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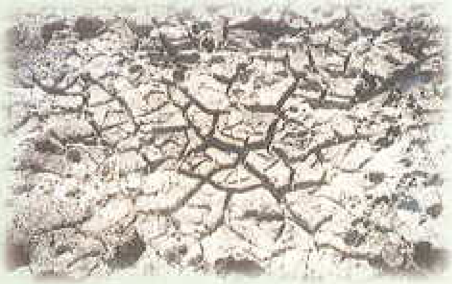

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WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
Chandrasekharpur, Bhubaneswar - 751023, Orissa, India
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PREFACE

Irrigation has contributed significantly to the growth and development in agricultural sector. Many developing countries including India accelerated the growth rate and boosted agricultural production by bringing more areas under irrigation. However, irrigation induced soil degradation became a major threat to the irrigated agriculture with surfacing the twin problems of soil salinization and sodification. Major reason of irrigation induced land degradation in command areas is poor water management i.e. over application by farmers, excess seepage throughout the irrigation system, absence of or inadequacy of drainage infrastructure etc. In India waterlogging and salinity has been associated with irrigated agriculture since early beginning. The total waterlogged and salt affected areas in the country due to several causative factors have been estimated by about 4.5 million ha and 8.6 million ha, respectively. Problem of irrigation induced soil degradation became a major issue of concern during last decade, particularly in the command areas of arid and semi-arid tracts. Unfortunately, the ground water quality in these areas is also poor making irrigation a challenging task.

In order to study different soil degradation processes and their impact on hydro-physical behaviour of soils, a study entitled **"Hydraulic properties and irrigation induced land degradation dynamics in different command areas"** was undertaken as a research project at WTCER. Initially the study was carried out in Mula command area of Western Maharashtra. This study will also be extended to some other command areas. The authors feel pleased to document and present the results of the study for Mula command area. For conciseness of the document, results of only selected soil profiles, which are representative of major area in different reaches of Mula command, have been considered in this paper. However, detailed information on physical, chemical and hydro-physical properties of all 40 soil profiles is also available. Authors will feel happy to share this information with interested scientists/research organizations/government departments etc and welcome suggestions/comments/constructive criticism on the work presented in this document. Authors express their sincere gratitude to Honorable DDG (NRM) and ADG (IWM) for constant support and encouragement. Authors are thankful to the scientific and technical staff of All India Coordinated Research Project on Water Management, Rahuri centre for their support and assistance. Authors are thankful to the staff of SWPR-laboratory of WTCER, Bhubaneswar for their help. Word-processing and typographical assistance rendered by Mrs. Minati Padhi is acknowledged.

(Authors)

Contents

SUMMARY

Soil salinization and sodification have emerged as twin problems in irrigated areas in general and canal command areas in particular. A study has been carried out to assess irrigation induced land degradation in Mula command area of Western Maharashtra. Command area is divided into two main branches i.e. Mula left bank canal (MLBC) and Mula right bank canal (MRBC) consisting 10100 ha and 70700 ha net CCA, respectively. Canal conditions are poor mainly due to illegal withdrawal and inadequate maintenance. Soils of clay, clay loam and sandy clay loam texture are predominant in the command area. Sugarcane and cotton are the major cash crops being preferred by the farmers. Pearlmillet, sorghum, pulses and groundnut are the important kharif crops and sorghum, sunflower, wheat and gram are important rabi crops. Canal water quality is very good but ground water quality is poor to marginal. In order to study irrigation induced land degradation in Mula command area, soil profiles were exposed at 40 selected locations belonging to representative soil series inside the command area and similar soil series outside the command area. Depth-wise bulk soil samples were collected from all the soil profiles during January, 2004. Undisturbed soil cores were also collected to determine saturated hydraulic conductivity. Stead-state infiltration rates were determined close to sampling locations. Results of the study showed that intensive irrigation practices have brought marginal to large changes in the properties of soils of command area over similar soils outside the command area. Soil pH, ECe, ESP, saturated hydraulic conductivity, infiltration rate, dispersion and swelling properties deviated to a large extent in the soils of MLBC and head reach of MRBC. Soil pH and ECe varied considerably in the middle reach of MRBC as compared to similar soils outside the command. Only marginal changes were noticed in the properties of soils of tail reach of MRBC over similar soils outside the command area. Major areas of MLBC and head reach of MRBC have been turned saline-sodic to sodic in nature. In the middle reach of MRBC major areas can be classified as saline to saline-sodic. However, major areas under tail reach of MRBC are normal in reaction and salinity has been observed in some parts, which is temporary in nature and limited only to surface soil layers. In entire command area of 80800 ha, saline, saline-sodic and sodic soils are spread over 31655 ha, 17515 ha and 12270 ha area, respectively in different reaches. Marginal to strong degradation is noticed in about 75% of the total command area. However, condition of MLBC and head reach of MRBC is alarming and deserves immediate attention. Results on soil-water retention and water transmission properties showed that the drainage conditions of poorly drained soils under MLBC and head reach of MRBC

are badly aggravated due to excessive dispersion and deflocculation leading to high runoff losses. High dispersion of silt and clay coupled with excessive swell-shrink behaviour make soils' workability/management a difficult task. Besides judicious use of irrigation water at farm level, efforts must be made to improve the canal conditions to control water losses due to various reasons. Mass awareness needs to be created amongst farming communities to avoid wasteful use of water and land degradation due to excessive irrigation practices. Efforts must be made to discourage surface irrigation to high water demanding crops like sugarcane. Sugarcane cultivation should be restricted through pressurized irrigation systems only. Farmers should be encouraged to use locally available sulphonated press mud cake as a chemical amendment on degraded sodic soils in MLBC and head reach of MRBC. Details of degradation in respect of different reaches and parts of command area, extent of the problem, results of practical utility and recommendations for sustainable management of soils are described in this paper. Reclamative and preventive measures for the soils of different reaches are also given. For sustainable management of command area, first priority should be given to reclamation of degraded lands in entire MLBC and head reach of MRBC.

1. INTRODUCTION

India has made significant investments in creating irrigation potential of about 58M ha. However, the irrigated areas, which have contributed significantly in increasing food grain production are now facing serious problem of rise in ground water-table and soil salinization. Such problems are now serious in areas that have received canal irrigation. The impact of soil degradation in irrigated areas are due to soil salinization and waterlogging has not been evaluated adequately. It is clear that non-judicious use of irrigation water, irrespective of its quality, lead to soil salinization and sodification. Continuous accumulation of salts in root zone results into soil salinization. These salts may come from irrigation water, mineral dissolution, precipitation, capillary rise or all of the above reasons. The process of sodification initiates with replacement of exchangeable calcium by sodium.

Irrigated soils exhibit differential physico-chemical behaviour at temporal scale. Physical properties of irrigated soils limit its productivity. Irrigated soils, if not managed properly, deteriorate in hydraulic properties e.g. infiltration rate, saturated hydraulic conductivity, unsaturated hydraulic conductivity, soil-water diffusivity, soil-water retention etc. The exchange phase-solution phase behaviour of these soils is highly sensitive to water management inputs. Flocculation, deflocculation, dispersion, swelling, ESR-SAR relationships are the major processes responsible for changes in hydro-physical behaviour of soils due to irrigation induced salinization or sodification. When irrigation is practiced, water remains in equilibrium with soil and slowly infiltrates downward. The composition of the soil solution is decided by mineralogy, water quality and exchange phase-solution phase behaviour of the soils.

In several canal irrigated tracts of the country, the excess of inflow over outflow from the ground water basin has caused the degradation of basic soil resources in terms of waterlogging and soil salinization. There are four components of input to a ground water basin; viz., i) recharge from rainfall and irrigations, ii) recharge from influent streams and man-made canals, iii) recharge from artificial recharge facilities, and iv) recharge due to excess of subsurface inflow over outflow. Likewise, there are four components of outflow from a ground water basin. These are i) ground water withdrawal from wells, tube wells ii) evapotranspiration from the water-table, iii) seepage to effluent streams and artificial drains, and iv) excess of subsurface outflow over inflow. If the inflow to an aquifer system is more than the outflow, the water-table rises and over time reaches to root zone, thereby causing waterlogging and secondary salinization. On the other hand if the outflow is more than inflow, the aquifer experiences a fall in the water-table, which may cause water quality problems and land subsidence.

Observations of water-table data over a period shows that in almost all the irrigation commands of the country the water-table has a rising trend after the introduction of canal irrigation. The trend of water-table rise in different irrigation commands is given in Table 1. Rising water-table causes waterlogging and soil salinization, resulting in

Table 1 : Trends of water-table rise in selected irrigation commands

Irrigation command	Rise of water-table (m/annum)
Mahi Right Bank Canal Command(MRBC), Gujarat	0.28
Rajasthan Canal Command (IGNP), Rajasthan	0.29-0.88
Western Yamuna and Bhakara Canal Command, Haryana	0.30-1.00
Sirhind Canal Command, Punjab	0.10-1.00
Sharda Sahayak Canal Command, Uttar Pradesh	0.68
Malprabha Canal Command, Karnataka	0.60-1.20
Nagarjuna Sagar Irrigation Project, Andhra Pradesh	0.32
Sriram Sagar Irrigation Project, Andhra Pradesh	0.26

(Source: Sharma and Paul, 1999)

loss of agricultural production. It has been estimated that on an average about 10 per cent of the total canal command area in the country is suffering from waterlogging. The time lag between the introduction of canal irrigation system and appearance of waterlogging is more in arid and semi-arid tracts and less in high rainfall areas. It is

Table 2 : Extent and distribution of salt-affected soils in India (000 ha)

State	Waterlogged area			Salt affected area			
	Canal command	Non classified	Total	Canal command	Outside canal	Coastal	Total
Andhra Pradesh	266.4	72.6	339.2	1239.4	390.6	283.3	813.3
Bihar	362.6	NA	362.6	224.0	176.0	NIL	400.0
Gujarat	172.6	311.4	484.0	540.0	327.1	302.3	455.0
Haryana	229.8	45.4	275.2	455.0	NA	NIL	455.0
Karnataka	36.0	NA	36.0	51.4	266.6	86.0	404.0
Kerala	11.6	NA	11.6	NA	NA	26.0	26.0
Madhya Pradesh	57.0	NA	57.0	220.0	22.0	NIL	242.0
Maharashtra and Goa	6.0	105.0	111.0	446.0	NA	88.0	534.0
Orissa	196.3	NA	196.3	NA	NA	400.0	400.0
Punjab	198.6	NA	198.6	392.6	126.9	NIL	519.5
Rajasthan	179.5	168.8	348.3	138.3	983.8	NIL	1122.0
Tamil Nadu	18.0	109.9	127.9	256.5	NA	83.5	340.0
Uttar Pradesh	455.0	1525.6	1980.0	606.0	689.0	NIL	1295.0
West Bengal	NA	NA	NA	NIL	NA	800.0	800.0
Total	2189.4	2338.1	4527.5	3469.1	3027.0	2069.1	8565.2

(Source: Tyagi 1999)

due to the fact that in high rainfall areas the ground water-table is at relatively shallow depth than that in the low rainfall areas.

Waterlogging and salinity has been associated with irrigated agriculture since early beginning. The total waterlogged and salt affected areas in the country (Table 2) due to several causative factors have been estimated at about 4.5 M ha and 8.6 M ha, respectively. In view of the magnitude of the problem, it was seriously felt to carry-out a comprehensive study on irrigation induced land degradation dynamics in different command areas of semi-arid region. In the beginning Mula command area of Western Maharashtra has been chosen for this study and results are presented in the following sections.

2. SYSTEM DETAILS OF MULA COMMAND AREA IN WESTERN MAHARASHTRA

Mula command area on Mula dam is under Mula sub-basin of Godavari main basin. The river Mula rises in western ghat near Harishchandragad in the high range of Sahyadri hills. Mula dam is located on Mula river near the village Baragaon Nandur in Rahuri tehsil of Ahmednagar district. The dam was constructed during 1968-69. The catchment area of the dam is about 2274 km^2. After construction of dam, water was released first in 1971-72. The command area was fully developed in 1975-76. The dam has gross storage capacity of 736 Mm^3. This is an earthen type of dam which is 2857 m long. The command area is divided into Mula right bank canal (58 km) and Mula left bank canal (18 km). The net CCA of MRBC and MLBC is about 70700 ha and 10100 ha, respectively. Mula command area caters the irrigation needs of Rahuri, Newasa, Shevgaon and Pathardi tehsils of Ahmednagar districts of Maharashtra state.

3. SOILS OF MULA COMMAND AREA

About 50% soils in the command area are classified as deep soils whereas shallow and medium depth soils are 25% each. Soils of the area are almost plain and extensively being cultivated for various crops. These soils come under upper and lower Maharashtra Deccan plateau. It covers the rain shadow and scarcity zone. Important parent material is basalt. Very gently sloping to nearly level plains (Spur and Summits) consist of moderately deep to deep, imperfect to well drained, slightly to moderately saline, moderate to high alkaline, calcareous, clayey and cracking, Vertic Haplusterts, Typic Haplusterts and Typic Haplustepts with moderate erosion, moderate to high water holding capacity and high quantum of bases on the exchange complex. The soils are dominated by smectitic/beidelitic type of clay minerals. Rolling type of topography is observed in the command area.

Soils of the command area can be divided into three textural classes i.e. clay (Fine montmorillonitic isohyperthemic family of Typic Haplustert), clay loam (Fine loamy montmorillonitic isohyperthemic family of Vertic Haplustept) and sandy clay loam (Loamy mixed isohyperthemic family of tropic Lithic Ustorthent). Clay and clay loam soils are dominated by smectitic/ badelitic type of clay minerals, exhibit tremendous swell-shrink behaviour and together constitute about 75-80% area. For the present study, sampling sites were selected in different reaches of MRBC and MLBC which pertain to the above three soil textural classes. In order to compare the effect of irrigation and injudicious use of water, profiles under similar soil series were also selected from rainfed areas outside the command. For estimation of aerial extent of irrigation induced land degradation it was assumed that the soils under similar series under similar land-use management will have similar problems.

4. LAND USE IN MULA COMMAND AREA

Pearlmillet, sorghum, pulses and groundnut are important kharif crops, while sorghum, sunflower and gram are important rabi crops. In addition, the sugarcane, cotton, fruits & vegetables are also grown in the command area. Kharif pulses like pigeonpea, green gram, and black gram are grown in some pockets. In summer, groundnut is cultivated under irrigated conditions. Banana, pomegranate, guava & citrus are the main fruit crops in the region.

5. MAJOR SOIL CONSTRAINTS IN MULA COMMAND AREA

- Shallow and barren soils are prone to degradation and water erosion.
- Scanty rainfall & prolonged intermittent dry spells affect crop growth leads to crop failure in some years
- Salinity and alkalinity in deep, clay soils due to continuous, injudicious and over irrigation
- High clay content and swelling nature of the clay minerals makes soil workability a difficult task
- Soils are dominated by montmorillonitic/smectitic/beidelitic clay minerals, which enhance runoff losses.

6. MAJOR PROBLEMS OF WATER MANAGEMENT IN MULA COMMAND AREA

Major problems of water management in Mula command area are described below:-

- In most of the command area, the development work at macro level is done through command area development. However, to achieve maximum irrigation efficiency of applied water, each field has to be developed at micro level at farm stage. This remains to be done at many places resulting in poor distribution of irrigation water.
- Below the outlet, the farmer has to take care for maintenance of field channel upto his farm to avoid seepage and overflow losses of water. Cleaning the field chan-

nel frequently and making it free from weed, leads to high water availability. At many places, the channels are used as dumping ground for farm waste.

- Wherever well irrigation is developed, the farmers are aware of irrigation layouts at their appropriate sizes. On the basis of soil types, slope of the land and types of crops, the appropriate layout should be prepared for achieving highest irrigation efficiency irrespective of sources of water either from well or canal. In the command area, the irrigation layouts are not laid properly resulting in uneven distribution of water.
- Canal water is released through fixed rotation in the command. It rarely takes into consideration the soil type and growth stage of the crop. As such, the uncertainty results in over irrigation which further deteriorates the lands.
- In the modernization of the canal system, each outlet is expected to deliver the water at the rate of 10 litres/second. However, actual measurement reveals fluctuations from 18 to 28 litres/second. Usually during night hours, flow rate increases. This results in prolonging the irrigation schedule/rotation.
- Agro-practices of the farmers in command area remained as dryland farmers. There is a need to educate farmers on scientific water application methods, remunerative cropping practices, irrigation schedules and critical growth stages of crops.
- With availability of irrigation water, farming practices need to be changed in respect of varietal adoption, fertilizer use, plant protection cover, tillage operation etc. Rarely it is adopted by the farmers in view of the water availability in the command area. Water being a carrier for nutrients, calls for additional input investments.
- There is lack of know-how of managing one-cusec flow of water. Appropriate training to the farmers as well as field functionaries needs to be imparted. In Vertisols, releasing one-cusec of flow in a field channel at a time, results into heavy losses of soil through erosion and water through seepage and over-flow. As such, it is required to distribute the one-cusec flow either into 2 to 3 halves to achieve higher irrigation efficiency.
- Usually, farmers apply the water when water releases from the canal. Irrespective of type of soil and stage of crops, excess irrigation is being given resulting in poor irrigation efficiency, low productivity, and development of secondary salinity.
- Use of ground water, as well as canal irrigation water at appropriate time with optimum depth of water to the crop is necessary to enhance the crop yield and water-use efficiency. Many farmers are not aware of these techniques. Appropriate training need to be imparted.
- Due to indiscriminate use of irrigation water, many fertile fields are becoming unproductive due to development of secondary salinity and sodicity.

7. CANAL CONDITIONS IN MULA COMMAND AREA

Canal conditions are not very good in Mula canal command. Canals are lined only in parts. Collapsing canal banks can be often observed in most part of the command. The erosion, collapsing of canal banks and serious canal deterioration can be frequently seen due to fast flowing water, unstable embankment due to water saturated or unsuitable soils, burrow pits or cattle climbing. All the above problems resulted in collapse of the embankment, serious canal deterioration, reduced flow and frequent disruption of irrigation supply. This is why the canals require frequent maintenance. Steep canal slopes in Mula command have resulted in erosion of canal bottom, progressively digging- in of canal, erosion of side slopes and collapse of the embankment in the command. This has resulted in eroding away the lower slopes, collapse of embankment, destruction of neighbouring fields or canals. In some parts of the command area, too small canals, too low canal bunds, obstructions in the canal were also observed, which most often resulted in eroding away of the lower slope, low water supply, high water losses and unequal water distribution. Water distribution in major parts of the command area can be rated as 'poor'. Main reasons of poor water distribution are illegal off-takes, uncontrolled and inadequate off-takes, uncontrolled and inadequate distribution, inadequate diversions, damaged and inadequate structures, inadequate water distribution etc.

8. IRRIGATION WATER QUALITY IN MULA COMMAND AREA

Quality wise water of MRBC and MLBC can be considered excellent. Canal water contains 2 to 3 meL^{-1} salt concentration with normal pH. Water quality does not deteriorate till the tail end of both the canal commands. However, ground water varies in quality parameters in different regions. In general, well water contains 5 to 50 meL^{-1} salt concentration with pH values ranging from 7.0 to 7.6. In some places sodium absorption ratio is as high as 7 $m\ mol^{1/2}\ L^{-1/2}$. Thus, the ground water quality is marginal to poor. This type of waters can be conjunctively used for irrigation on sodic soils in MLBC and sodic soils in the head reach of MRBC.

9. AIM AND SCOPE OF THE PRESENT STUDY

Present study is focused mainly on irrigation induced soil degradation in different reaches of Mula command area. Work has been carried out with the main objective to study the changes in hydro-physical behaviour of dominant soils with change in irrigation intensity and irrigation induced soil salinization and sodification; and to study the effect of irrigation induced soil salinization and sodification on dispersion and swelling behaviour of these soils.

10. SOIL SAMPLING IN MULA COMMAND AREA

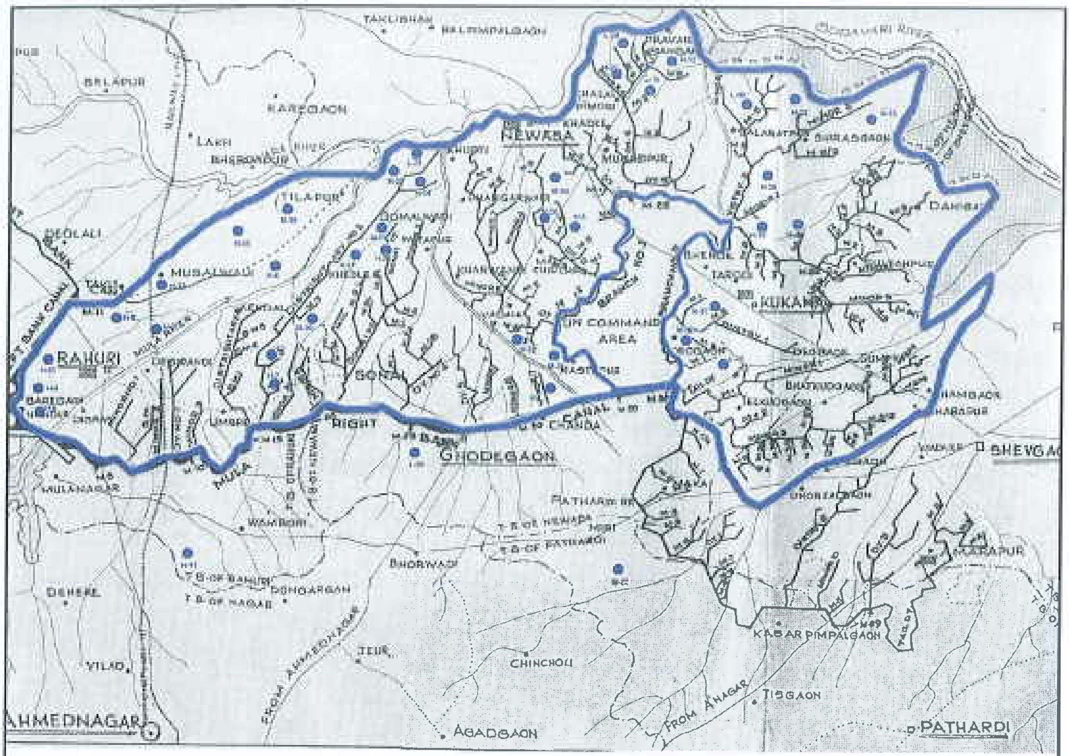
The command area was surveyed for identifying the locations, which are affected by irrigation induced degradation processes such as soil salinization and sodification. On

6th and 7th January 2004 the entire command area was surveyed for identifying the bench mark locations. On 8th and 9th January 2004, depth-wise soil samples were collected from various locations inside the command area and comparable profiles were dug outside the command area. Names of the villages where soil profiles were exposed are given in Table 3 and their locations on command area map are described in Figure 1. The command area consists of two main canals i.e. Mula right bank canal (MRBC) and Mula left bank canal (MLBC). MRBC consists of considerably higher area (about 70700 ha) as compared to MLBC (about 10100 ha). Therefore, one distributory each was selected in head, middle and tail reaches of MRBC. However, soil sampling was made in head, middle and tail reaches of MLBC. In head reach of MRBC, distributory No.3 was selected for soil sampling. Distributory No.3 was again divided into head, middle and tail reaches. In head reach location, soil sampling site was selected near Pimpari village where soil sampling was done in the farm land of

Table 3 : Names of the villages in Mula command area where soil profiles were exposed

Villages in Mula left bank canal command	Villages in Mula right bank canal command		
	Head reach	Middle reach	Tail reach
Bargaon	Pimpari	Rastapur East	Devgaon
Bargaon	Pimpari	Rastapur East	Devgaon
Bargaon	Amalner	Rastapur West	Ramdaspur
Aradgaon	Khedle	Mali Chinchore	Bhende
Rajura	Khedle	Mukundpur	Tarodi
Aradgaon	Vasoda	Mukundpur	Tarodi
Valan	Khupti	Pravara Sangam	Salabatpur
Tilapur	Khupti	Pravara Sangam	Salabatpur
Tilapur	Gonegaon	Pravara Sangam	Shirasgaon

Shri D.L.Jamdar. Two more profiles were selected within 3 to 4 km range between Pimpari and Amalner villages. In the middle of the distributory, soil sampling sites were selected between Khedle and Amalner villages in Rahuri tehsil. Samples were collected from three locations in cultivated fields of Shri J.K.Makone, Shri J.B.Kulkarni and Shri Y.P.Marathe. In the tail end of distributory No. 3, three profiles were selected between Khupti and Gonegaon villages in Rahuri tehsil. For this purpose three farmers selected where Shri B.D.Rode, Shri J.P.Yadav and Shri M.P. Desmukh. Four composite soil samples were collected from each profile by dividing the profile into 0-20cm, 20-40cm, 40-60 cm and >60cm layers. Infiltration studies were carried out using double ring infiltrometer technique near the soil sampling sites. Besides depth-wise composite soils samples, soil cores were also collected in metallic rings (10 cm diameter and 20 cm long) from 0-20cm, 20-40cm and 40-60 cm depths for determining saturated hydraulic conductivity.



• *Indicates soil sampling location in Mula command area*

Figure 1. Soil sampling locations in Mula command area

In the middle reach of MRBC, chanda minor and other minors extending towards Pravara Sangam were selected. This extended area was again divided into head, middle and tail reaches. In the head reach, soil profiles were selected between Rastapur east and Rastapur west villages from the cultivated land. For this purpose farm land of Shri A.B.Dahatonde, Shri T.R.Desmukh and Shri D.P.Chaudhari were selected. In the middle reach, soil profile were selected between Malichinchori and Mukundpur villages in Newasa tehsil and in the tail reach, soil profiles were selected near Pravara Sangam village in Newasa tehsil of Ahmednagar district. In the tail reach of MRBC, Deogaon branch No.2 and extended areas upto Salabatpur and Shirasgaon villages were selected for soil sampling. This area was divided into head, middle and tail reaches, where soil profiles were concentrated nearby Deogaon, Nandursikari and Ranzani villages in Shevgaon tehsil of Ahmednagar district.

In MLBC, entire canal command was divided into head, middle and tail reaches as this canal is having almost uniform type of soils and cropping pattern. In head reach of MLBC, soil samples were collected from Bargaon village from the cultivated fields of Shri A.B. Todmal. In middle reach, soil profiles were selected near Aradgaon village from the cultivated field of Sopanrao Tanpure. In the tail reach, soil samples were collected between Valan and Tilapur villages in Rahuri tehsil under Ahmednagar district. Besides soil sampling inside the command area, representative soil profiles each for clay, clay loam and sandy clay loam textures were selected from Dhamori, Vanjuli and Deogaon villages of Ahmednagar district outside the command area.

All the soil samples were brought to the field laboratory of All India Coordinated Research Project on Water Management, Rahuri centre. Core samples were immediately saturated and used for determining saturated hydraulic conductivity in the laboratory by constant head and falling head methods. Bulk samples were air dried for one day and sun dried for three days, thereafter samples were processed using wooden morter and pestle. These bulk samples were packed into polybags and covered with cotton bags. Processed samples were transported to WTCER, Bhubaneswar for further laboratory analysis. Disturbed soil samples were used to determine basic physico-chemical properties, dispersion and swelling properties, and hydraulic properties. Hydraulic properties consist of moisture characteristics curves, unsaturated hydraulic conductivity functions, soil-water diffusivity functions etc.

In general, the soils of command area were fine in texture having considerable swelling-shrinkage behaviour, high consistency, and high smectitic clay content. Clay Soils exhibited very low infiltration rate coupled with low saturated hydraulic conductivity values. In some parts of the command area medium textured clay loam soils were also observed. Whereas in the tail end, in patches, in Newasa and Shevgon tehsil, light textured sandy clay loam soils were observed.

11. BRIEF METHODOLOGY OF SOIL ANALYSIS

All the analyses were carried out using standard methods. Methods of routine analysis are summarized in Table 4 and specific procedures implied during the present study are briefly described in the following section.

Table 4: Methods used for determination of basic soil properties

Parameters	Methods	Reference
Particle size distribution	Bouyoucos hydrometer	Day (1965)
pH	In supernatant liquid	Jackson (1973)
ECe	In saturation paste extract	Jackson (1973)
Organic Carbon	Wet-oxidation method	Nelson and Sommers (1982)
$CaCO_3$	Titration against 0.5 *M* HCl	El Mahi et al. (1987)
Saturation paste extract	Extract through vacuum	Richards (1954)
CEC	0.1*N* NaOAc-0.4 *N* NaCl	Gupta et al. (1985)
ESP	Alcoholic NH_4Cl method	Tucker (1971)

Steady-state infiltration: Steady-state infiltration was determined using double ring infiltrometer near the selected soil profile at all 40 locations in head middle and tail reaches of the command area.

Saturated hydraulic conductivity (Ks): Saturated hydraulic conductivity of the clay soil was determined by falling head method, while Ks of the clay loam and silt loam soils was determined by constant head method. Procedure followed for Ks determination was similar to that described by Klute and Dirkson (1986). All determinations were repeated three times. Ks was calculated by rearranging Darcy's equation for constant head determination as:

$$Ks = \frac{VL}{At\Delta H}$$

where,

V = Volume of water collected at steady-state, mL
L = Length of the soil samples, cm
A = Cross sectional area, cm^2
T = Time, h and
H = Hydraulic head difference, cm
For falling head determination as:

$$Ks = \left(\frac{aL}{At}\right)\log\frac{H1}{H2}$$

where

a = Cross sectional area of stand pipe, cm^2

L = length of the soil samples, cm

A = Cross sectional area of the sample, cm^2

T = time, h

H1 = Initial head, cm and

H2 = Final head, cm

Water retention characteristics curves: Water retention at and above 10 kPa was determined using a pressure plate apparatus. Procedure described by Bruce and Luxmoore (1986), was followed for deriving soil moisture characteristics curves.

Unsaturated hydraulic conductivity and diffusivity: From the experimental Ks values and complete water retention characteristics curve, unsaturated hydraulic conductivity and diffusivity functions were developed using RETC-computer code that uses van-Genuchten–Mualem equation (Mualem 1976, van Genuchten 1980 and van

Genuchten and Nielsen 1985) to transform water retention data to unsaturated hydraulic conductivity and soil-water diffusivity functions.

Dispersion index: Dispersion index as defined by Mustafa and Letey (1969) was calculated as:

$$Dispersion\ Index, \% = \left[\frac{Water\ dispersible(silt + clay)}{Total(silt + clay)}\right] \times 100$$

Twenty grams of < 2 mm soil was placed in a one litre cylinder and water was slowly added to it. The soil suspension was stroked forty times with a longer plunger. The percentage of silt + clay size particulate was determined by the hydrometer method (Day 1965) and termed as water dispersible silt + clay. Total silt + clay was also determined by the hydrometer method after completely dispersing the soil. Complete dispersion was achieved by chemical and physical means. The Hydrometer used in these determinations was a standard ASTM No. 152 H, with Bouyoucos scale, calibrated at 68 °F. All the determinations were replicated five times.

Coefficient of linear extensibility (COLE):

In the present study, swell-shrink behaviour has been expressed in terms of COLE. The method described by Schafer and Singer (1976) was used for COLE measurements. The COLE was calculated using equation COLE = (Lm – Ld)/Ld where, *Lm* is the moist rod length and *Ld* is the dry rod length in cm. Saturated paste (Black, 1965) of soil was made using 100g soil. The paste was left to stand for 24 hours. The end of a disposable syringe was cut-off. The soil paste was placed in the syringe and extruded on a dry metallic tray to form soil rod of 8 to 10 cm length. The rods were trimmed-off and moist length was kept 5 cm. The tray was then transferred into an oven for 24 hours at 50 °C. The dry length was carefully recorded using a fine thread and a calliper. In order to reduce error in determination, all the determinations were repeated five times.

12. SOILS OF OUTSIDE THE COMMAND AREA

12.1 A representative clay soil profile outside the command area

This was a representative black cotton soil profile with clay texture belonging to Fine montmorillonitic isohyperthemic family of Typic Haplustert. pH of the soil was consistent and varied in a narrow range of 7.9 to 8.0 (Table 5). ECe also varied in a narrow range of 1.8 to 2.2 dSm^{-1}. The ESP values were ≤ 2.0 throughout the profile. Organic carbon content was low and ranged from 0.21% in lower layers to 0.32% in the surface layer. Calcium carbonate content was > 2% throughout the profile except below 60 cm, where it was < 2.0%. Cation exchange capacity of the soil varied between 45.9 and 47.0

Table 5: Chemical and physical properties of a representative clay soil profile out side the command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	8.0	2.2	0.32	2.25	45.9	2.0	Normal
20-40	7.9	2.0	0.29	2.20	46.2	1.9	Normal
40-60	7.9	1.8	0.30	2.00	47.0	1.9	Normal
>60	8.0	2.0	0.21	1.87	46.9	2.0	Normal

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE
	Sand %	Silt %	Clay %	Texture				
0-20	34.5	9.2	56.3	Clay	2.1	3.5	7.0	0.05
20-40	34.0	9.2	56.8	Clay	2.0	-	7.1	0.05
40-60	31.8	10.7	57.5	Clay	2.0	-	7.1	0.04
>60	29.6	12.3	58.1	Clay	-	-	7.0	0.05

$cmolkg^{-1}$ in various layers. High cation exchange capacity was mainly due to high clay content (>50%) and montmorillonitic nature of the clay minerals. Saturated hydraulic conductivity was around 2.0 cm h^{-1}. Steady-state infiltration rate was 3.5 cm h^{-1}. Dispersion index ranged from 7.0 to 7.1% throughout the profile and co-efficient of linear extensibility ranged from 0.04 to 0.05. Soil moisture characteristics curves (Figure 2) showed that the soil could retain 0.41 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.24 cm^3cm^{-3} water at 1500 kPa suction resulting in considerably high 0.17 cm^3cm^{-3} available water. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity was 2×10^{-3} cm h^{-1} and 10 $cm^{-2}h^{-1}$, respectively.

Since this profile was chosen from rainfed area, where irrigation is not practices, soil did not show accumulation of salts or adverse effect on hydraulic properties.

12.2 A representative clay loam soil profile outside the command area

This was a normal soil profile with clay loam texture belonging to Fine loamy montmorillonitic isohyperthemic family of Vertic Haplustept. pH of the soil was 7.9 in upper

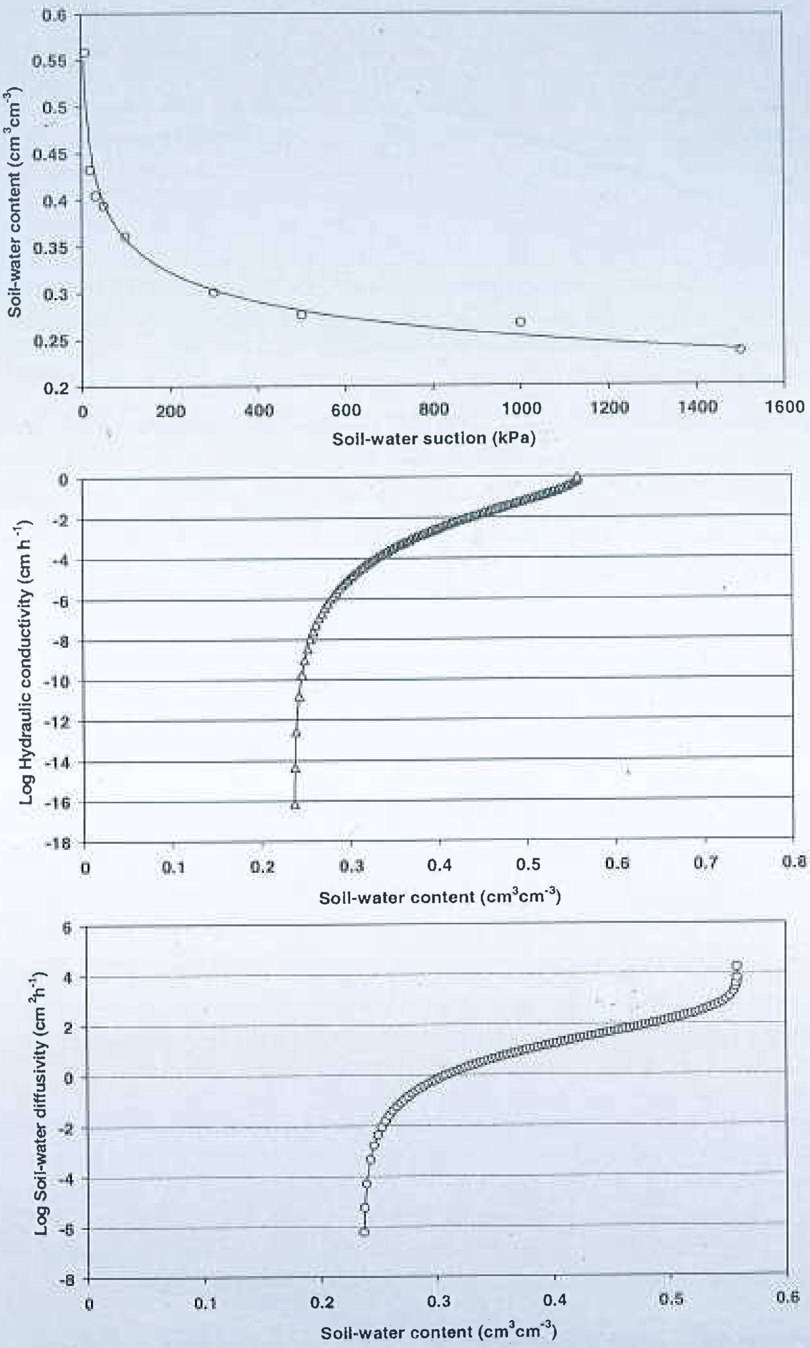


Figure 2: Soil water retention and transmission characteristics of a typical clay soil profile (averaged over all depths) out side the command area

Table 6: Chemical and physical properties of a representative clay loam soil profile out side the command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	7.9	1.6	0.31	1.6	39.9	1.8	Normal
20-40	7.9	1.4	0.25	1.5	40.1	1.8	Normal
40-60	7.5	1.3	0.25	1.0	40.5	1.4	Normal
>60	7.2	1.3	0.20	1.0	39.8	1.3	Normal

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE
	Sand %	Silt %	Clay %	Texture				
0-20	47.9	18.0	34.1	Clay loam	6.1	8.3	6.5	0.04
20-40	46.8	17.1	36.1	Clay loam	5.3	-	6.9	0.04
40-60	47.1	17.7	35.2	Clay loam	5.0	-	6.5	0.02
>60	46.3	17.8	35.9	Clay loam	-	-	6.3	0.02

layers and decreased to 7.2 in lower layers (Table 6). ECe was 1.6 dSm^{-1} in surface layer and decreased to 1.3 dSm^{-1} in lower layers. The ESP values were 1.8 in surface layers and remained < 1.4 in deeper layers. Thus, the soil was normal throughout the profile. Organic carbon content was low and ranged from 0.20% in lower layers to 0.31% in the surface layer. Calcium carbonate content was < 1.6% throughout the profile. Cation exchange capacity of the soil varied between 39.8 and 40.5 $cmolkg^{-1}$ in various layers. Saturated hydraulic conductivity values varied from 5.0 to 6.1 cm h^{-1} in various layers. Steady-state infiltration rate was 8.3 cm h^{-1}. Dispersion index was <7% throughout the profile and co-efficient of linear extensibility was also =0.04. Soil moisture characteristics curves (Figure 3) showed that the soil could retain 0.29 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.16 cm^3cm^{-3} water at 1500 kPa suction resulting in 0.13 cm^3cm^{-3} available water. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were 0.90 cmh^{-1} and 70 cm^2h^{-1}, respectively.

Since this profile was chosen from rainfed area, where irrigation is not practiced, soil did not show accumulation of salts and no adverse effect on soil hydro-physical behaviour was observed.

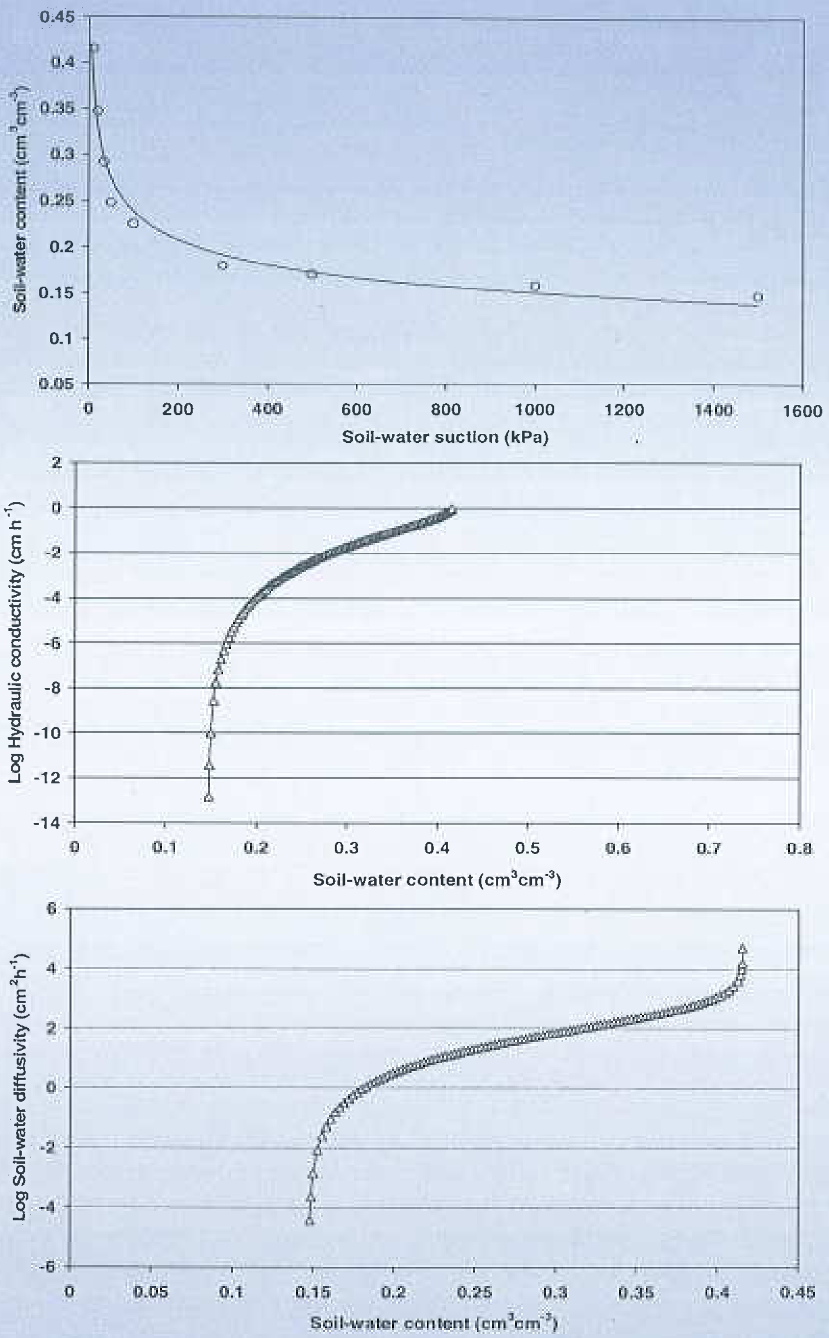


Figure 3: Water retention and transmission characteristics of a clay loam soil profile (averaged over all depths) out side the command area

12.3 A representative sandy clay loam soil profile outside the command area

This was a normal soil profile with sandy clay loam texture belonging to Loamy mixed isohyperthemic family of tropic Lithic Ustorthent. pH of the soil varied in a narrow range of 7.3 to 7.5 (Table 7). ECe was 0.24 dSm^{-1} at surface and decreased to 0.10 dSm^{-1} in lower layers. The ESP values were $\leq$ 1.2 in various layers. Thus, the soil was normal

Table 7: Chemical and physical properties of a representative sandy clay soil profile out side the command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	7.5	0.32	0.24	0.55	18.0	1.2	Normal
20-40	7.5	0.32	0.21	0.24	18.1	1.0	Normal
40-60	7.3	0.27	0.13	0.23	16.8	1.0	Normal
>60	7.3	0.26	0.10	0.13	15.4	1.1	Normal

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE
	Sand %	Silt %	Clay %	Texture				
0-20	53.4	18.5	28.1	Sandy clay loam	31.0	40.0	3.5	0.01
20-40	52.6	18.4	29.0	Sandy clay loam	29.3	-	4.0	0.01
40-60	51.3	20.5	28.2	Sandy clay loam	25.4	-	4.0	0.01
>60	49.5	19.8	30.7	Sandy clay loam	-	-	4.5	0.01

in reaction throughout the profile. Organic carbon content was low and ranged from 0.10% in lower layers to 0.24% in the surface layer. Calcium carbonate content was = 0.55% throughout the profile. Cation exchange capacity of the soil varied between 15.4 and 18.1 $cmolkg^{-1}$ in various layers. Saturated hydraulic conductivity was very high (25.4 to 31.0 cm h^{-1}) and steady-state infiltration rate was also high 40 cm h^{-1}. Dispersion index ranged from 3.5 to 4.5% throughout the profile and co-efficient of linear extensibility was also = 0.01. Soil moisture characteristics curves (Figure 4) showed that the soil could retain 0.19 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.08 cm^3cm^{-3} water at 1500 kPa suction resulting in 0.11 cm^3cm^{-3} available water. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were $1x10^{-2}$ cmh^{-1} and 90 cm^2h^{-1}, respectively.

This was a normal sandy clay loam soil profile, which was highly porous in nature. No salt accumulation was observed throughout the soil profile.

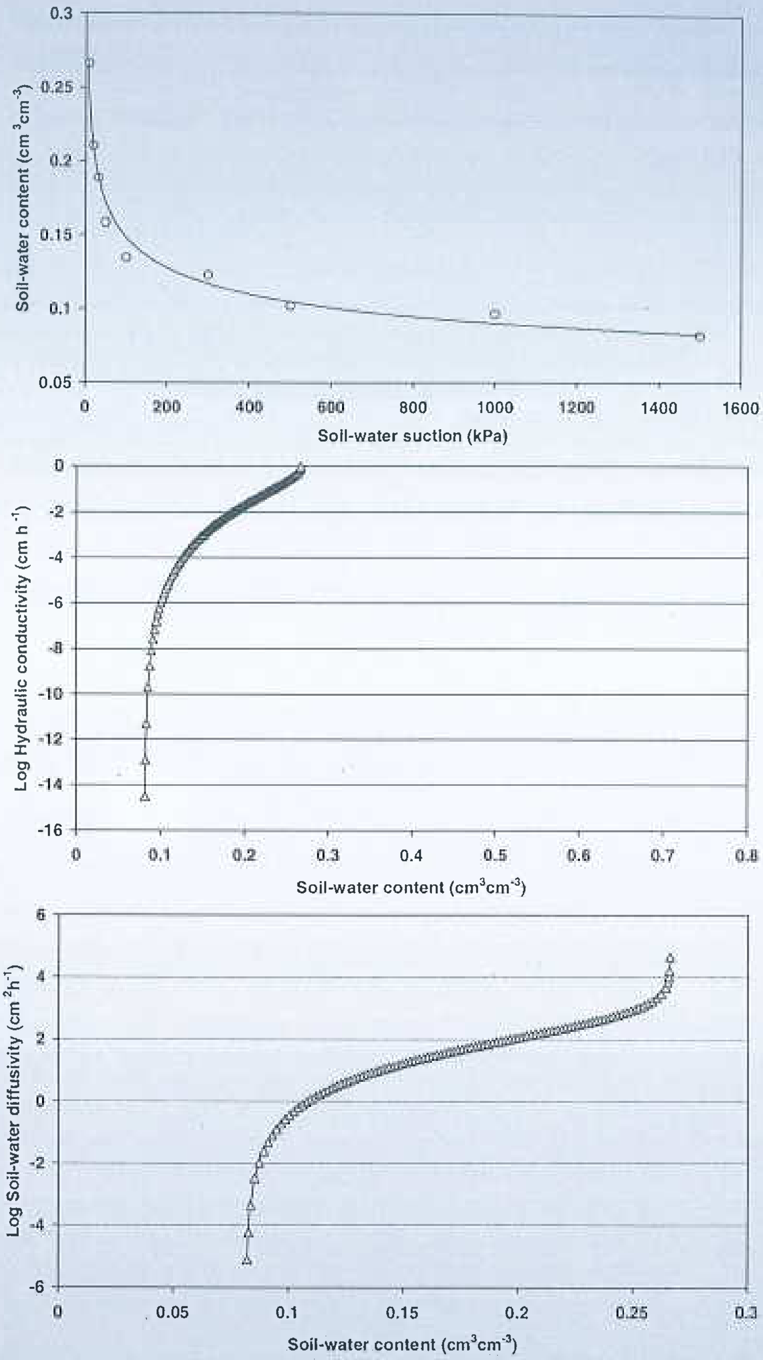


Figure 4: Soil water retention and transmission characteristics of a sandy clay soil profile (averaged over all depths) out side the command area

13. SOILS OF MULA LEFT BANK CANAL COMMAND AREA

13.1 Nature of the soils and extent of irrigation induced land degradation in Mula left bank canal command

Analysis of soil samples collected from different depths of nine soil profiles showed that pH of soils did not vary much in different depths. In general, pH values were uniform throughout the profiles (Table 8). In surface layers (0-20 and 20-40 cm) pH varied between 8.7 to 8.9. Electrical conductivity of saturated paste extract varied between 2.5 to 4.9 dSm^{-1} in 0-20 cm layer and between 2.4 to 5.1 dSm^{-1} in sub-surface layers. ESP of the soils in different depths was more than 15 indicating highly degraded condition of the soils. Texturally, 80% (8080 ha) of the soils in MLBC command were clay, and 20% (2020 ha) were clay loam. Pattern of degradation in Mula left bank canal command is depicted in Figure 5.

Data showed that 70% (7070 ha) of the MLBC command was affected by soil sodicity, 15% by saline-sodicity and 5% by salinity. Only 10% (1010ha) of the MLBC command was observed to be free from irrigation induced land degradation.

Table 8: Average physical and chemical properties (ranges) of nine soil profiles of Mula left bank canal command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Soil reaction
0-20	8.7-8.9	2.5-4.9	0.17-0.39	2.32-3.32	41.6-56.8	15.6-18.5	Saline sodic to Sodic
20-40	8.7-8.9	2.4-5.1	0.15-0.31	1.93-3.12	41.3-57.0	15.5-17.3	Saline sodic to Sodic
40-60	8.6-8.9	2.4-5.1	0.15-0.25	1.98-2.92	39.3-57.2	16.1-17.0	Saline sodic to Sodic
>60	8.5-8.8	2.4-5.0	0.13-0.17	2.00-2.74	37.3-56.9	15.7-17.1	Saline sodic to Sodic

Physical Properties

Depth	Textural Analysis				Ks	IR	DI	COLE
(cm)	Sand %	Silt %	Clay %	Texture	cm/h	cm/h	%	(cm.cm)
0-20	22.8-32.3	0.9-36.1	39.4-70.3	Clay loam to clay	0.05-1.8	0.1-2.1	7.2-20.1	0.09-0.20
20-40	23.6-33.3	0.3-35.6	39.0-70.1	Clay loam to clay	0.00-1.7	-	7.0-19.8	0.09-0.19
40-60	21.3-30.1	2.0-38.1	38.7-69.5	Clay loam to clay	0.00-1.5	-	7.3-19.5	0.09-0.20
>60	19.2-29.5	1.3-37.3	39.8-70.0	Clay loam to clay	-	-	6.9-18.3	0.09-0.19

(ECe = electrical conductivity of saturation paste extract, Org. C= organic carbon, CEC= cation exchange capacity, ESP= exchangeable sodium percentage, Ks= saturated hydraulic conductivity, IR= steady-state infiltration rate, DI= dispersion index, COLE= coefficient of linear extensibility)

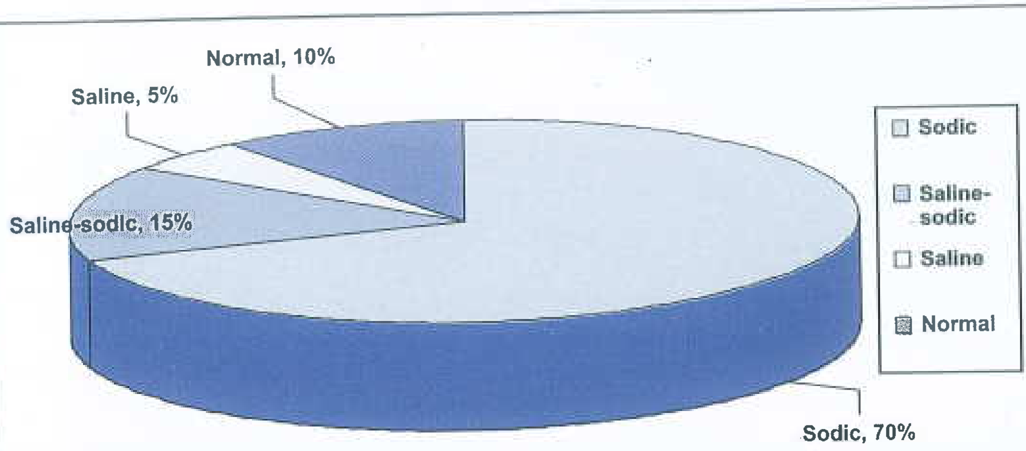


Figure 5: Distribution of problematic soils in Mula left bank canal command area

Saturated hydraulic conductivity of the soils ranged between 0.05 to 1.8 cmh^{-1} in 0-20 cm layer and remained very low (0.0 to 1.7 cm h^{-1}) in lower layers. In some cases it was difficult to determine saturated hydraulic conductivity even by following a falling head method. Steady-state infiltration rate also followed the similar trend and varied between 0.1 to 2.1 cm h^{-1} for different soils. Soils of MLBC command area were observed to be highly prone to dispersion. Dispersion index varied between 7.2 to 20.1%, 7.0 to 19.8%, 7.3 to 19.5% and 6.9 to 18.3% in 0-20 cm, 20-40 cm,40-60 cm and >60 cm depths, respectively. These soils showed very high swell-shrink potential as evident from coefficient of linear extensibility, which varied between 0.09 to 0.20, 0.09 to 0.19, 0.09 to 0.20 and 0.09 to 0.19 cm cm^{-1} in 0-20 cm, 20-40 cm, 40-60 cm and > 60 cm soil layers, respectively.

Comparison of physical and chemical properties of degraded clay soils of MLBC command area with the clay soil, outside the command showed that the faulty irrigation practices coupled with intensive cultivation have brought considerable changes in physical, chemical and hydro-physical behaviour of these soils.

13.2 Description of a representative soil profile under Mula left bank canal command

This profile (profile no. 6) was exposed at Bargaon village under Rahuri tehsil of Ahmednagar district. This was a sodic soil profile with clay texture. pH of the soil was considerably high and varied in a narrow range of 8.8 to 8.9 (Table 9). ECe also varied in a narrow range of 2.4 to 2.5 dSm^{-1}. The ESP values were considerably high in surface layer (18.2), and remained ≥17.5 in deeper layers. Thus, the soil was sodic throughout the profile. Organic carbon content was low and ranged from 0.13% in lower layers to 0.17% in the surface layer. Calcium carbonate content was > 2.7 % throughout the profile. Cation exchange capacity of the soil varied between 56.8 and 57.2 $cmolkg^{-1}$ in

Table 9: Physical and chemical properties of a representative soil profile Mula left bank canal command

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	8.9	2.5	0.17	3.21	56.8	18.2	Sodic
20-40	8.9	2.4	0.15	2.98	57.0	18.0	Sodic
40-60	8.9	2.4	0.15	3.10	57.2	17.9	Sodic
>60	8.8	2.4	0.13	2.78	56.9	17.5	Sodic

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE
	Sand %	Silt %	Clay %	Texture				
0-20	29.1	0.6	70.3	Clay	0.05	0.1	20.1	0.19
20-40	29.6	0.3	70.1	Clay	0.00	-	19.8	0.18
40-60	28.5	2.0	69.5	Clay	0.00	-	19.5	0.19
>60	28.7	1.3	70.0	Clay	-	-	18.3	0.19

various layers. High cation exchange capacity was mainly due to high clay content (>65%) and montmorillonitic nature of the clay minerals. Saturated hydraulic conductivity was very low (0.05 cmh^{-1}) indicating poor drainage conditions of the soil. Steady-state infiltration rate was also low (0.1 $cm\ h^{-1}$). Poor hydraulic conductivity and infiltration might be the result of i) very high clay content, ii) dominance of montmorillonitic minerals in the soil, iii) sodicity induced silt and clay dispersion, and iv) sodicity induced swelling of clay minerals. Dispersion index was >18% throughout the profile and co-efficient of linear extensibility was also >0.18. Soil moisture characteristics curves (Figure 6) showed that the soil could retain 0.52 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.31 cm^3cm^{-3} water at 1500 kPa suction resulting in considerably high (0.21 cm^3cm^{-3}) available water. Like saturated hydraulic conductivity, unsaturated hydraulic conductivity and soil-water diffusivity functions were badly influenced by irrigation induced sodicity. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were $1x10^{-4}$ cmh^{-1} and 0.1 cm^2h^{-1}, respectively.

Poor hydraulic and transmission characteristics showed that the soil was adversely affected by over irrigation and needs immediate attention for proper management. Though the soil showed high available water capacity, but its poor water transmission and high sodium concentration mostly interferes with the plant growth and development. High dispersion also aid to formation of surface seals and crusts rendering germination of seeds a great problem. This soil needs immediate arrangement for drainage.

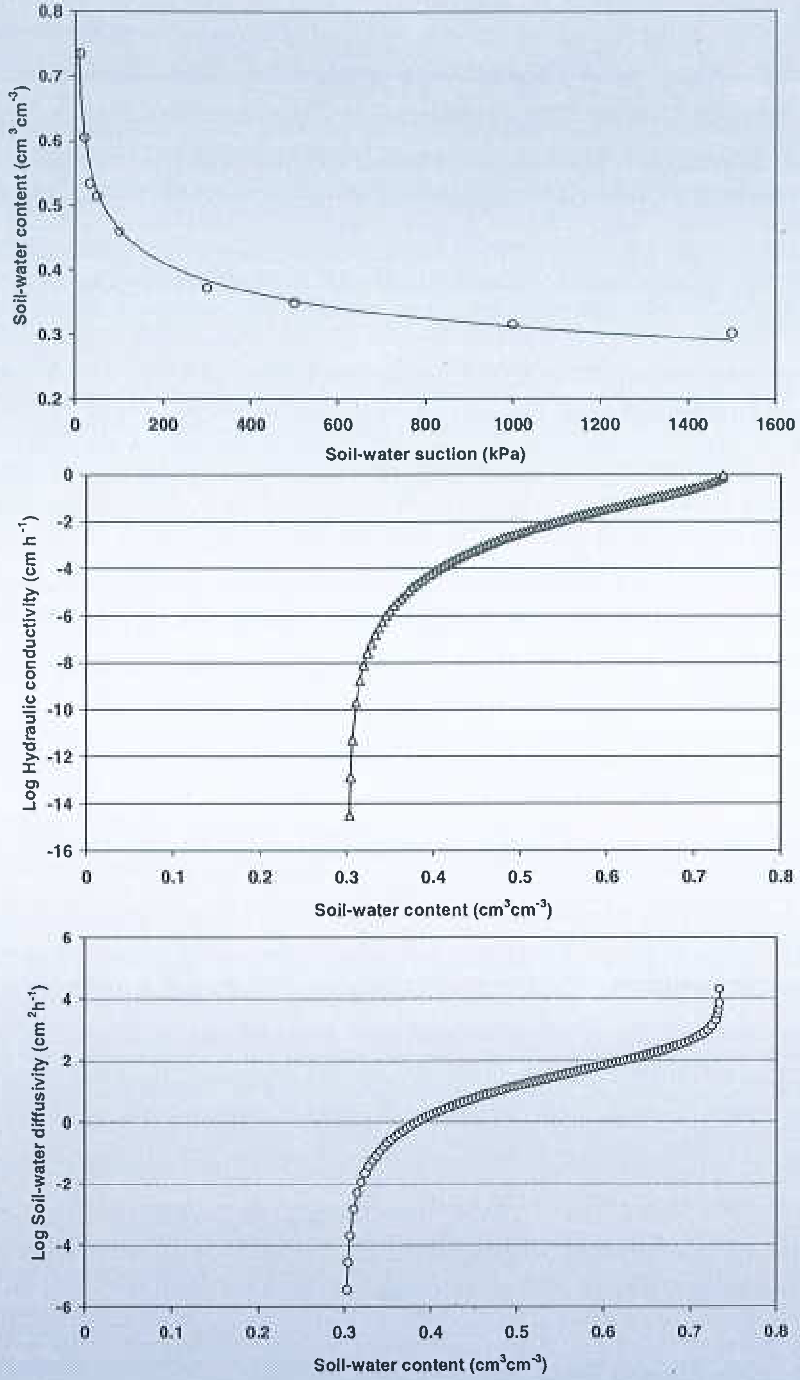


Figure 6: Soil water retention and transmission characteristics of a typical soil profile (averaged over all depths) of Mula left bank canal command

13.3 Findings of practical utility and recommendations for Mula left bank canal command

- Majority (80%) of the soils of MLBC command are clay in texture and only 20% (2020 ha) soils are clay loam in texture.
- Soil pH in different depths of the studied profiles was > 8.5 and ECe varied between 2.4 to 5.1 dSm^{-1}, indicating the soils are saline sodic to sodic in reaction.
- About 70% (7070 ha), 15% (1515 ha) and 5% (5050 ha) of net (10100 ha) CCA under MLBC was affected by the problems of sodicity, saline-sodicity and salinity, respectively.
- Only 10% of the MLBC command area was observed to be free from irrigation induced lad degradation.
- Data on saturated hydraulic conductivity, unsaturated hydraulic conductivity, soil-water diffusivity and steady-state infiltration rate showed that the problem of degradation was so acute in some soils that no drainage was observed even for 2 days.
- Soils of the entire command are highly prone to silt and clay dispersion coupled with very high swell-shrink potential. This phenomenon enhances runoff losses and makes soil workability/management a difficult task.
- MLBC command area warrants immediate attention for soil and crop management as compared with different reaches of MRBC command area.

13.4 Preventive and reclamative measures for the soils of Mula left bank canal command

A. Measures for sodic soils

Preventive measures

- For preventing soils of the command area from alkalinity, it is necessary to provide proper drainage system. Provision of field channels to drain crop lands should be made and for collecting drainage effluent proper network of drains be made.
- Conjunctive use of ground and canal water for irrigation also helps in preventing development of sodicity in the soils.
- Regular green manuring, FYM application, and residue incorporation is observed to be the most effective measure in preventing development of soil alkalinity.
- Being water exhaustive crop, cultivation of sugarcane should be avoided or it should be cultivated using drip irrigation method.
- Deep ploughing once in three years on medium and heavy textured soils help preventing soil alkalinity.

Reclamative measures

- Use of chemical amendments such as Gypsum is the most effective way of reclaiming alkali soils in the command areas. Powdered gypsum should be broadcasted and incorporated in 10 to 15 cm depth in case of medium textured soils and 15 to 20 cm in case of heavy textured soils. After broadcasting, gypsum should be thoroughly mixed by discing the field or using tractor driven cultivator.
- In this area several sugar factories are in operation. These sugar factories produce huge quantity of press mud. The press mud contains considerably high concentrations of calcium. Use of sulphonated press mud effectively reclaims alkali soils.
- Ground water in this area often contains 30-40 meL^{-1} salt concentration. If such marginal quality water is used for irrigation in conjunction with canal water, it improves the movement of water through the soils and also helps in lowering the ESP levels. Therefore, conjunctive use of saline ground water with canal water is a very good option for managing alkali soils in Mula command area.
- Reclamation of sodic lands becomes more effective if the provisions for drainage are made. Due to uneven distribution of rainfall, unfavourable characteristics and flat topography, these soils produce high volume of runoff which creates the problem of surface drainage. Construction of appropriate graded bunds can solve this problem to some extent. The water below the bunds can safely be collected and stored in farm ponds and can be used for recharging ground water and also for life saving irrigation.
- Sesbenia green manuring, application of FYM and incorporation of crop residues are equally effective in reclaiming alkali soils as that of saline soils.
- Cotton, barley, sugarbeet etc crops can be successfully grown on alkaline lands under Mula command conditions.
- Fertilizers should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils. Ammonium sulphate should be preferred as nitrogen fertilizer till the soils are reclaimed.

B. Measures for saline-sodic soils

Preventive measures

- Conjunctive use of ground and canal water for irrigation helps in preventing development of sodicity in the soils.
- Sesbenia green manuring is the most efficient management option for lowering the salt concentration in the profile.

- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc also help in preventing saline-sodicity development.
- Cultivation of water exhaustive crops like sugarcane should be avoided. Since sugarcane is the most important crop of this area, it should be raised with drip irrigation method.
- Irrigation should be practiced with drip method in sugarcane, cotton, groundnut etc. and with sprinkler method in close-growing crops like wheat, barley, onion etc. Low energy precision water application devices can also be tried.
- Provision for surface drainage should be made. Proper collection and disposal of drainage effluent needs to be ensured.

Reclamative measures

- Ground water in this area often contains 30-40 meL^{-1} salt concentration. If such quality water is used in conjunction with canal water, it improves the movement of water through the soils and also helps in lowering the ESP levels. Therefore, conjunctive use of saline ground water with canal water is a very good option for managing saline-alkali soils in Mula command area.
- Sesbenia green manuring is observed to be the most efficient method for reclamation of saline-alkali soils.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. help in rapid reclamation of these soils.
- Scraping of surface soils is the most effective management measure for the saline-alkali soils.
- Use of chemical amendments such as Gypsum is the most effective way of reclaiming alkali soils in the command areas. Powdered gypsum should be broadcasted and incorporated in 10 to 15 cm depth in case of medium textured soils and 15 to 20 cm in case of heavy textured soils. After broadcasting, gypsum should be thoroughly mixed by discing the field or using tractor driven cultivator.
- In this area several sugar factories are in operation, these sugar factories produce huge quantity of press mud. The press mud contains considerably high concentrations of calcium. Use of sulphonated press mud effectively reclaims alkali soils.
- Provision of surface and sub-surface drainage should be made to ensure proper flushing of salts. Flushing should be ensured by furrow method on properly levelled lands.

- Choice of salt tolerant crops such as cotton is also one of the best options to control salinity and alkalinity development in the soil. Tolerance to salinity varies a great deal, almost 10 fold, amongst the crop plants and to a lesser extent amongst their genotypes. These inter- and intra-genic variations in salt tolerance of plants can be exploited for selecting crops or varieties that produce satisfactory yields under a given root zone salinity.
- For sowing of various crops ridge method should be adopted and seeds of the crops should be sown on the side of the ridge within the capillary fringe just above the irrigation water in furrows.
- In this area cotton-wheat-dhaincha, dhaincha-wheat-cowpea or maize-wheat-green gram sequences should be preferred over other sequences.
- Fertilizer should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils. Ammonium sulphate should be preferred as nitrogen fertilizer till the soils are reclaimed.

14. SOILS OF HEAD REACH OF MULA RIGHT BANK CANAL COMMAND AREA

14.1 Nature of the soils and extent of irrigation induced degradation in head reach of Mula right bank canal command

Analysis of soil samples collected from different depths of nine soil profiles showed that pH values were higher (8.6 to 8.9) in surface (0-20 cm) layer as compared with lower layers (Table 10). In lower depths pH varied between 8.0 to 8.8 in different soils. Values of ECe of saturation paste extract were higher (3.1 to 5.4 dSm^{-1}) in 0-20 cm layer as compared with lower layers of soil profile. ESP values varied between 15.4 to17.3, 14.3 to 17.3, 6.5 to 17.8 and 1.3 to 18.1 in 0-20 cm, 20-40 cm, 40-60 cm and >60 cm layers of different soil profiles indicating differential degradation status of the soils under this command area. Texturally 70% (7000 ha) of the soils in MRBC head reach command were clay, 25% (2500 ha) clay loam and 5% (500 ha) were sandy clay loam. Pattern of soil degradation in head reach of MRBC command is depicted in Figure 7.

Data showed that 30% (3000 ha) of the total command area under head reach of MRBC is affected by soil sodicity, 50% (5000 ha) by saline-alkalinity and 10% (1000 ha) by soil salinity. Only 10% (1000 ha) of the head reach of MRBC was observed to be free from irrigation induced land degradation.

Saturated hydraulic conductivity of the soils ranged between 0.3 to 4.2 cm h^{-1}, 0.2 to 10.4 cm h^{-1} and 0.2 to 12.5 cm h^{-1} in 0-20 cm, 20-40 cm and 40-60 cm layers of different

Table 10 : Average physical and chemical properties (ranges) of nine soil profiles of Head reach of Mula right bank canal command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Soil reaction
0-20	8.6-8.9	3.1-5.4	0.15-0.36	2.41-3.21	23.2-52.7	15.4-17.3	Saline sodic to Sodic
20-40	8.0-8.8	2.8-5.5	0.14-0.32	1.96-3.10	24.2-51.6	14.3-17.3	Saline to Sodic
40-60	8.2-8.8	2.9-5.3	0.09-0.27	1.98-2.62	19.2-52.1	06.5-17.8	Saline to Sodic
>60	8.0-8.8	3.0-5.4	0.07-0.30	2.02-2.34	19.0-52.1	01.3-18.1	Saline to Sodic

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE (cm.cm)
	Sand %	Silt %	Clay %	Texture				
0-20	29.8-53.3	7.5-37.3	29.8-62.7	Sandy CL to clay	0.3-4.2	0.6-7.0	7.4-12.3	0.07-0.13
20-40	28.7-54.2	7.9-37.6	31.6-63.4	Sandy CL to clay	0.2-10.4	—	8.3-12.0	0.04-0.13
40-60	28.7-53.3	6.4-38.0	31.3-64.3	Sandy CL to clay	0.2-12.5	—	7.9-12.0	0.02-0.12
>60	26.0-55.2	9.3-39.0	30.9-63.3	Sandy CL to clay	—	—	7.3-12.0	0.01-0.11

(ECe = electrical conductivity of saturation paste extract, Org. C= organic carbon, CEC= cation exchange capacity, ESP= exchangeable sodium percentage, Ks= saturated hydraulic conductivity, IR= steady-state infiltration rate, DI= dispersion index, COLE= coefficient of linear extensibility)

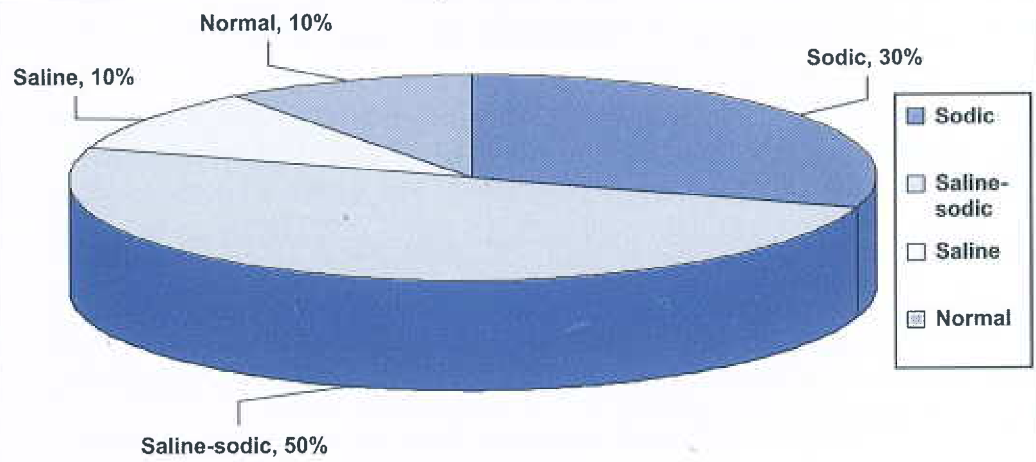


Figure 7: Distribution of problematic soils in head reach of Mula right bank canal command area

soil profiles, respectively. Drainage condition of sodic soils of the command area was observed to be very poor. Infiltration rate varied between 0.6 to 7.0 cm h^{-1} in different soils. Sodic soils of the command area exhibited high dispersion behaviour and dispersion index varied between 7.4 to 12.3%, 8.3 to 12.0%, 7.9 to 12.0% and 7.3 to 12.0% in 0-20 cm, 20-40 cm, 40-60 cm and > 60 cm layers of the soil profiles, respectively. Sodic clay soils of the command area showed very high swell-shrink potential as evident from very high (0.11 to 0.13 cm cm^{-1}) COLE values.

Comparison of physical and chemical properties of different textured soils of MRBC-head reach command area with the similar textured soils outside the command revealed that the irrigation and crop management practices have brought undesirable changes in all three textured soils in terms of physical, chemical and hydro-physical behaviour of these soils.

14.2 Description of a representative soil profile under head reach of Mula right bank canal command

A representative soil profile (profile no. 2) was exposed at Pimpari village under Rahuri tehsil of Ahmednagar district. This was a sodic soil profile with clay texture. pH of the soil was considerably high and varied in a narrow range of 8.8 to 8.9 (Table 11). ECe

Table 11: Physical and chemical properties of a representative soil profile under head reach of Mula right bank canal command

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	8.9	3.2	0.21	3.21	50.3	16.8	Sodic
20-40	8.8	3.1	0.15	3.26	48.7	17.1	Sodic
40-60	8.8	3.0	0.16	3.10	51.3	16.9	Sodic
>60	8.8	3.1	0.17	2.90	49.6	16.5	Sodic

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE
	Sand %	Silt %	Clay %	Texture				
0-20	31.7	12.6	55.7	Clay	0.3	0.8	12	0.12
20-40	30.4	13.3	56.3	Clay	0.2	-	11	0.12
40-60	31.0	14.1	54.9	Clay	0.2	-	12	0.12
>60	26.7	20.1	53.2	Clay	-	-	10	0.10

also varied in a narrow range of 3.0 to 3.2 dSm^{-1}. The ESP values were considerably high in surface layer (16.8), and remained >16 in deeper layers. Thus, the soil was sodic throughout the profile. Organic carbon content was low and ranged from 0.17% in lower layers to 0.21% in the surface layer. Calcium carbonate content was $\geq$ 3% throughout the profile. Cation exchange capacity of the soil varied between 48.7 and 51.3 $cmolkg^{-1}$ in various layers. High cation exchange capacity was mainly due to high clay content (>50%) and montmorillonitic nature of the clay minerals. Saturated hydraulic conductivity was very low (= 0.3 cmh^{-1}) indicating poor drainage conditions of the soil. Steady-state infiltration rate was also low (0.8 cm h^{-1}). Poor hydraulic conductivity and infiltration might be the result of i) very high clay content, ii) dominance montmorillonitic minerals in the soil, iii) sodicity induced silt and clay dispersion, and iv) sodicity induced swelling of clay minerals. Dispersion index was >11% throughout the profile and co-efficient of linear extensibility was 0.12. Soil moisture characteristics curves (Figure 8) showed that the soil could retain 0.49 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.31 cm^3cm^{-3} water at 1500 kPa suction resulting in considerably high (0.18 cm^3cm^{-3}) available water. Like saturated hydraulic conductivity, unsaturated hydraulic conductivity and soil-water diffusivity functions were badly influenced by irrigation induced sodicity. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were $1x10^{-3}$ cmh^{-1} and 10 cm^2h^{-1}, respectively.

Poor hydraulic and transmission characteristics showed that the soil was badly affected by over irrigation and needs immediate attention for proper management. Though the soil showed high available water capacity, but its poor water transmission and high sodium concentration mostly interferes with the plant growth and development. High dispersion also lead to formation of surface seals and crusts, rendering germination of seeds a great problem. This soil needs immediate arrangement for drainage.

14.3 Findings of practical utility and recommendations for head reach of MRBC

- About 70%, 25% and 5% soils of head reach of MRBC command area can be classified as clay, clay loam and sandy clay loam in texture.
- Reaction-wise surface soils (0-20 cm) were saline-sodic to sodic in nature and subsurface soils (>20 cm) were saline to sodic in nature.
- Out of 10,000 ha command area under head reach of MRBC, 30%, 50% and 10% areas were affected by the problem of soil sodicity, saline-sodicity and salinity, respectively.
- Only 10% (1000 ha) area of head reach of MRBC was observed to be free from irrigation induced land degradation.

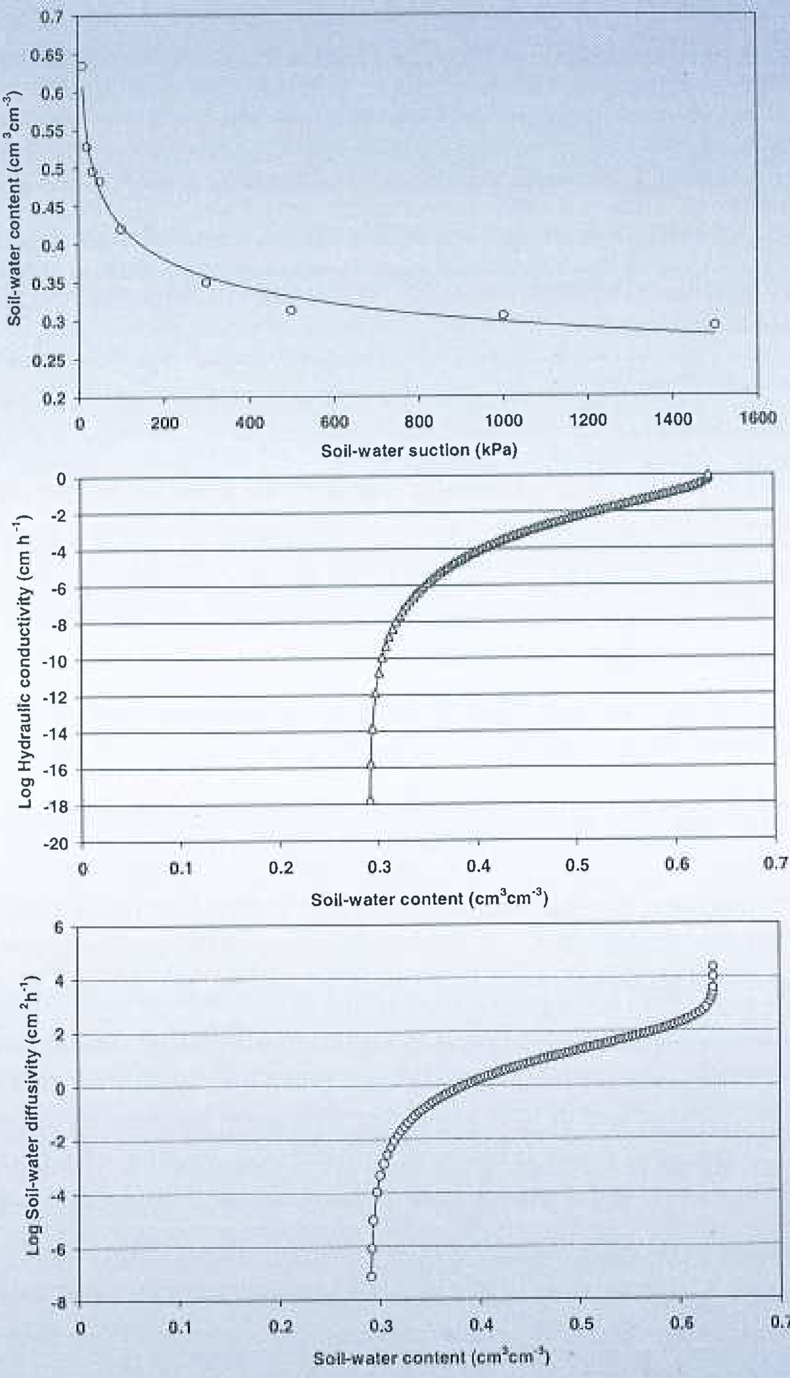


Figure 8: Soil water retention and transmission characteristics of a typical soil profile (averaged over all depths) in head reach of MRBC

- Most of the clay and clay loam soils showed very poor drainage condition by exhibiting poor water transmission characteristics.
- Sodic soils of the command retained very high moisture at all soil-water suction points as compared with similar soils out side the command area.
- Clay and clay loam soils of the command were highly prone to silt and clay dispersion, and very high swell-shrink potential leading to high runoff losses.
- The command area warrants immediate attention for managing the degraded soils.

14.4 Preventive and reclamative measures for the soils of head reach of Mula right bank canal command

A. Measures for sodic soils

Preventive measures

- For preventing soils of the command area from alkalinity, it is necessary to provide proper drainage system. Provision of field channels to drain crop lands should be made and for collecting drainage effluent proper network of drains be made.
- Conjunctive use of ground and canal water for irrigation also helps in preventing development of sodicity in the soils.
- Regular green manuring, FYM application, and residue incorporation is observed to be the most effective measure in preventing development of soil alkalinity.
- Being water exhaustive crop, cultivation of sugarcane should be avoided or it should be cultivated using drip irrigation method.
- Deep ploughing once in three years on medium and heavy textured soils help preventing soil alkalinity.

Reclamative measures

- Use of chemical amendments such as Gypsum is the most effective way of reclaiming alkali soils in the command areas. Powdered gypsum should be broadcasted and incorporated in 10 to 15 cm depth in case of medium textured soils and 15 to 20 cm in case of heavy textured soils. After broadcasting, gypsum should be thoroughly mixed by discing the field or using tractor driven cultivator.
- In this area several sugar factories are in operation. These sugar factories produce huge quantity of press mud. The press mud contains considerably high concentrations of calcium. Use of sulphonated press mud effectively reclaims alkali soils.
- Ground water in this area often contains 30-40 meL^{-1} salt concentration. If such marginal quality water is used for irrigation in conjunction with canal water, it

improves the movement of water through the soils and also helps in lowering the ESP levels. Therefore, conjunctive use of saline ground water with canal water is a very good option for managing alkali soils in Mula command area.

- Reclamation of sodic lands becomes more effective if the provisions for drainage are made. Due to uneven distribution of rainfall, unfavourable characteristics and flat topography, these soils produce high volume of runoff which creates the problem of surface drainage. Construction of appropriate graded bunds can solve this problem to some extent. The water below the bunds can safely be collected and stored in farm ponds and can be used for recharging ground water and also for life saving irrigation.
- Sesbenia green manuring, application of FYM and incorporation of crop residues are equally effective in reclaiming alkali soils as that of saline soils.
- Cotton, barley, sugarbeet etc crops can be successfully grown on alkaline lands under Mula command conditions.
- Fertilizers should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils. Ammonium sulphate should be preferred as nitrogen fertilizer till the soils are reclaimed.

B. Measures for saline-sodic soils

Preventive measures

- Conjunctive use of ground and canal water for irrigation helps in preventing development of sodicity in the soils.
- Sesbenia green manuring is the most efficient management option for lowering the salt concentration in the profile.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc also help in preventing saline-sodicity development.
- Cultivation of water exhaustive crops like sugarcane should be avoided. Since sugarcane is the most important crop of this area, it should be raised with drip irrigation method.
- Irrigation should be practiced with drip method in sugarcane, cotton, groundnut etc. and with sprinkler method in close-growing crops like wheat, barley, onion etc. Low energy precision water application devices can also be tried.
- Provision for surface drainage should be made. Proper collection and disposal of drainage effluent needs to be ensured.

Reclamative measures

- Ground water in this area often contains 30-40 meL^{-1} salt concentration. If such quality water is used in conjunction with canal water, it improves the movement of water through the soils and also helps in lowering the ESP levels. Therefore, conjunctive use of saline ground water with canal water is a very good option for managing saline-alkali soils in Mula command area.
- Sesbenia green manuring is observed to be the most efficient method for reclamation of saline-alkali soils.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. help in rapid reclamation of these soils.
- Scraping of surface soils is the most effective management measure for the saline-alkali soils.
- Use of chemical amendments such as Gypsum is the most effective way of reclaiming alkali soils in the command areas. Powdered gypsum should be broadcasted and incorporated in 10 to 15 cm depth in case of medium textured soils and 15 to 20 cm in case of heavy textured soils. After broadcasting, gypsum should be thoroughly mixed by discing the field or using tractor driven cultivator.
- In this area several sugar factories are in operation, these sugar factories produce huge quantity of press mud. The press mud contains considerably high concentrations of calcium. Use of sulphonated press mud effectively reclaims alkali soils.
- Provision of surface and sub-surface drainage should be made to ensure proper flushing of salts. Flushing should be ensured by furrow method and properly levelled lands.
- Choice of salt tolerant crops such as cotton is also one of the best options to control salinity and alkalinity development in the soil. Tolerance to salinity varies a great deal, almost 10 fold, amongst the crop plants and to a lesser extent amongst their genotypes. These inter- and intra-genic variations in salt tolerance of plants can be exploited for selecting crops or varieties that produce satisfactory yields under a given root zone salinity.
- For sowing of various crops ridge method should be adopted and seeds of the crops should be sown on the side of the ridge within the capillary fringe just above the irrigation water in furrows.
- In this area cotton-wheat-dhaincha, dhaincha-wheat-cowpea or maize-wheat-green gram sequences should be preferred over other sequences.

- Fertilizer should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils. Ammonium sulphate should be preferred as nitrogen fertilizer till the soils are reclaimed.

15. SOILS OF MIDDLE REACH OF MULA RIGHT BANK CANAL COMMAND AREA

15.1 Nature of the soils and extent of irrigation induced degradation in middle reach of Mula right bank canal command

Analysis of ten soil profiles studied in middle reach of MRBC consisting of Newasa and Ghodegaon branches and covering an area of 44000 ha revealed that the soil salinity is the main problem of this area. Data presented in Table 12 showed that soil pH values ranged between 8.2 to 8.7 in surface layers (0-40 cm) and remained low (7.6 to 8.6 and 7.3 to 8.5) in > 40 cm layers. Electrical conductivity values of saturated paste

Table 12: Average physical and chemical properties (ranges) of ten soil profiles of Middle reach of Mula right bank canal command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Soil reaction
0-20	8.2-8.7	4.3-5.4	0.22-0.47	1.32-3.72	22.0-54.3	3.2-16.8	Saline to saline sodic
20-40	8.2-8.7	4.2-5.3	0.17-0.37	0.63-3.92	19.3-52.1	2.3-16.4	Saline to saline sodic
40-60	7.6-8.6	3.7-5.1	0.14-0.29	0.54-3.20	20.8-54.8	1.3-16.0	Normal to saline sodic
>60	7.3-8.5	2.0-4.9	0.13-0.24	0.41-2.74	21.3-53.1	0.9-14.7	Normal to saline sodic

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE (cm.cm)
	Sand %	Silt %	Clay %	Texture				
0-20	18.5-48.2	19.2-32.9	31.7-53.2	Sandy CL to clay	1.1-22.1	1.3-29.0	3.2-8.2	0.03-8.2
20-40	19.8-49.6	17.1-33.1	32.2-54.6	Sandy CL to clay	0.8-17.0	—	3.2-8.2	0.02-8.2
40-60	17.6-49.3	25.3-33.1	23.4-54.8	Sandy CL to clay	1.0-17.9	—	4.0-9.2	0.02-9.2
>60	15.4-52.9	19.2-33.4	34.8-52.9	Sandy CL to clay	—	—	3.7-7.1	0.01-7.1

(ECe = electrical conductivity of saturation paste extract, Org. C= organic carbon, CEC= cation exchange capacity, ESP= exchangeable sodium percentage, Ks= saturated hydraulic conductivity, IR= steady-state infiltration rate, DI= dispersion index, COLE= coefficient of linear extensibility) extract ranged between 4.3 to 5.4 dSm^{-1}, 4.2 to 5.3 dSm^{-1}, 3.7 to 5.1 dSm^{-1} and 2.0 to 4.9 dSm^{-1} in 0-20 cm, 20-40 cm, 40-60 cm and > 60 cm layers of different soil profiles, respectively. ESP of the soils varied widely between 3.2 to 16.8, 2.3 to 16.4, 1.3 to 16.0 and 0.9 to 14.7 in 0-20 cm, 20-40 cm, 40-60 cm and > 60 cm layers, respectively. Surface layers were saline to saline-sodic, while sub-surface layers were normal to saline-sodic in reaction. Distribution of soils in various categories has been depicted in Figure 9.

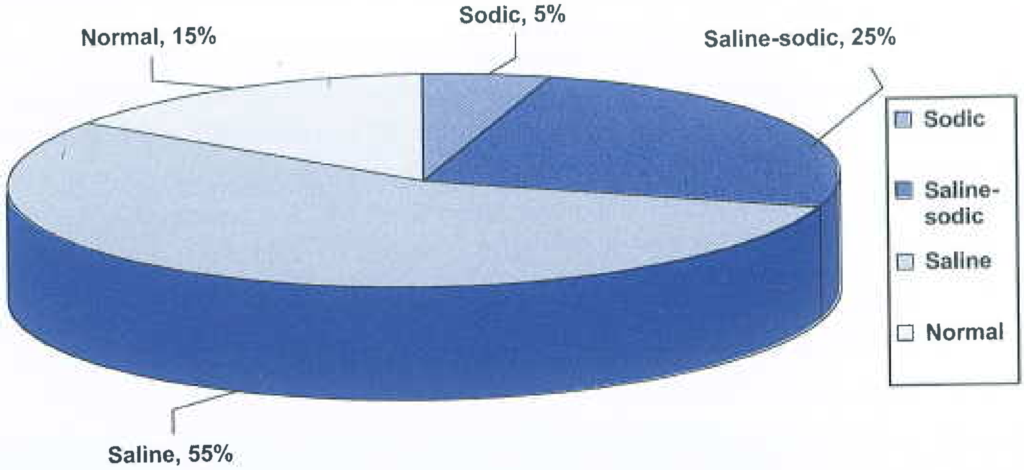


Figure 9: Distribution of problematic soils in middle reach of Mula right bank canal command area

Data showed that out of 44000 ha area under middle reach of MRBC, 5% (2200 ha), 25% (11000 ha) and 55% (24200 ha) area was affected by the problems of soil sodicity, saline-sodicity and salinity, respectively. About 6600 ha (15%) area was observed to be free from problems.

Texturally, 50%, 40% and 10% of the soils of this command area can be classified as clay, clay loam and sandy clay loam. Saturated hydraulic conductivity ranged between 1.1 to 22.1 cm h^{-1}, 0.8 to 17.0 cm h^{-1} and 1.0 to 17.9 cm h^{-1} in 0-20 cm, 20-40 cm and > 40 cm depths of soil profile, respectively. Steady-state infiltration rate varied between 1.3 to 29.0 cm h^{-1}. In general, the drainage conditions of clay loam and sandy clay loam soils was highly satisfactory. However, in some patches occupied by clay soils, particularly saline-sodic clay soils, drainage was impeded. Dispersion and swelling behaviour of the clay loam and sandy clay loam soils was satisfactory but that of clay soils was poor. In some saline-sodic clay soils, dispersion index was as high as 9.2%.

Comparison of soils under middle reach of MRBC with similar textured soils outside the command revealed that the pH and EC of the soils have changed to a large extent and caused a serious problem of soil salinity.

15.2 Description of a representative soil profile under middle reach of Mula right bank canal command

This profile was selected in the Eastern side of Rastapur village under Newasa tehsil of Ahmednagar district. This was a mixed type of soil profile with clay texture having saline-sodic properties in surface and saline properties in deeper layers. pH of the soil was considerably high and varied in a narrow range of 8.5 to 8.7 (Table 13). ECe also varied in a narrow range of 4.9 to 5.2 dSm^{-1}. The ESP values were considerably high in surface layer (16.2), and remained <15 in deeper layers. Thus, the soil was saline sodic in 0-40 cm layer and saline thereafter. Organic carbon content ranged from 0.17% in lower layers to 0.47% in the surface layer. Calcium carbonate content was > 3% throughout the profile except deepest layer. Cation exchange capacity of the soil varied between 42.1 and 49.3 $cmolkg^{-1}$ in various layers. High cation exchange capacity was mainly due to high clay content (>50%) and montmorillonitic nature of the clay minerals. Saturated hydraulic conductivity was low (d" 1.2 cmh^{-1}) indicating beginning of poor drainage conditions of the soil. Steady-state infiltration rate was 1.8 cm h^{-1}. Poor

Table 13: Physical and chemical properties of a representative soil profile under middle reach of Mula right bank canal command

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Reaction
0-20	8.6	5.2	0.47	3.72	45.6	16.2	Saline sodic
20-40	8.7	5.0	0.31	3.92	49.3	15.2	Saline sodic
40-60	8.6	5.1	0.29	3.01	47.2	13.2	Saline
>60	8.5	4.9	0.17	1.72	42.1	12.1	Saline

Physical Properties

Depth (cm)	Textural Analysis				Ks	IR	DI	COLE
	Sand %	Silt %	Clay %	Texture	cm/h	cm/h	%	
0-20	18.5	28.8	52.7	Clay	1.2	1.8	8.2	0.08
20-40	19.8	26.5	53.7	Clay	0.9	-	7.0	0.07
40-60	17.6	27.6	54.8	Clay	1.0	-	9.2	0.08
>60	15.4	32.3	52.3	Clay	-	-	7.1	0.07

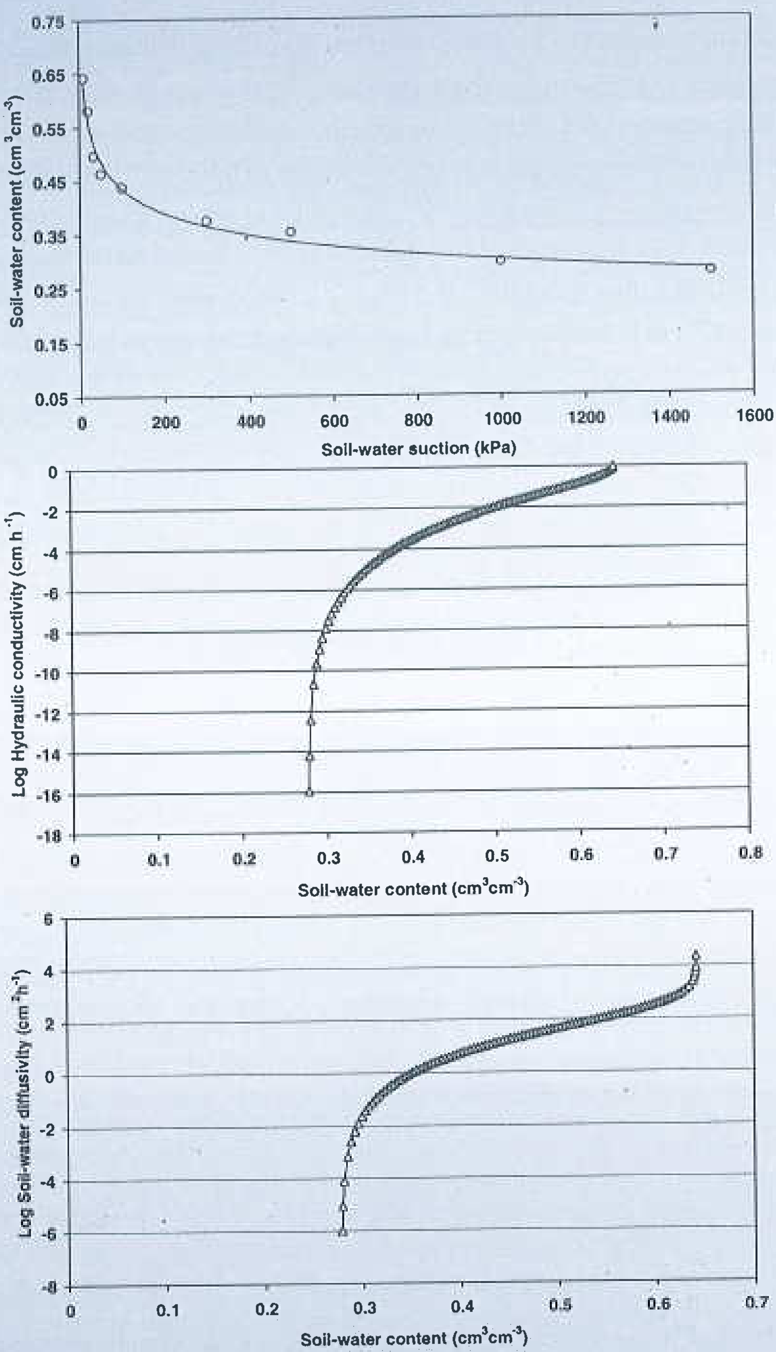


Figure 10: Water retention and transmission characteristics of a typical soil profile (averaged over all depths) in middle reach of MRBC

hydraulic conductivity and infiltration might be the result of i) very high clay content, ii) dominance montmorillonitic minerals in the soil, iii) sodicity induced silt and clay dispersion, and iv) sodicity induced swelling of clay minerals. Dispersion index was >7% throughout the profile and co-efficient of linear extensibility was also >0.07. Soil moisture characteristics curves (Figure 10) showed that the soil could retain 0.48 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.32 cm^3cm^{-3} water at 1500 kPa suction resulting in considerably high (0.16 cm^3cm^{-3}) available water. Like saturated hydraulic conductivity, unsaturated hydraulic conductivity and soil-water diffusivity functions were badly influenced by irrigation induced sodicity. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were 1×10^{-3} cmh^{-1} and 27 cm^2h^{-1}, respectively.

Data on hydraulic and transmission characteristics showed that the soil was partially affected by over irrigation and needs attention for proper management. Though the soil showed high available water capacity, but its poor water transmission and high sodium and other salt concentration mostly interferes with the plant growth and development.

15.3 Findings of practical utility and recommendations for middle reach of MRBC

- About 50%, 40% and 10% soils of the area are clay, clay loam and sandy clay loam in texture, respectively.
- About 5% (2200ha), 25% (11000 ha) and 55% (24200 ha) soils of the command area are affected by the problem of sodicity, saline-sodicity and salinity, respectively.
- Out of 44000 ha area under middle reach of MRBC command, only 6600 ha area is free from irrigation induced problems.
- Soil salinity has emerged as a major threat to irrigated agriculture in this area. However, the problem of salinity was limited to surface (0-40 cm) soil layers in sandy clay loam and clay loam soils.
- Problematic clay soils showed uniformity throughout the profile, indicating difficulties in their management.
- Water transmission and dispersion are observed to be satisfactory in clay loam and sandy clay loam soils. However, poor water transmission in saline-sodic clay soil makes these soils poorly drained.
- Preventive and reclamative measures should be immediately taken-up to manage the affected lands of this command area.

15.4 Preventive and reclamative measures for the soils of middle reach of Mula right bank canal command

A. Measures for saline soils

Preventive measures

- Leaching of salts is the most important preventive measure by which salt accumulation in soil profile can be avoided. Leaching can be facilitated by flooding the land preferably before onset of Monsoon. Furrow method should be preferred for leaching the salts than wild flooding. Land leveling increases efficiency of leaching.
- Sesbenia green manuring is the most efficient preventive measure for avoiding salt concentration in the profile.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. prevents salinity development in the soil.
- Irrigation with poor quality ground water should be avoided on the normal and saline soils in the command area.
- For irrigating the crops, proper irrigation schedules, appropriate depth of water and proper irrigation methods should be adopted.
- Cultivation of water exhaustive crops like sugarcane should be discouraged. Since sugarcane is the most important crop of this area, it should be raised with drip irrigation method.
- For preventing development of salinity, it is advisable to go for deep ploughing once in three years. This is highly useful in medium and light textured soils to expose normal soil for cultivation.
- Provision for surface drainage should be made. Proper collection and disposal of drainage effluent needs to be ensured.

Reclamative measures

- Scraping of surface soils is the most effective management measure for the salt affected soils
- Leaching of salts is a reclamative measure too. Leaching helps in rapid reclamation of saline soils. Leaching can be facilitated by flooding the land preferably before onset of Monsoon. Furrow method should be preferred for leaching the salts than wild flooding. Land leveling increases efficiency of leaching.
- Sesbenia green manuring is observed to be the most efficient method for reclamation of saline soils.

- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. help in rapid reclamation of saline lands.
- Choice of salt tolerant crops such as cotton is also one of the best options to control salinity development in the soil. Tolerance to salinity varies a great deal, almost 10 fold, amongst the crop plants and to a lesser extent amongst their genotypes. These inter-and intra-genic variations in salt tolerance of plants can be exploited for selecting crops or varieties that produce satisfactory yields under a given root zone salinity. Salt tolerance of some of the major crops of the locality is given in Table 14.

Table 14: Salt tolerance of some important agricultural crops being grown in Mula command area.

Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Chickpea	Broadbean	Wheat	Barley
Beans	Maize	Mustard	Cotton
Sesame	Groundnut	Cowpea	Sugarbeet
Onion	Sugarcane	Oats	Safflower
Carrot	Radish	Sorghum	
Mungbean	Cauliflower	Soybean	
	Chillies	Spinach	
		Pearlmillet	
		Muskmelon	

- Cultivation of water exhaustive crops like sugarcane should be restricted through drip irrigation or other pressurized irrigation methods only.
- Provision of surface and sub-surface drainage should be made to ensure proper flushing of salts. Flushing should be ensured using furrow method on properly levelled lands.
- For sowing of various crops ridge method should be adopted and seeds of the crops should be sown on the side of the ridge within the capillary fringe just above the irrigation water in furrows.
- In this area cotton-wheat-dhaincha, dhaincha-wheat-cowpea or maize-wheat-green gram sequences should be preferred over other sequences.
- On the salt affected soil of the command area fertilizer should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils.

B. Measures for saline-alkali soils

Preventive measures

- Conjunctive use of ground and canal water for irrigation helps in preventing development of sodicity in the soils.

- Sesbenia green manuring is the most efficient management option for lowering the salt concentration in the profile.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc also help in preventing saline-sodicity development.
- Cultivation of water exhaustive crops like sugarcane should be avoided. Since sugarcane is the most important crop of this area, it should be raised with drip irrigation method.
- Irrigation should be practiced with drip method in sugarcane, cotton, groundnut etc. and with sprinkler method in close-growing crops like wheat, barley, onion etc. Low energy precision water application devices can also be tried.
- Provision for surface drainage should be made. Proper collection and disposal of drainage effluent needs to be ensured.

Reclamative measures

- Ground water in this area often contains 30-40 meL^{-1} salt concentration. If such quality water is used in conjunction with canal water, it improves the movement of water through the soils and also helps in lowering the ESP levels. Therefore, conjunctive use of saline ground water with canal water is a very good option for managing saline-alkali soils in Mula command area.
- Sesbenia green manuring is observed to be the most efficient method for reclamation of saline-alkali soils.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. help in rapid reclamation of these soils.
- Scraping of surface soils is the most effective management measure for the saline-alkali soils.
- Use of chemical amendments such as Gypsum is the most effective way of reclaiming alkali soils in the command areas. Powdered gypsum should be broadcasted and incorporated in 10 to 15 cm depth in case of medium textured soils and 15 to 20 cm in case of heavy textured soils. After broadcasting, gypsum should be thoroughly mixed by discing the field or using tractor driven cultivator.
- In this area several sugar factories are in operation, these sugar factories produce huge quantity of press mud. The press mud contains considerably high concentrations of calcium. Use of sulphonated press mud effectively reclaims alkali soils.
- Provision of surface and sub-surface drainage should be made to ensure proper flushing of salts. Flushing should be ensured by furrow method on properly levelled lands.
- Choice of salt tolerant crops such as cotton is also one of the best options to control salinity and alkalinity development in the soil. Tolerance to salinity varies a

great deal, almost 10 fold, amongst the crop plants and to a lesser extent amongst their genotypes. These inter- and intra-genic variations in salt tolerance of plants can be exploited for selecting crops or varieties that produce satisfactory yields under a given root zone salinity.

- For sowing of various crops ridge method should be adopted and seeds of the crops should be sown on the side of the ridge within the capillary fringe just above the irrigation water in furrows.
- In this area cotton-wheat-dhaincha, dhaincha-wheat-cowpea or maize-wheat-green gram sequences should be preferred over other sequences.
- Fertilizer should be applied @ 20 to 25% more than the recommended doses of fertilizers as nutrient availability in these soils is poor as compared to normal soils. Ammonium sulphate should be preferred as nitrogen fertilizer till the soils are reclaimed.

16. SOILS OF TAIL REACH OF MULA RIGHT BANK CANAL COMMAND AREA

16.1 Nature of the soils and extent of irrigation induced degradation in tail reach of Mula right bank canal command

Analysis of nine soil profiles studied in tail reach of MRBC consisting of Kukana and Amarapur branches of Mula command covering about 17000 ha area revealed that the damage due to irrigation induced land degradation is comparatively less in this part of the command area than head and middle reaches of MRBC. In 0-40 cm layers of different profiles, pH values ranged between 7.5 to 8.3 and thereafter 7.2 to 8.2 (Table 15). EC_e values ranged between 0.37 to 4.2 dSm^{-1}, 0.25 to 4.1 dSm^{-1}, 0.27 to 3.7 dSm^{-1} and 0.29 to 3.4 dSm^{-1} in 0-20 cm, 20-40 cm, 40-60 cm and > 60 cm layers of soil profiles, respectively. ESP remained < 4.1 in different soil layers across the command area. Close examination of data showed that the problem of salinity in patches was limited only to 0-40 cm depth, below which all the soils were normal. Distribution of problematic soils is depicted in Figure 11.

Data showed that 35% (5950 ha) of the command was affected by soil salinity. But the problem of salinity was limited to 0-40 cm depth only and remaining part of soil profiles were normal in reaction. Out of 17000 ha command area, 11050 ha land was observed to be free from irrigation induced degradation.

Texturally, 30%, 40% and 30% areas under tail reach of MRBC can be classified as clay, clay loam and sandy clay loam, respectively. Since a large area is under medium and coarse textured soils, no drainage related problems were observed. High values of saturated hydraulic conductivity (1.5 to 27.0 cm h^{-1}) and steady-state infiltration rate (2.1 to 32.0 cm h^{-1}) were recorded. Silt and clay dispersion and swell/shrink problems were minimal and have least impact on soil health.

Comparison of water retention and water transmission properties of soils of command area with those outside the command showed that these properties did not deviate much from their normal values.

Table 15: Average physical and chemical properties (ranges) of nine soil profiles of Tail reach of Mula right bank canal command area

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Soilreaction
0-20	7.6-8.3	0.37-4.2	0.19-0.31	0.60-2.54	19.2-53.6	1.1-4.1	Normal to saline
20-40	7.5-8.3	0.25-4.1	0.16-0.30	0.50-2.01	20.1-54.2	0.9-3.7	Normal to saline
40-60	7.2-8.2	0.27-3.7	0.15-0.27	0.53-2.32	20.5-53.2	1.1-3.9	Normal
>60	7.3-8.0	0.29-3.4	0.13-0.29	0.40-2.00	20.3-50.8	1.0-2.1	Normal

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE (cm.cm)
	Sand %	Silt %	Clay %	Texture				
0-20	29.6-57.3	8.7-37.9	29.7-53.1	Sandy CL to clay	1.5-27.0	2.1-32.0	4.1-7.2	0.03-0.06
20-40	29.1-55.1	9.0-38.2	31.2-53.7	Sandy CL to clay	1.4-25.0	—	3.0-7.1	0.03-0.06
40-60	31.6-53.2	9.0-37.7	32.5-54.2	Sandy CL to clay	1.0-23.0	—	3.0-6.5	0.02-0.05
>60	35.6-52.8	8.9-37.9	29.0-53.8	Sandy CL to clay	—	—	3.0-6.3	0.01-0.06

(ECe = electrical conductivity of saturation paste extract, Org. C= organic carbon, CEC= cation exchange capacity, ESP= exchangeable sodium percentage, Ks= saturated hydraulic conductivity, IR= steady-state infiltration rate, DI= dispersion index, COLE= coefficient of linear extensibility)

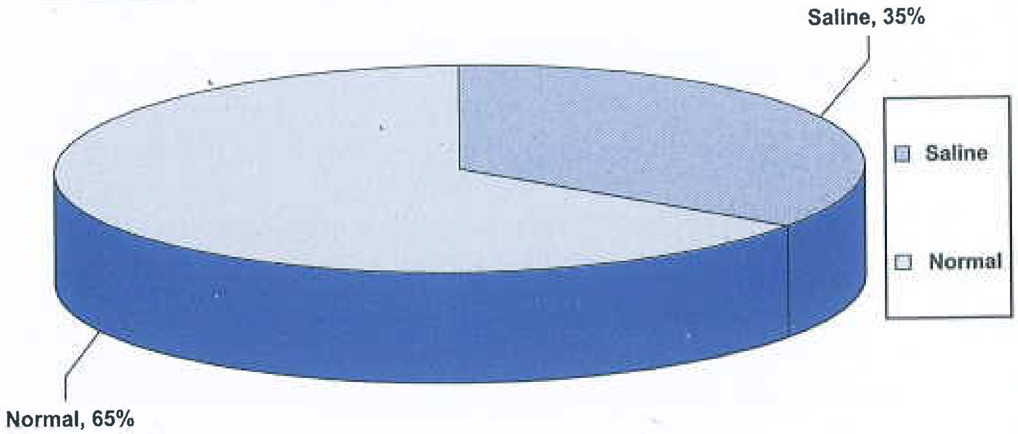


Figure 11: Distribution of problematic soils in tail reach of Mula right bank canal command area

16.2 Description of a representative soil profile under tail reach of Mula right bank canal command

This profile (profile no. 36) was exposed at Devgaon village under Shevgaon tehsil of Ahmednagar district. This was a mixed soil profile with sandy clay loam texture. pH of the soil varied from 8.0 to 8.3 (Table 16). ECe varied from 3.4 to 4.2 dSm^{-1}. The ESP value was 4.1 at surface and declined depth wise thereafter. Thus, the soil was saline in 0-40 cm depth and normal thereafter. Organic carbon content was low and ranged from 0.27% in lower layers to 0.31% in the surface layer. Calcium carbonate content was >2% upto 40 cm depth and <2% thereafter. Cation exchange capacity of the soil varied between 38.7 and 40.6 $cmolkg^{-1}$ in various layers. Saturated hydraulic conductivity was 4-7 cm h^{-1} at surface indicating good drainage conditions of the soil. Steady-state infiltration rate was 5.1 cm h^{-1}. Dispersion index was < 6.1% throughout the profile and co-efficient of linear extensibility was < 0.05. Soil moisture characteristics curves (Figure 12) showed that the soil could retain 0.37 cm^3cm^{-3} water at 33 kPa soil-water suction and 0.24 cm^3cm^{-3} water at 1500 kPa suction resulting in considerably high (0.13 cm^3cm^{-3}) available water. At field capacity moisture content, values of unsaturated hydraulic conductivity and soil-water diffusivity were $5x10^{-3}$ cmh^{-1} and 54 cm^2h^{-1}, respectively.

Table 16: Physical and chemical properties of a representative soil profile under tail reach of Mula right bank canal command

Chemical properties

Depth (cm)	pH	ECe dS/m	Org C. %	$CaCO_3$ %	CEC cmol/kg	ESP	Soilreaction
0-20	8.3	4.2	0.31	2.0	40.6	4.1	Saline
20-40	8.3	4.1	0.29	2.1	40.1	3.7	Saline
40-60	8.2	3.7	0.27	1.9	38.7	3.9	Normal
>60	8.0	3.4	0.29	1.7	39.0	2.1	Normal

Physical Properties

Depth (cm)	Textural Analysis				Ks cm/h	IR cm/h	DI %	COLE (cm.cm)
	Sand %	Silt %	Clay %	Texture				
0-20	39.6	25.2	35.2	Clay loam	4.7	5.1	5.4	0.05
20-40	39.1	25.9	35.0	Clay loam	4.5	-	5.1	0.04
40-60	39.0	24.9	36.1	Clay loam	3.7	-	5.0	0.04
>60	37.5	25.3	37.2	Clay loam	-	-	6.1	0.05

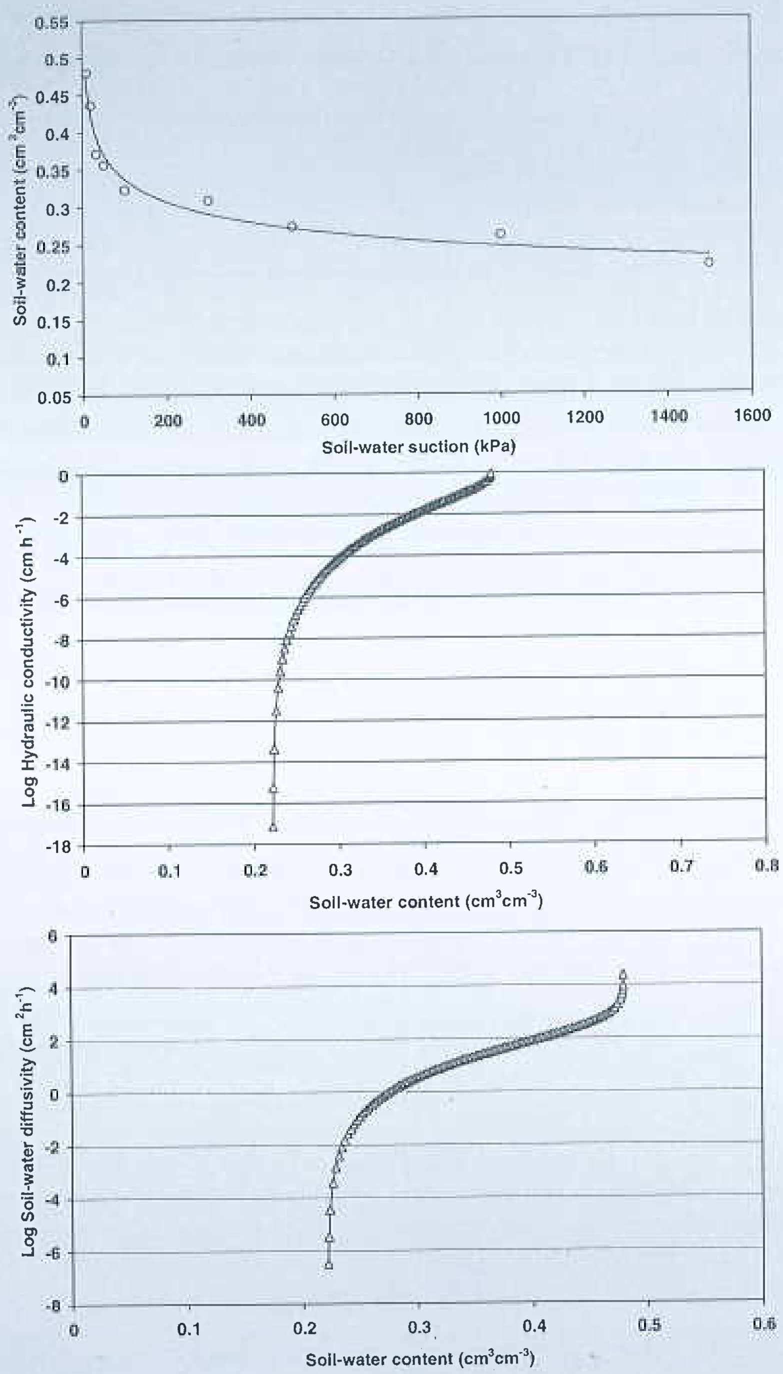


Figure 12: Water retention and transmission characteristics of a representative soil profile (averaged over all depths) in tail reach of MRBC

Hydraulic and transmission characteristics of the soil were not affected by over irrigation but excess salts in upper layers needs immediate attention for proper management. High salt concentration mostly interferes with the plant growth and development. This soil needs immediate attention for salt removal.

16.3 Findings of practical utility and recommendations for tail reach of MRBC

- Analysis of the soil profiles revealed that the problem of soil salinity exists only in patches.
- The problem of salinity is limited to 0-40 cm depth in clay loam soils and only to 0-20 cm depth in sandy clay loam soils.
- There is no problem related to soil permeability or drainage. Whatever saline soils are there, they are of temporary in nature and can be easily reclaimed by flushing-out the salts.
- About 65% (11050 ha) of the total command area (17000 ha) is free from problems and salinity of temporary nature was observed in 5950 ha area.
- Fine textured soils are existing in 30% (5100 ha) area and 70% area is under medium and coarse textured soils.
- Water retention and transmission behaviour of the soils under tail reach of MRBC was very close to the similar soils outside the command area.

16.4 Preventive measures for the soils of tail reach of Mula right bank canal command

Though, the soils of this part of the command area are very close in behaviour to similar soils outside the command. However, in some parts development of soil salinity is also observed, particularly in clay and clay loam soils. Such saline soils are temporary in nature and salinity is limited only to surface soil layers. Preventions must be taken on such soils to avoid development of potential salinity in future. Some preventive measures are suggested below.

- Leaching of salts is the most important preventive measure by which salt accumulation can be avoided. Leaching can be facilitated by flooding the land preferably before onset of Monsoon. Furrow method should be preferred for leaching the salts than wild flooding. Land leveling increases efficiency of leaching.
- Sesbenia green manuring is the most efficient preventive measure for avoiding salt concentration in the profile.
- Application of FYM @ 10 t/ha before onset of monsoon every year and incorporation of crop residues like sugarcane trash, groundnut husk etc. prevents salinity development in the soil.

- Irrigation with poor quality ground water should be avoided on the normal and saline soils in the command area.
- For irrigating the crops, proper irrigation schedules, most appropriate depth of water and proper irrigation methods should be adopted.
- Cultivation of water exhaustive crops like sugarcane should be restricted in the areas where drip and pressurized irrigation systems are used.
- For preventing development of salinity, it is advisable to go for deep ploughing once in three years. This is highly useful in medium and light textured soils to expose normal soil for cultivation.
- Provision for surface drainage should be made. Proper collection and disposal of drainage effluent needs to be ensured.

17. OVERALL SCENARIO OF IRRIGATION INDUCED LAND DEGRADATION IN MULA COMMAND AREA

Data presented in Table 17 indicate that irrigation practices have brought marginal to large changes in physical and chemical properties of soils in different reaches of Mula command area. Soil pH, ECe and ESP showed tremendous increase in entire MLBC and head reach of MRBC. Water transmission properties such as saturated hydraulic conductivity and steady-state infiltration rate declined considerably making soils almost impermeable.

Table 17: Comparison of surface soil properties under different reaches of MCA with soils outside the command.

Soil properties	MLBC	MRBC			Outside command
		Head	Middle	Tail	
pH	8.7-8.9	8.6-8.9	8.2-8.7	7.6-8.3	7.5-8.0
EC (dSm^{-1})	2.5-4.9	3.1-5.4	4.3-5.4	0.37-4.2	0.32-2.2
ESP	15.6-18.5	15.4-17.3	3.2-16.8	1.1-4.1	1.2-2.0
Ks (cm/h)	0.05-1.8	0.3-4.2	1.1-22.1	1.5-27.0	2.1-31.0
IR (cm/h)	0.1-2.1	0.6-7.0	1.3-29.0	2.1-32.0	3.5-40.0
DI (%)	7.2-20.1	7.4-12.3	3.2-8.2	4.1-7.2	3.5-7.0
COLE (cm/cm)	0.09-0.20	0.07-0.13	0.03-8.2	0.03-0.06	0.01-0.05
Reaction	Saline-sodic to sodic	Saline-sodic to sodic	Saline to saline-sodic	Normal to saline	Normal

Undesirable changes in these soil properties not only adversely affect crop growth and development but increased dispersion and swell-shrink potential (COLE) accelerate the runoff losses leading to enhanced soil erosion. In the middle reach of MRBC, major problem is soil salinity. Difference in the soils of middle reach of MRBC and similar soils outside the command is evident in terms of salt content (ECe). In the tail reach of MRBC, most of the soil properties are matching with those outside the command indicating least impact of irrigation on soil health. This may be because canal water availability is less in this part of command area as compared with head and middle reaches of MRBC. Faulty irrigation practices and poor soil and crop management have brought lot of changes in physical, chemical and hydro-physical behaviour of the soils of Mula command area. Damage due to irrigation induced soil salinization and sodification is much more alarming in Mula left bank canal command as compared with Mula right bank canal command (Table 18).

Table 18: Area affected by irrigation induced problems in Mula command

Reaches of MCA	Command area (ha)	Affected area (ha)	Affected area as % of total
MLBC	10100	9090	90%
MRBC	71000	52350	73.7%*
MCA as a whole	81100	61440	75.8%*

*Out of which, about 5950 ha area is under temporary salinity

Out of 10,000 ha command area under MLBC, about 90% is degraded. Degraded area of MLBC can be mainly characterized as sodic lands with clay texture, which are very difficult to reclaim or even manage. Soil status of MLBC warrants immediate attention and needs to be reclaimed immediately if the soils are to be cultivated on sustainable basis. In 9090 ha land of MLBC, reclamative measures must be immediately taken-up, while on remaining 1010 ha area regular preventive measures are recommended. Soil status of MRBC is relatively better than MLBC. In MRBC about 74% of the total 71000 ha command area is damaged due to irrigation induced degradation. However, this damaged land includes 5950 ha temporarily saline area under tail reach of MRBC. Thus, potentially damaged area in MRBC is around 65%. In the head reach of MRBC major problem is saline-sodicity of the soils (Table 19). About 5000 ha land is affected by saline-sodicity; mainly on clay textured black soils. Sodic soils also prevail on about 3000 ha area. These soils need immediate reclamative measure. Though the soil types in MLBC and MRBC are almost similar, there is major difference in cropping pattern. Under MLBC command sugarcane is a prevalent crop, while in head reach of MRBC many other crops are also being grown alongwith sugarcane.

In the middle reach of MRBC, major problem is soil salinity. Middle reach covers maximum area of the command (44000 ha). Problems of soil salinity and saline-sodicity

Table 19: Problematic and non-problematic areas (ha) under different reaches of Mula command area.

Reaches of MCA	Normal (ha)	Saline (ha)	Saline-sodic(ha)	Sodic (ha)	Total (ha)
MLBC	1010	505	1515	7070	10100
MRBC					
Head	1000	1000	5000	3000	10000
Middle	6600	24200	11000	2200	44000
Tail	11050	5950	-	-	17000
Total	**19660**	**31655**	**17515**	**12270**	**81100**

prevail on 24200 ha and 11000 ha area, respectively. Data presented in Table 17 showed that the conversion of saline soils to saline-sodic and subsequently to sodic soils is faster in this part of the command area than the other parts. Thus, this area should also be given attention in terms of both reclamative and preventive measures to manage degraded soils and to avoid conversion of normal soils into degraded soils. In the tail reach of MRBC about 5950 ha area is under temporary soil salinization. This salinity is limited only to surface soil layers and be easily washed or flushed out due to better soil permeability, thus referred as temporarily saline soils. However, preventive measures should also be taken-up in this part of the command area, particularly on clay sols. In totality, 61440 ha area of Mula command is affected by irrigation induced land degradation that can be classified as 31655 ha saline lands, 17515 ha saline-sodic lands and 12270 ha sodic lands.

18. DEPTH-WISE SALT DISTRIBUTION IN THE SOILS OF MULA COMMAND AREA

In clay soils of head reach, where sodicity is a problem, pH remained uniform throughout the profile. ESP of the soil was higher at surface but remained almost uniform throughout the profile. This was mainly due to Vertic nature of the soils, where swell-shrink phenomenon self plough the soils. Uniform sodicity development throughout the profile poses serious threats for management. When entire profile is affected by irrigation induced sodicity, it becomes very difficult to manage. Thus, under such conditions, integrated efforts are needed to manage the lands. In these soils surface drainage is the most important physical improvements to control development of sodicity. Providing drainage, whether surface or sub-surface, help in improvement of these soils. For sustainable use, drainage should be coupled with application of chemical amendments such as gypsum. Gypsum requirement should be calculated considering full depth of the profile. After application of amendments, proper flooding is needed to flush out desorbed sodium on the clay complexes. Besides application of effective amendments, regular green manuring should be considered on priority by the farmers. Incorporation of FYM before onset of monsoon also helps a lot in bringing down ESP levels of the soils considerably.

In saline-sodic soils of middle reaches in the canal command, salt content often rises to more than critical levels. In saline clay soils ECe values remained uniform throughout the profile. pH also varied in a narrow range. This shows that salt distribution was uniform throughout the profile. This was mainly due to Vertic nature of the soils. Alternate shrinking and swelling distribute the salts thoroughly throughout the soil profile. Like development of sodicity, the transition between salinity and alkalinity also poses serious problems for management. Since the saline-sodic nature is uniform throughout the depth, management practices are also similar to those of sodic soils. The only deference between these two soils is that frequent flushing of salts from the soil is needed in case of later.

In light textured saline-sodic soils, distribution of salts and ESP was not uniform because irrigation induced degradation was noticed only in surface layers and less impact was observed in lower depths. Thus the soils can be easily managed by providing slight drainage, use of gypsum or press mud, application of FYM and by including green manuring crops in the rotation.

Menace of irrigation induced salinity was observed in the middle reaches of MRBC and the problem was observed in all three textured soils. In clay soils, values of ECe were very high and observed uniform throughout the profile. Under such conditions high osmotic potential of soil-water does not permit plants to take-up water and at the same time high concentration of salts interfere with the plant roots rendering growth and development of crops in poor conditions. Thus in clay soils flushing of salts, provision of drainage, application of FYM, green manuring and selection of salt tolerant crops are the major options. In medium and light textured saline soils, salt accumulation is mostly observed in surface layers. Thus light textured saline soils can be easily reclaimed by frequent flooding and other soil properties can be improved by application of FYM.

19. PRIORITIZING THE PROBLEM AREAS IN MULA COMMAND

Waterlogged areas mostly exist adjacent to canals, especially where drainage facilities are poor, canal levels are higher than ground level and where ground water is not pumped at rates sufficient enough to arrest rise in ground water-table due to seepage from canals. In these lands, provision of drainage is considered to be the quicker way for their rehabilitation. Provision of horizontal subsurface drains at 1.5-2 m depth and 12-24 m interval in black soils are sufficient for facilitating growing of crops within 2-3 years on lands lying barren for a considerable time. However, technological, economic, social and political considerations will be the major bottlenecks for large scale amelioration of saline soils through subsurface drainage. Safer disposal of drainage effluent is another problem. Most attractive option is to maximize their use by crops either through irrigation or inducing contributions of water-table towards consumptive use of crops. Management strategies for crop production in saline soils after the installation of drainage thus include proper selection of crops and varieties, irrigation management (method, frequency, leaching management and conjunctive use of canal and drainage waters) and cultural practices (seeding technology and fertility management). The importance of salinity control through irrigation system improvement, as it is more logical because of its preventive nature and cost effectiveness. A shift from conventional to newer, i.e. micro-irrigation systems like drip and sprinkler, would not only reduce irrigation demands but also minimize the drainage requirements. Results of the present study indicate that a top priority should be assigned to reclamation of sodic and saline-sodic areas of MLBC. Since the problem is mostly on clay soils, long term managerial measures need to be planned in this area. Second priority should be assigned to head reach of MRBC, where major problem is saline-sodicity. Problems of middle reach of MRBC can be taken-up at third priority level, because medium and coarse textured soils are prevalent in about 50% area under this part of the command. In the tail reach of the command area, only preventive measures can take due care of soil health.

20. RESULTS OF PRACTICAL UTILITY AND RECOMMENDATIONS FOR MULA COMMAND AREA

The following points of practical importance have been emerged from the present study. Based on the results of the study, some recommendations are also made.

- The command area is dominated by clay soils except in tail reach of Mula right bank canal. About 80% (about 8000 ha) soils of Mula left bank canal and 50% (about 35000 ha) of Mula right bank canal are clay in texture. Remaining soils are clay loam to sandy clay loam in texture. Behaviour of clay loam soils is similar to that of clay soils mainly due to smectitic clay mineralogy.
- Considering pH, ECe and ESP values, soils of MLBC and head reach of MRBC are mostly affected by sodicity and saline-sodicity, soils of middle reach of MRBC are affected by salinity to saline-sodicity and some soils of tail reach of MRBC are affected by temporary salinity.
- About 70% (7070 ha), 15% (1515 ha) and 5% (5050 ha) of the total (10100 ha) area under Mula left bank canal command was affected by the problems of sodicity, saline-sodicity and salinity, respectively.
- Out of 10,000 ha command area under head reach of Mula right bank canal, 30%, 50% and 10% areas were affected by the problem of soil sodicity, saline-sodicity and salinity, respectively.
- In middle reach of Mula right bank canal command, about 5% (2200ha), 25% (11000 ha) and 55% (24200 ha) soils of the command area are affected by the problem of sodicity, saline-sodicity and salinity, respectively.

- In tail reach of Mula right bank canal, about 65% (11050 ha) of the total command area (17000 ha) is free from problems and salinity of temporary nature was observed in 5950 ha area.
- Out of 80800 ha area of Mula command, about 61440 ha is affected by irrigation induced land degradation that can be classified as 31655 ha as saline, 17515 ha as saline-sodic and 12270 ha as sodic. However, saline area includes 5950 ha temporarily saline lands, where salinity problem is limited to surface layers only.
- Results on soil-water retention and water transmission properties showed that the drainage conditions of poorly drained soils under MLBC and head reach of MRBC are badly aggravated due to excessive dispersion and deflocculation leading to high runoff losses. High dispersion of silt and clay coupled with excessive swell-shrink behaviour make soils' workability/management a difficult task.
- Conditions of soils under MLBC and head reach of MRBC are highly alarming and situation warrants immediate attention for reclaiming affected lands and preventing normal lands from irrigation induced degradation.
- Besides judicious use of irrigation water at farm level, efforts must be made to improve the canal conditions to control water losses due to various reasons.
- Farmers must-be made aware to control canal bank collapses and reducing steep slopes. For this purpose farmers should be trained to use simple techniques such as use of sand bags, asbestos sheets to strengthen canal banks, set up wooden planks/asbestos sheets over canals for cattle climbing, repairing burrow pits, cleaning canals by removing grass or other obstruction, reducing steep slopes by constructing temporary canal falls of naturally available wooden stems/branches, using PVC pipes to convey water under too steep conditions, maintaining canal sections to avoid overtopping etc.
- Farmers of the area need to be trained in proper land shaping and grading of the fields, proper maintenance of the field channels, adoption of appropriate irrigation layout etc. Farmers should also be trained and made aware of improved water management techniques such as optimum irrigation scheduling, optimum depth of irrigation, conjunctive use of ground and canal water, adopting water-use efficient cropping systems, water-use efficient irrigation methods etc.
- Mass awareness needs to be created amongst farming communities to avoid wasteful use of water and land degradation due to excessive irrigation practices.
- On-farm demonstrations on preventive and reclamative measures for managing affected areas should be taken on farmers fields. Simple and effective agro-technique such as sesbenia green manuring should be demonstrated in all the reaches of command area. Green manuring is a very effective preventive as well as a reclamative measure under all kinds of degradation in Mula command area.

- Farmers should be encouraged to use locally available sulphonated press mud cake as a chemical amendment on degraded sodic soils in MLBC and head reach of MRBC.
- Efforts must be made to discourage surface irrigation to high water demanding crops like sugarcane. Sugarcane cultivation should be restricted through pressurized irrigation systems only.

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