crop with the same layout to evaluate the long term effect of different rates of pre-plant application of PME along with different combinations of N, P and K on the changes in soil physico-chemical properties, fertility status, exchangeable cations, and cane yield. The TDE was applied at graded doses (main plot treatments viz., TDE @1.25, 2.5, 3.75 and 5 lakhs litres ha^{-1}) thoroughly mixed and allowed for natural oxidation. Different combinations of NPK fertilizers *viz.,* N alone, NP, NK, PK, NPK and control (without NPK) were imposed as subplot treatments. The results revealed that the application of graded doses of TDE significantly increased the yield of sugarcane (Table 93). An increased cane yield of 23.4, 35.7, 46.8 and 58.0 per cent were recorded due to the application of TDE @ 1.25, 2.5, 3.75 and 5.0 lakh litres ha^{-1} respectively over control. The cane yield differences among applications of N and NK, NP and NPK were not significant indicating that the supply of K through TDE is sufficient. The interaction effect revealed that TDE application @ 1.25 lakh litres ha^{-1} together with NP fertilizer is the most suitable combination of nutrient management for good sugarcane harvest. It is noteworthy that the application of inorganic fertilizers omitting K and 25 per cent N and P, in combination with 1.25 lakh litres ha^{-1} of TDE gave high yield as that of NPK combination leading to a saving of K. The graded doses of TDE along with NP significantly increased the soil available nutrients, organic carbon content besides improving soil physico-chemical properties. (Tables 111, 112 & 113)

Table 111. Effect of TDE and fertilizers on sugarcane yield (t ha^{-1})

TDE (lakh lit ha^{-1}`)	C	N	NP	NK	PK	NPK	Mean
C	46.0	57.9	72.2	69.6	54.5	79.6	**63.3**
1.25	54.9	76.3	93.1	73.6	75.9	95.1	**78.1**
2.5	61.3	86.1	96.9	87.2	86.0	97.9	**85.9**
3.75	72.7	93.5	101.1	93.7	91.9	104.2	**92.9**
5	86.4	103.5	106.3	95.9	100.0	107.8	**100.0**
Mean	**64.3**	**83.5**	**93.9**	**84.0**	**81.6**	**96.9**	
	M	S	M x S	S x M			
CD (0.05)	3.7	3.6	8.1	7.9			

Plate 9. Application of TDE as pre-plant in the experimental field

Table 112: Effect of TDE on Physic-Chemical Properties of Soil

TDE	pH	EC	Ex. Ca	Ex. Mg	Ex. Na	Ex. K	ESP
(lakh lit /ha)		(dS m^{-1})	(cmol (p+) kg^{-1})				(%)
C	8.32	0.11	7.37	3.29	1.39	0.24	11.41
1.25	8.10	0.12	8.16	4.16	1.39	0.32	9.91
2.5	7.88	0.13	8.23	4.22	1.39	0.38	9.78
3.75	7.74	0.14	8.35	4.43	1.40	0.46	9.56
5	7.38	0.15	8.54	4.84	1.43	0.52	9.28
CD (0.05 %)	0.15	0.005	0.52	0.20	NS	0.013	

Table 113 Effect of TDE on organic carbon and available nutrient status of post harvest soil

TDE	OC	Avail. N	Avail. P	Avail. K	Avail Zn	Avail Fe	Avail Cu	Avail Mn
(lakh lit / ha)	(%)	(kg ha^{-1})			(mg kg^{-1})			
C	0.39	134	16.94	216	2.01	9.06	1.73	13.27
1.25	0.77	179	17.73	322	2.32	11.49	2.23	16.02
2.5	0.82	191	18.49	364	2.43	12.39	2.38	16.81
3.75	0.89	200	19.32	390	2.63	13.18	2.69	17.80
5	0.92	206	20.05	403	2.80	14.36	2.89	17.98
CD (0.05 %)		7.7	0.67	11.60	0.12	0.32	0.17	0.15

Experiment II (TDE -along with Irrigation Water)

To study the long term effect of application of TDE through irrigation water, the experiment – II was conducted with the same layout as 10th crop of long term experiment which is in progress since 2002 in a randomized block design with six treatments and replicated four times. The TDE was discharged @ 1.00, 0.50, 0.33, 0.25 and 0.20 lakh liters ha^{-1} to get the dilutions of 1: 10, 1:20, 1:30, 1:40 and 1:50 dilutions, respectively. It was applied four times at 40 days interval starting from 45th day after planting. The results revealed that irrigation with TDE at 1:10 dilution resulted in higher yield of sugarcane. The cane yield was increased to the tune of 47 per cent in 1:10 and 41 per cent in 1:20 over control. The TDE application favourably influenced the organic carbon, available nutrients and exchangeable cations in the soil. (Table 114, 115 & 116)

Table 114. Effect of TDE at different dilutions on sugarcane yield (t/ha)

Treatments	Yield
C	78.00
1 : 10	115.0
1 : 20	110.0
1 : 30	102.0
1 : 40	96.0
1 : 50	90.0
SE d	2.8
CD (0.05 %)	6.1

Table 115. Effect of TDE at different dilutions on physic-chemical properties of soil

Treatments	pH	EC	Ex. Ca	Ex. Mg	Ex. Na	Ex. K	ESP
		(dS m^{-1})	(cmol (p+) kg^{-1})				(%)
C	8.38	0.09	7.56	3.95	1.63	0.39	11.80
1 : 10	7.85	0.37	12.3	6.17	1.65	0.89	7.91
1 : 20	7.88	0.32	11.7	5.99	1.60	0.88	8.17
1 : 30	7.98	0.25	10.9	5.73	1.55	0.82	8.35
1 : 40	8.10	0.27	10.7	5.60	1.58	0.78	8.83
1 : 50	8.19	0.22	10.1	5.35	1.57	0.71	8.97
SE d	0.23	0.01	0.30	0.26	0.07	0.03	0.37
CD (0.05 %)	NS	NS	0.70	0.56	NS	0.07	0.80

Table 116. Effect of TDE at different dilutions on organic carbon and available nutrient status of post-harvest soil

Treatments	OC	Avail. N	Avail. P	Avail. K	Avail Zn	Avail Fe	Avail Cu	Avail Mn
	(%)	(kg ha^{-1})			(mg kg^{-1})			
C	0.49	234	17.7	272	4.89	13.40	2.07	9.97
1 : 10	0.89	281	27.9	499	6.39	17.40	4.63	13.9
1 : 20	0.81	270	25.0	470	6.27	16.22	3.99	13.1
1 : 30	0.76	261	24.1	449	5.82	16.70	3.91	12.5
1 : 40	0.74	257	23.7	437	5.80	16.30	3.57	12.1
1 : 50	0.73	250	23.2	425	5.72	15.40	3.51	10.7
SE d	0.04	13	1.1	12	0.17	0.47	0.18	0.4
CD (0.05 %)	0.08	29	2.4	25	0.35	1.00	0.38	0.9

11. ALTERNATE LAND USES

This experiment was started in December 1998 at Anbil Dharmalingam Agricultural College and Research Institute farm to assess the performance of different tree species in alkali soils under rainfed conditions. This experiment was started during the year 2000 in Split plot design with three replications. In this experiment the Main plots consists of two different methods of planting viz., pit method (2'x 2'x2') and auger hole method (30 cm dia.with 90 cm depth). In the subplot treatments different tree species were included viz., Tamarind, Bamboo, Teak, *Casurina, Acacia nilotica, Leuceana leucocephala, Prosopis, Neem, Subabul, Eucalyptus and Dalbergia sisoo* (Table 117). The initial soil pH was 9.2, EC was 0.24 dS/m and ESP of 26.0. The observations were made on survival, diameter, height and girth from fifth year onwards.

11.1 Evaluation of Tree Species Suitable for Salt Affected Soils under Rainfed Condition

Seedlings of 10 tree species were planted in pits filled with mixture of red earth, sand and farmyard manure with recommended spacing to find out the survival of tree species in salt affected soils under rainfed condition. Four months after planting survival percentage was found to be highest with. 92.6 % for tamarind and bamboo followed by Acacia, Prosopis, Neem and Subabul (survival percentage is above 85 %) while Casuarina, Eucalyptus and Teak recorded the lowest survival percentage. The Survival percentage of different tree species is given in Table 118.

At 5th year of planting the results of the experiment revealed that, the survival percent was highest for T*amarindus indica, Bambusa bamboo* followed by *Lueceana leucocephala, Acacia leaucophloea, Azardiracta indica*. The plant height was highest in *Lueceana leucocephala* followed by *Prosopis juliflora*, *Dalbergia sisso* and *Acacia leucophloea*. In case of girth at stump height (GSH) and girth at breast height (GBH), higher values were recorded in *Prosopis juliflora*, *Lueceana leucocephala* and *Azadirachta indica* trees followed by *Acacia leucophloea* and *Dalbergia sisoo*.

Table 117. Survival percentage of different tree species four months after planting

Sl.No	Name of tree species	Spacing	No of seedlings planted	No of Seedlings survived	Survival %
1.	Tamarind(*Tamarindus indica)*	5x5	27	25	92.6
2.	Bamboo *(Bambusa bamboo)*	5x5	27	25	92.6
3.	Teak (*Tectona grandis)*	2x2	27	10	37.0
4.	Casurina	1x1	27	15	55.6
5.	Velvel *(Acacia leucophloea)*	4x4	27	24	88.9
6.	Prosopis *(Prosopis juliflora)*	4x4	27	23	85.2
7.	Neem *(Azadirachta indica)*	5x5	27	23	85.2
8.	Subabul *(Lueceana luecocephala)*	1x1	27	24	88.9

9.	Eucalyptus	1x1	27	14	51.9
10.	Shisam *(Dalbergia sisoo)*	4x4	27	20	74.1

Table 118. Biometric observation on tree species at 5th year of planting

Tree species*	Survival percent	Height (cm)	GSH (cm)	GBH (cm)
1. *Tamarindus indica*	92.6	387.5	21.3	15.8
2. *Bambusa bamboo*	92.6	541.3	13.2	12.5
3. *Azadirachta indica*	85.2	487.0	31.2	22.8
4. *Prosopis juliflora*	85.2	642.6	39.3	27.2
5.*Lueceana luecocephala*	88.9	712.1	32.9	25.7
6.*Acacia leucophloea*	88.9	603.6	27.3	24.2
7. *Dalbergia sisso*	74.1	632.7	27.5	20.1
SEd	3.20	28.52	1.95	1.44
CD (P=0.05)	7.83	69.8	4.76	3.52

* Three species could not survive under alkali soil environment (Teak, Casurina and Eucalyptus)

After five years the soil pH, EC and ESP were analysed and the values are given in Table 31. Among the tree species the soil pH varied between 8.1 to 8.5 from initial level of 9.2. The *Prosopis juliflora* recorded the lowest pH of 8.1 (15 -30 cm depth) followed by *Acacia leucophloea, Azadirachta indica* and *Lueceana luecocephala* (8.2). The reduction in soil pH was more in surface layers than in subsurface layers since the planting was taken in pit method for a depth of 45 cm. Similarly tree species like *Azardiracta indica, Prosophis juliflora, Leuceana leucocephala, Acacia leucophloea* and *Dalbergia sisoo* significantly lowered the soil ESP (Table 119).

Table 119. Effect of different tree species on soil pH and ESP at 5th year of planting

Tree species	Soil depth (cm)	EC dSm^{-1}	pH	ESP
Tamarindus indica	15-30	0.08	8.3	20.56
	30-60	0.16	8.4	21.25
	60-90	0.26	8.5	22.6
Bambusa bamboo	15-30	0.09	8.5	22.70
	30-60	0.12	8.5	22.88
	60-90	0.16	8.6	24.66
Azadirachta indica	15-30	0.07	8.2	17.92
	30-60	0.11	8.2	18.68
	60-90	0.17	8.4	21.43
Prosopis juliflora	15-30	0.12	8.1	17.63
	30-60	0.15	8.3	17.83
	60-90	0.17	8.4	18.60

Lueceana luecocephala	15-30 30-60 60-90	0.09 0.12 0.15	8.2 8.4 8.5	17.0 17.9 19.0
Acacia leucophloea	15-30 30-60 60-90	0.05 0.07 0.09	8.2 8.3 8.5	16.93 19.0 22.02
Dalbergia sisoo	15-30 30-60 60-90	0.11 0.14 0.17	8.4 8.4 8.6	18.32 18.97 20.68

11.2 Evolving Planting Techniques with Amendments for Raising Tree Crops in Sodic Soils under Rainfed Condition

This experiment was conducted to find out the suitable planting techniques for tree crops in sodic soils under rainfed conditions. The main plot treatment consists of four planting techniques viz., Pit system(M1), Pit (2′x2′x2′) with Auger hole (60cm) (M2), and Pit(2′x2′x2′) with Auger hole(120cm) (M3) and the sub plot consists of three treatments viz., gypsum at 50 % GR (S1), Spent wash (150 ml / kg of soil) (S2) and Gypsum at 25 % GR + 50 % spent wash (S3). The tree species neem and tamarind were tested in this experiment. Neem seedlings were planted during December 1999 and tamarind seedlings were planted during December 2000.A spacing of 2.5 x 2 m for neem and 5 x 5 m for tamarind was adopted and seedlings were supported with supplemental watering during dry spell. The initial soil profile characteristics of the experimental field are given in Table 120.

Table 120. Soil Profile Characteristics of the Experimental Field

Soil Depth (cm)	pH	EC (dSm^{-1})	ESP
0 – 15	8.7	0.18	25.6
15 – 30	8.9	0.25	29.3
30 – 60	9.3	0.58	30.1
60 – 90	9.3	0.40	30.9

i) Neem

The survival percentage and height of neem seedlings as affected by the treatments is given in the Tables 121 and 122. The results revealed that among the planting techniques, pit with auger hole of 60 cm depth recorded higher level of survival (94.81 %) and plant height of 294.5 cm.

Table 121. Survival percent of neem seedlings at 18 months after planting

Treatments	Gypsum @ 50% GR	Spentwash @150 ml/kg of soil	Gypsum @ 25% GR + 50% spentwash	Mean
Pit System (2′x2′x2′)	80.21	85.42	89.58	85.07
Pit (2′x2′x2′) with auger hole (60 cm)	93.75	92.76	97.92	94.81
Pit (2′x2′x2′) with auger hole (120 cm)	86.45	87.50	89.58	87.84
Mean	86.80	88.56	92.56	

Table 122. Height of neem seedlings (cm) at 18 months after planting

Treatments	Gypsum @ 50% GR	Spentwash @150 ml / kg of soil	Gypsum @ 25 % GR + 50 % spentwash	Mean
Pit System (2′x2′x2′)	132.0	164.8	215.8	170.8
Pit (2′x2′x2′) with auger hole (60 cm)	242.0	310.4	330.5	294.3
Pit (2′x2′x2′) with auger hole (120 cm)	174.8	198.6	239.7	204.3
Mean	182.9	224.6	262.0	

Among the amendments tried, combination of gypsum at 25 % GR and 50 % spentwash observed higher survival percent and height of 92.36 and 262 cm, respectively showing the superiority. Other treatments, viz., gypsum alone at 50 % GR and spentwash alone resulted in a mean survival percent of 86.80 and 88.56 and plant height of 183.1 and 224.6 cm, respectively. Among the combination of planting techniques and amendments, planting neem seedlings at pit with auger hole of 60 cm depth filled with gypsum at 25 % GR and spentwash at 50 % recorded the highest survival percentage of 97.92 and height of 330.5 cm at 18 months after planting.

ii) Tamarind

The effect of planting methods and different amendments on soil pH and EC at different depths are given in Table 123. In tamarind also, pit with auger hole method had significant influence in reducing the pH in the root zone of 0-90 cm depth whereas pit method did not have any influence on pH at 60-90 cm depth. Among the amendments, gypsum was effective in reducing the soil pH, followed by application of gypsum @ 25 % GR and DSW @ 75 ml/kg of soil. There was no significant influence in EC of the soil in root zone irrespective of the planting technique and amendments applied as the soils are non-saline.

Plate 10. ***Tamarindus indica*** **in alkali soil**

Plate 11. Project Coordinator Dr.P.S. Minhas (Centre) with AICRP scientists and DEAN at Agro-forestry farms of ADAC&RI, Tiruchirapalli

Table 123. Effect of Planting Technique and Amendments on Soil pH and EC at 24 Months after Planting of Tamarind

pH						EC (dSm^{-1})					
Treat	**Depth**	**S_1**	**S_2**	**S_3**	**Mean**	**Treat**	**Depth**	**S_1**	**S_2**	**S_3**	**Mean**
M_1	0-15	7.94	8.17	7.88	8.00	**M_1**	0-15	0.18	0.2	0.15	0.18
	15-30	8.07	8.24	8.29	8.20		15-30	0.2	0.28	0.23	0.24
	30-60	8.33	8.67	8.93	8.64		30-60	0.35	0.37	0.35	0.36
	60-90	9.10	8.98	9.17	9.08		60-90	0.87	1.11	0.93	0.97
M_2	0-15	8.06	8.92	8.10	8.36	**M_2**	0-15	0.26	0.31	0.23	0.27
	15-30	8.19	8.35	8.30	8.28		15-30	0.31	0.34	0.34	0.33
	30-60	8.38	8.57	8.48	8.48		30-60	0.32	0.35	0.39	0.35
	60-90	9.13	8.73	8.95	8.94		60-90	0.67	0.81	0.97	0.82
M_3	0-15	8.01	8.26	8.19	8.15	**M_3**	0-15	0.22	0.28	0.16	0.22
	15-30	8.27	8.57	8.45	8.43		15-30	0.27	0.32	0.22	0.27
	30-60	8.34	8.89	8.52	8.58		30-60	0.56	0.35	0.29	0.40
	60-90	9.15	8.95	8.8	8.97		60-90	1.1	1.23	1.24	1.19

The effect of planting technique and amendments on girth at stump height (GSH) and girth at breast height (GBH) for tamarind are given in Tables 124 and 125, respectively. At 30 months after planting of tamarind, pit with auger hole to a depth of 120 cm and 60 cm recorded tree girth of 17.2 and 17.0 cm respectively. Among the amendments, application of gypsum @ 50 % GR recorded tree girth of 18 cm followed by combined application of gypsum @ 25% GR + DSW @ 75 ml kg^{-1} of soil (16.5 cm). The effect of planting technique and amendments on girth of seedlings at Breast height (GBH) showed similar trend.

Table 124. Effect of planting techniques and amendments on girth at stump height (GSH) of tamarind at 30 months (cm)

Treatments	Gypsum	DSW	Gypsum +DSW	Mean
Pit system	17	14.5	15.9	15.9
Pit with auger hole (60cm)	19	15.1	16.7	17.0
Pit with auger hole (120cm)	19	15.6	16.8	17.2
Mean	**18**	**15.1**	**16.5**	
	M	**S**	**M at S**	**S at M**
SEd	0.48	0.36	0.41	0.52
CD	1.18	0.87	1.36	1.28

Table 125. Effect of planting techniques and amendments on girth at base height (GBH) of tamarind at 30 months (cm)

Treatments	Gypsum	DSW	Gypsum +DSW	Mean
Pit system	13.1	10.6	11.8	11.8
Pit with auger hole (60cm)	13.7	11.3	12.3	12.4
Pit with auger hole (120cm)	14.2	11.4	12.9	12.8
Mean	**13.7**	**11.1**	**12.3**	
	M	**S**	**M at S**	**S at M**
SEd	0.38	0.32	0.51	0.46
CD	0.93	0.79	1.24	1.13

The biometric observation recorded in neem (108 months old) revealed that the highest girth at stump height (43.2 cm) and girth at breast height (36.4 cm) are highest in pit with auger hole method of planting (M3). Among the amendments, the highest girth at stump height (GSH) and girth at breast height (GBH) were observed in application of DSW @ 75 ml/kg soil + gypsum @ 25 % of GR for the excavated soil (41.4 and 35.9 cm, respectively).

In case of tamarind (96 months old) tree the pit with auger whole method (M3) recorded a highest plant height of 3.42 m which was on par with other planting methods. There is no significant difference in tree height between application of gypsum alone or in combination with spent wash (Table 126 & 127). The highest GBH of 39.5 cm was recorded in the pit with auger hole (120 cm) planting method (M_3).

Table 126. Effect of planting techniques and amendments on GSH and GBH of Neem (108 months old)

	GSH (cm)				GBH (cm)			
Treat	**S_1**	**S_2**	**S_3**	**Mean**	**S_1**	**S_2**	**S_3**	**Mean**
M_1	32.2	36.9	38.6	35.9	26.5	30.2	32.2	29.6
M_2	38.3	38.5	44.5	40.4	31.2	31.2	36.7	33.0
M_3	43.8	40.5	45.3	43.2	33.7	36.5	38.9	36.4
Mean	38.3	39.8	41.4		30.5	32.6	35.9	
	M	S	M x S	S x M	M	S	M x S	S x M
SEd	1.09	0.45	1.02	0.70	1.16	0.40	1.12	0.69
CD (P=0.05)	2.66	0.89	2.41	1.43	2.84	0.81	2.21	1.36

Table 127. Effect of planting techniques and amendments on tree height and GBH of Tamarind (96 months old)

	Tree height (m)				GBH (cm)			
Treat	**S_1**	**S_2**	**S_3**	**Mean**	**S_1**	**S_2**	**S_3**	**Mean**
M_1	3.36	3.45	2.80	3.20	27.4	28.0	35.8	30.4
M_2	2.89	3.53	2.92	3.11	31.2	36.5	29.6	32.4
M_3	3.26	3.65	3.36	3.42	39.7	42.3	36.6	39.5
Mean	3.17	3.54	3.03		32.8	35.6	34.0	
	M	S	M x S	S x M	M	S	M x S	S x M
SEd	0.10	0.11	0.19	0.17	1.05	0.88	1.41	1.27
CD (P=0.05)	NS	0.232	NS	NS	2.578	NS	NS	NS

Salient Findings

In general, the pit with auger hole (120 cm) was the best method of planting for establishment and growth of tree species (Neem and Tamarind) under rainfed sodic soil condition. However, the amendments DSW @ 75 ml / kg soil with gypsum @ 25 % GR for neem and DSW @ 150 m l/ kg of soil for tamarind were found to be better for establishment and growth.

12. OPERATIONAL RESEARCH PROJECTS

The ICAR-Central Soil Salinity Research Institute and many State Agricultural Universities are engaged in studying salt-affected soils and developing reclamation technologies and strategies. Several innovative technologies have been developed and on-farm tested. Gypsum-based sodic soil reclamation, sub-surface drainage of water-logged saline lands, salt tolerant crop varieties and improved agro forestry techniques are some of the well-adapted technologies in the country. Reclamation of 2.18 million ha of salt-affected soils (2.07 million ha barren sodic soils and 0.11 million ha saline soils) has contributed more than 17 million tons of food grains per annum to the country's food basket, with additional annual income of Rs. 15.5 billion, and employment generation of 2.8 million man-days. Other technologies of management of salt-affected soils, viz. alternate land-use systems, saline aquaculture, cultivation of salt tolerant crop varieties, agro-forestry, phytoremediation, bioremediation etc. have positively impacted food and nutritional security, women empowerment, involvement of landless labourers and minimizing rural migration etc. The ongoing consistent research efforts for the management and reclamation of such soils would hopefully continue ensuring food security in the country. The Government needs to make policies favorable for implementation of reclamation technologies in the country.

12.1 ORP on Sodic Soil Reclamation Technology using Gypsum

To demonstrate the reclamation technology of sodic soil using Gypsum and distillery spent wash and other management practices. Six farmers were selected in different locations of Tiruchirapalli district based on soil test values. Gypsum requirement was estimated based on soil test and reclamation was done. Initial and post harvest soil samples were collected and analysed for pH, EC, ESP. Grain and straw yield was recorded after harvest. The results showed that application of gypsum @ 50 % GR along with package of practice significantly increased the grain and straw yield of rice. The grain yield increased to the tune of 1674 to 2300 kg / ha at various locations due to application of gypsum @ 50 % GR along with package of practice when compared to control.

Regarding the initial soil properties at various locations, pH varied from 8.7 to 10.3, EC varied from 0.42 to 1.36 and ESP varied from 23 to 42. The post-harvest soil analysis revealed that application of gypsum considerably reduced the pH and ESP of soil. The pH reduced to the level of 8.3 - 8.7 and ESP to the level of 13 - 20. There is no considerable change in EC of the soils.

12.2 ORP on DSW Reclamation Technology

Six farmers were selected in different locations of Trichirappalli district based on soil test values. Distillery spent wash was applied @ 5 lakh liters per hectare and DSW reclamation technology procedure was followed. Initial and post harvest soil samples were collected and analysed for pH, EC, ESP. Grain and straw yield was recorded after harvest.

The results showed that application of DSW @ 5 lakh litres per hectare along with package of practice significantly increased the grain and straw yield of rice. The grain yield increased to the tune of 1560 to 2428 kg / ha in various locations due to application of DSW along with package of practice when compared to control.

The initial soil properties at various locations indicated that pH varied from 8.6 to 10.0, EC varied from 0.68 to 1.18 dSm^{-1} and ESP varied from 24 to 32 %. The post harvest soil analysis revealed that application of DSW considerably reduced the pH and ESP of soil. The pH reduced to the level of 8.3 - 8.8 and ESP to the level of 14 - 19 %. Application of DSW slightly increased the EC of post-harvest soil.

Plate 12. ORP on DSW application

13. IMPACT ANALYSIS OF SODIC SOIL RECLAMATION IN MANIKANDAM BLOCK OF TRICHY DISTRICT

Impact Analysis studies have been carried out in Manikandam block of Trichy district and it was observed that the knowledge level of the farmers on management of salt affected soils was increased to the tune of 78 percent and Skills on utilization and adoption of technologies was increased to the tune of 64 percent. Due to the adoption of Soil Reclamation practices, the pH level in the problem soils has considerably reduced. Initially the pH level in these soils ranged from 8.7 to 9.8 and after reclamation, it has been brought down to 8.0 to 8.4 and similarly the ESP ranged from 20.5 – 25.3 per cent initially was brought down to 13.8 – 16.4 per cent after reclamation.

As a result of the above factors, there was an increase in the rice productivity in these salt affected soils from a minimum of 1645 kg/ha to a maximum of 2780 kg/ha. On the whole the rice productivity per ha in Manikandam block has been phenomenally increased to the tune of 32.26 per cent and the productivity is enhanced to 6080 kg/ha. The Net Income in the Salt affected Soils has increased from Rs.34, 275/ha (prior reclamation) to Rs.64,500/ha (post-reclamation). The respective B.C. ratio has also adequately risen from 1.22 to 1.95. Besides these economic parameters, there was also a Social Impact. Due to the adoption of reclamation practices and best management practices, there was an increase in labour requirement per farm and on an average an additional 48 mandays/ha to carry out the suggested management practices. This paves way for additional employment generation in rural sector. Overall, the implemented technologies have produced significant impact on the knowledge level, awareness & adoption of the farmers, their income and livelihood from farming besides enhancing employment prospects of agricultural labourers. Hence, scaling up of sodic soil reclamation technologies will bring overall benefit to the economy.

14. SUMMARY

Delineation and Characterization of Salt affected soils

- Out of the 21404 ha of total geographical area of Manikandam block, about 3667 ha are salt affected soils. The area under two types of salt affected soils is 1167 and 2500 ha are strongly and moderately salt affected soils respectively
- In Tiruchirappalli district, out of the total geographical area of 4, 40,412 ha, 7,362 ha are slightly salt affected, 10,729 ha are moderately salt affected and 64 ha are strongly salt affected.

Reclamation of Sodic Vertisols in Conjunction with Soil and Water Conservation Practices under Rainfed Conditions

- Field experiments were conducted for four years (1995-99). The results of the first year (95-96) indicated that raised bed with 405cm/30cm size produced significantly highest sunflower seed yield and it was comparable with 270/30cm and 135/30cm beds. Among the organic amendments, application of FYM (12.5 t/ha) gave significantly the highest seed yield of sunflower which was on par with all other organic amendments applied.
- During second year (96-97), bed size of 270/30cm produced significantly the highest seed yield of sunflower and it was superior to all other treatments. In sub-plot treatments, application of FYM produced the highest seed yield of sunflower and it was comparable only with pressmud applied plot. During third year, the trial was abandoned due to heavy and continuous rain and subsequent failure of the sunflower crop.
- During the fourth year (1998-99), 405/30cm raised bed produced significantly higher seed yield and it was comparable with 270/30cm bed size. Among the organic amendments, application of FYM @ 12.5 t/ha produced the highest seed yield and it was comparable with application of pressmud (12.5 t/ha).

ORP on Sodic soil Reclamation Technology

- The results showed that grain yield of rice increased to the tune of 1674 to 2300 kg / ha at various locations due to application of gypsum @ 50 % GR along with package of practice when compared to control. The pH of soil reduced to the level of 8.3 - 8.7 and ESP to the level of 13-20 due application of gypsum from the initial level of 8.7-10.0 and 23-42, respectively.
- Regarding DSW technology, grain yield of rice increased to the tune of 1560 to 2428 kg / ha in various locations due to application of DSW along with package of practice when compared to control. The pH of the soil reduced to the level of 8.3 - 8.8 and ESP to the level of 14 - 19 % due to application of DSW from the initial level of 8.6 -10.0 and 24 -32, respectively.

Evaluation of Plants for Sodicity Tolerance

a. Crops and Varieties

- The coarse grained rice variety TRY 1 and fine grained variety ADT 45 tolerates up to an ESP of 26
- Green gram variety Pusa Bold tolerates an ESP of 16.
- At higher ESP level of 36, pearlmillet cultivar UCC 17 performed better with minimum yield loss.
- Upto an ESP of 16, the other crops *viz*., Maize (COH M4), Sunflower (CO 4), Sesame (CO 1), Bhendi (Parbhani Kranti), Cluster bean (Pusa Naubuhar) performed better with minimum yield loss.
- The threshold ESP for the sunflower variety CO4 and hybrid TCSH1 were 16.5 and 13.0, respectively.
- The ESP at 50% yield reduction for sunflower variety CO4 and hybrid TCSH1 were 37 and 34, respectively
- The threshold ESP for okra varieties were 13.5, 15.5 and 16 for hybrid No10, Arkha anamika and Parbhani kranti, respectively.
- The ESP at 50% yield reduction for okra varieties were 31, 34 and 30 for hybrid No10, Arkha anamika and Parbhani kranti, respectively
- The results of the field experiment (2014) with cotton showed that among the varities and hybrid tested under different ESP levels, the hybrid (Bt cotton) cotton RCH-20 has performed better and recorded higher yield (2954 kg ha^{-1}) at all ESP leves compared to varieties (Surabhi and SVPR – 2).
- The results of the field experiment (2019) with sorghum revealed that 50 per cent grain yield was recorded in the cultivars viz., Co 30, Red local and Irungu local at the ESP of 32 per cent whereas in the cultivar K12 recorded 50 per cent yield at 24 ESP level which is clearly indicated that the cultivars Co 30, Red local and Irungu local could be grown in the sodic soil having the ESP up to 32 per cent wheras the cultivar K12 can be recommended to the sodic soil having the ESP level up to 24 per cent
- The results the field experiment with onion revealed that more than 50 per cent yield could be achieved up to 24 ESP level. Among the varieties Co 5 (seed) and local (Bulb), the performance of Co 5 was superior over local. Hence, it is concluded that the onion can be grown in sodic soil up to the ESP level of 24 where the 50 per cent of yield can be obtained.

Trees Species

- At 5th year of planting the survival percent was highest for T*amarindus indica, Bambusa bamboo* followed by *Lueceana leucocephala, Acacia leaucophloea, Azardiracta indica*.
- In general, the pit with auger hole (120 cm) was the best method of planting for establishment and growth of tree species (Neem and Tamarind) under rainfed sodic soil condition. However, the amendments DSW @ 75 ml / kg soil with gypsum @

25 % GR for neem and DSW @ 150 m l/ kg of soil for tamarind were found to be better for establishment and growth.

Effect of Levels of N and Organic Materials/ Green Manures on the Performance of Rice under Sodic Soil Conditions

- Addition of urea @ 112.5 kg N/ha with organics like daincha or subabul or FYM or rice husk ash @ 5 t/ha, 15 t /ha and 5 t /ha respectively will result in higher grain yield and also improves soil fertility and apparent N recovery.

Site Specific Nutrient Management for rice in salt affected soils of Tamil Nadu

- Reclamation of alkali soil with gypsum of Distillery Spent Wash (DSW) increased the indigenous N supply. The amendments did not have profound influence on indigenous P supply while reclamation of alkali soil with gypsum decreased indigenous K supply and that by DSW increased the same.
- The total N, P and K uptake by rice increased with reclamation of alkali soil either with gypsum or DSW. Similarly, the N, P and K requirement to produce one tonne of rice also increased with reclamation.
- In OFT, the mean fertilizer N requirement for a yield target of 6 kg/ ha was 162 and 137 kg/ ha under no amendment and gypsum reclamation. But for DSW reclaimed alkali soils, the mean nutrient requirement was 30 and 134 kg N ha during I and II year of reclamation, respectively. Hence, DSW, apart from soil reclamation also adds organic matter and potassium and saves N in first year of reclamation.
- For a yield target of 6 kg/ ha in both years, mean P requirement as per SSNM approach varied between 25 to 35 kg P_2O_5 ha irrespective of the amendment used.
- In on farm trials, the fertilizer K requirement varied between 66 to 76 kg K_2O ha for a yield target of 60 kg/ ha irrespective of the amendments, which is higher than the general recommendations.

Integrated Farming System suitable for problem soil areas of Tamil Nadu

- In comparison with a pure crop program for 0.40 ha, the IFS program (0.30 ha for crop and 0.10 ha for poultry and fisheries) has yielded high net returns and BC ratio of 2.36 which is 1.33 higher than the crop alone program.

Water Quality Map of Tamil Nadu from Existing Data Base

- The water quality map of Tamil Nadu was prepared in 1:250,000 scale. The results indicate that 73.2% of water samples were found to be of good quality, 21.1% moderately saline and 5.7% were saline.

Intensive Investigations on Ground Water Quality of Tamil Nadu
Inland Districts
Tiruchirapalli District

- Of the 597 water samples collected from Tiruchirapalli district, 365 (61%) are good. 90 (15%) marginally saline, 53 (8.8 %) saline, 15 (2.5 %) high SAR saline, 27 (4.5 %) marginally alkali, 41 (6.8 %) alkali and 6 (1%) highly alkali .

Perambalur District

- Among the total samples (680) collected from Perambalur district, the distribution of good, Marginally saline, saline, high SAR saline, marginally alkaline, alkaline and alkaline were 52.4,26.8, 3.2, 0.88, 10.4 and 5.88 per cent respectively.

Ariyalur district

- Among the total samples (835) collected from Ariyalur district, 67.8 % is coming under good quality, 6.35 is marginally saline, 19.9 % is marginally alkaline, 3.54 % is alkaline, and 2.04 % is saline.

Namakkal district

- Among the total samples collected from Namakkal district, 62.3 % is coming under good quality, 27.1 is marginally saline, 6.5 % is marginally alkaline, 1.9 % is alkaline, and 8.5 % is saline.

Coastal districts

- **Kanyakumari district**
  Out of the total samples collected from Kanyakumari district, 73.02% is coming under good quality, 12.57 % is marginally saline, 14.81% is saline water and 3.16 % is under high SAR saline categories.
- **Tirunelveli district**
  Out of the total samples collected from Tirunelveli district 57 per cent of groundwater found under good quality, (18%) Marginally saline, (4%) Saline, (11%) Marginally alkali, (8%) Alkali, (1%) High-SAR saline and (1%) High alkali.
- **Thoothukudi District**
  Out of the total samples collected from Thoothukudi District district 51 per cent of groundwater found under good quality, (21%) marginally saline, (13%) saline, (3%) marginally alkaline, (2%) alkaline, (7%) high SAR saline and (3%) high alkaline.
- **Ramanathapuram**
  Out of the total samples collected in Ramanathapuram district, 10% is characterized under good quality, 10 % is marginally saline, 4 % is saline, 1 % is marginally alkaline, 10 % is alkaline, 46 % high SAR saline and 19 % high alkaline.
- **Pudukkottai**
  Out of the total samples collected in Pudukkottai district 45 per cent of groundwater were found as good quality and its remaining samples were found in

different categories of water quality *viz.,* Marginally saline (12%), Saline (1%), High-SAR saline (4%), Marginally alkali (14%), Alkali (14%) and High alkali (10%).

- **Tanjore district**
  Out of the total samples collected in Tanjore district, 84.2 % is coming under good quality, 2.19 % is marginally saline, 9.3 % is marginally alkaline, 3.6 % is alkaline, 0.46 % is saline and 0.25 % high SAR saline.
- **Thiruvarur**
  Out of the total samples collected in Thiruvarur district, 83.2 % is coming under good quality, 9.93 % is marginally saline, 3.72 % is marginally alkaline, 1.24 % is alkaline, 0.62 % high SAR saline and 1.24 % highly alkaline.
- **Nagapattinam district**
  Out of the total samples collected in Nagapattinam district, 72.6 % is characterized under good quality, 12.7 % is marginally saline, 7.8 % is saline, 2.9 % is marginally alkaline, 2.9 % is alkaline, and 0.4 % high SAR saline.
- **Cuddalore**
  Out of the total ground water samples collected from Cuddalore district, 69.9 per cent is coming under good quality, 16.27 per cent is marginally saline, 9 per cent is saline water, 0.8 per cent is marginally alkali and 3.4 per cent is under high alkali categories.
- **Villupuram district**
  Out of the total ground water samples collected from Villupuram district, only 9.09 per cent of samples were of good quality, Villupuram district of the coastal blocks. Alkali accounted for 69.3% among all samples, with 12.87 per cent (marginal Alkali), 8.71 per cent (marginal saline) and 4.54 per cent (marginal saline) following closely behind (high SAR saline).
- **Chengalpattu**
  Out of 250 samples collected in Chengalpattu district alkali accounted for 45% followed by marginal alkali (31%), 16% of samples comes under the good quality and 4% of samples comes under the marginal saline and Highly alkali each.
- **Tiruvallur district**
  In Thiruvallur district, 34 per cent is characterized under good quality, 2 percent under marginally saline, 41 per cent as marginally alkali and 23 per cent is characterized as alkali.

Scheduling irrigation with alkali water for sugarcane under sodic soil condition using drip irrigation

- Drip irrigation with 80% PE registered significantly the highest cane yield of 102.96 and 98.84 t/ha respectively for plant and ratoon crops.

Fertigation to sugarcane under drip irrigation using ameliorated alkali water

- Drip irrigating to sugarcane at 80% PE (paired row system) with gypsum at 50% GR recorded the highest average cane yield of 104.9 t ha^{-1}.

- Drip irrigation to sugarcane saved irrigation water up to 29.5% as compared to furrow irrigation.
- Drip irrigation with gypsum bed treated water in combination with soil application of gypsum @ 50% GR recorded the highest average cane yield of 113.4 t ha^{-1}
- Drip irrigation with gypsum bed treated water in combination with soil application of gypsum @ 50% GR reduced the soil pH and ESP.

Drip Irrigation to Vegetables in Alkali Soil using Amended Alkali Water

- The soil application of gypsum @ 50 % GR significantly increased the yield of both Okra (12.6 % in 2009 – 10 and 12.8 % in 2010-11) and cluster bean (22.1 % in 2009 – 10 and 20.9 % in 2010-11). Among the irrigation treatments, drip irrigation of spent wash treated water recorded the highest yield in Okra and drip irrigation of gypsum bed treated water recorded highest yield in cluster bean crop.

Drip Irrigation to Cotton in Alkali Soils using Ameliorated Alkali Water

- Drip irrigation with gypsum bed treated alkali water along with sodic soil reclamation using distillery spentwash @ 5 lakh litres ha^{-1} found to be best practice for enhancing cotton productivity in sodic soil with a sustainable use of alkali water.

Effect of Conjunctive use of Canal and Sodic Water on Rice based Cropping Systems

- During shortage or limited supply of canal water, conjunctive use of canal and alkali water in 1:1 cyclic mode for rice and alkali water alone for greengram or vegetables can be recommended for alkaline environment of Cauvery irrigation command area.
- For amending alkali water gypsum bed method proved to be superior.
- Continuous use of alkali water for rice and greengram or vegetables resulted in yield decline of 25% in rice and 37% in greengram and 20% in brinjal with increased ESP of 25-34.
- Greengram (Pusa bold or VBN(GG) 2) or brinjal (Co2) can be recommended as follow-up after rice with alkali water irrigation for higher profitability.
- The change in chemical properties of soil viz., pH and ESP due to use of canal + alkali water was observed to be better than use of alkali water alone for both crops.

Long Term Effects of Distillery Effluent on Soil Properties and Yield of Sugarcane

- Application of inorganic fertilizers omitting K and 25 per cent N and P, in combination with 1.25 lakh litres ha^{-1} of TDE as preplant application or at 1:1 dilution for growing crop gave high yield leading to a saving of K. The graded doses of TDE along with NP significantly increased the soil available nutrients, organic carbon content besides improving soil physico-chemical properties.

15. FUTURE THRUST

- Intensification of water quality survey in other parts of Tamil Nadu will enable us to have a clear understanding on the development of problem soils in future. Accordingly suitable management options could be drawn for mitigating the stress due to salinity and sodicity hazards.
- Utilization of Raw Distillery Spent Wash (DSW) as an alternate source for reclamation of sodic soil in view of depletion of mineral resources of the Nation (gypsum).
- Minimising the use of saline /alkali water in crop production by modernized irrigation systems including land management options which prevent the accumulation of more salts in soil per crop.
- Intensification of research on mitigating salinity hazards in coastal areas of Tamil Nadu in view of changing climatic conditions.
- Establishments of different IFS models in the farmer's holdings of different regions of Tamil Nadu based on the availability of resources.

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