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Central Soil Salinity Research Institute
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Status of salt affected soils in Nain Farm – Past and Present

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Director
Central Soil Salinity Research Institute
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Phone: 0184-2290501, Fax: 0184-2290480
E-mail: director@cssri.ernet.in
Website: www.cssri.org

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E-mail: jobs.ipp@gmail.com

Dr. Alok K. Sikka
Deputy Director General (NRM)

Indian Council of Agricultural Research
Krishi Anusandhan Bhawan II
Pusa, New Delhi - 110 012
Email: aksikka@icar.org.in
Tel. : 011-25848364 Fax : 011-25848366

FOREWORD

Agricultural scenario in India is rapidly changing in response to various factors. Managing the change and meeting the growing and diversified needs in the production to consumption chain is paramount. Nearly 7.0 million ha of agricultural land is affected by varying degrees of salt problems in the country. The affected area is likely to increase in the near future due to secondary salinization in irrigation commands and lift irrigated schemes, increasing dependence of agriculture on poor quality waters in the semi-arid and arid regions, sea water intrusion and brackish water aquaculture in coastal regions. For the past five decades, CSSRI has been playing a crucial role in managing such lands and enhancing crop and water productivity. The Institute has carried out extensive research on reclamation and management of salt affected soils and poor quality water throughout the country. The institute's research farm and outreach stations are strategically located in different agro-ecological regions for tackling diverse aspects of soil and water salinity problems. Main farm at Karnal, spread over an area of 82 ha, represents reclaimed alkali soils underlain with fresh water aquifer. Over the years, the institute established research farms at Gudha (Distt. Karnal) focusing on highly alkaline soils, Sampla (Distt. Rohtak) representing waterlogged saline soils and Mundlana (Distt. Sonepat) for saline sodic soils. Research on efficient utilization of alkali waters for irrigation was undertaken at Bhaini Majra Farm (Distt. Kaithal) while research on agroforestry were conducted at Sarswati Forest at Bichhian (Distt. Kurukshetra). Studies on the reclamation of calcareous saline soils are being conducted at Bir Reserve Forest at Hisar and in waterlogged areas at village Puthi (Distt. Hisar). All these research farms showcase technologies for reclamation and management of problem soils and made direct impacts in the region convincing the farming community.

It is a matter of great satisfaction that the Institute has recently started research activities on nearly 11 ha area at Nain Farm (Distt. Panipat), which represents multiple problems associated with soil and water salinity. I am sure the Institute will successfully tackle the problems at Nain Farm by deploying proven technologies and carrying out further strategic research that will lead to enhanced crop and water productivity. The present Technical Bulletin describes basic characteristics of the farm's soil and water and will act as a benchmark for future research. This Technical Bulletin also describes reclaimability and potential uses of the problem soils of Nain and the areas around it. I am sure that this farm will also become a success story of CSSRI like many other farms reclaimed by CSSRI in the past.

October 8, 2013

(Alok K. Sikka)

CONTENTS

EXECUTIVE SUMMARY

Salt affected soils of Nain Experimental Farm (Village Nain, District Panipat, Haryana) were surveyed, characterized and classified for reclamation and management. It also provides primary input for soil characteristics prior to planning any research experiment for arable crops. Historically, the farm area (10.8 ha) was a barren, flat scrub land showing thick salt efflorescence/crust with high soil salinity at surface with saline ground water. Located in the Indo-Gangetic alluvial plain under semi-arid climate, these soils are highly variable and complex saline and sodic in nature. The presence of *calcretes* (calcium carbonates nodules/concretions) and *ferricretes* (iron oxides nodules) showed irreversible precipitation of calcium, iron and manganese in sodic soils under poor drainage condition. These soils also showed variable soil texture, lack distinct horizon development and showed ustic soil moisture regime, thus, classified as Haplustepts under the USDA Soil Taxonomy. Highly saline soils are classified at phase level. Sodic character is shown at the sub-group level following modified classification. The non-availability of good quality water (canal/tubewell) restricted its use for arable cropping. Seepage and accumulation of salty parent materials caused high soil salinization in soil profiles at lower topographic zone. The spatial variability studies using grid sampling method is used for mapping spatial distribution of soil salinity /alkalinity and soluble ions. The dominance of chlorides and sulfates of sodium, calcium and magnesium in saline soils and the presence of carbonates and bicarbonates in sodic soils showed necessity for salt leaching and gypsum treatment for reclamation. Soils with low to moderate salinity are suggested for growing salt tolerant varieties with necessary soil and water management practices. Highly saline and sodic soils may be used for acquaculture or for forestry plantations. The quality of ground water at shallow depth (80 ft) is saline and unfit for irrigation. It may be used in cyclic or mixed mode with good quality water. The quality of drainage water is good but is available in monsoon season only. These soils are also used for brick kilns and industrial development purposes such as Thermal Power generation, Fertilizer Manufacturing (NFL) and Oil Refinery (IOC) plants in nearby areas. In areas where good quality irrigation water is available, these soils were used for growing rice and wheat.

INTRODUCTION

During eighties, phenomenal success in land reclamation had improved soil productivity and livelihood security in arid and semi-arid regions of Haryana State. Using gypsum based technology developed by the CSSRI, the extent of salt affected soils reduced from 0.54 M ha (Abrol and Bhumbla 1971) to 0.23 M ha (NRSA 1996, Mandal *et. al.*, 2010). Due to exploitation of good quality ground water for irrigation, the increased extent under poor quality ground water caused a serious concern. Lack of adequate rainfall and expansion of canal network caused a serious problem in central Haryana leaving a significant area dependent only on either saline or sodic ground water for irrigation. Continuous use of such waters induced soil salinization/alkalization and higher osmotic pressure in root zone rendering these soils unproductive and unsuitable for arable cropping. Based on the preliminary survey and observation by the scientific team of experts from CSSRI Karnal, an experimental farm covering 10.8 ha area was identified and selected to develop technologies for management of salt affected soils and poor quality water at Nain village, District Panipat, Haryana. The present bulletin includes compilation of a comprehensive database on soil characteristics and spatial variability of soil salinity that can be used to assess reclaimability and to suggest suitable land uses. Such inventory would help in planning research experiments at the farm scale, monitoring the status of the benchmark sites and upscaling of research results at other similar sites of the region.

Several reports are available on the spatial extent and distribution of salt affected soils in the Indo-Gangetic plains of Haryana. Satellite imageries showed complex associations of soil, vegetation and water in salt affected soil and poor quality ground water regions in central Haryana (Plate 1) The studies conducted by Agarwal and Yadav (1954) and Bhargava *et. al.*, (1980) showed salt accumulation at micro-depressions and weathering of feldspar (plagioclase) minerals through hydrolysis and carbonation. Rajkumar *et. al.*, (2010) reported *in-situ* localized alteration of minerals of salt affected soils. Sumner and Naidu (1998) reported weathering of plagioclase, feldspars, hornblende and other sparingly soluble minerals that release Ca and Mg ions in arid calcareous soils. In the Gangetic plains, the depressions are acting as a collector of seasonal run-off and salt; the concavities lead to the formation of salt affected soils. Satellite imageries (Plate 1 and 2) showed grey to white tone, reflecting significant salt accumulation in areas with restricted drainage (Sethi *et.*

al., 2012). Historically, the farm land was barren and covered by *Prosopis juliflora* and other salt resistant grasses and plants (Plate 3).

Plate 1: IRS imagery (2006) showing salinity related land degradations in Panipat district

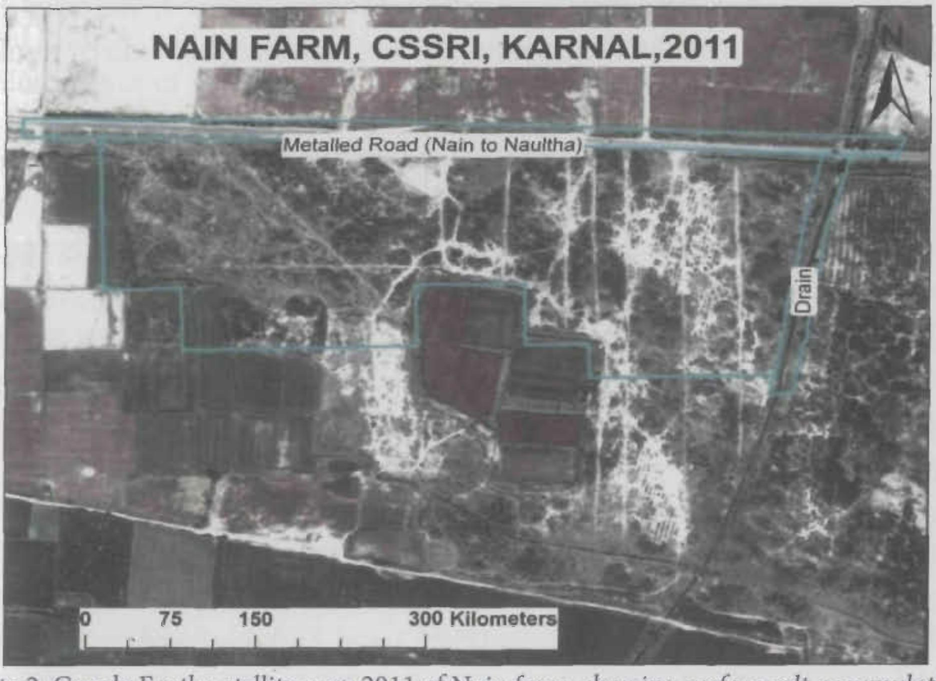
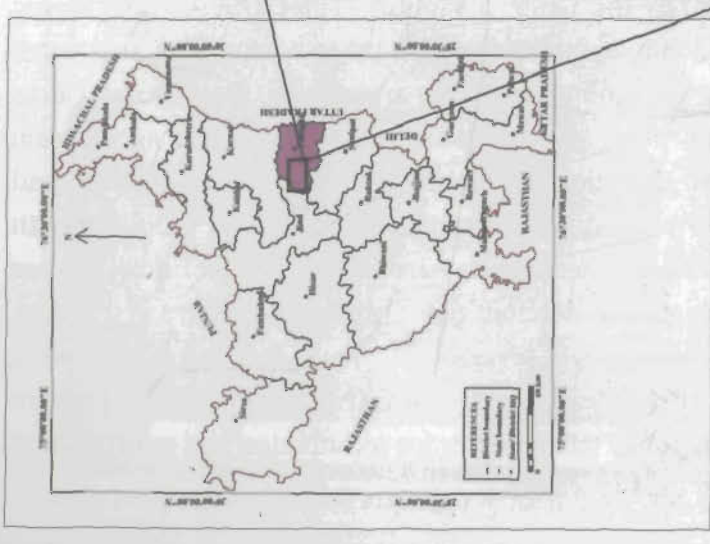


Plate 2: Google Earth satellite map 2011 of Nain farm, showing surface salt accumulation

Plate 3: Picture showing salty surface at Nain farm during 2011

LOCATION OF NAIN FARM

The CSSRI experimental farm is located at Nain village, West of the Panipat Gohana road, 25 km from Panipat town (District Panipat) and is about 65 kms from Karnal. Geographically, it extends from 29°19′7.09″ to 29°19′10.0″N latitude and 76°47′30.0″ to 76°48′0.0″E longitude and is located at an elevation of 230 to 231 m above MSL (Fig. 1). The area is surrounded by industrial units of IOCL Panipat Refinery, State Thermal Power Station and Fertilizer Production Unit of NFL. The nearby areas are irrigated by the Western Yamuna Canal. Due to topographic limitations and lack of water course, the farm area is yet to receive the canal water and is primarily dependent on ground water for irrigation. The historical data showed severe alkalinity and poor quality ground water restricting agricultural activity. Introduction of canal irrigation in adjoining areas, efforts of HLRDC and farmers' interests led to the reclamation of large areas for arable cropping with limited productivity. As a result, the areas which were earlier used for brick kilns are presently under intensive agriculture. Mechanized farming, availability of gypsum, farmers' awareness and infrastructure development have facilitated improving agricultural productivity. The farm area (10.8 ha) was transferred to CSSRI Karnal in 2011 to conduct research and refine technologies for reclamation and management of salt affected soils and poor quality waters.



Location of Haryana in India and Panipat district in Haryana

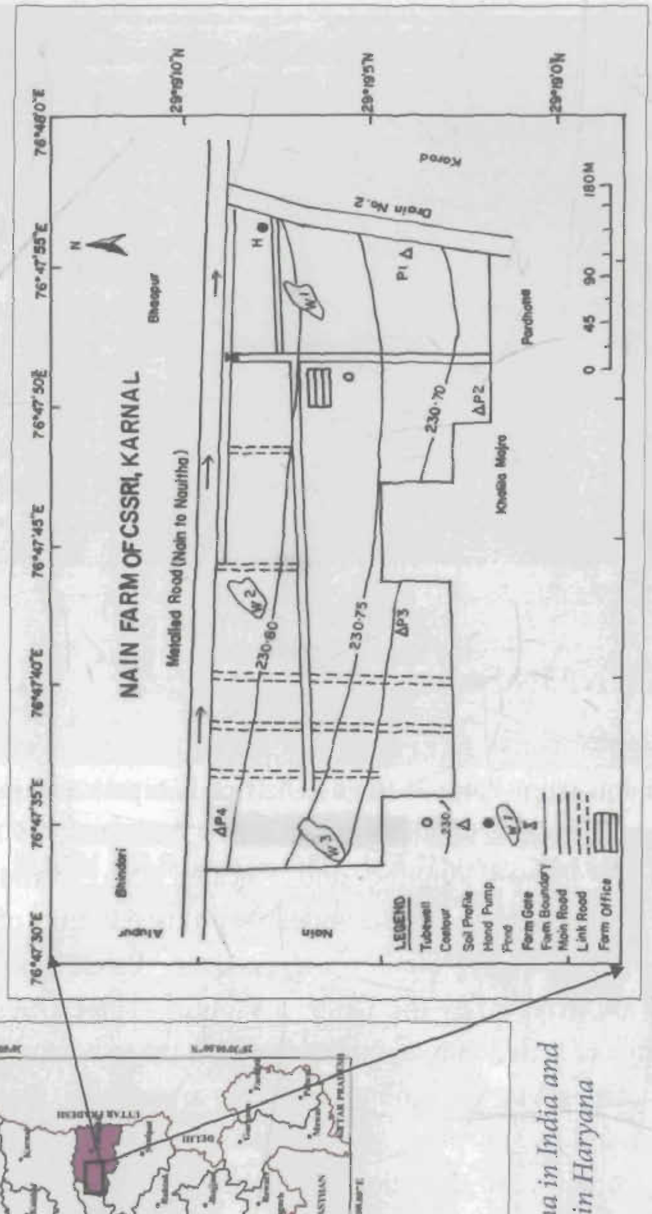


Fig. 1: Location map of Nain Farm in Panipat district of Haryana

CLIMATE

The water balance and climatic data at Nain Farm are presented in Fig. 2. The climate is semi-arid, sub-tropical and monsoonal receiving an average annual rainfall of 678 mm. The maximum rainfall is received between July and October amounting to 548 mm, which accounts for 81% of the total annual rainfall. The remaining 19 % rainfall is received between January and March. The average annual evaporation is 1598 mm. With increasing air temperature and atmospheric water demand, evaporation rate increases gradually from January to June. During the rainy season (July-September) evaporation rate remain lower and further increases till October and starts decreasing during November-December. The period between July to October remains water surplus, while remaining period is water deficit. The mean maximum and minimum temperatures were 37.9°C and 6.2°C respectively, indicating seasonal climate. The mean summer (MSST) and winter soil temperatures (MWST) were 38.3°C and 5.9°C, respectively. Mean annual soil temperature (MAST) is 26.5°C that showed hyperthermic soil temperature regime. Soil moisture regime is primarily ustic.

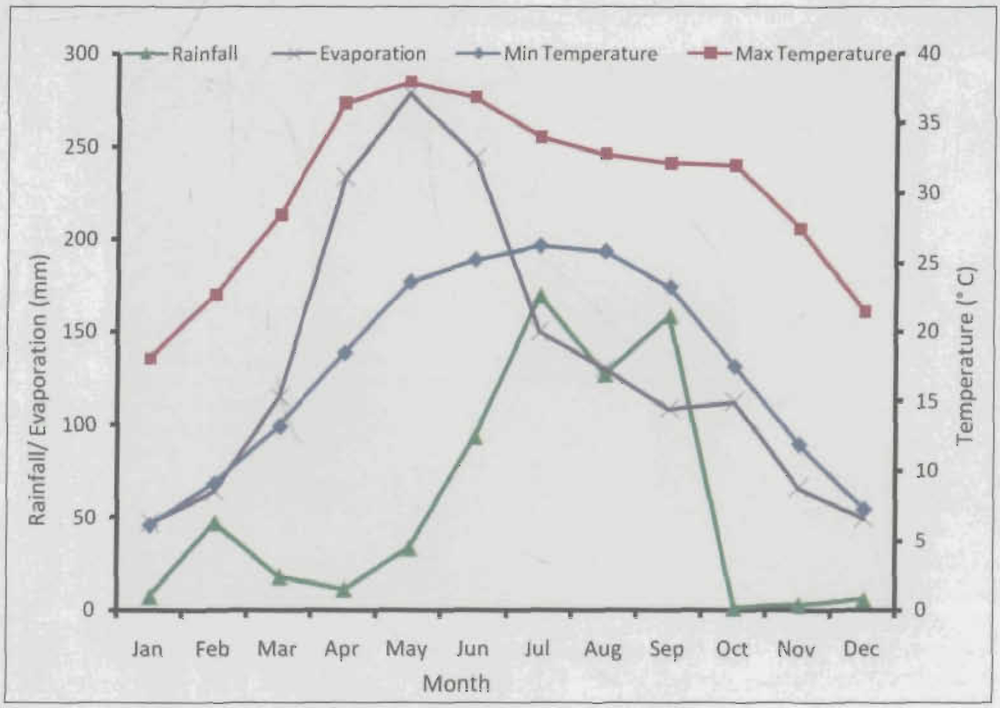


Fig. 2 : Water balance of Nain farm

VEGETATION

Being a part of village (Panchayat) land, it remained unattended for a long time and led to the emergence of naturally growing trees, bushes and shrubs commonly found in salty land with poor quality (saline) groundwater. A vegetation survey of 10 m x 10 m grid for tree species and 2 m x 2 m grid for grass/ herb species around representative soil profiles underlain with saline groundwater was carried out during August 2011. Though the vegetation type and density varied spatially, but the dominant species were mainly *Prosopis juliflora* (Babool), *Azadirachta indica* (Neem), *Ziziphus numularia* (Jharberi) and *Dalbergia sissoo* (Sisham). The growth and spatial spread of *Prosopis juliflora* is prominent and covered maximum area (Plate 4). The site also had some salt tolerant grasses and herbs as *Sporobolus marginatus*, *Saccharum spontanium* (Kans), *Cynodon dactylon* (Dub grass), *Suaeda fruticosa* (Noon-khari), *Kochia indica* (Bui) and *Calotropis procera* (Aak) *etc*. The abundance of common vegetation is given in Table 1.

Plate 4 : Picture showing natural vegetation in salty land at Nain farm during 2011

Table 1: Intensity of vegetation species growing at the soil profile site in Nain farm

Sr. No	Name of the species	Intensity (%)			Sr. No	Name of the species	Intensity (%)		
	Tree species	S1*	S2*	S3*		Grasses and herbs	S1*	S2*	S3*
1.	*Prosopis juliflora*	95	97	94	1.	*Sporobolus marginatus*	81	78	39
2.	*Azadirachta indica*	2	-	3	2.	*Saccharum spontanium*	3	4	3
3.	*Zizyphus numularia*	-	-	2	3.	*Cynodon dactylon*	5	11	48
4.	*Dalberjia sissoo*	-	-	1	4.	*Suaeda fruticosa*	9	5	-
5.	*Capparis decidua*	2-	-	1	5.	*Kochia indica*	-	2	6
6	*Phoenix dactylifera*	1	-	-	6.	*Calotropis procera*	2	-	4

**S1, S2 and S3 indicate respective soil profiles*

FARM SURVEY, SOIL AND WATER SAMPLING

Preparation of the basemap and design for soil sampling

The Survey of India topographic map on 1:25,000 scale (53C/15/SW), cadastral map and Global Positioning System (GPS) with moderate accuracy (Trundle Geo Explore 2008 series) were used for the farm survey. The topographic map indicated contours between 230 to 231 m above MSL. The GPS was also used for elevation data and used for generating contours in the farm. Two reference objects, road and drain were used for georeferencing. The farm boundary, roads, irrigation channels, drains and settlements were digitized to develop a basemap. The farm area (10.8 ha) was divided into 50 m x 50 m grids and marked on the basemap. The centre of the grid was selected for collection of depth wise soil samples. The soil samples were collected using a post-hole auger to a depth of 150 cm. The locations of soil sampling sites were marked on the basemap which is connected with an attribute table to record physico-chemical properties of soils.

Field studies and laboratory analysis of soil samples

Field studies were carried out for land characteristics such as surface topography, salt accumulation, natural vegetation, moisture content, slope, degree and aspects, drainage and water table depth. Thus, four soil profiles were studied at representative sites and morphological parameters such as depth, texture, colour, structure, consistence, pore, concretion, root, lime and moisture content were recorded for identifying the diagnostic horizons and its nomenclature (Soil Survey Division Staff 2004, Soil Survey Staff 1998). Horizon-wise soil samples were collected for laboratory analysis. Soil auger bores were also studied to understand variations and establish the extent of the soil profile boundary. For locating profile sites, GPS assisted latitude and longitude data were recorded and were marked on the basemap. The soil samples were analyzed for physico-chemical characteristics such as pH of saturated soil paste and EC of saturation extract; composition of saturation extract viz, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-; exchange properties such as CEC and ESP; particle size analysis for sand, silt and clay, organic matter and calcium carbonate content using standard method (Jackson 1986, Richards 1954). Soil textural classes were derived from USDA Triangular Textural Diagram. Calcium carbonate was estimated by Collin's Calcimeter (Jackson 1986).

CHARACTERISTICS OF SOIL PROFILES

Soil morphology

The morphological properties of soils were studied as per the guidelines of Soil Survey Division Staff (2004). Diagnostic horizons were identified based on the differentiating characteristics such as colour, texture, structure, consistence, porosity, concretion, mottle, root distribution and lime content. Additionally, land characteristics for topography, landform, land use, irrigation/drainage, infrastructure, water table depth and quality were also studied to understand genesis, formation and development of salt affected soils. Fig. 3 shows the diagnostic layers of soil profiles (Pedon) in the farm. The Pedon 1 (P1) and Pedon 2 (P2) are located in South-East and South of the farm while Pedon 3 (P3) and Pedon 4 (P4) are located at the centre and North-West of the farm. The common natural vegetation includes *Prosopis juliflora* and salt tolerant grasses. The farm area lies between 230 to 231 m contours with gentle slope (0-1%) extending from South East to North West. The characteristics of diagnostic horizon and parent materials showed alluvial formation under the old alluvial plains of the Ganges and Yamuna (Sachdev *et. al.*, 1995) originating from the Himalayas. The temperature and rainfall data showed semi-arid climate with hyperthermic soil temperature and ustic soil moisture regimes. It lies in the agro-ecological zone No. D 3.3 with 90-120 days growing period (Sachdev *et. al.*, 1995). The site was lying barren for a long time due to soil salinization, poor quality ground water and lack of good quality canal irrigation facility. A thick (2-3 cm) salt encrustation on soil surface is common in the farm. The water table lies at 20-40 ft depth and the water is saline, while good quality water lies at a depth >800 ft.

Pedon 1 *Pedon 2* *Pedon 3*

Fig. 3: Soil profiles at Nain farm

Soil colour is an important property influenced by soil moisture and organic matter contents and the presence of inorganic oxides as salts, mottles or concretions (Table 2). It also guides the stages of mineral weathering, nature (humified /coarse) of organic matter and the aeration status in soil. The colour ranges from brownish yellow (10YR6/6) to yellowish brown (10YR5/6M) in P1, yellowish brown (10YR5/6D) to dark yellowish brown (10YR4/6M) in P2, brownish yellow (10YR6/6D) to dark yellowish brown (10YR 4/4M) in P3 and very pale brown (10YR 7/4D) to yellowish brown (10YR5/4M) in P4. The dark colour in B-horizon is ascribed to higher moisture content arising from the seasonal waterlogging in P1. The water from the adjoining drain apparently seeped through the sandy mass and accumulated at a depth below the surface. In P2, the darker colour is associated with lower chroma and values and the higher moisture content. The presence of ferromanganese concretions (*ferricretes*) also corroborates the prevalence of seasonal waterlogging at 73-145 cm depth. The presence of ferricretes also indicated active pedogenic processes in B horizon with the natural (seasonal) water cycles (Szabolcs 1989, Bhattacharyya *et. al.*, 2009). In P3, the soil colour changes from brownish yellow (10YR6/6D) at surface to dark yellowish brown (10YR 4/4M) in B-horizon, due to changes of

Table 2 : Morphology of soil profiles at Nain farm

Horizon	Depth (cm)	Soil colour	Soil texture	Structure	Consistence	Porosity	Concretions / mottling		Roots	Lime
							Ferricretes (%)	Calcretes(%)		
Pedon1: Coarse loamy, mixed Sodic Haplustepts*										
A1	0-16	10YR 6/6	ls	c-m1sbk	dl, mfr, wso wpo	f, fn	-	-	c, co-md	e
AB	16-42	10YR 6/4	sl	m1sbk	mfr, ws wp	c, fn	-	-	c, co-md	e
Bw1	42-77	10YR 5/4	sl	m2sbk	mfi, ws wp	c, fn	2-4mm, 20-30	-	c, md	e
Bw2	77-112	10YR 4/6	sl	m2sbk	mfr, ws wp	f, fn	4-6mm, 30-40	-	f, fn	es
Bw3c	112-150	10YR 4/4	sl	m2sbk	mfr, wss wps	vf, vfn	-	2-4cm, 40-60	f, fn	ev
BCc	150-180	10YR 5/6	l	c-m1sbk	mfr, ws wp	vf, vfn	-	6-8cm, 60-80	vf, fn	ev
C	180-220	10YR 5/6	l	c-m1sbk	mfr, ws wp	vf, fn/md	-		-	ev
Pedon 2: Fine-loamy, mixed Typic Haplustepts (Saline Phase)**										
A1	0-23	10YR 5/6	sl	c1gr-m1sbk	dl, mfr, wss wps	f, c-md/fn	-	-	c, co-md	e
AB	23-73	10YR 4/6	sl	m1sbk-c1gr	mfr, wss wps	f, c-md/fn	-	-	f, md-fn	e
Bw1	73-110	10YR 4/4	scl	f-m2 abk	mfi, wvs wvp	c, md-fn	2-4mm, 40-50	-	f, fn-md	es
Bw2	110-145	10YR 4/6	scl	c-m1 abk	mfi, ws wp	f, fn	4-6mm, 60-80	-	f, fn	es
B3c	145-170	10YR 5/6	sl	cgr-m1sbk	mfi, ws wp	f, fn	-	4-6cm, 50-70	vf, vfn	ev
BCc	170-192	10YR 4/6	sl	m1sbk	mfi, wss wps	vf, vfn	-	6-8cm, 60-80	-	ev
Cc	192-252	10YR 4/6	l	c1gr-m1sbk	mfr, wss wps	--	-	2-5cm, 40-50	-	ev
Pedon 3: Coarse-loamy, mixed Sodic Haplustepts*										
A1	0-20	10YR 6/6	sl	c1gr-m1sbk	dh, mfr, wss wps	f, c-md	-	-	c, md	e
AB	20-60	10YR 5/6	sl	c3sbk	mfi, ws wp	c, fn	-	-	f, fn	es
Bw1	60-85	10YR 4/4	scl	c3abk	mfi, wvs wvp	f,fn	c, fn ft	-	f, fn*	es
Bw2	85-132	10YR 4/4	sl	m2sbk	mfi, ws wp	f, fn	c, fn, ft	-	vf, vfn	es
B2c	132-158	10YR 5/6	sl	m2sbk	mfr, wss wps	vf, vfn	f, fn, ft	6-8cm, 40-60	-	ev
BCc	158-175	10YR 5/4	l	m2sbk	mfr, wss wps	vf, vfn	f, fn, ft	6-10cm, 70-80	-	ev
Cc	175-229	10YR 5/6	l	c3sbk	mfi, wvs wvp	-	-	2-5cm, 40-60	-	ev
Pedon 4: Coarse-loamy, mixed Typic Haplustepts**										
A1	0-22	10YR 7/4	sl	c1gr-m1sbk	dh, mfr, wss wps	f, fn	-	-	m, md	e
B1	22-53	10YR 5/4	sl	fn1abk	mfi, wss wps	f, fn	-	-	c, md	e
B2	53-85	10YR 5/3	sl	fn1sbk	mfi, ws wp	f, fn	-	-	c, fn	e
B3c	85-117	10YR 5/4	sl	fn1sbk	mfr, ws wp	vf, vf	-	4-6cm, 20-40	vf, fn	es
Cc	117-160	10YR 5/4	sl	c3sbk	mfr, ws wp	-	-	6-8cm, 60-80	-	ev

** Verma et. al., (2007), **Sachdev et. al., (1995) # Soil colours are moist colour except at the surface horizon* moisture content, textural variation and presence of ferromanganese mottles at 60-175 cm depth. Very pale brown (10YR7/4D) soil colour at surface in P4 changes to yellowish brown (10YR 5/3M) due to changes in moisture content and finer soil texture.

Soil structural development is commonly related to the texture, organic carbon and the presence of inorganic oxides that facilitate binding of soil particles (Table 2). In P1, soil structure is weak, coarse to medium sub-angular blocky in A horizon and changes to moderate medium subangular blocky in B horizon with finer soil texture. The degree consistency (stickiness and plasticity) accordingly changes from weak at surface to moderate at B-horizon. The porosity also changes from few, fine to common at surface to finer at B-horizon. In P2, soil structure is coarse weak granular at surface and changes to moderate medium sub-angular blocky in B-horizon, due to change in soil texture from sandy loam to sandy clay loam. It also alters the consistence from friable to firm with moderate stickiness and plasticity. In P3, soil structure altered from coarse granular to strong coarse sub-angular blocky due to increase of clay content from 10 to 21% at surface and B-horizons, respectively. The increase of $CaCO_3$ contents from 2 to 6% enhanced structural compaction at the lower part of B-horizon. Due to the changes in clay content from 16 to 19% in P4, soil structure changes from coarse medium sub-angular blocky in A-horizon to fine angular blocky in B-horizon.

These pedons exhibited thick (20-60 cm) layers of $CaCO_3$ concretions (*kankar*) with variable size accumulated at a depth of 1m and extends to 2.5 m. The size of *kankar* varied from 2-4 cm to 6-10 cm in B and C-horizons, respectively. These concretions are hard, compact and impermeable to water and nutrients and caused temporary waterlogging, anaerobic conditions and poor hydraulic properties. Such layer extends from lower part of B-horizon to C-horizon with fine to coarse parent materials. The depth and thickness of such layer showed the extent of pedogenesis in the old alluvial plain of central Haryana (Sharma *et. al.*, 2006). The thickness of kankar layer varied from 68 cm in P1 to 105 cm in P2, while it is intermediate in P3 (97 cm) and P4 (75 cm). In the field, the effervescence with dilute HCl showed positive relation with the extent of calcium carbonate in soil. Due to deep rooted natural vegetation and coarse soil texture, the root penetration (50 cm) played critical role in soil structure development in the upper part of the soil profile.

PHYSICAL AND CHEMICAL PROPERTIES OF SOIL PROFILES

Particle size classes and exchange properties

The particle size data is presented in Table 3. At surface, the average clay, sand and silt content are 11.4% (range 5.5-16.7%), 70.1% (62.0-81.4%) and 18.4% (13.0-21.2%) indicating sandy loam to loamy sand texture. In B-horizon, clay and silt contents increased to17.6% (17.2-18.8%) and 24.8% (20.1-28.1%), while sand decreased to 57.4% (54.5-60.9%) indicating illuviation of finer particles to lower layers. The silt and clay content increased significantly from surface to lower depths in P1, P2 and P3 while the sand content decreased gradually with increasing depth. The textural variation in P4 remained uniform in all depths.

The cation exchange capacity (CEC) varies from 9.8 to 13.6 cmol (p^+) kg^{-1} at surface and 5.74 to 20.4 cmol kg^{-1} at B-horizon. The CEC increased with increasing depth in P1 [(10.6 to 22.8 cmol (p^+) kg^{-1})], P2 [(13.6 to 19.7 cmol (p^+) kg^{-1})] and P3 [(9.8 to 12.1 cmol (p^+) kg^{-1})] and decreased in P4 [(12.2 to 5.74 cmol (p^+) kg^{-1})]. Such data also indicated the presence of non expanding clay minerals such as illite and kaolinite. The ESP values vary from 16.4 to 77.1 and 19.9 to 68.8 at surface and B-horizons, respectively. The higher ESP in P3 is proportional to the clay content. The ESP increases with increasing depth in P1 and varies with soil pH. It decreased with increasing depth in P3 and is variable in P2. The low to moderate ESP values in P4 showed neutral nature.

Calcium carbonate

The $CaCO_3$ content varies from 1% to 2.5% at surface while significant accumulation was found at 1m depth below the surface (Table 3). It increased from 1.2% to 9% at B-horizon in P2 that increased to 10.2% in C-horizon, indicating processes of calcification. The $CaCO_3$ content (<2mm) is 13% in P1, 9.3% in P2, 12.3% in P3 and 3.6% in P4 that corroborate with the thickness of *kankar* layers for P1 (68 cm), P2 (107 cm), P3 (97 cm) and P4 (75 cm), respectively. The calcretes showed more compaction in P1 and P3 than P2 and P4. The $CaCO_3$ precipitated at 112, 132, 145 and 85 cm depths in P1, P3, P2 and P4, respectively. It acts as a restricting layer for water movement and root development. The size of calcretes

Table 3 : Physico-chemical properties of soils at Nain farm

Depth (cm)	pHs	ECe dSm^{-1}	Na^+	K^+	$Ca^{2+}+Mg^{2+}$	HCO_3^-	Cl^-	SO_4^{2-}	OC	ESP	$CaCO_3$	CEC cmol kg^{-1}	Sand	Silt	Clay
			me L^{-1}						%				%		
Pedon 1: 29°19'04.1"N and 76°47'55.1"E Coarse loamy, mixed Sodic Haplustepts, grasses, *Prosopis Juliflora* grown, Water table depth <2.5 m															
0-16	9.0	58	1217	5.7	10	2.0	500	71.9	0.45	30.9	2.1	10.6	81.4	13.0	5.5
16-42	9.4	31	659	0.6	7	1.5	240	69.5	0.30	43.9	1.4	8.0	57.5	25.1	17.4
42-77	9.5	13	243	.01	5	1.5	95	56.3	0.27	44.0	1.3	14.5	58.3	20.7	20.9
77-112	9.6	10	183	0.1	5	2.0	75	20.9	0.18	54.0	1.9	13.0	63.8	18.8	17.3
112-150	9.7	10	207	0.1	5	2.0	69	19.2	0.22	55.3	10.1	11.5	59.2	25.2	15.5
150-180	9.6	11	234	0.1	5	2.0	77	25.8	0.19	58.0	13.2	20.4	39.9	34.9	25.1
180-220	9.5	15	301	0.1	5	2.0	92	30.5	0.24	55.0	15.1	22.8	48.8	27.6	23.5
Pedon 2: 29°19'02.9"N and 76°47'50.3"E, Fine-loamy, mixed Typic Haplustepts (Saline Phase), *Prosopis Juliflora* grown, Water table depth <3.5 m															
0-23	8.5	71	1908	1.0	48	0	500	71.8	0.34	25.0	1.2	13.6	68.6	18.9	12.3
23-73	8.2	45	1241	0.5	45	1.5	240	71.1	0.31	20.0	1.3	13.9	58.6	21.8	19.5
73-110	8.4	20	406	02	17	1.5	95	68.6	0.22	29.0	1.6	19.7	54.8	20.1	25.1
110-145	8.5	21	273	02	20	2.0	75	66.4	0.28	21.2	2.1	12.1	54.1	24.3	21.6
145-170	8.1	23	469	01	41	2.0	69	64.5	0.22	29.5	8.8	16.6	70.0	16.2	13.8
170-192	8.7	25	469	0.1	63	2.0	77	59.9	0.24	33.3	9.0	19.7	55.8	25.7	18.4
192-252	8.7	19	336	0.1	55	2.0	91	64.3	0.25	37.5	10.2	14.7	48.0	35.4	16.5
Pedon 3: 29°19'04.5"N and 76°47'42.4"E Coarse-loamy, mixed Sodic Haplustepts, partly barren, grasses grown, Water table depth >5m															
0-20	10.0	82	2577	3.0	5	5.5	775	126.5	0.25	77.1	2.52	9.8	68.5	20.5	10.9
20-60	9.5	28	505	0.4	6	1	210	69.5	0.27	68.8	1.05	11.4	59.5	23.2	17.2
60-85	9.0	14	257	0.1	17	0.5	87	56.3	0.24	50.0	1.89	10.4	58.3	20.8	20.8
85-132	8.9	13	248	0.1	19	0.5	75	54.5	0.24	57.0	6.51	11.7	59.1	23.5	17.2
132-158	9.0	19	414	0.2	29	1.5	118	53.0	0.25	60.4	7.77	12.1	55.4	29.7	14.8
158-175	9.0	21	381	0.1	32	1	130	69.9	0.24	56.4	12.82	7.3	40.6	43.2	16.0
175-229	8.9	17	269	0.2	33	1	97	64.7	0.24	45.9	16.17	9.8	34.1	47.2	18.5
Pedon 4: 29°19'08.4"N and 76°47'34.8"E Coarse-loamy, mixed Typic Haplustepts, grasses and *Prosopis Juliflora* grown, Water table depth >5m															
0-22	7.7	14.1	174	1.0	49	3	86	64.1	0.49	16.4	1.1	12.2	62.0	21.2	16.7
22-53	8.0	21.3	273	0.8	51	2	134	65.6	0.28	19.9	0.2	7.5	65.1	19.9	14.8
53-85	8.0	25.3	321	0.9	50	1.5	166	68.9	0.18	34.9	0.2	6.7	60.5	19.7	19.7
85-117	8.2	25.4	326	0.8	60	2	176	67.4	0.18	40.9	1.1	5.74	57.1	30.8	11.9
117-160	8.4	21.3	274	0.7	52	1	140	68.1	0.18	23.8	6.1	8.00	57.1	26.2	16.6

($CaCO_3$ concretion), abundance and thickness of layer determine the nature of induration and permeability in soils. The calcretes occupied 60% and 70% area in P1 and P3 and 50% and 60% in P2 and P4, respectively. At surface, the $CaCO_3$ content is low (1.1-1.3%) in P2 and P4, and higher (2.1-2.5%) in P1 and P3. The calcretes precipitated at lower part of B-horizon and extends to C-horizon in all pedons. The size of calcretes is 4-6 cm at B-horizon and 6-8 cm in BC-horizon in P1, P2 and P3 while smaller size (2-4 cm) occurred in C-horizon of P2 and P3. Low $CaCO_3$ at surface favour response to gypsum application to neutralize strong to moderate sodicity in P3 and P1, respectively.

Organic carbon

In general, the organic carbon content was <1% at surface and sub-surface layers of salt affected pedons (Table 3). It ranges from 0.25 to 0.49% at surface layer that decreased with depth. The alkali soil (pHs 10.0) showed low organic matter due to dispersion and solubilization of humified organic carbon at higher pH. The type of vegetation determines the nature and extent of organic matter in soils. At Nain farm, the growth and abundance of *Prosopis juliflora* trees/ bushes and different grasses, absence of arable farming in undisturbed soils produced enough organic matter suitable for soil fertility development. At surface, the organic carbon content is categorized as low in all pedons.

Soil reaction, salt content and composition of soluble salts

Soil reaction (pHs) of saturated paste showed that soils of the Nain farm are neutral to strongly sodic in nature (Table 3). At surface, slight, moderate and strong sodicity is shown in P2, P1 and P3, respectively while P4 is neutral in reaction. In P1, the pHs increased from 9.0 at surface to 9.7 at lower layers and relates to higher ESP (54-58) and clay content (20-25%). In P3, surface soil is strongly sodic and changes to moderate to slightly sodic with increasing depth. Strong sodicity at surface is possibly due to accumulation of Na^+ and bicarbonate salts through run-off. The decrease of sodicity in lower depth is associated with coarse texture and higher $CaCO_3$ content. P2 is characterized as slightly sodic with moderate ESP, fine texture and moderate organic carbon content.

The electrical conductance (ECe, dS m^{-1}) in P1, P2 and P3 showed moderate to high soil salinity at surface which decreased with increasing depth. Lack of agricultural activity and high evaporation demand caused high salt accumulation at lower topographic position. Salt leaching occurred through coarse soil texture resulting in moderate soil salinity even below the surface. At surface, soil salinity is higher in P3 followed by P1, P2 and P4 apparently due to its lower topographic position.

Salt composition showed dominance of Na^+, Cl^- and SO_4^{2-} while Ca^{2+} and Mg^{2+} and HCO_3^- are also present. Significant amount of sodium is found at surface soils of P1, P2 and P3 that decreased with increasing depth. The preponderance of sodium over other ions in P1, P2 and P3 with coarse texture strata showed the possibility of sodium release from silicate minerals under alkaline condition (Bhargava and Bhattacharjee 1982). The higher contents of Ca^{2+} and Mg^{2+} restricted development of sodicity in P2 (17-63 me L^{-1}) and P4 (49-60 me L^{-1}), while moderate Ca^{2+} and Mg^{2+} (17-33 me L^{-1}) in P3 reduced pHs from 10.0 at surface to 9.0 below 60 cm depth. In P1 and P3, high K^+ content at surface is due to higher sodicity at surface. The high HCO_3^- content at surface in P3 caused higher sodicity, while slight sodicity in P1 and initiation in P4 is due to the dominance of Cl^- and SO_4^{2-} ions over HCO_3^-. K status throughout the soil profile reflects the presence of K-bearing minerals such as illite and biotite while Ca^{2+} and Mg^{2+} contents indicate the presence of Ca-bearing minerals such as calcite and dolomite.

SPATIAL VARIABILITY OF SOILS

Soil sampling scheme and data analysis

The centre point of each grid (50 m x 50 m) was used for collection of soil samples at 0-15, 15-30, 30-60 and 60-90 cm depths (174 Nos). These were analyzed for physico-chemical properties such as pHs, ECe, soluble cations (Na^+, K^+, Ca^{2+} and Mg^{2+}), and anions (CO_3^{2-}, HCO_3^- and Cl^-) and SAR was calculated using standard methodology (Richards 1954, Jackson 1986). The coordinates of soil samples were transferred to the basemap and linked to an attribute table. The physico-chemical properties were entered in an EXCEL sheet and attached with the coordinates (latitude-longitude) of soil sample location stored in ARC GIS (ESRI). Spatial interpolation was done to assess the spatial variability of soil properties using Inverse Distance Weighing (IDW) method (Nalder and Wein 1998). It calculates a weighted average of the values of a soil property for the known location and allows estimation of such value at un-sampled location. The output map showed spatial variability of soil properties for pHs, ECe, Na^+, Ca^{2+} and Mg^{2+}, Cl^- and HCO_3^- and SAR. The

Table 4 : Depth-wise distribution of area for different soil properties at Nain farm

Soil property	Range in property	Depth (cm) of soil sampling			
		0-15	15-30	30-60	60-90
		(% of the total area)			
pHs	<8.2	67.0	62.9	56.4	39.6
	8.2-8.5	29.0	24.4	37.2	39.6
	>8.5	4.0	10.6	6.3	20.8
ECe (dS m^{-1})	<4	8.7	11.0	8.0	5.0
	4-8	16.9	15.6	11.6	9.9
	8-15	25.4	27.6	32.9	31.0
	15-30	31.2	33.2	46.0	54.0
	>30	17.8	12.5	1.4	Tr.
Na^+ (me L^{-1})	<100	25.9	27.3	16.0	10.0
	100-200	35.4	37.5	27.4	23.3
	200-300	14.7	16.7	47.3	59.6
	>300	24.0	18.5	9.3	7.0
$Ca^{2+} + Mg^{2+}$ (me L^{-1})	<20	27.9	26.7	18.3	21.9
	20-40	29.4	22.1	39.8	46.0
	40-60	20.4	33.6	31.9	24.3
	>60	22.2	17.6	10.1	7.6
HCO_3^- (me L^{-1})	<2	1.9	17.7	9.6	34.5
	2-3	27.8	49.8	56.0	37.5
	3-4	43.8	25.1	25.0	11.9
	4-5	17.6	3.2	5.0	6.9
	>5	8.7	3.9	4.2	9.2
Cl- (me L^{-1})	<50	32.7	32.6	29.8	24.2
	50-100	16.8	20.0	16.8	18.0
	100-200	27.0	27.5	39.8	49.8
	>200	23.3	19.9	13.5	7.9
SAR	<13	7.1	13.1	6.3	3.2
	13-30	23.5	30.0	16.0	11.9
	30-45	22.2	13.3	21.9	16.5
	45-80	30.5	31.9	45.1	50.2
	>80	16.6	11.6	10.6	18.2

categories of soil salinity (ECe) and alkalinity (pHs) were identified (Richards 1954). The depth-wise extent of salt affected soils was calculated and is presented in Table 4. The maps for spatial distribution of salt affected soils are presented in Figs. 4-10.

Variability of soil salinity and alkalinity

A wide range of soil salinity (< 4 to >30 dS m^{-1}) was found at surface (0-15 cm) and sub-surface depths (15-30, 30-60 and 60-90 cm). Surface soils with moderate (ECe 8-30 dS m^{-1}) and strong (ECe >30 dS m^{-1}) salinity covered 57% and 18% area,respectively. The extent of moderately saline soils (ECe 8-30 dS m^{-1}) increased from 61% at 15-30 cm depth to 85% at 60-90 cm depth, while areas of slightly saline soil (ECe 4-8 dS m^{-1}) decreased from 16 to 10% and severely saline soil below 12% at 15-30 cm and 60-90 cm, respectively (Fig. 4).

The soil reaction showed sodic nature ranging from <8.2 to 8.9 (Fig. 5). The areas under sodic soils ranged from 33 to 60% at different depths. Soil sodicity is higher at 30-60 cm (43%) and 60-90 cm (60%) depths apparently due to the presence of fine textured sub-surface layers.

Variability of soluble cations, anions and SAR

Based on the concentration of calcium plus magnesium in soil samples, four categories viz; A (0-20 me L^{-1}), B (20-40 me L^{-1}), C (40-60 me L^{-1}) and D (>60 me L^{-1}) were identified. The B and C categories covered 50% area at surface and increased to 56, 71 and 72 % at 15-30, 30-60 and 60-90 cm depths, respectively. The areas under D category showed decreasing trend from 22% at surface to 17, 10 and 7 at 15-30, 30-60 and 60-90 cm depths, respectively (Fig. 6).

The chloride content ranged from 50 to 200 me L^{-1} and is characterized as A (0-50 me L^{-1}), B (50-100 me L^{-1}), C (100-200 me L^{-1}) and D (>200 me L^{-1}) categories, respectively. Soils with B and C categories covered 4% area at surface (0-15 cm) while the area increased to 47, 56 and 68% at 15-30, 30-60 and 60-90 cm depths, respectively. Soils with D category covered 23% areas at surface and decreased to 20, 13 and 8% at 15-30, 30-60 and 60-90 cm depths, respectively (Fig. 7).

The sodium concentrations ranged from < 100 to >300 me L^{-1} and are categorized as A (< 100 me L^{-1}), B (100-200 me L^{-1}), C (200-300 me L^{-1}) and D (>300 me L^{-1}) to understand the ranges and their variations. The areas under B and C categories covered 50% area at surface (0-15 cm) that increased to 54%, 75% and 83% at 15-30,

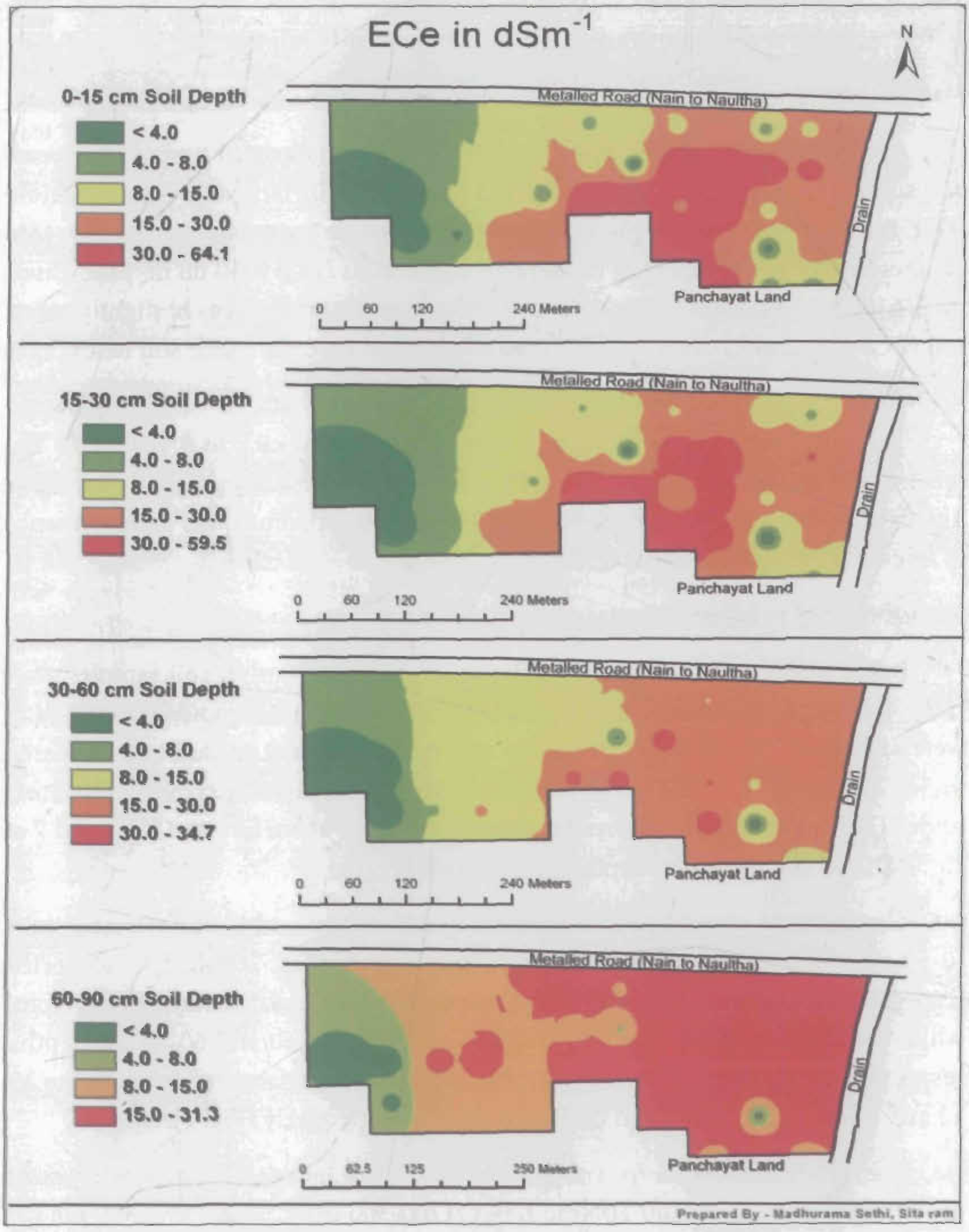


Fig. 4 : Variation of soil salinity (ECe) in Nain Farm

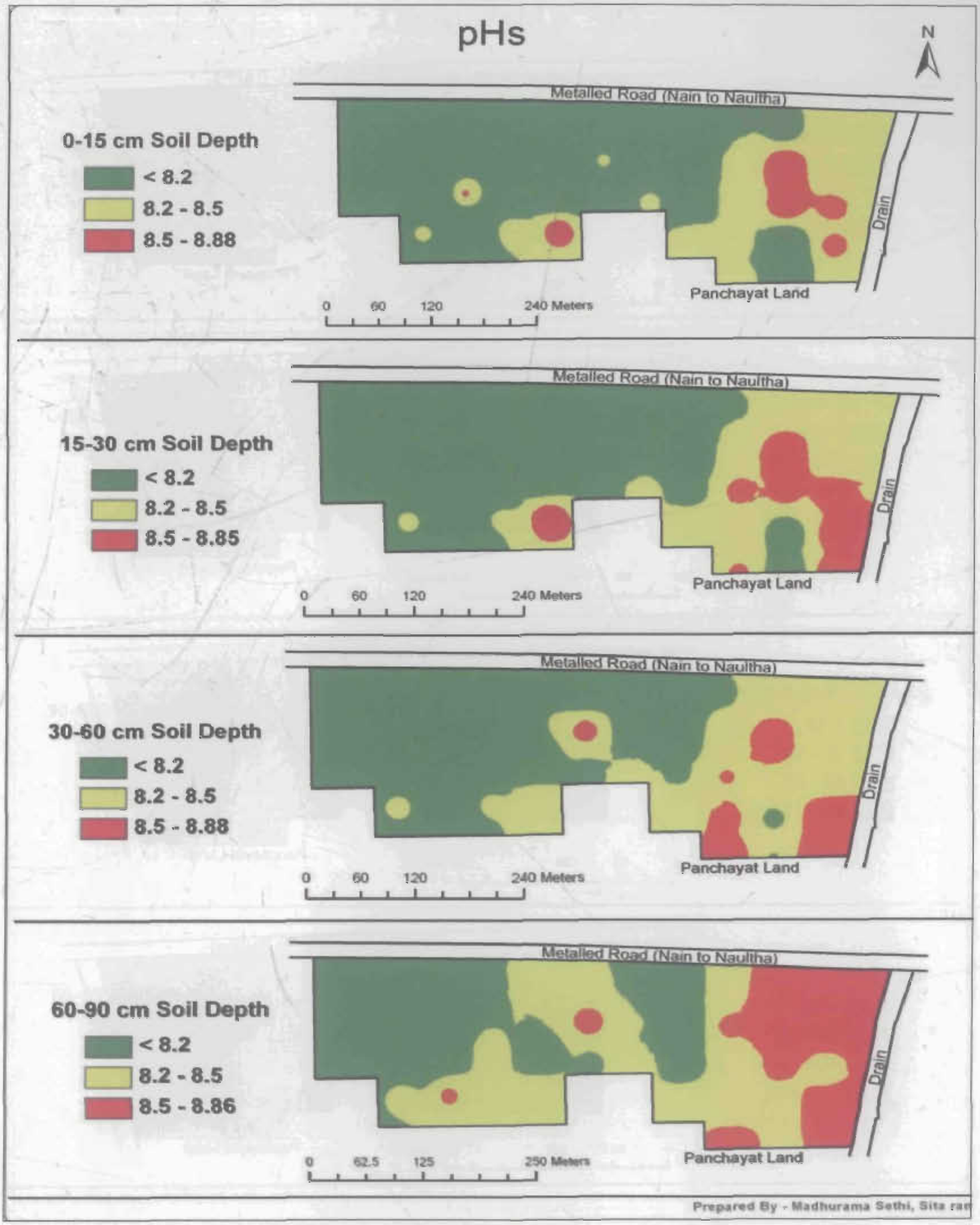


Fig. 5 : Variation of soil pH in Nain Farm

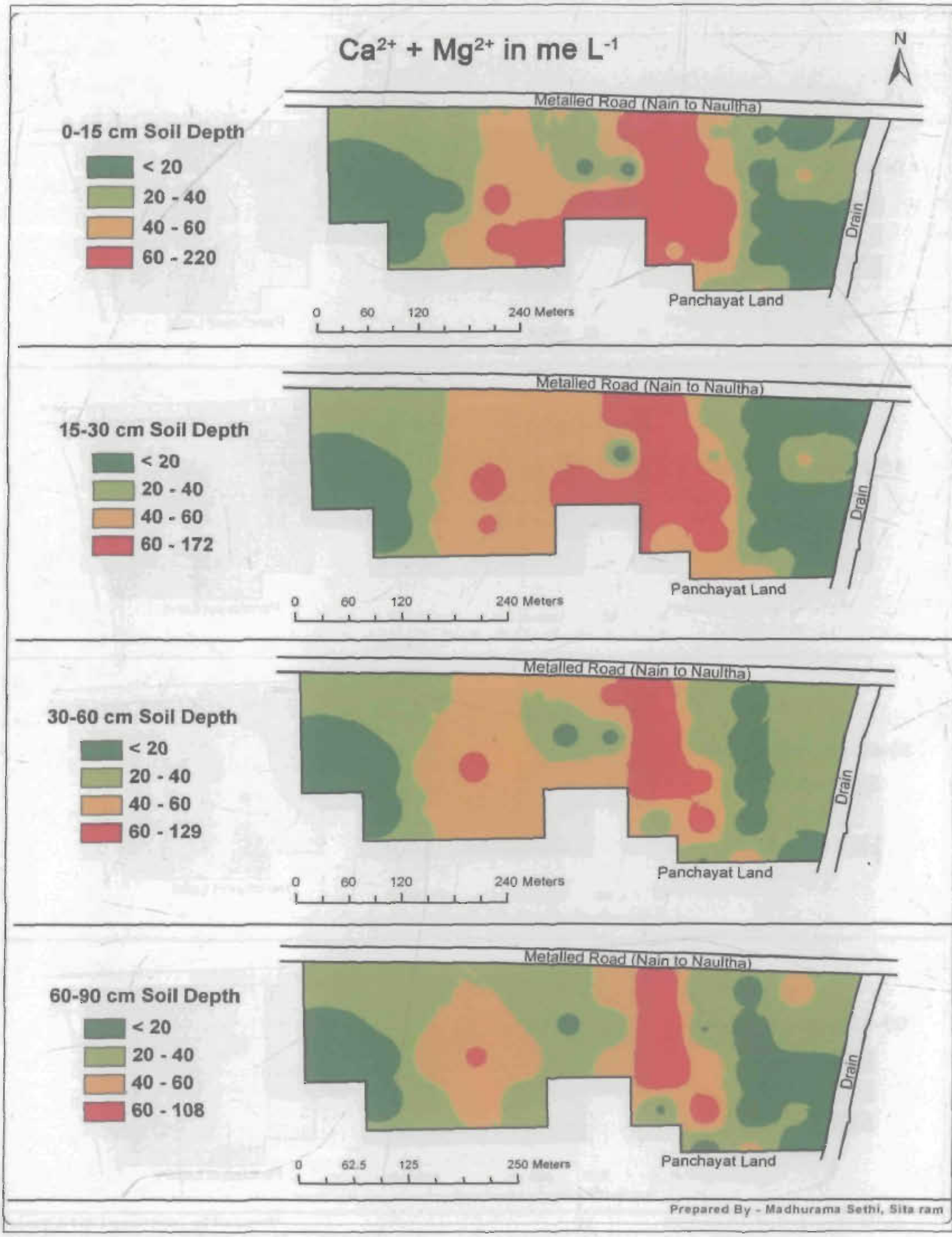


Fig. 6 : Variation of soil Ca^{2+}+ Mg^{2+} content in Nain Farm

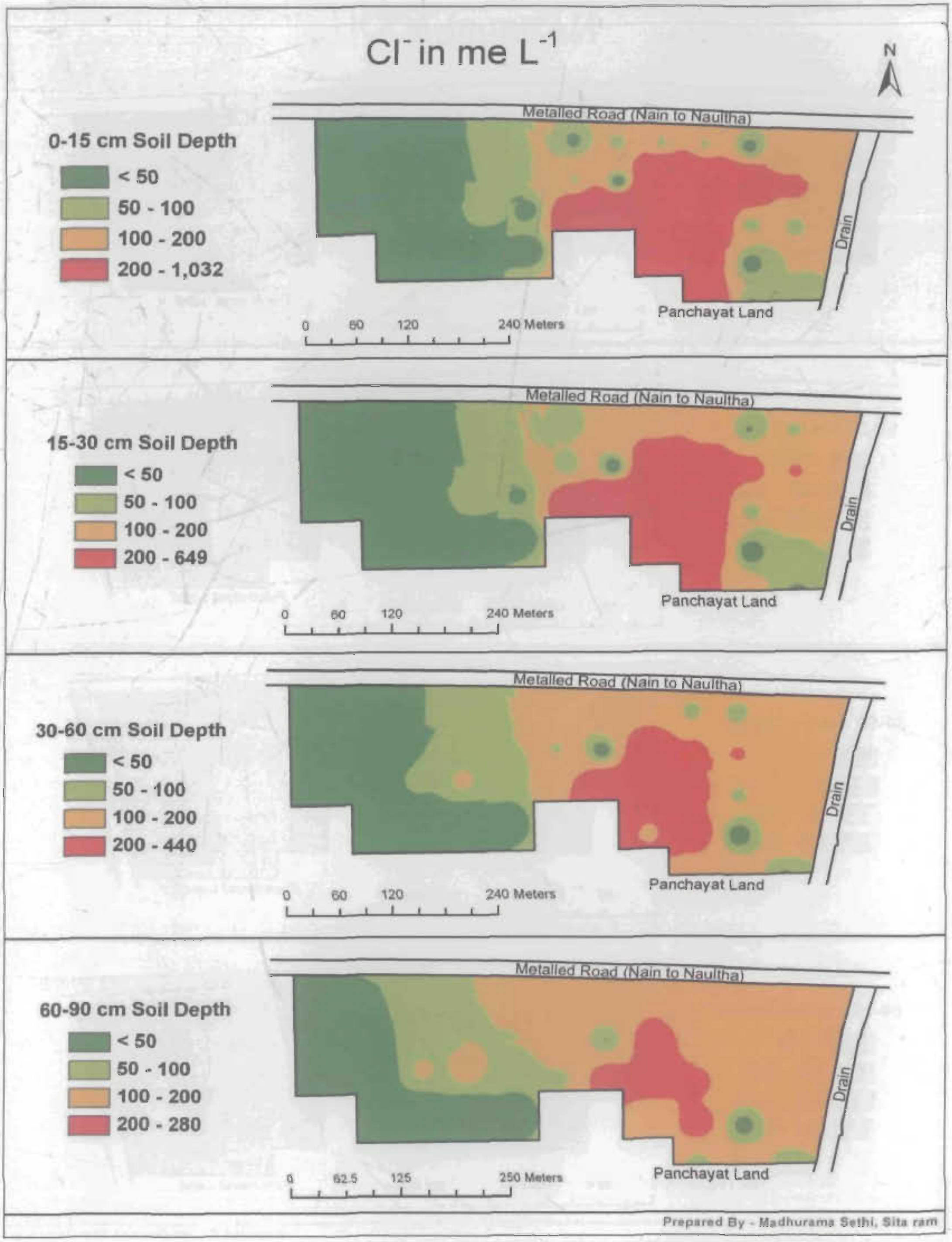


Fig. 7 : Variation of soil Cl^- content in Nain Farm

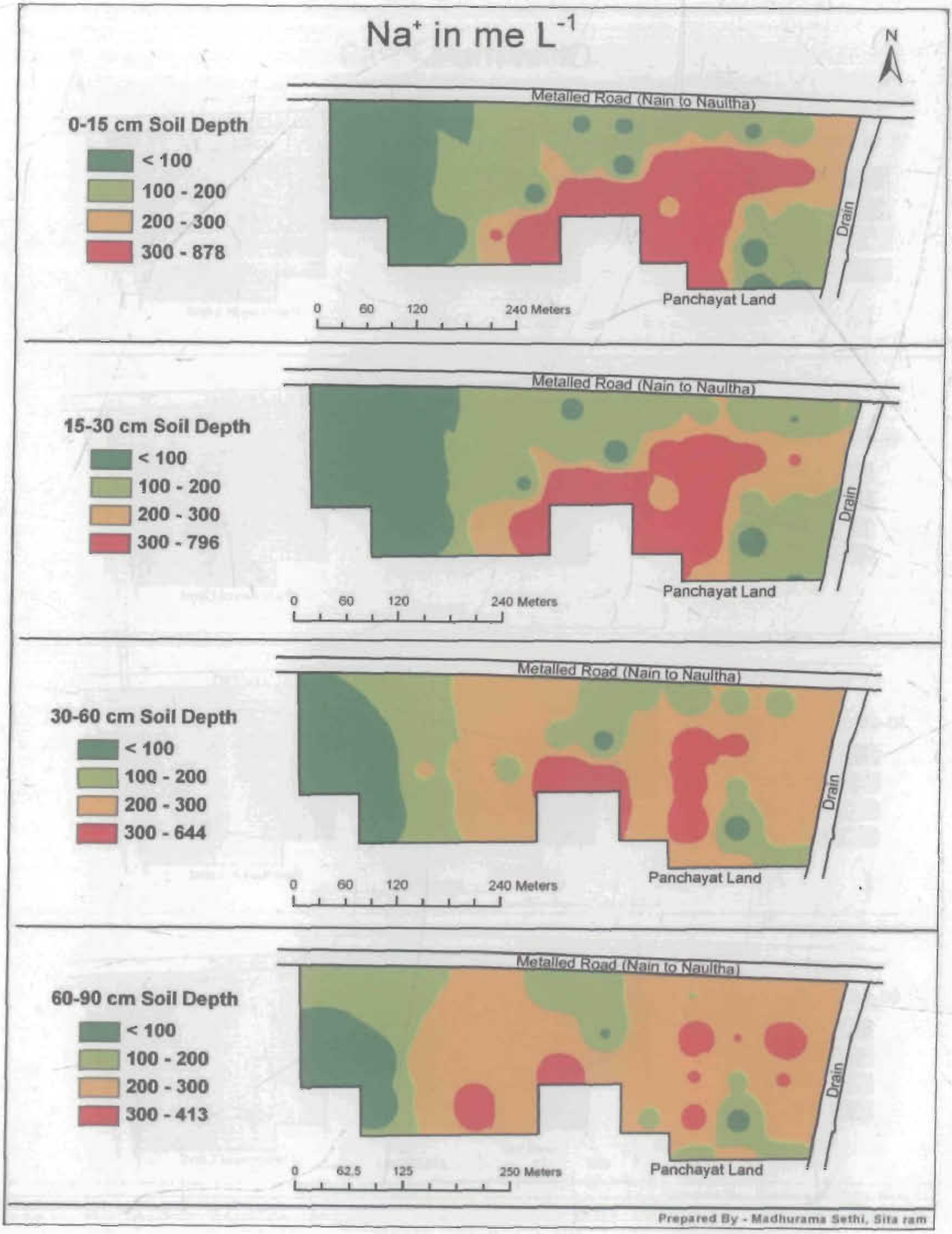


Fig. 8 : Variation of soil Na^+ content in Nain Farm

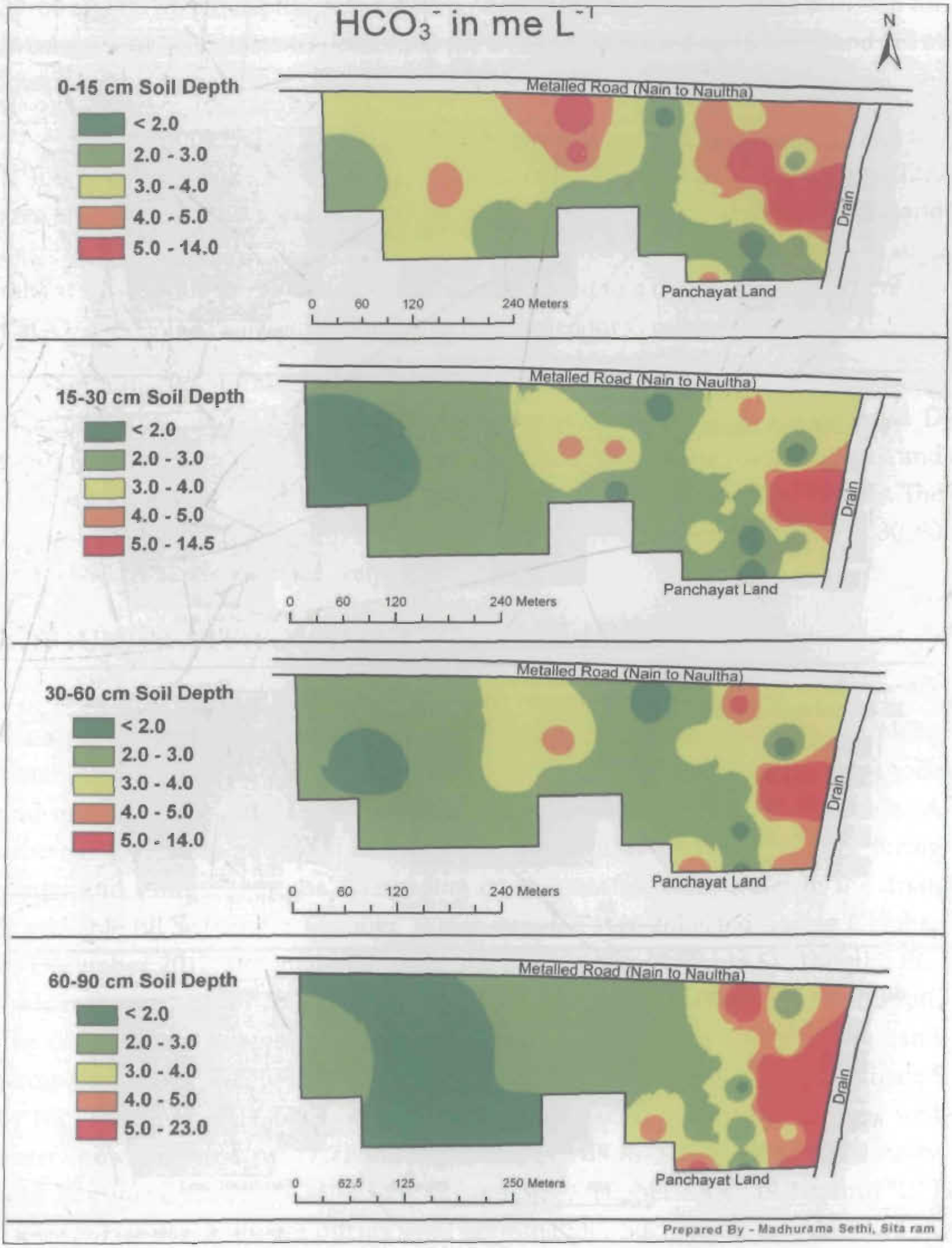


Fig. 9 : Variation of soil HCO_3^- content in Nain Farm

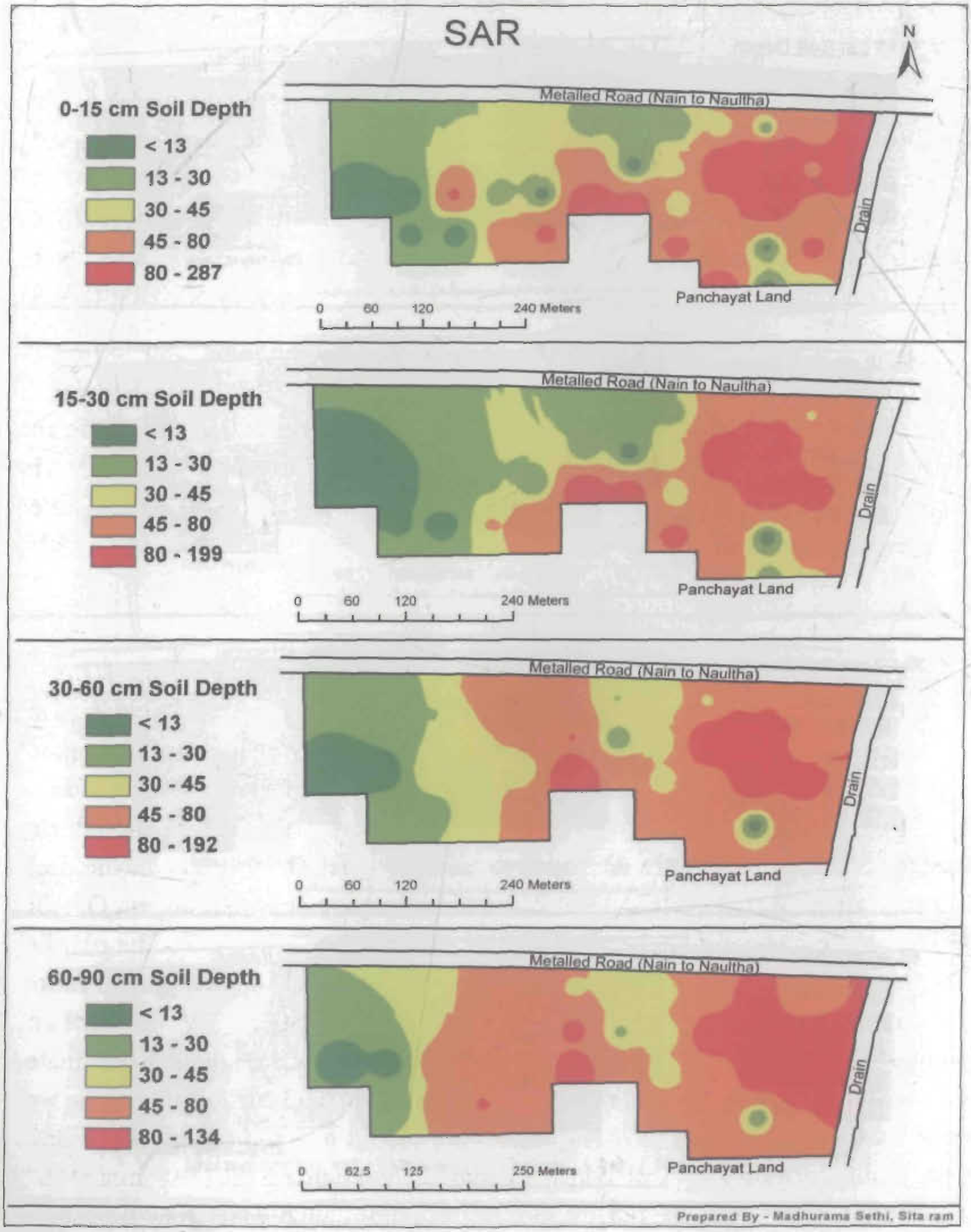


Fig. 10 : Variation of soil SAR in Nain Farm

30-60 and 60-90 cm depths, respectively. At surface, higher area (24%) is shown for D category of Na^+ concentration (>300 me L^{-1}) and decreased to 18%, 9% and 7% at lower depths, respectively (Fig. 8).

The bicarbonate content ranges from 2 to 5 me L^{-1} and is classified as A (<2 me L^{-1}), B (2-4 me L^{-1}) and C (>4 me L^{-1}). The B category of HCO_3^- level covered 72% area at surface while it increased to 75% and 81% at 15-30 and 30-60 cm depths and decreased to 49% at 60-90 cm depth. The data showed higher accumulation of such salts at surface due to runoff and leaching that extend to a depth of 60 cm, where the $CaCO_3$ concretion layers exist. Similar trend is noted for C category of HCO_3^- (Fig. 9).

Sodium Adsorption Ratio (SAR) of soils varies from 13 to 80 indicating alkaline nature. These are classified as A (13-30), B (30-45), C (45-80) and D (>80) respectively. The A and B categories covered 47% area at 0-15 cm depth and decreased to 43, 38 and 28% at 15-30, 30-60 and 60-90 cm depths, respectively. The C and D categories covered 47% at surface that increased to 55 and 68% at 30-60 and 60-90 cm depths, respectively (Fig. 10).

GROUNDWATER QUALITY

A natural drain is passing through the boundary (East side) of the farm. A hand pump (40 ft) was dug in the farm premises during April 2012 for drinking water purpose. Two ponds (West and East side of the farm) are in operational mode and one more is proposed to meet the demands for experimental irrigation. A tubewell (80 ft deep), installed in April-May 2012, is also used for irrigation during winter and summer seasons. Depending on the rainfall, fresh water in the drain is available till September/October. Water samples were collected during October to December 2012 and analyzed using standard methods (Table 5). The pH, EC, ionic composition, RSC and SAR of pond indicate normal water fit for irrigation. The drain water is also of good quality; suitable for irrigation. Water of the hand pump showed alkaline pH (8.23) and slight to moderate EC (5.8 dS m^{-1}) dominated by Na^+, Ca^{2+}+Mg^{2+}, Cl^-, SO_4^{2-} and HCO_3^- with SAR of 11.3 $mmol^{½}L^{-½}$. Tube well water showed neutral pH (7.7) and higher EC (13 dS m^{-1}) indicating high salinity with dominance of Na^+, Ca^{2+}+Mg^{2+}, Cl^- and SO_4^{2-}. Higher SAR (19.3 $mmol^{½}L^{-½}$) showed limitations for use during seed germination. Such water may be used in cyclic mode with good quality water preferably for salt tolerant crops and forestry/ fruit plantations.

Table 5 : Water Quality in Nain Farm

Water samples (location and depth)	pH	ECiw (dS m^{-1})	Cations (me L^{-1})			Anions (me L^{-1})				RSC* (me L^{-1})	SAR** (m $mol^{1/2}$ $L^{-1/2}$)
			Na^+	$Ca^{2+}+Mg^{2+}$	K^+	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-		
Pond 1 (Village side)	8.7	1.1	8.9	3.2	0.2	4.5	4.1	0.2	2.7	0.3	7.3
Pond 2 (Drain side)	8.8	1.1	9.3	2.9	0.2	4.2	4.9	0.4	2.8	0.5	7.8
Drain	8.8	1.6	10.2	6.2	0.7	5.5	5.9	0.7	4.5	0.0	5.6
Hand Pump (40 ft)	8.2	5.9	46.0	25.8	0.3	30.0	34.5	0.2	5.4	0.0	11.3
Tube well (80 ft)	7.7	13.0	103.7	57.2	0.5	81.0	60.1	0.0	6.2	0.0	19.3

*$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+}+Mg^{2+})$ **$SAR = \{ Na^+/(Ca^{2+}+Mg^{2+})^{1/2}\}$

LIMITATIONS AND POTENTIAL USE

Soils of the experimental farm at Nain village represent a typical alluvium of the old Gangetic plain showing abrupt variations of soil textures from sandy loam to sandy clay loam and significant occurrence of $CaCO_3$ concretions (*calcretes*) and Fe/Mn mottles (*ferricretes*) at a depth below the surface. These soils are poorly drained and developed a perched water table causing seasonal waterlogging during post-monsoon season. Topographical position, lack of agricultural operations and favourable weathering conditions of parent materials during seasonal waterlogging, facilitated formation and accumulation of salts through runoff. Higher salt content and the presence of sub-surface loam /sandy clay loam layers and nodules / concretions of Ca, Fe and Mn in Pedon 1, 2 and 3 showed severely salt affected soils with limitations of salinity, alkalinity and waterlogging. Located in lower topographic position, Pedon 4 showed higher salt content at sub-surface layers indicating the influence of salty ground water. Pedon 1 is characterized as moderately sodic and highly saline with dominance of soluble sodium chloride and sulfate salts. Due to low Ca^{2+} and Mg^{2+} content and moderate ESP (at surface), gypsum application @ 1-2 t ha^{-1} is required to reduce ESP followed by flushing with good quality water to remove excess soluble salts. Pedon 2 is a highly saline and salt composition showed dominance of soluble sodium, calcium and magnesium chloride and sulfates. It can be treated with good quality water to remove excess soluble salts. The presence of sandy clay loam soil at sub-surface depth and higher ESP and $CaCO_3$ content below surface may disturb the equilibrium between soluble and exchange phase and hence indicate possibility of alkalinity development after leaching. Treatment with low dosage of gypsum (4-6 t ha^{-1}) would be required for reclamation Pedon 4 needs leaching with good quality water for removal of excess soluble salts and may be used for growing arable crops such as rice and mustard (salt tolerant varieties) with proper soil and water management practices. Presence of salty ground water and lack of canal water restrict the use of highly saline and alkali soils (Pedon 2) for cropping and it is suitable for fisheries development projects or forestry plantations.

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ANNEXURE - I

Morphology of Soil Profiles

Pedon 1

The profile is developed on the old alluvium plain of the Trans-Gangetic Plain with very gentle slope (0-1%) from North West to South East. It is located near the drain, intersecting the farm boundary (29°19′04.1″N and 76°47′55.1″E) and also showed slight erosion and salt encrustation at surface. The soil profile is dry at surface, moist in the control section and wet at the lower part of the solum. The water table depth is 20-30 ft which is mostly saline in nature. High water table formation is also found at a depth of 2 m. *Prosopis juliflora* is the common vegetation. The drainage condition is poor to imperfect. Soil morphology showed brownish yellow to dark yellowish brown, loamy sand to sandy loam texture and weak, coarse to medium subangular blocky A horizon. B-horizon is 70 cm thick, light to dark yellowish brown colour, sandy loam to loam texture and showed moderate medium sub-angular blocky structure. It is strongly saline and moderately sodic in nature. Significant amounts of ferricretes and calcretes lie between 42-112 cm and 112-180 cm depths. It is distributed in the South-East of the farm.

A1 0-16 cm. Brownish yellow (10YR 6/6 D); loamy sand; coarse to weak medium subangular blocky structure; dry hard, moist friable, wet slightly sticky and slightly plastic; few fine pores, common coarse to medium roots; weak effervescence; clear smooth boundary, white salt encrustation (2-3 cm) present at the surface.

AB 16-42 cm. light yellowish brown (10YR6/4M); sandy loam; weak, moderate subangular blocky structure; moist friable, wet sticky and plastic; common fine pores; common coarse to moderate roots; weak effervescence, gradual smooth boundary.

Bw1 42-77 cm. Yellowish brown (10YR5/4M); sandy loam; moderate medium subangular blocky; moist friable, wet sticky and plastic; common fine pores; ferromanganese concretions (*Ferricretes*) 2-4 mm in diameter about 20-30% by volume; common moderate roots; slight effervescence with dilute HCl; clear smooth boundary; moist horizon when examined.

Bw2 77-112 cm. Dark yellowish brown (10YR 4/6M); sandy loam; moderate medium subangular blocky; moist friable, wet sticky and plastic; few fine pores; ferromanganese concretions *Ferricretes*) 4-5 mm in diameter about

30-40% by volume; few fine roots; strong effervescence with dilute HCl; gradual smooth boundary; moist horizon when examined.

Bw3c 112-150 cm. Dark yellowish brown (10YR 4/4M); sandy loam; coarse to weak medium subangular blocky; moist friable, wet sticky and plastic; very few very fine pores; calcium carbonate concretions (*calcretes*) of size 2-5 cm present 40-60 % by volume; few fine roots; violent effervescence with dilute HCl; moist horizon when examined.

BCc 150-180 cm. Yellowish brown (10YR 5/6 M), loam; weak coarse to medium subangular blocky; moist friable, wet sticky and plastic; very few fine to moderate pores; calcium carbonate concretions (*calcretes*) of size 6-8 cm present 60-80 % by volume; very few very fine roots; violent effervescence with dilute HCl; moist horizon when examined.

C 180-220 cm. Yellowish brown (10YR 5/6); loam; weak coarse to medium subangular blocky; moist friable, wet sticky and plastic; very few fine/ medium pores; violent effervescence with dilute HCl; wet horizon and seepage of water from shallow water table, when examined.

Pedon 2

The profile is located in South end of the farm near the farmers' field and drain (29°19′02.9″N and 76°47′50.3″E). It showed slight erosion and thick salt encrustation at the surface. The soil profile is dry at surface, moist in the control section and wet at the lower part of the solum. The water table depth is 20-30 ft and water is saline in nature, while perched water table exists at 2 m. *Prosopis juliflora* is the common vegetation. The drainage condition is poor to imperfect. Soil morphology showed yellowish brown to dark yellowish brown, sandy loam texture and weak, coarse, granular to medium subangular blocky A horizon. It is slightly sodic and strongly saline in nature. B-horizon is 119 cm thick, yellowish brown to dark yellowish colour, sandy clay loam to loam texture and showed fine to moderate medium sub-angular/angular blocky structure. It is strongly saline and slightly sodic in nature. Significant amounts of ferricretes and calcretes are located between 73-145 cm and 145-252 cm depths, respectively.

A1 0-23 cm. Yellowish brown (10YR 5/6 D); sandy loam; coarse granular to weak medium subangular blocky structure; dry hard, moist friable, wet slightly sticky and slightly plastic; few common to medium/fine pores, common coarse to medium roots; weak effervescence; gradual smooth boundary, white dry salt encrustation (2-3 cm) present at the surface.

AB 23-73 cm. Dark yellowish brown (10YR4/6M); sandy loam; weak, moderate subangular blocky structure; moist friable, wet slightly sticky and slightly plastic; common medium/fine pores; few, moderate/fine roots; weak effervescence, gradual smooth boundary.

Bw1 73-110 cm. Dark yellowish brown (10YR4/4M); sandy clay loam; fine to moderate medium angular blocky; moist firm, wet very sticky and very plastic; common medium/fine pores; ferromanganese concretions (*Ferricretes*) 2-4 mm in diameter about 40-50% by volume; few fine/moderate roots; strong effervescence with dilute HCl; clear smooth boundary; moist horizon when examined.

Bw2 110-145 cm. Dark yellowish brown (10YR 4/6M); sandy clay loam; weak coarse to medium subangular blocky, moist friable, wet sticky and plastic; few fine pores; ferromanganese concretions (*Ferricretes*) 4-6 mm in diameter about 60-80% by volume; few fine roots; strong effervescence with dilute HCl; clear smooth boundary; moist horizon when examined.

B3c 112-150 cm. Dark yellowish brown (10YR 5/6M); sandy loam; coarse to weak medium subangular blocky; moist friable, wet sticky and plastic; very few very fine pores; calcium carbonate concretions (4-6 cm) present 50-70% by volume; very few very fine roots; violent effervescence with dilute HCl; moist horizon when examined.

BCc 170-192 cm. Dark yellowish brown (10YR4/6M) sandy loam; weak medium subangular blocky; moist friable, wet slightly sticky and slightly plastic; very few, very fine pores; calcium carbonate concretions (6-8 cm) present 60-80% by volume; violent effervescence with dilute HCl; wet horizon when examined.

Cc 192-252 cm. Dark yellowish brown (10YR 5/6M), loam; strong coarse subangular blocky structure; moist firm, wet slightly sticky and slightly plastic; calcium carbonate concretions (2-5 cm) present 40-50% by volume; violent effervescence with dilute HCl; wet horizon when examined.

Pedon 3

The profile is located at centre of the farm (29°19′04.5″N and 76°47′42.4″E) and showed alkaline salt crust at surface. The soil profile is dry at surface, moist in the control section and below. The water table depth is 50-75 ft and water is saline in nature. A shallow water table exists at 4 m depth. *Prosopis juliflora* is the common vegetation and the drainage condition is poor to imperfect. Soil morphology showed brownish yellow to yellowish brown, sandy loam texture and weak, coarse, granular to medium subangular blocky A-horizon. B-horizon is 115 cm thick, yellowish brown to dark yellowish brown in colour, sandy clay loam to sandy loam/loam in texture and moderate, medium sub-angular/angular blocky structure. It is strongly saline and strongly sodic in nature. Significant amounts of ferromanganese mottles and calcium carbonate concretions (*calcretes*) are located at 60-175 cm depth.

A1 0-20 cm. Brownish yellow (10YR 6/6 D); sandy loam; coarse granular to weak medium subangular blocky structure; dry hard, moist friable, wet slightly sticky and slightly plastic; few coarse to medium pores, common medium roots; weak effervescence; gradual smooth boundary, white dry salt encrustation (2-3 cm) present at the surface.

AB 20-60 cm. Yellowish brown (10YR 5/6 M); sandy loam; strong coarse subangular blocky; moist firm, wet sticky and plastic; common fine pores; few fine roots; strong effervescence with dilute HCl, gradual smooth boundary.

Bw1 60-85 cm. Dark yellowish brown (10YR 4/4 M); sandy clay loam; strong coarse angular blocky; moist firm, wet very sticky and plastic; few fine roots; common fine faint Ferromanganese mottles; few fine roots; strong effervescence with dilute HCl; clear smooth boundary, moist horizon when examined.

Bw2 85-162 cm. Dark yellowish brown (10YR 4/4M); sandy loam; moderate medium subangular blocky; moist firm wet sticky and plastic; few fine roots; common fine faint Ferromanganese mottles; very few very fine roots; strong effervescence with dilute HCl; clear smooth boundary.

B2c 132-158 cm. Yellowish brown (10YR 5/6M); sandy loam; moderate medium subangular blocky structure; moist friable, wet slightly sticky and slightly plastic; very few fine pores; few fine faint Ferromanganese mottles; calcium carbonate concretions (4-6cm) 40-60% by volume; violent effervescence with dilute HCl; clear smooth boundary.

BCc 158-175 cm. Yellowish brown (10YR 5/4M); loam; moderate medium subangular blocky structure; moist friable, wet slightly sticky and slightly plastic; very few very fine pores; few fine faint ferromanganese mottles; calcium carbonate concretions (6-8 cm) 70-80% by volume; violent effervescence with dilute HCl; clear smooth boundary.

Cc 175-229 cm. Yellowish brown (10YR 5/6M); loam; coarse strong subangular blocky; moist firm, wet very sticky and very plastic; calcium carbonate concretions (2-5 cm) present 40-60% by volume; violent effervescence with dilute HCl.

Pedon 4

The profile is located in North-West side of the farm (29°19′08.4″N and 76°47′34.8″E) close to the main road. The soil profile is dry at surface and moist below. The water table depth is 30-40 ft and water is saline in nature. *Prosopis juliflora* is the common vegetation. The drainage condition is poor to imperfect. Soil morphology showed very pale brown colour, sandy loam texture and weak, coarse, granular to medium subangular blocky A-horizon. B-horizon is 95 cm thick, yellowish brown to brown colour, loam texture and weak fine angular to subangular blocky structure. It is moderately saline in nature. Significant amounts of calcium carbonate concretions (*calcretes*) are located at 85-117 cm depth.

A1 0-22 cm. Very pale brown (10YR 7/4D); sandy loam; coarse granular to weak medium subangular blocky structure; dry hard, moist friable, wet slightly sticky and slightly plastic; few fine pores; moderate medium roots and slight effervescence with dilute HCl, clear smooth boundary.

B1 22-53 cm. Yellowish brown (10YR 5/4M); sandy loam; weak fine angular blocky structure; moist firm, wet slightly sticky and slightly plastic; few fine pores; common medium roots and slight effervescence with dilute HCl, gradual smooth boundary.

B2 53-85 cm. Brown (10YR 5/3M); sandy loam; weak fine subangular blocky; moist firm, wet sticky and plastic; few fine pores; common fine roots; slight effervescence with dilute HCl; gradual smooth boundary.

B3c 85-117 cm. Yellowish brown (10YR 5/4M); sandy loam; weak fine subangular blocky structure; moist friable wet sticky and plastic; very few very fine pores; calcium carbonate concretions (4-6 cm) present 20-40% by volume; violent effervescence with dilute HCl; clear smooth boundary.

Cc 117-160 cm. Yellowish brown (10YR5/4M); sandy loam; strong coarse subangular blocky; moist friable, wet sticky and plastic; calcium carbonate concretions (6-8 cm) present 60-80% by volume; violent effervescence with dilute HCl.