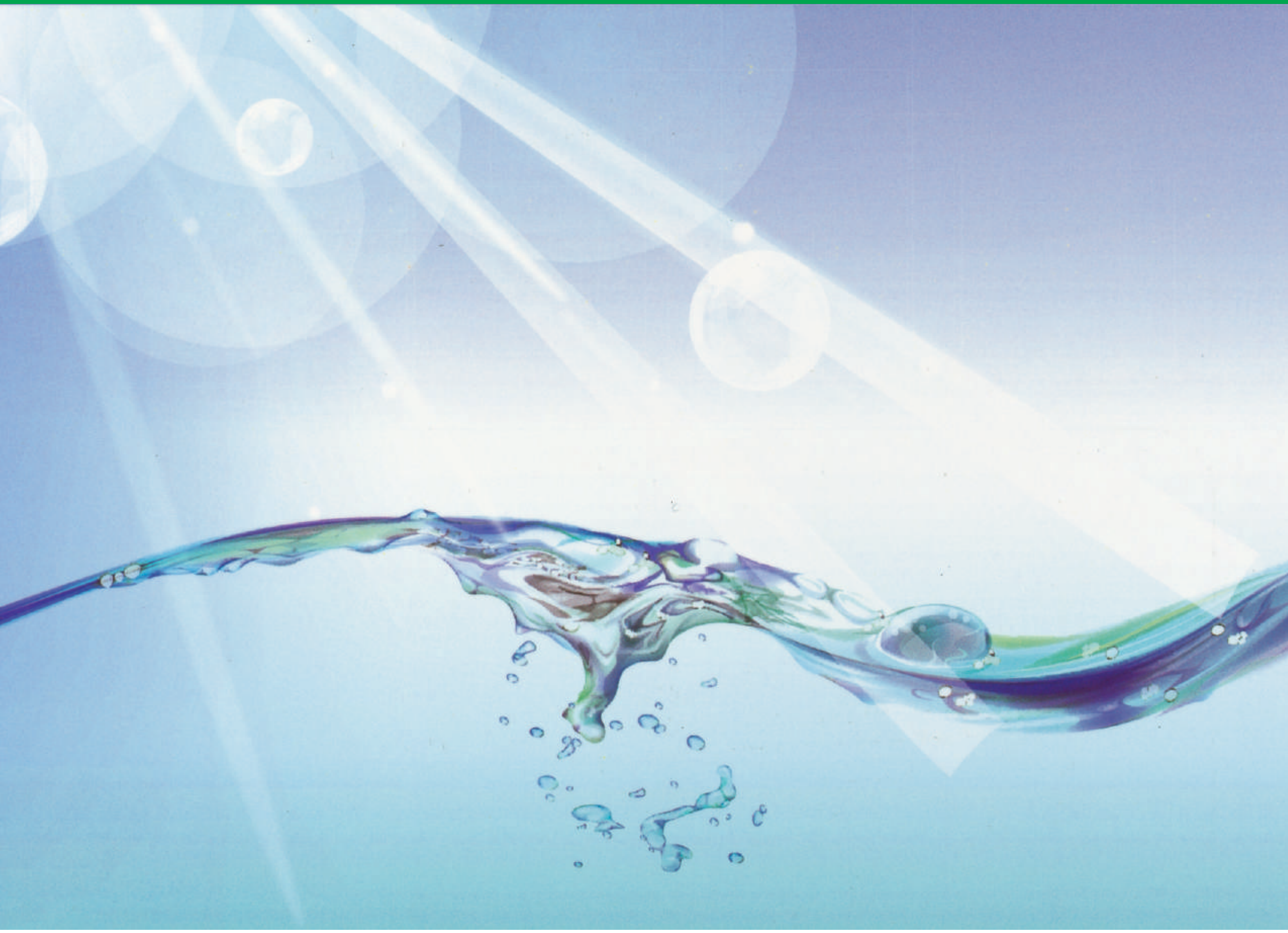
Journal of Soil Salinity and Water Quality

Volume: 16 No. 1 2024 ISSN 0976 – 0806



Indian Society of Soil Salinity and Water Quality

Central Soil Salinity Research Institute

Karnal-132 001 (India)

Indian Society of Soil Salinity and Water Quality

(Registration No: ROS-088, Dated 6th August 2008)
Website: www.issswq.in

For online submission of articles (https://epubs.icar.org.in/index.php/JoSSWQ). For subscription, editorial enquiry and advertisements, please contact: issswq2008@gmail.com, dagarjc@gmail.com, dsbundela@gmail.com.

Membership Subscription

SNo.	Category of Membership	Subscription charges	
		Inland (₹)	Foreign ($)
1.	Life Member	4,000	250
2.	Annual Member	450	50
3.	Student Member (One year)	250	25
4.	Institutional Member (Lump sum for 30 years)	25,000	-
5.	Institutional Member (Annual)	3,500	-

Membership fee may be sent through Multicity cheque only in favour of Indian Society of Soil Salinity and Water Quality, payable at Kamal. The payments can also be deposited online into Society account (Through NEFT) with intimation to society office (Secretary/Treasurer).
Name of account holder: **Indian Society of Soil Salinity and Water Quality**; **Account number: 30451467955** (Saving Bank account); **IFS Code: SBIN0000665**; Bank and Branch: **State Bank of India, Main Branch, Karnal**

Journal of Soil Salinity and Water Quality

Journal of Soil Salinity and Water Quality (JSSWQ) serves as an official organ of the Indian Society of Soil Salinity and Water Quality (ISSSWQ) for the publication of reviews, research papers and short communications as per constitution and by-laws of the society. Soft and hard copy of the journal are sent free to all its members. All disputes are subject to the exclusive jurisdiction of competent court and forums in Kamal only. The society does not assume any responsibility for opinion by the authors in the articles and no-material in any form can be reproduced without the prior permission of the society. The society is not responsible for any delay, whatsoever, in publication/ delivery of the periodicals to the subscribers due to unforeseen circumstances or postal delay. The society does not vouch for any claims made by the advertisers of products and services. The publishers and the editors shall not be held liable for any consequences in the event of such claim not being honoured by the advertisers.

ISSN 0976-0806

Journal of Soil Salinity and Water Quality

Volume 16 | 2024 | Number 1

CONTENTS

Acknowledgement

Indian Society of Soil Salinity and Water Quality, ICAR-Central Soil Salinity Research Institute, Karnal, is Thankful to the Indian Council of Agricultural Research, New Delhi for Financial Assistance to Support the Publication of the Journal.

Journal of Soil Salinity and Water Quality 16(1), 1-15, 2024

Characterization and Classification of Ber (*Ziziphus mauritiana*) Growing Soils of Rewari District, Haryana

Sumantra Arya*[1], Rameshwar Singh[2], Dinesh[1], MK Jat[1] and PK Yadav[2]

[1]Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar-125004, Haryana, India
[2]Regional Research Station, Chaudhary Charan Singh Haryana Agricultural University, Bawal-123501, Rewari, Haryana, India
**Corresponding author's E-mail: sumantrasheoran@gmail.com*

Abstract

The eight soil profiles of ber–growing orchards in different locations, *viz*., Bhurthla (P1), Zahidpur (P2), Boriya Kamalpur (P3), Lodhana exposed (P4), Khaliawas (P5), Jiwra (P6), Rajawas (P7), and Regional Research Station, Bawal (P8) of Rewari district were exposed, and their morphological, physicochemical characteristics were studied, and soils were classified. For this purpose, visual interpretation of IRS–P6 satellite imagery (FCC) at 1:50000 scale was collected to prepare the base map of the study area. Then soil samples in each horizon of the soil profile were collected after performing ground truth. The soil of surface horizons varied from coarsely weak single–grained to moderately weak granular, but the soil of subsurface horizons varied from coarsely structureless single–grained to medium weak subangular blocky in structure. Bulk density varied from 1.33–1.59 Mg m^{-3} and the soil water content varied from 5.89–9.11 at 0.03 MPa and 1.50–5.5 MPa at 1.5 MPa. The soil reaction of the pedons varied from neutral (pH 7.3) to alkaline (pH 9.23), and the soil was non–saline and soil organic carbon varied from 0.07–0.78%. The exchangeable cations Na^+, Mg^{2+}, Ca^{2+}, and K^+ were 0.40–5.60, 0.20–3.12, 0.10– 1.56, and 0.01–0.10 cmol$_{(P+)}$ kg^{-1}. The soils of the study area were sandy, mixed, Hyperthermic, *Typic Ustipsamments* for Pedon 1, 2, 3, 6, 7 and 8; whereas Pedon 4 was sandy mixed (calcareous) hyperthermic *Typic Ustipsamments* and Pedon 5 was coarse sandy mixed (calcareous) hyperthermic Fluventic Ustipsamments.

Key words: Pedon, characteristics, classification, *Ziziphus mauritiana*, soils

Introduction

Soil is the dynamic and active natural body that continuously interacts between the hydrosphere, biosphere, lithosphere and atmosphere. Basic knowledge about the morphological, physical, chemical, and mineralogical content of soils helps to develop a better understanding from characterization and classification point of view. Soil categorization is essential to determining the potential and constraints of a particular location for the crop under study, whether through proper or alternate land use planning. Soil characterization aims to categorise soils and quantify their physical and chemical properties, which may reveal information about the soil's capacity to function that is only sometimes evident from the survey (Sanchez *et al*., 2003). Soil formation may be due to the translocation of parent material from one place within the soil or to fluventic and alluvial deposition. Other reasons may be eluviation and illuviation that occur within the soil profile. Soil classification aids in organising our knowledge, making it easier for expertise and technology to be transferred from one location to another, and aids in comparing soil characteristics (Sashikala *et al*., 2019). There is an immense need for agricultural diversification in light of the following: land degradation caused by salinity or alkalinity; sinking average land holding due to fragmentation; decreased productive cultivable land due to imbalanced fertiliser use and rapid industrialization; water scarcity as a result of imbalanced seasonal rainfall; and natural disasters that cause soil erosion and the loss of fertile top soils. Similar statements were given by Lal (2013).

As a result of this, among alternative land use plans, horticultural crops are more cost–effective and nutritious and are preferable for farmers' choice. Ber (*Ziziphus mauritiana* L.) belongs to the Rhamnaceae family and originated in the Indo–Malaysian region of southeast Asia. It is a semi–arid fruit that has a majority share of cultivation in the Rewari district, Haryana. The water requirement is much lower than that of other crops, and it is suitable under agroclimatic and agroecological conditions, which prevents desertification of lands under cultivation. Because of its remarkable tolerance to adverse agro–climatic conditions, it is one of India's most important fruit crops. A report by the Agriculture and Farmers Welfare Department (Government of India) on the area and production of horticulture crops for 2023–24 (1st Advance estimate: https://agriwelfare.gov.in/en/StatHortEst) stated that in India, it covers an area of 51.7 lakh hectares and produces 548.3 metric tonnes per year and in Haryana, the total estimated area and production are 43.9 thousand hectares and 546.2 thousand metric tons, respectively. In the Rewari district of Haryana, there is a lack of literature on site characteristics for establishing ber orchards, their influence on soil fertility status, plant nutrient availability, soil characterization and classification of land capability and suitability, particularly for fruit crops. As a result, this study was planned to fulfill the objective of characterising and classifying Ber–growing soils in the Rewari district of Haryana.

Material and Methods

Description of study areas

Under the alluvial and sandy tract, the Rewari district (1559 sq. km) is situated between 27.52–28.50°N latitude and 76.0–76.5°E longitudes. It shares boundaries with the Alwar district of Rajasthan in the south, Gurgaon in the east, Jhajjar in the north, and Mahendergarh in the west. It has vast alluvial and sandy tracts and dunes attaining a height of 30 m, surrounded by the Aravalli Hills tract. Some of the dunes support light vegetation, while others shift depending on the wind's direction. The hill ranges are part of the great Aravalli chain and contain valuable mineral deposits and natural meadows. The land elevation in the area varies from 232 m in the north to 262 m above mean sea level in the south. The master slope of the area is towards the north. The district broadly forms part of the Indo–Gangetic alluvial plain of the Yamuna subbasin. Apart from tube–well irrigation, the Sahibi and Krishnawati rivers are seasonal sources of irrigation in the southwest only during the southwest monsoon. Rewari district has a semi–arid, hot climate with scorching summers and freezing winters. The soil temperature and moisture regime lie in the hyperthermic and ustic ranges. The district is located in the pre–Cambrian rock domain of the Aravali Mountains. These are exemplified by the Delhi Super Group of rocks, which are limited to the southern region of Haryana and date back between 2500 and 1600 million years. Shale, slate, phyllite, pelitic schist, crystalline and impure limestones, marbles, and calc–schist with thinly bedded quartzite intercalations are among the group of predominant rock types (Datta *et al.*, 2016). The common natural vegetation that lies in the district is *Zizyphus jujuba* (Ber), *Acacia catechu* (Khair), *Ficus religiosa* (Pipal), *Ficus bengalensis* (Bargad), *Azadirchata indica* (Neem), *etc*. The district's major *kharif* crops are *Pennisetum glaucum* (Bajra) and *Gossypiumd spp.* (Cotton). The major *rabi* crops grown in the district include *Triticum aestivum* (wheat), *Brassica spp.* (mustard), *etc*. The study area received rainfall of 656.8 mm during 2020–2021 (Data from the Meteorological Observatory (RRS Bawal, CCSHAU Hisar) and lay in the Western (HR–2) agroclimatic zone, Trans–Gangetic plain agroclimatic region and Northern plain and central highland agro-ecological sub-region (Sethi *et al.*, 2018).

Image interpretation and ground truth verification

Visual interpretation of IRS–P6 satellite imagery (FCC) at 1:50000 scale (Fig. 1) was done for the preparation of a base map (Fig. 2) of the study area. Remote sensing data under Rewari district was taken from the NRSC (http://www.nrsc.gov.in). Satellite sensor used was LIS III, having rows 95 and 51, and an IRS resource set FCC image of Rewari district was used for a better understanding of the study area (Sethi *et al.*, 2018). Geomorphic features were interpreted

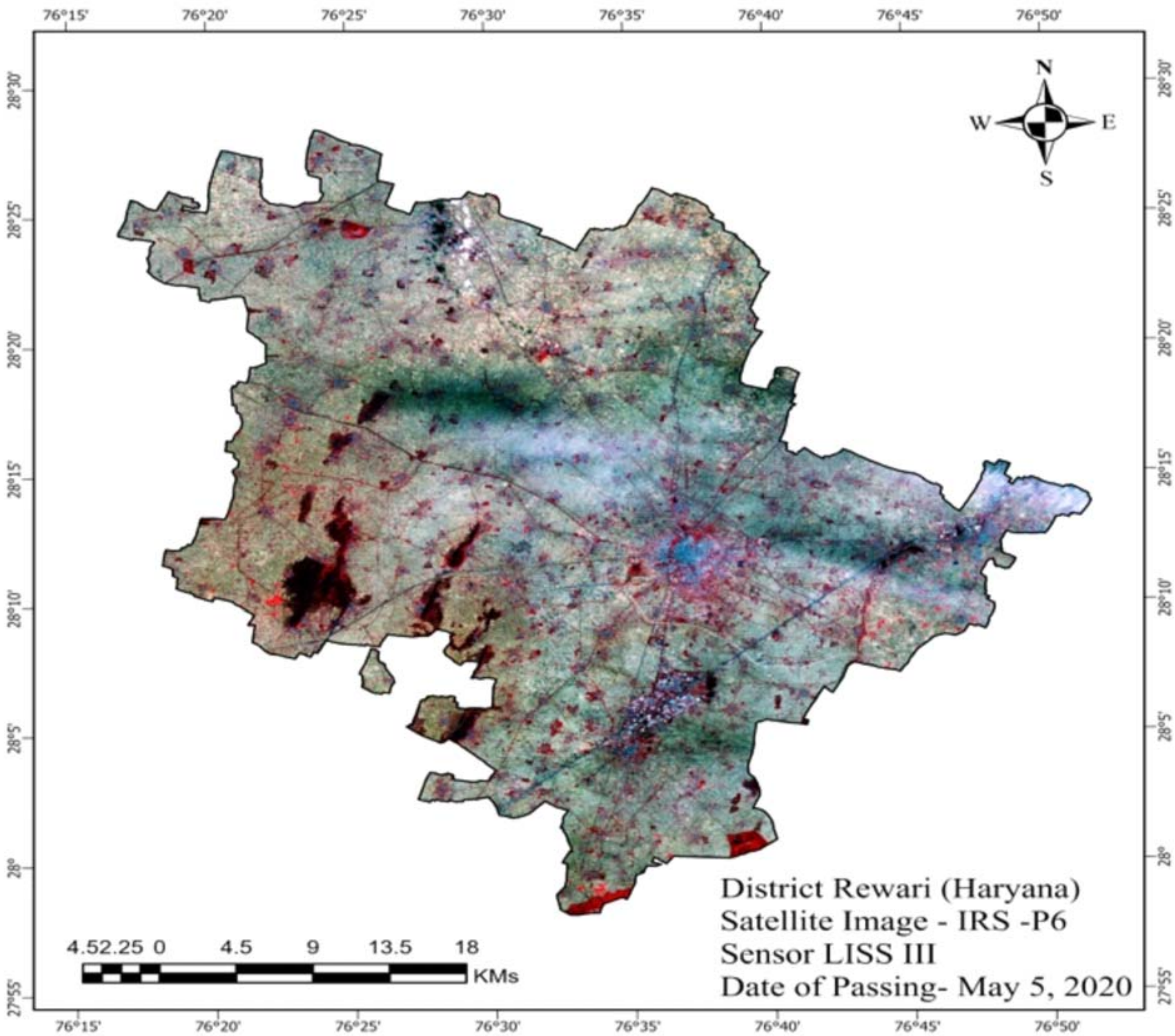


Fig. 1 FCC of IRS P-6, LISS III during May 5, 2020

based on key image elements such as shape, tone or colour, pattern, shadow, association, and texture (Jena *et al.,* 2016). A location map (Fig. 2) was created for the soil survey. A route through the different locations was taken to validate various orchard locations through ground truthing within the study area. A general description of the studied pedons is shown below in Table 1.

Profile study and sample collection

Based on the soil variations and dominance of ber orchards, eight locations were selected for the profile study (Fig. 2). A detailed profile study was carried out, and morphological, pedogenic, and soil site characteristics were recorded as per the standard procedures to characterize and classify the soils. The method described by the Soil Survey Division Staff (2017) and IARI (1971) was followed to study the soil profile in detail. Horizon–wise samples were also collected for laboratory analysis.

Physicochemical characterization of soil

The soil colour was determined using the Munsell colour chart by matching moist soil with different colour chips (Fig. 3). Horizon–wise samples from all respective depths were collected from representative pedons for soil texture determination by quantifying the sand, silt and clay particles using International Pipette method (Piper, 1950). Bulk density and Particle density were estimated by the core sampler (Blake, 1965) and Pycnometer using distilled water as the displacing fluid (Means and Parcher, 1963)

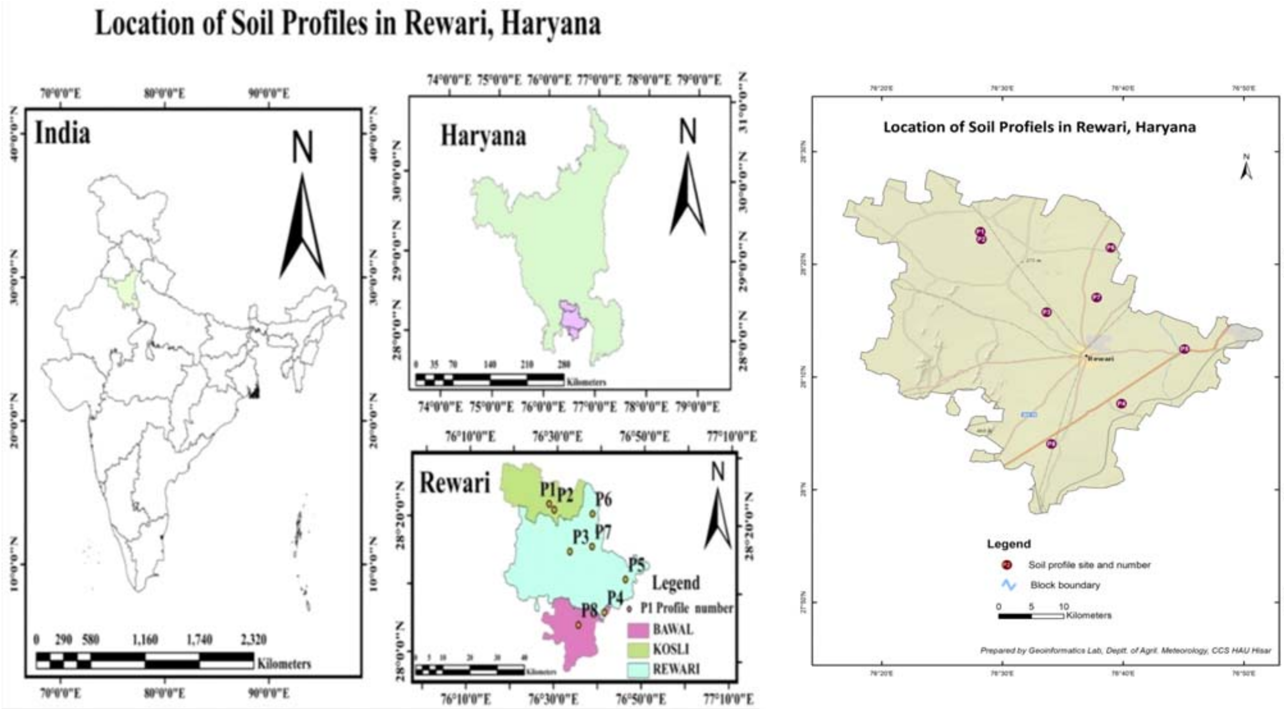


Fig. 2 Location and base map of study area

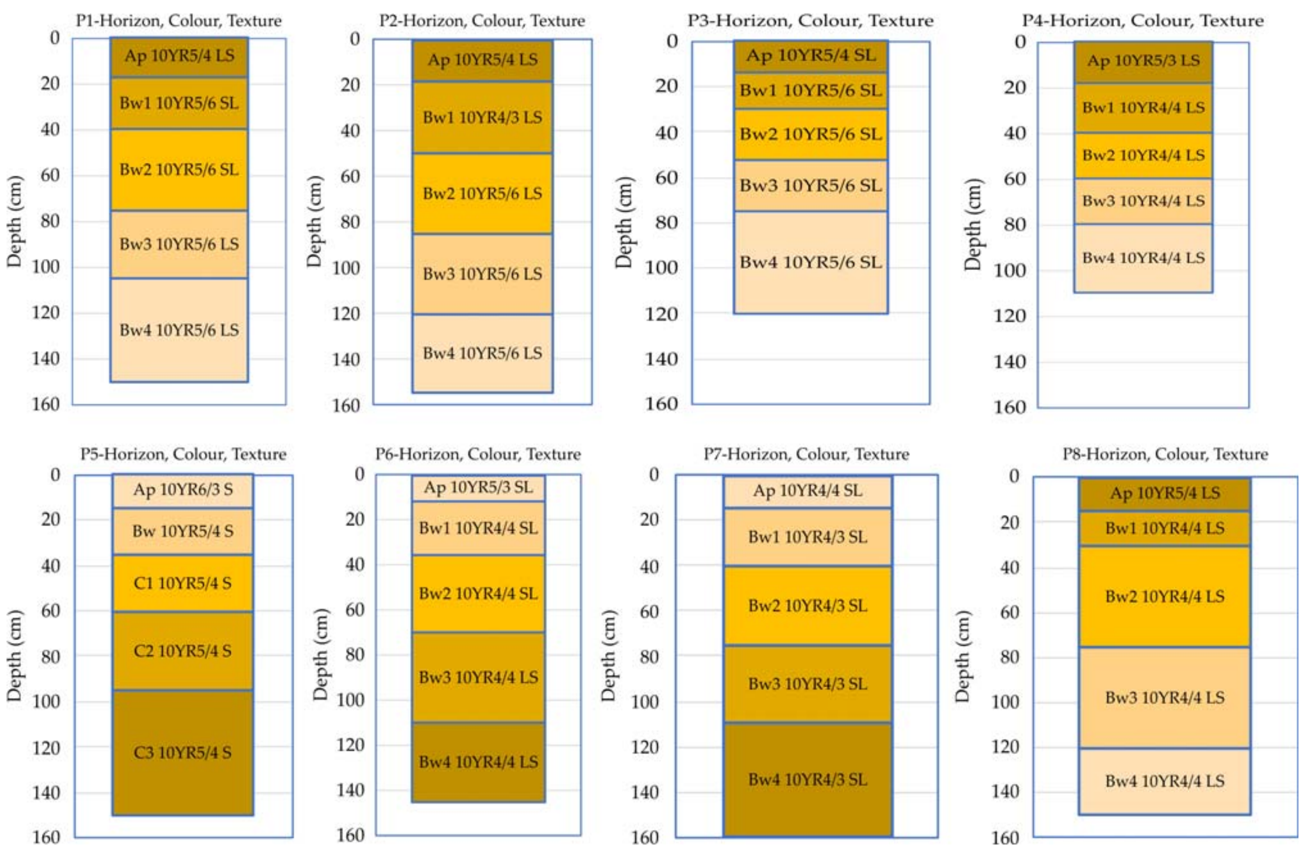


Fig. 3 Horizination of studied pedon

Table 1. Location and site characteristics of studied soils in Rewari district

Pedon	Village	Latitude	Longtidue	Elevation (ft)	Establishment year	Tehsil	Physiography	Drainage Material	Parent	Slope %	Slope Direction
P1	Bhurthla	28°38'089" N	76°46'961" E	173	2001	Kosli	Nearly Level	Excessively drained	Alluvium	1–3	N–S
P2	Zahidpur	28°22'223" N	76°28'248" E	190	2004	Kosli	Nearly Level	Excessively drained	Alluvium	1–3	N–S
P3	Boriya Kamalpur	28°15'750" N	76°33'650" E	186	2014	Kosli	Nearly Level	Excessively drained	Alluvium	1–3	N–S
P4	Lodhana Ki Dhani	28°07'626" N	76°39'849" E	200	2016	Rewari	Level	Somewhat Excessively Drained	Alluvium	0–1	N–S
P5	Khaliyawas	28°12'483" N	76°45'076" E	191	2001	Dharuheda	Gently Sloping	Somewhat Excessively Drained	Alluvium	1–3	N–S
P6	Jiwra	28°21'482" N	76°38'965" E	178	1998	Jatusana	Nearly Level	Somewhat Excessively Drained	Alluvium	1–3	N–S
P7	Rajawas	28°17'057" N	76°37'790" E	182	2016	Rewari	Nearly Level	Well drained	Alluvium	0–1	N–S
P8	RRS Bawal	28°04'059" N	76°34'050" E	75	1980	Bawal	Level	Somewhat Excessively Drained	Alluvium	0–1	N–S

methods, respectively. Soil moisture content at 0.03 MPa and 1.5 MPa were determined using Pressure plate apparatus (Bruce and Luxmoore, 1986). The available water content was computed as the difference between soil water content at field capacity and the permanent wilting point. Soil pH was determined using a pH meter consisting of a glass electrode in soil and water (1:2) suspension at room temperature (Jackson 1967). Electrical conductivity (dS m^{-1}) was determined using a conductivity meter in soil: water (1:2) suspension at room temperature (25°C) (Jackson, 1967). Organic carbon was determined by the Walkley and Black rapid titration method (Jackson, 1967). The calcium carbonate was estimated by the rapid titration method (Piper, 2019). Exchangeable calcium and magnesium were determined by using 1 *M* KCI triethanolamine buffer solution (pH 8.2) and titrating the leachate with a standard EDTA solution using muroxide and EBT as an indicator (Richard, 1954). Exchangeable sodium and potassium were determined by leaching the soil with a 1 *M* ammonium acetate (pH 7) solution. Na^+ and K^+ from the leachate were estimated using a flame photometer (Jackson, 1967).

Soil classification

Keys to Soil Taxonomy (Soil Survey Staff, 2022) were used to classify soils according to their morphological and physicochemical characteristics.

Results and Discussion

The pedon features, which include soil depth, horizon designation, horizon boundary, soil colour, texture, structure, consistency, soil reaction, porosity, roots, nodules, concretions, nature of cracks, nature of clay films, coarse fragments, and other special features, describe the soil body, its appearance, features and general characteristics as expressed in the profile of the soil.

Morphological characteristics

Alluvium parent material makes the studied Pedons extremely deep. However, Pedon 3 was shallow (Fig. 4; Table 2). The deep profile depth suggests a prolonged weathering process that most likely started in humid surroundings and slowed

Table 2. Morphological characteristics of studied pedons

Pedon	Depth (cm)	Horizon Designation	Boundary	Colour	Texture	Structure	Roots	Reaction with 0.1 *M* HCL
P1	0–17	Ap	cs	10YR 5/4	LS	c1sg	fc	–
	17–40	Bw1	cs	10YR 5/6	SL	c0sg	fc	–
	40–75	Bw2	ds	10YR 5/6	SL	c0sg	mf	–
	75–105	Bw3	ds	10YR 5/6	LS	c0sg	mf	–
	105–150	Bw4	ds	10YR 5/6	LS	c0sg	mf	–
P2	0–18	Ap	cs	10YR 5/4	LS	c1sg	fc	–
	18–50	Bw1	cs	10YR 4/3	LS	c1sg	fc	–
	50–85	Bw2	cs	10YR 5/6	LS	c1sg	cc	–
	85–120	Bw3	cs	10YR 5/6	LS	c1sg	cc	–
	120–155	Bw4	cs	10YR 5/6	LS	c1sg	-	–
P3	0–14	Ap	cs	10YR 5/4	SL	c1gr	vfc	–
	14–30	Bw1	cs	10YR 5/6	SL	c1gr	vfc	–
	30–52	Bw2	cs	10YR 5/6	SL	m1sbk	mf	–
	52–75	Bw3	cs	10YR 5/6	SL	m1sbk	mf	–
	75–120	Bw4	cs	10YR 5/6	SL	c1gr	-	–
P4	0–18	Ap	cs	10YR 5/3	LS	m0g	fm	–
	18–50	Bw1	ds	10YR 4/4	LS	c0sg	fm	–
	50–70	Bw2	ds	10YR 4/4	LS	c0sg	cf	e
	70–90	Bw3	ds	10YR 4/4	LS	c0sg	ff	e
	90–120	Bw4	ds	10YR 4/4	LS	c0sg	–	es
P5	0–15	Ap	cs	10YR 6/3	S	c0sg	fm	–
	15–45	Bw	cs	10YR 5/4	S	c0sg	fm	
	45–70	C1	ds	10YR 5/4	S	c0sg	cc	e
	70–105	C2	ds	10YR 5/4	S	c0sg	cc	e
	105–160	C3	ds	10YR 5/4	S	c0sg	cc	–
P6	0–12	Ap	cs	10YR 5/3	SL	m1gr	vfm	–
	12–36	Bw1	gs	10YR 4/4	SL	m1sbk	fc	–
	36–70	Bw2	gs	10YR 4/4	SL	m1sbk	cc	–
	70–110	Bw3	ds	10YR 4/4	LS	c0sg	cc	–
	110–145	Bw4	ds	10YR 4/4	LS	c0sg	cc	–
P7	0–15	Ap	cs	10YR 4/4	SL	m1g	fm	–
	15–40	Bw1	cs	10YR 4/3	SL	m1gr	fm	–
	40–75	Bw2	ds	10YR 4/3	SL	m1sbk	fm	–
	75–109	Bw3	ds	10YR 4/3	SL	m1sbk	fm	–
	109–160	Bw4	ds	10YR 4/3	SL	m1sbk	-	–
P8	0–15	Ap	cs	10YR 5/4	LS	cosg	cf	–
	15–30	Bw1	cs	10YR 4/4	LS	cosg	cf	–
	30–75	Bw2	ds	10YR 4/4	LS	cosg	cf	–
	75–120	Bw3	ds	10YR 4/4	LS	cosg	cc	–
	120–150	Bw4	ds	10YR 4/4	LS	cosg	cc	–

Soil texture: sl = sandy loam, cl = clay loam, ls-loamy sand;
Roots: ff = fine few, fc = fine common, fm = fine many, cm = coarse many, cf = coarse few;
Consistency: sh = slightly hard, l = loose, fr = friable, sfi = slightly firm, ss = slightly sticky, sp = slightly plastic, ms = moderately sticky, mp = moderately plastic, vs = very sticky, vp = very plastic;
Structure: m = medium size, sbk = sub-angular blocky, sg = single grain, 1 = weak structure, 2 = moderate structure, 3 = strong structure.
Boundary: cs = clear smooth, gs = gradual smooth, cw = clear wavy.

Fig. 4 Profile Study (P1–P8)

down over time with the current moderate environmental conditions as reported by Sharma *et al*. (2011). Pedon 1, 2, and 3 were levelled and had low to moderate erosion, excessive drainage, and slow profile development. Pedon 4 and Pedon 7 were formed on a nearly level physiographic position on moderately sloping land with good to excess drainage. Pedon 5, Pedon 6, and Pedon 8 were formed on gently sloping, nearly level–to–level plains with well–drained land. Soil colour, which indicates direct or indirect information about the physical, chemical, and biological characteristics of the soil, is one of the most significant morphometric traits. The colour of the soil can be used to infer the climatic conditions under which this parent material is developed. The soils of the investigated pedons were dark yellowish brown and pale brown to brown, with 10YR being the prevailing hue. Value varied from 4 to 5, and the chromas were 3 to 6. Differences in texture, topography, mineralogical and chemical composition, and soil moisture regimes may all contribute to the difference in soil colour observed among different layers (Dinesh *et al*., 2017). The darker colour of the surface soil may be due to the higher organic carbon content deposited through the accumulation of organic matter upon return of root biomass and rhizodeposition (Mahapatra *et al.* 2000). Pedon 5 had sandy soils because of its fluventic nature due to the nearness of the Sahibi River. Pedons 2, 4, and 8 had loamy sand soils, and Pedons 1, 3, 6, and 7 were sandy loam to loamy sand textures. In general, soils of the subsurface horizons were finer–grained than the surface, and overlying horizons might be due to the illuviation of clay. However, most soil is made up of sand, which might be due to the alluvial, fluventic and silicious sandy parent material. Mahajan *et al.* (2007) supported this observation, who also reported that more sand fractions were recorded in the soils due to the presence of sandstone, siltstone, granite, *etc.*

Surface structure of soil varied from coarsely weak single–grained to moderately weak granular, while it varied from coarse structureless single–grained to medium weak sub–angular blocky subsurface, indicating a process of profile development. Sharma *et al.* (1996) observed that the soil structure was weakly developed in coarse–textured soils compared to more developed soil structures in alluvial plains and moderately developed in piedmont plains and flood plains. Moreover, the variation in soil structure reflects the physiographic position of the pedons. The consistency of different pedons varied from non–sticky to slightly sticky and these results are in agreement with Tomar and Bhat (2023). The roots in different pedons varied from very fine to coarse in diameter and from very few to common in abundance. Because of the deep–rooted system of fruit plants, improved aeration, and impacts of soil management, root biomass increased with depth. Subsurface soils of Pedon 4 and 5 showed a reaction with 0.1 *M* HCl, which produced effervescence in the form of bubbles, indicating the presence of calcium carbonate in the form of concretions or nodules. Calcium carbonate may be formed in situ due to the calcification process under aridic climatic conditions (Sahoo *et al.,* 2019).

Physical characteristics

Along with different horizons Ap, Bw1, Bw2, Bw3, Bw4 and Bw5 were found to show soil profile development (Table 3). Similar findings were also reported by Surwase *et al.* (2023). The mechanical constituents of soils of all the pedons indicated that sand content was higher in upper horizons and decreased down the depth, except Pedon P5, in which sand content was higher in subsurface layers due to fluventic parent material. Clay and silt content in the profile increased with depth; after that, it decreased with increasing depth. This might be due to the illuviation of clay particles. Similar findings were also reported by Srinivasan *et al.* (2013) and Satish *et al.* (2018). The dominance of sand in mechanical fraction might be due to the dominance of physical weathering and silica and alluvial deposits over time. Sand is negatively and significantly correlated with silt ($r = -0.96^{**}$) and clay ($r = -0.95^{**}$), respectively, due to the dominance of the sand fraction percentages. Similar findings were also reported by Tomar and Bhat (2023). The loamy sand texture is dominant in the study area, as also reported by Datta *et al.* (2016) and Basak *et al.* (2016) in the soils of Rewari and Mahendragarh districts. Pedon 5 showed higher values of bulk density (1.59 Mg m^{-3}), whereas it was the lowest for Pedon 3 (1.32 Mg m^{-3}). The bulk density of soil increases with increasing depth (Singh and Agrawal, 2005). A critical look at the bulk density data showed that it increased with the increment in the depth of the soil, which might be due to the accumulation of finer fractions and heavy minerals eluviated from the surface horizon (Nayak *et al.*, 2002; Marathe *et al.*, 2003). The increase in bulk density with depth was attributed to decreasing organic matter, increased compaction, and less soil aggregation, and this was similar to earlier findings (Singh and Agrawal, 2005; Sireesha and Naidu, 2013). Bulk density had been positively and significantly correlated with sand ($r = 0.45^{**}$; Table 4) due to the dominance of sand fraction and particle density ($r = 0.32^{**}$), which are supported by Tomar and Mohammad (2023). The porosity of soil varied from 25 to 48% and generally decreased with soil depth. In all the Pedons, moisture retention values at field capacity and permanent wilting point varied from 5.50–9.11 MPa and 1.50–5.89 MPa. The highest (9.11, 5.89 MPa) and lowest (5.5, 1.50 MPa) moisture released was recorded in surface forces and

Table 3. Physical characterization of studied pedons

Pedon	Horizon	Depth	Texture	Sand (%)	Silt (%)	Clay (%)	Bulk density (Mg m^{-3})	Particle density (Mg m^{-3})	Pore space (%)	Moisture retention (MPa)		Water content
										0.3	1.5	
P1	Ap	0-17	Loamy Sand	81.80	9.30	8.90	1.33	2.22	40	7.30	3.86	3.44
	Bw1	17-40	Sandy Loam	78.50	11.50	10.00	1.42	2.22	36	6.21	3.20	3.01
	Bw2	40-75	Sandy Loam	75.70	12.70	11.60	1.43	2.42	41	7.19	4.14	3.05
	Bw3	75-105	Loamy Sand	80.80	10.40	8.80	1.45	2.50	42	8.40	4.32	4.08
	Bw4	105-150	Loamy Sand	81.40	10.00	8.60	1.47	2.85	48	8.10	4.26	3.84
P2	Ap	0-18	Loamy Sand	82.90	8.20	8.90	1.33	2.47	46	6.11	3.21	2.90
	Bw1	18-50	Loamy Sand	82.30	8.80	8.90	1.35	2.51	46	6.23	3.50	2.73
	Bw2	50-85	Loamy Sand	81.10	10.20	8.70	1.39	2.53	45	7.13	3.68	3.45
	Bw3	85-120	Loamy Sand	80.80	10.40	8.80	1.40	2.56	45	7.47	3.98	3.49
	Bw4	120-155	Loamy Sand	80.70	10.50	8.80	1.42	2.58	45	5.89	2.78	3.11
P3	Ap	0-14	Sandy Loam	81.30	8.60	10.10	1.33	2.22	40	6.11	1.50	4.61
	Bw1	14-30	Sandy Loam	80.40	9.00	10.60	1.33	2.22	40	6.34	2.68	3.66
	Bw2	30-52	Sandy Loam	74.10	12.60	13.30	1.33	2.35	43	7.28	3.13	4.15
	Bw3	52-75	Sandy Loam	76.70	10.80	12.50	1.42	2.38	40	8.48	3.40	5.08
	Bw4	75-120	Sandy Loam	80.30	9.30	10.40	1.42	2.45	42	8.98	2.46	6.52
P4	Ap	0-18	Loamy Sand	82.50	8.70	8.80	1.33	2.38	44	6.67	3.57	3.10
	Bw1	18-50	Loamy Sand	81.80	9.30	8.90	1.33	2.42	45	6.83	3.72	3.11
	Bw2	50-70	Loamy Sand	80.00	10.80	9.20	1.42	2.46	42	7.02	4.41	2.61
	Bw3	70-90	Loamy Sand	80.70	10.50	8.80	1.42	2.52	44	6.02	3.05	2.97
	Bw4	90-120	Loamy Sand	81.40	9.90	8.70	1.33	2.55	48	5.96	2.87	3.09
P5	Ap	0-15	Sandy	89.06	5.44	5.50	1.48	2.58	43	5.90	2.92	2.98
	Bw	15-45	Sandy	89.50	4.60	5.90	1.53	2.60	41	6.23	3.11	3.12
	C1	45-70	Sandy	89.54	4.26	6.20	1.55	2.62	41	6.19	3.30	2.89
	C2	70-105	Sandy	91.09	3.81	5.10	1.58	2.62	40	6.17	3.56	2.61
	C3	105-160	Sandy	92.02	3.68	4.30	1.59	2.63	40	5.50	3.30	2.20
P6	Ap	0-12	Sandy Loam	82.50	8.70	8.80	1.33	2.18	39	5.80	3.01	2.79
	Bw1	12-36	Sandy Loam	77.10	10.60	12.30	1.42	2.22	36	7.94	4.56	3.38
	Bw2	36-70	Sandy Loam	72.80	13.50	13.70	1.43	2.22	36	8.88	5.53	3.35
	Bw3	70-110	Loamy Sand	74.20	12.40	13.40	1.45	2.25	36	6.33	3.41	2.92
	Bw4	110-145	Loamy Sand	81.40	10.00	8.60	1.48	2.28	35	7.28	4.11	3.17
P7	Ap	0-15	Sandy Loam	76.30	12.00	11.70	1.33	2.22	40	7.72	3.40	4.32
	Bw1	15-40	Sandy Loam	75.90	12.80	11.30	1.33	2.22	40	7.23	3.81	3.42
	Bw2	40-75	Sandy Loam	75.40	12.40	12.20	1.42	2.28	38	8.20	4.09	4.11
	Bw3	75-109	Sandy Loam	74.20	11.70	14.10	1.42	2.31	39	9.11	5.89	3.22
	Bw4	109-160	Sandy Loam	74.10	12.60	13.30	1.42	2.35	40	8.80	5.44	3.36
P8	Ap	0-15	Loamy Sand	81.90	9.80	8.30	1.45	2.35	38	7.30	4.50	2.80
	Bw1	15-30	Loamy Sand	81.90	9.70	8.40	1.48	2.22	33	7.55	4.10	3.45
	Bw2	30-75	Loamy Sand	78.20	12.40	9.40	1.51	2.22	32	7.90	4.35	3.55
	Bw3	75-120	Loamy Sand	80.10	10.60	9.30	1.51	2.00	25	7.95	4.10	3.85
	Bw4	120-150	Loamy Sand	81.00	11.40	7.60	1.55	2.50	38	7.90	3.95	3.95

subsurface horizon of P7 and P3 at 0.03 MPa and 1.50 MPa, respectively, because water is retained in the soil by capillary and adsorptive forces, which is mainly a function of clay and mineralogy (Dinesh *et al.,* 2017). This might be because higher and lower clay–containing horizons have higher and lower retention capacities, respectively, at field capacity and permanent wilting points. Different soil textures are primarily responsible for variances in moisture retention across all tensions. Since drainage happens when suction is increased from field capacity to permanent wilting point, it can be explained that finer particles have a more significant effect on soil retention behaviour than

Table 4. Correlation matrix among physico-chemical properties

Parameter	Sand	Silt	Clay	Bulk density	Particle density	0.3MPa	1.5Mpa	Organic C	Porosity	Av water content
Sand	1									
Silt	-0.958**	1								
Clay	-0.954**	0.828**	1							
Bulk density	0.454**	-0.393*	-0.477**	1						
Particle density	0.552**	-0.501**	-0.555**	0.324**	1					
0.3MPa	-0.613**	0.585**	0.587**	0.050^{NS}	-0.264^{NS}	1				
1.5MPa	-0.417**	0.432**	0.365*	0.220^{NS}	-0.152^{NS}	0.672**	1			
Organic C	0.123^{NS}	-0.077^{NS}	-0.161^{NS}	0.045^{NS}	-0.302^{NS}	-0.183^{NS}	-0.002^{NS}	1		
Porosity	0.214	-0.219	-0.188^{NS}	-0.394*	0.735**	-0.305^{NS}	-0.304^{NS}	-0.343*	1	
Av water content	-0.353*	0.300^{NS}	0.377*	-0.175^{NS}	-0.182^{NS}	0.585**	-0.207^{NS}	-0.240^{NS}	-0.071^{NS}	1

*and ** indicate significant at <0.05 and 0.01, respectively

sand content. Water retention also rose significantly with increased texture fineness (Tomar and Bhat, 2023). Singh *et al*. (2015) reported that basaltic parent material had higher water retention capacity than those developed on sandstone and shale at different tensions due to higher clay content. Moisture retention was positively and significantly correlated with clay (r= 0.59** and r= 0.37*) and silt (r= 0.59** and r= 0.37*) at 0.03 MPa and 1.5 MPa suction pressure, respectively. This might happen due to the overdominance of sand fraction deposited over time due to the alluvium and fluventic nature of the parent material. An increase in clay content raises moisture retention at different suctions, as reported by Tomar and Bhat (2023). Available water content values varied from 2.20 to 6.52. The highest (6.52) available water content was reported in Pedon 5, whereas it was lowest (2.20) in Pedon 3. Available water content is positively and significantly correlated with clay (r= 0.38*) this finding is supported by Tomar and Bhat (2023).

Chemical characteristics

The pH of soil samples varied from 7.30–9.23, indicating slightly alkaline to moderately alkaline in reaction (Table 5). The highest pH (9.23) was recorded in pedon P7, and the lowest pH (7.3) was recorded in pedon P8. In general, the pH of soils increased with increasing depth; this could be due to the leaching of exchangeable bases from the upper layers due to rainfall (Gogoi *et al*. 2018). pH is negatively and significantly correlated to organic carbon (r= –0.379*) (Table 6). The electrical conductivity (EC) of all the soils varied from 0.07 to 1.13 dS m^{-1}, which lies in the non–saline range. In general, EC increased with increasing soil depth. The well–drained conditions in the soil help in removing excess salts from the percolating and drainage water (Satish *et al*. 2018). The electrical conductivity of all the pedons indicated that the soils were non–saline. EC revealed that all the soils were low in soluble salt content, which might be due to the light texture of the soils (Sahoo *et al*, 2019). The data above indicates that most soils were found to be alkaline rather than saline, as also reported by Basak *et al*. (2016). EC is negatively and significantly correlated (–0.66**) with organic carbon. A negative correlation between soil salinity and soil organic carbon was also reported by Hassani *et al*. (2024). The soils were low to medium in organic carbon. Organic carbon content was reported to be higher in surface soils than in subsurface soils, and it decreased with increasing depth, and this is in agreement with Basak *et al*. (2016). Surface soils are rich in organic carbon; this might be due to crop residue and leaf litter in surface soil compared to sub–surface soil, as reported by Gupta Choudhury *et al*. (2016) and Singh *et al*. (2020). The organic carbon in the soils of all the pedons varied from 0.09 to 0.78%. The highest (0.78%) organic carbon content was recorded in pedon P8 and the lowest (0.09%) was recorded in pedon P4. Organic carbon is negatively and significantly correlated with $CaCO_3$

Table 5. Chemical characterization of studied pedons

Pedon	Horizon	Depth	pH_2	EC_2 (dS m^{-1})	OC (%)	$CaCO_3$ (%)	Exchangeable Cations (cmol$_{(p+)}$ kg^{-1}) Na^+	Mg^{2+}	Ca^{2+}	K^+
P1	Ap	0-17	8.70	0.17	0.78	ND	0.77	0.48	0.25	0.11
	Bw1	17-40	8.30	0.15	0.70	ND	0.56	0.34	0.17	0.09
	Bw2	40-75	8.60	0.14	0.68	ND	0.71	0.43	0.21	0.07
	Bw3	75-105	8.90	0.16	0.62	ND	0.75	0.46	0.23	0.04
	Bw4	105-150	8.90	0.15	0.31	ND	0.74	0.44	0.22	0.02
P2	Ap	0-18	8.10	0.09	0.68	ND	0.40	0.26	0.13	0.05
	Bw1	18-50	8.20	0.11	0.65	ND	0.44	0.31	0.14	0.04
	Bw2	50-85	8.60	0.11	0.58	ND	0.60	0.32	0.15	0.03
	Bw3	85-120	8.70	0.17	0.58	ND	0.76	0.49	0.24	0.04
	Bw4	120-155	8.80	0.27	0.48	ND	1.08	0.68	0.29	0.05
P3	Ap	0-14	8.30	0.16	0.58	ND	0.75	0.44	0.23	0.10
	Bw1	14-30	8.40	0.19	0.56	ND	0.82	0.61	0.28	0.09
	Bw2	30-52	8.40	0.17	0.48	ND	0.78	0.52	0.26	0.07
	Bw3	52-75	8.10	0.42	0.21	ND	2.60	0.82	0.38	0.06
	Bw4	75-120	7.93	0.53	0.16	ND	2.80	0.86	0.42	0.08
P4	Ap	0-18	8.75	0.11	0.28	ND	0.50	0.29	0.15	0.06
	Bw1	18-50	8.35	0.79	0.26	ND	3.33	2.42	0.90	0.05
	Bw2	50-70	8.23	1.06	0.22	0.5	5.40	2.93	1.42	0.04
	Bw3	70-90	8.45	1.13	0.18	0.5	5.60	3.12	1.56	0.04
	Bw4	90-120	8.70	0.90	0.09	1.5	4.50	2.80	1.20	0.03
P5	Ap	0-15	8.64	0.10	0.58	ND	0.45	0.28	0.14	0.05
	Bw	15-45	9.05	0.09	0.58	ND	0.48	0.26	0.11	0.04
	C1	45-70	9.16	0.09	0.48	0.5	0.48	0.23	0.10	0.04
	C2	70-105	9.18	0.10	0.39	0.5	0.52	0.29	0.13	0.03
	C3	105-160	9.07	0.14	0.39	0.5	0.63	0.44	0.21	0.02
P6	Ap	0-12	7.97	0.12	0.68	ND	0.48	0.36	0.19	0.07
	Bw1	12-36	8.45	0.12	0.58	ND	0.53	0.39	0.20	0.05
	Bw2	36-70	8.60	0.14	0.58	ND	0.55	0.41	0.21	0.04
	Bw3	70-110	8.75	0.18	0.48	ND	0.78	0.52	0.21	0.04
	Bw4	110-145	8.78	0.18	0.48	ND	0.79	0.53	0.22	0.03
P7	Ap	0-15	8.63	0.16	0.38	ND	0.77	0.43	0.23	0.10
	Bw1	15-40	9.10	0.24	0.36	ND	0.96	0.60	0.35	0.10
	Bw2	40-75	9.22	0.26	0.32	ND	0.98	0.64	0.35	0.09
	Bw3	75-109	9.23	0.25	0.28	ND	0.93	0.68	0.33	0.08
	Bw4	109-160	9.12	0.28	0.18	ND	0.81	0.58	0.25	0.07
P8	Ap	0-15	7.30	0.10	0.78	ND	0.42	0.28	0.09	0.05
	Bw1	15-30	7.65	0.09	0.78	ND	0.41	0.29	0.10	0.03
	Bw2	30-75	7.70	0.07	0.68	ND	0.31	0.23	0.07	0.01
	Bw3	75-120	7.75	0.10	0.58	ND	0.44	0.28	0.10	0.02
	Bw4	120-150	8.35	0.09	0.39	ND	0.47	0.31	0.11	0.01

(r= –0.447**; Table 6). Of 8 pedons, P4 and P5 were calcareous, having $CaCO_3$ content to some extent. Only subsurface soils have $CaCO_3$ content; this could be caused by calcium moving downward and precipitating as carbonate or by calcium decomposing (Vedadri and Naidu, 2018). The data table indicated that the $CaCO_3$ content of ber orchard soils varied from traces to 1.50%, mainly in subsurface horizons, which agrees with earlier reports (Basak *et al.*, 2016). In sand dunal topo–sequences of Haryana, Ahuja *et al.* (1997) also reported in situ formation of $CaCO_3$. Out of 8 pedons, P4 and P5 were calcareous, having $CaCO_3$ content to some extent. Among exchangeable bases, sodium was the dominant cation [0.–5.6 cmol$_{(p+)}$kg^{-1}], followed by calcium

Table 6. Correlation matrix among physico-chemical properties

Parameter	pH	EC	Oranic C	Na	Mg	Ca	K	$CaCO_3$
pH	1							
EC	-0.039 ^{NS}	1						
Organic C	-0.379*	-0.662**	1					
Na	-0.077 ^{NS}	0.991**	-0.652**	1				
Mg	-0.020 ^{NS}	0.983**	-0.607**	0.967**	1			
Ca	0.006 ^{NS}	0.983**	-0.608**	0.973**	0.989**	1		
K	0.131 ^{NS}	-0.015 ^{NS}	0.007 ^{NS}	-0.044 ^{NS}	-0.071 ^{NS}	-0.024 ^{NS}	1	
$CaCO_3$	0.190 ^{NS}	0.560**	-0.447**	0.580**	0.611**	0.599**	-0.282 ^{NS}	1

*and ** indicate significant at <0.05 and 0.01, respectively

Table 7. Soil taxonomy

Pedons	Order	Suborder	Great group	Subgroup	Family
P1	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic
P2	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic
P3	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic
P4	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Calcareous Hyperthermic
P5	Entisols	Psamments	Ustipsamments	Fluventic Ustipsamments	Coarse sandy mixed Calcareous Hyperthermic
P6	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic
P7	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic
P8	Entisols	Psamments	Ustipsamments	Typic Ustipsamments	Sandy mixed Hyperthermic

[0.10 to 1.56 $cmol_{(p+)}kg^{-1}$], magnesium [0.2 to 3.12 $cmol_{(p+)}kg^{-1}$], and potassium [0.01 to 0.10 $cmol_{(p+)}kg^{-1}$], respectively. In general, exchangeable Ca^{2+}, Mg^{2+}, and Na^{+} levels increased with depth. Similar findings were also reported by Datta *et al.* (2016) while studying the soils of Rewari district, Haryana. The rising trend in exchangeable Ca^{2+}, Mg^{2+} and Na^{+} was mainly attributable to the leaching of soil solution from surface horizons and subsequent adsorption on exchange sites beneath the surface horizons and exchangeable bases were correlated with EC (Table 6). The results agree with Lingade *et al.* (2008) and Datta *et al.* (2016). Exchangeable Na^{+}, Mg^{2+}, and Ca^{2+} positively and highly significantly correlated with EC (r= 0.99** for all exchangeable cations Na^{+}, Mg^{2+}, and Ca^{2+}).

Soil taxonomy

Soil formation may be due to the translocation of parent material from one place within the soil or to fluventic and alluvial deposition. Other reasons may be eluviation and illuviation that occur within the soil profile. The taxonomic classification of the soils of Rewari district was done into different order, suborders, great groups, subgroups, and families based on morphological, physical, and physicochemical properties, as well as their thermal and moisture regimes (according to Soil Taxonomy, Soil Survey Staff 2022). Soils were classified into Entisols order, Psamments suborder, and Ustipsamments great group (Table 7). Horizontal differentiation and pedogenic development were absent from the immature soils under Entisols formed from the recently released alluvial parent material. Suborder Psamments include entisols with coarse textures, high drainage, little available water–holding capacity, and frequent, lighter irrigation requirements. Ustic soil of the present moisture regime has a rainfall of 300–1000 mm, lead to classify as great groups of ustipsamments. Because the temperature stays high, it's classified as hyperthermic (22^{o} to < 28^{o}). Similar observations were also recorded by Mahapatra *et al*. (2019). Soils in the study area were classified as sandy mixed hyperthermic type ustipsamments, except P4 and P5, which were classified as sandy mixed (calcareous) type ustipsamments and coarse sandy mixed

Table 8. Soil classification

Pedon	Soil Classification
Pedon 1	Sandy mixed Hyperthermic Typic Ustipsamments
Pedon 2	Sandy mixed Hyperthermic Typic Ustipsamments
Pedon 3	Sandy mixed Hyperthermic Typic Ustipsamments
Pedon 4	Sandy mixed (Calcareous) Hyperthermic Typic Ustipsamments
Pedon 5	Coarse sandy mixed (calcareous) Hyperthermic Fluventic Ustipsamments
Pedon 6	Sandy mixed Hyperthermic Typic Ustipsamments
Pedon 7	Sandy mixed Hyperthermic Typic Ustipsamments
Pedon 8	Sandy mixed Hyperthermic Typic Ustipsamments

(calcareous) fluventic ustipsamments, respectively, as shown in Table 8. Fluventic represents the material deposited by excessive flooding by the river along with calcareous nodules found during the profile study.

Conclusions

Soils developed over alluvium parent material, with a deep soil profile depth of more than 120 cm. Surface soils are darker in colour and vary from yellowish brown to brown to dark brown. The texture varied from sandy loam to loamy sand with coarse, weak, single–grained to moderately weak granular surface structure, while the subsurface horizon varied from coarse, structureless, single–grained to medium–weak sub–angular blocky structure. Soils of the study area vary from slightly alkaline to moderately alkaline in soil reaction, and electrical conductivity is in the non–saline range. The soil organic carbon varied from 0.09 to 0.78%. Ten per cent of soil contained organic carbon more than 0.7% of organic carbon. Sodium and potassium are the dominant exchangeable base cations, respectively. The soils of the study area were classified as sandy, mixed, hyperthermic, Typic Ustipsamments (Pedon 1, 2, 3, 6, 7, 8), and sandy mixed (calcareous) hyperthermic *Typic Ustipsamments* (Pedon–4) and coarse sandy mixed (calcareous) Hyperthermic *Fluventic Ustipsamments* (Pedon–5).

Acknowledgments

The senior author thanks the Head of the Department of Soil Science, CCSHAU Hisar, and the Regional Director, RRS, Bawal, for help and support regarding work. We thank Dr. Anurag (Asstt. Scientist, Agricultural Metrology Department) for guidance regarding satellite data and site identification using Remote sensing Data. I also thank Mr Pawan, Mr Ankush Kamboj, and Mr Ankit Yadav for their guidance regarding the mapping and statistical analysis of the study area.

References

Ahuja RL (1997) Characterization and classification of soils on sand dune toposequences of Haryana. *Agropedology,* **7**: 1–13.

Basak N, Sethi M, Datta A, Yadav AK, Chinchmalatpure AR, Khurana ML and Barman A (2016) Distribution and characteristics of salt–affected soils of Mahendragarh District in Haryana. *Journal of Soil Salinity and Water Quality* **8(2)**: 153–163.

Blake GR (1965) Bulk density. In: Black CA (Ed) *Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling*. Agronomy and Soil Science Society of America, Madison, IL, pp 374–390.Bruce RR and Luxmoore RJ (1986) *Water Retention: Field Methods. Methods of Soil Analysis*, p 663–686.

Datta A, Sethi M, Basak N, Yadav AK, Chinchmalatpure AR, Khurana ML. and Barman A (2016). Salt–affected soils of Rewari District, Haryana: distribution and characteristics. *Journal of Soil Salinity and Water Quality* **8(2)**: 144–152.

Dinesh, Bhat MA and Grewal KS (2017) Characterization and classification of soils on different geomorphic units of North–Eastern Haryana, India. *Agropedology,* **27(02)**: 103–116.

Gogoi A, Talukdar MC, Basumatary A and Baruah U (2018) Characterization and classification of the soils of Dorika watershed of Assam using GIS and Remote Sensing Techniques. *Journal of the Indian Society of Soil Science* **66(4)**: 341–350.

Gupta Choudhury S, Srivastava S, Singh R, Chaudhari SK, Sharma DK, Singh SK. and Sarkar D (2014) Tillage and residue management effects on soil aggregation, organic carbon dynamics and yield attribute in rice–wheat cropping system under reclaimed sodic soil. *Soil and Tillage Research* **136**: 76–83.

Hassani A, Smith P and Shokri N (2024) Negative correlation between soil salinity and soil organic carbon variability. *Proceedings of the National Academy of Sciences* **121**: e2317332121.

IARI (1971) *Soil Survey Manual*, All India Soil and Land Use Survey Organization, IARI, New Delhi, 121p.

Jackson ML (1967) *Soil Chemical Analysis*. Printice Hall of India Pvt. Ltd., New Delhi, p. 498

Jena R, Duraisami VP, Sivasamy R, Shanmugasundaram S, Krishnan R, Padua S, Bandyopadhyay S, S. R, Ray P, Deb roy P, Singh S, Ray S (2019) Characterization and Classification of Soils of Jirang Block in Meghalaya Plateau. *Agropedology* **26**(01): 47-57.

Lal R (2013) Soil and Sanskriti. *Journal of the Indian Society of Soil Science* **61**: 267-274.

Lingade SR, Srivastava R, Prasad J. and Saxena RK (2008) Occurrence of sodic Vertisols in Nagpur district, Maharashtra. *Journal of the Indian Society of Soil Science* **56(2)**: 231–232.

Mahajan A, Sharma SK, Gupta RD and Sharma R (2007). Morphological, physical and chemical properties of soils from North West Himalayas. *Bulgarian Journal of Agricultural Science* **13(5)**: 607.

Mahapatra SK, Nagdev R, Gopal R, Surya JN, Meena RK, Yadav RP and Singh SK (2019). Characterization and classification of the soils of Buraka micro-watershed in Haryana for integrated development. *Journal of the Indian Society of Soil Science* **67(2)**: 125–136.

Mahapatra SK, Walia CS, Sidhu GS, Rana KPC, Tarsem L (2000) Characterization and classification of the soils of different physiographic unit in the subhumid ecosystem of Kashmir region. *Journal of Indian Society of Soil Science* **48**: 572–577.Marathe RA, Mohanty S and Singh S (2003) Soil characterisation in relation to growth and yield of Nagpur Mandarin (Citrus reticulata Blanco). *Journal of the Indian Society of Soil Science* **51(1)**: 70-73.

Means RE and Parcher JV (1963) *Physical properties of soils*. CE Merrill Books, University of Michigan, Michigan, p 464.

Nayak RK, Sahu GC and Nanda SSK (2002) Characterization and classification of the soils of Central Research Station, Bhubaneswar. *Agropedology* **12**: 1–8.

Piper CS (2019) Soil and plant analysis. Scientific Publishers, Jodhpur, India, 368p.

Piper CS (1950) Soil and Plant Analysis. International Public Inc, New York, NY, USA, 263p.

Richards LA (ed) (1954) Diagnosis and improvement of saline and alkali soils. USDA Handbook, Washington, DC, p 160.Sahoo J, Dinesh D, Bhat MA, Anil AS and Anurag A (2019) Characterization and classification of soils of selected watershed area of Haryana, North–west India. *The Indian Journal of Agricultural Sciences* **89(11)**: 1942–1947.

Sanchez PA, Palm CA and Buol SW (2003). Fertility capability soil classification: A tool to help assess soil quality in the tropics. *Geoderma,* **114(3-4)**: 157-185.

Sashikala G, Naidu MVS, Ramana KV, Nagamadhuri KV, Reddy A, Sudhakar P and Krishna TG (2019). Characterization and classification of soils in semi-arid region of Tatrakallu village of Anantapuramu District in Andhra Pradesh. *Journal of the Indian Society of Soil Science* **67(4)**: 389-401.

Satish S, Naidu MVS, Ramana KV, Munaswamy V, Reddy GP and Sudhakar P (2018) Characterization and classification of the soils of Brahmanakotkur watershed in Kurnool district of Andhra Pradesh. *Journal of the Indian Society of Soil Science* **66(4)**: 351–361.

Sethi M, Basak N, Datta A, Chinchmalatpure AR, Khurana ML, Yadav AK and Barman A (2018) *Mapping and Extent of Salt affected Soils in Rewari and Mahendragarh Districts of Haryana State using Remote Sensing and GIS*. Technical Bulletin: ICAR–CSSRI/Karnal/2018/07, 1–43p.

Sharma BD, Mukhopadhyay SS and Jassal HS (2011) Morphological, chemical and mineralogical characterization of developing soils and their management in western Shiwalik Himalayas. *Archives of Agronomy and Soil Science* **57(6)**: 609-630.

Sharma BD, Sidhu PS, Singh G and Mukhopadhyay SS (1996) Elemental distribution and mineralogy of arid zone soils of Punjab. *Journal of the Indian Society of Soil Science* **44(4)**: 746-752.

Singh IS and Agrawal HP (2005) Characterization, genesis and classification of rice soils of eastern region of Varanasi, Uttar Pradesh. *Agropedology* **15(1)**: 29-38.

Singh R, Singh RS and Gupta PK (2015). Moisture Release Behaviour of Orange-Growing Soils Developed from Different Parent Materials in Jhalawar District of Rajasthan. *Journal of the Indian Society of Soil Science* **63(2)**: 159–165.

Singh R, Verma TP, Tailor BL, Singh RS, Sharma SS., Jat MK and Singh SK (2020) Soil Resource Mapping by Using Geo-Spatial Technologies in Hot-Moist Semiarid Region (AESR 4.2) of South-Eastern Rajasthan. *Journal of Soil Salinity and Water Quality* **12(2)**: 256–270.

Sireesha PVG and Naidu MVS (2013) Studies on genesis, characterization and classification of soils in semi-arid agro-ecological region: A case study in Banaganapalli mandal of Kurnool district in Andhra Pradesh. *Journal of the Indian Society of Soil Science* **61(1)**: 167–178.

Soil Survey Division Staff (2017) *Soil Survey Manual*. United States Department of Agriculture Handbook No. 18, 603p.

Soil Survey Staff .2022. *Keys to Soil Taxonomy* (13th edition), USDA, National Resource Conservation Service, Washington D.C. p 401.

Srinivasan R, Natarajan A and Kumar KA (2013) Characterization of major cashew-growing soils of Dakshina Kannada district of Karnataka. *Agropedology* **23(2)**: 59-64.

Surwase SA, Singh SK, Reddy GP, Kadu PR, Mohekar DS, Naitam RK and Deshmukh PS (2023) Characterization and Classification of Soils in a Toposequence of the Semi-arid Basaltic Landscape of Western India. *International Journal of Plant and Soil Science* **35(19)**: 876–887.

Tomar D and Bhat MA (2023) Morphology, genetic relationships and classification of soils of selected micro–watersheds in north–west India. *Indian Journal of Ecology* **50(5)**: 1251–1264.

Vedadri U and Naidu MVS (2018). Characterization, classification and evaluation of soils in semi-arid ecosystem of Chillakur mandal in SPSR Nellore district of Andhra Pradesh. *Journal of the Indian Society of Soil Science* **66(1)**: 1–19.

Received: February 27, 2024; Accepted: June 19, 2024

Journal of Soil Salinity and Water Quality 16(1), 16-24, 2024

Effect of Saline Groundwater Irrigation on Performance of Different Brinjal Genotypes in Loamy Sand Alluvial Soil of Punjab, India

BK Yadav[1]*, Naveen Garg[1], AS Dhatt[2], MK Sidhu[2] and RL Meena[3]

[1]*Punjab Agricultural University, Regional Research Station, Bathinda-151 001, Punjab, India*
[2]*Department of Vegetable Science, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
[3]*Project Coordinating Unit, AICRP- SAS&USW, ICAR-CSSRI, Karnal-132001, Haryana, India*
**Corresponding author's E-mail: bkyadav74@pau.edu*

Abstract

A two year experiment was conducted to evaluate the performance of different brinjal genotypes under saline groundwater (EC = 4.35 dS m^{-1}) in a loamy sand alluvial soil of south-western Punjab. It was observed that the soil dehydrogenase, acid phosphatase and alkaline phosphatase activity was decreased by 9%, 12% and 18%, respectively, and soil $pH_{1:2}$, $EC_{1:2}$, available P and K were higher by 10%, 143%, 6% and 3%, respectively, in soil irrigated with saline groundwater as compared to canal water irrigation. Similarly, the mean numbers of fruits per plant, fruit yield per plant and fruit weight over all genotypes was also 28%, 17% and 24% higher with saline water irrigation. Further, the saline groundwater irrigated plants contained higher nutrient content in leaves and fruits. The leaves from saline groundwater irrigated plants had 6%, 9%, 10% and 10% higher P, Ca, Na and K than those from canal groundwater irrigated plants, whereas, the corresponding increase in fruits was 5%, 6%, 8% and 9%. It was concluded that irrigation with saline groundwater (EC = 4.35 dS m^{-1}) exerts positive effect on plant growth, yield and its contributing traits of most of the brinjal genotypes in a well-drained and low fertility loamy sand alluvial soil due to higher nutrient availability in saline water. The maximum yield was recorded by genotype PBS (203 kg ha^{-1}) followed by PBL-215 (152 kg ha^{-1}) in the year 2018 and KBSR-343-1 (426 kg ha^{-1}) followed by BL-2013-4-3-1 (358 kg ha^{-1}) in the year 2019 under saline groundwater irrigation during the study.

Key words: Brinjal genotypes, Fruit yield, Nutrient content, Saline groundwater, Soil enzymes, Soil nutrients

Introduction

Water scarcity is the major constraint in agricultural system in the arid and semi-arid regions (Inalpulat *et al.,* 2014). The vegetable crop production is largely affected by drought stress (water deficit or low water availability) in many regions of the world (Passioura, 2007). The groundwater in South-Western Punjab is highly saline to saline, similar to brackish water with salinity ranging from 300 to 15000 ppm and therefore crop productivity is low in the region. Saline groundwater irrigation adversely affects every aspect of vegetable crop development *viz.* morphology, physiological function and yield (Colla *et al.*, 2010). Vegetables play major role in human nutrition and brinjal is one of the most important vegetable crops all over the world. Some vegetables have found to be shown positive effect of saline groundwater irrigation like initial increase in spinach yield with moderate saline groundwater (Osawa, 1963). The relative salt responses of various crops are often dependent upon soil type and other environmental factors (Levitt, 1972). Rana (1985) reported that salt tolerance ability varies from crop to crop and there was no obvious effect of salinity was found on brinjal growth, however, growth of the brinjal plants was not uniform. One of the most effective ways to overcome salinity problems is the introduction of salt tolerant varieties/hybrids. Keeping these points in view, the present research was undertaken to investigate the response of different brinjal genotypes under saline irrigation on growth, yield and nutrient content in plants as well as soil enzymes activity and soil nutrients availability.

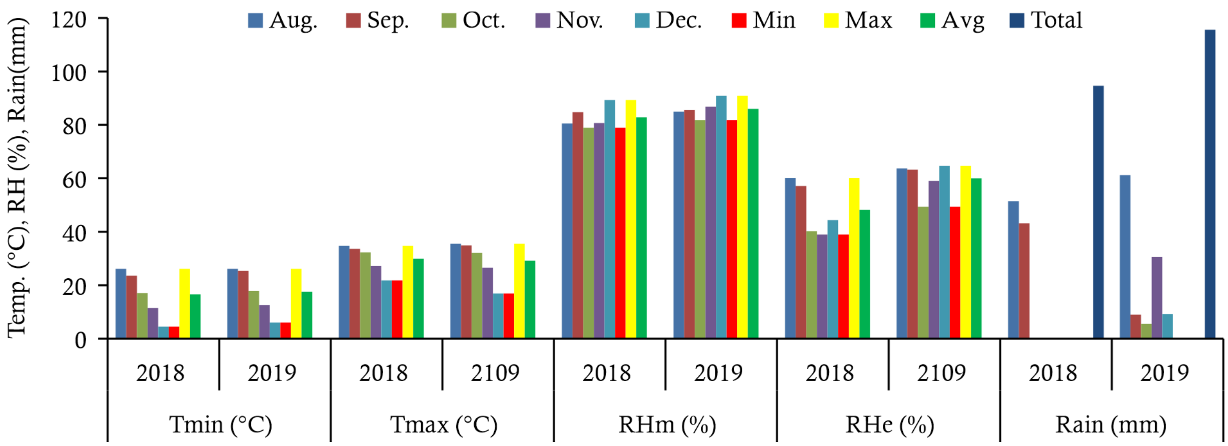


Fig. 1 Weather conditions during the crop growth period, RHm-Relative Humidity in Morning, RHe-Relative Humidity in Evening

Material and Methods

Weather conditions during the crop

The weather data during the crop growth period was recorded at meteorological weather station, Punjab Agricultural University, Regional Research Station, Bathinda. The monthly average value of climatic parameters and total precipitation and evaporation during the crop are presented in Fig. 1. The value of T_{min} ranged from 4.5-26.1 °C with mean 16.6 °C in 2018 and 6.0-26.1 °C with mean 17.6 °C in 2019. However, the value of T_{max} ranged from 21.8-34.7 °C with mean 29.9 °C in 2018 and 16.9-35.5 °C with mean 29.2 °C in 2019. Similarly, the morning relative humidity (RH_m) ranged from 78.9%-89.3% with mean 82.8% and 81.8%- 90.9% with mean 86% in 2018 and 2019, respectively. Whereas, the evening relative humidity (RH_e) ranged from 39.0%-60.1% with mean 48.2% and 49.4%- 64.7% with mean 60% in 2018 and 2019, respectively. In the season 2018, the rain was received only in the month of August and September, while in 2019 it was received from August to December, which was 22.2% higher (115.6 mm) than 2018 (94.6 mm).

Chemical composition of water

The different properties of canal water as well as groundwater (tubewell water) are given in Table 1. The quality of canal water found to be good, however, the groundwater was saline in nature and SAR and EC_{iw} values were more than the permissible limit.

Table 1. Chemical composition of water quality used under the study (Average of 2 years)

Particulars	Canal water	Groundwater
EC_{iw} (dS m^{-1})	0.33	4.35
Na^+ (me l^{-1})	0.88	34.92
Ca^{+2}+ Mg^{+2} (me l^{-1})	2.06	7.94
Cl^{-1} (mel^{-1})	0.53	8.16
CO_3^{-2} (mel^{-1})	Nil	Nil
HCO_3^- (mel^{-1})	1.63	7.10
K (mg l^{-1})	0.67	7.65
RSC (mel^{-1})	Nil	Nil
SAR (mel^{-1})	0.86	17.52

Field experiment

The field experiment was conducted during summer seasons of 2018 and 2019 at Jodhpur Romana farm of Punjab Agricultural University, Regional Research Station, Bathinda located at 30°09"36' N latitude, 74°55"28' E longitude and altitude of 211 m above mean sea level. The first year trial was conducted with a limited number of genotypes i.e. seven. However, due to the positive results obtained in the first year, the number of genotypes was increased to 10 in the second year. Out of 7 genotypes evaluated in the first year, 5 were repeated in the second year. Two entries (PBR 26 and PBR 236) evaluated in the first year were not evaluated in the second year as their fruit quality attributes were not favorable. According to USDA soil classification the experimental soil was Aridisols with loamy sand in texture having 80.1% sand, 12.2% silt and 7.7% clay. Perusal of initial properties of the experimental soil revealed that the nutrients availability was slightly high in canal water irrigated plots as compared to saline groundwater irrigated plots, however, the soil pH and electrical conductivity were slightly high in the latter. There were two types of irrigation water quality, canal water of 0.33 dS m^{-1} EC and saline groundwater of 4.35 dS m^{-1} EC. Thirty five days old nursery of all genotypes was transplanted with geometry of 60 (row to row) × 45cm (plant to plant) spacing. The number of rows and number of plants per row was 6 and 5, respectively and number of replications were three. The crop was fertilized with 62.5 kg N, 62.5 kg P_2O_5 and 30 kg K_2O per ha through urea, single superphosphate and muriate of potash, respectively. Recommended cultural and plant protection measures were taken to control weeds, insect-pests and diseases (Anonymous, 2018).

Soil sampling and analysis

After final fruit picking and before uprooting the plants, soil samples of 0-15 cm soil layer were collected from 5 places in each plot using of soil auger. Afterwards, soil samples were gently mixed and about half kg soil samples were brought in the laboratory. Further the soil samples were distributed in two parts and one part was stored at 4ºC for analysing soil enzyme activities. The other part was dried in shed, passed through 2 mm sieve and stored at room temperature for analysing chemical properties of the soil. The dehydrogenase activity, a measure of total microbial activity, was assayed in soil samples. The samples were incubated with 2, 3, 5-triphenyl tetrazolium chloride and triphenyl formazan produced subsequently was determined by a spectrophotometer at 485 nm (Tabatabai, 1982). Acid and alkaline phosphatases were assayed by the method of Tabatabai and Bremner (1969), with an acetate buffer (pH 5.4) and a Borax-NaOH buffer (pH 9.4), respectively, using p-nitrophenyl phosphate as the substrate, after reacting 1 g soil for 1 h at 35 ºC. The chemical properties of soil such as soil reaction (pH), electrical conductivity (EC), organic carbon (OC), available P and K, Na and Ca were determined by standard methods as described by Jackson (1973).

Yield components

A random sample of 10 plants of each genotype under both water qualities were selected for yield component. The average number of fruits per plant, average fruit weight and average yield per plant was recorded for each genotype under both water qualities.

Plant sampling and analysis

At the time of final picking, leaves and fruit samples of each genotype from both the water qualities were collected and washed with distilled water. The brinjal plant leaves and fruit samples were cut gently and dried at 60 °C in a forced air oven for 72 h to determine the concentration of P, K, Ca and Na. Dry samples (0.5 g) were wet digested using di-acid mixture (HNO_3:$HClO_4$). After digestion, phosphorus is detected at 470 nm by colorimetric analysis with ammonium meta vanadate. The flame photometer was used to determine the concentration of K, Ca and Na as described by Singh *et al.* (1999).

Statistical analysis

The experimental data on various aspects were subjected to analysis of variance (ANOVA) procedure laid out for split-split plot design (Rangaswamy, 2014) and tested for significance by Fisher's Least Significant Difference (LSD) test at 5% level of significance ($P \leq 0.05$).

Results and Discussion

Effect of water quality on soil biological properties

Effect of irrigation water quality on soil biological properties after both the years were presented in Fig. 2. The quality of irrigation water produced significant differences ($P \leq 0.05$) in dehydrogenase activity (DHA), acid phosphates (Acid-P) and alkaline phosphatase (Alk-P) in both the year. Irrespective of crop variety the DHA ranged from 39.54 to 44.23 and 43.56 to 47.54 µgTPF produced per gram dry soil with saline groundwater and canal water, respectively during 2018. Whereas, it ranged from 42.43 to 45.43 and 45.76 to 48.98 µgTPF produced per gram dry soil with saline groundwater and canal water during 2019.

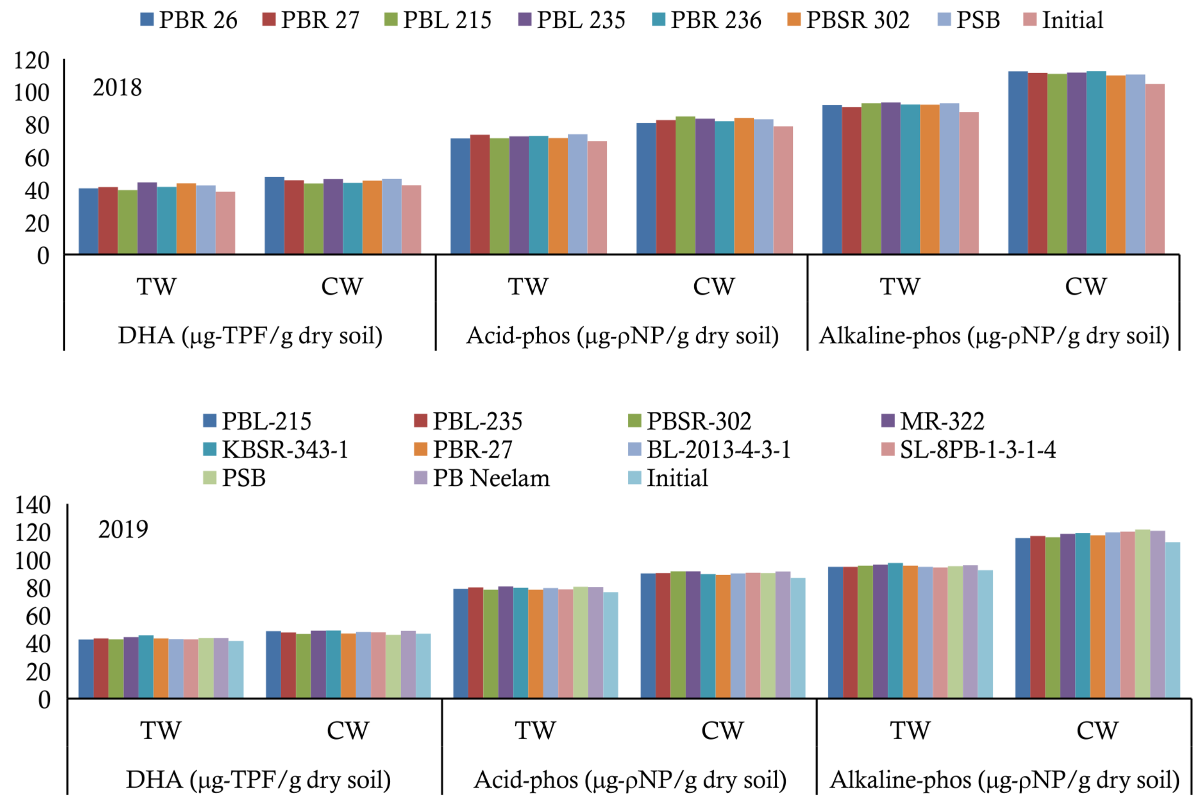


Fig. 2 Effect of water quality on soil enzymes, TW-Tubewell Water, CW-Canal Water

Decrease in soil DHA was reported by 8.05% in 2018 and 9.14% in 2019 with saline groundwater irrigation as compared to canal water irrigation. Singh *et al.* (2018) also observed that the saline groundwater irrigation (EC = 9 and 12 dS m^{-1}) decreased dehydrogenase activity by 35.8% and 54.8% compared to good quality water, respectively. The salinity lowers microbial activity, microbial biomass, and affects the microbial community structure (Andronov *et al.,* 2012). Salinity impacts microbes through two basic mechanisms: osmotic influence and specific ion effects (Oren, 2001). The soluble salts lower the osmotic potential of the soil water (making it more negative), pulling water out of cells and potentially killing microorganisms and roots through plasmolysis. Microbes find it more difficult to remove water from the soil when their osmotic potential is low (Oren, 2001).

Acid phosphatase activity was significantly (P≤0.05) influenced by water quality. Higher acid phosphatase activities (Fig. 2) were reported with canal groundwater during both the years. The Acid-p ranged from 71.23 to 73.76 and 80.65 to 84.65 µg-ρNP produced per gram dry soil with saline groundwater and canal water during 2018.While, it ranged from 78.33 to 80.65 and 88.98 to 91.45 µg-ρNP produced per gram dry soil with saline groundwater and canal water during 2019. Saline groundwater irrigation decreased the Acid-p by 12.63% and 12.09% during the 2018 and 2019 irrespective of brinjal varieties.

The alkaline phosphatase activity was significantly (P≤0.05) higher with canal water during the year 2018 and 2019. Similar to Acid-p, the Alk-p ranged from 90.35 to 93.23 and 109.76 to 112.43µg-ρNP produced per gram dry soil with saline groundwater and canal water during 2018 and from 94.27 to 97.45 and 115.45 to 121.54µg-ρNP produced per gram dry soil with saline groundwater and canal water during 2019. Irrespective of brinjal varieties reduction in Alk-p was reported by 17.19% and 19.43% during the 2018 and 2019. Soil enzymes are a kind of unique protein with special biochemical and catalytic capabilities that are engaged in a variety of key biochemical activities in soil and have a strong association to soil fertility (Bohme *et al.,* 2005). Higher Acid-p and Alk-p activity was reported with canal water as compared to saline groundwater during the study years. The water salinity has been found to reduce acid and alkaline phosphatase activity which may be due to reduction in soil microbial biomass and bacterial growth rate, and all these characteristics influenced biogeochemical cycling (Rousk *et al.,* 2011). The negative effect of salinity on soil enzyme activities was also reported by Rietz and Haynes (2003), Sardinha *et al.* (2003), Tripathi *et al.* (2006) and Yadav *et al.* (2022).

In the present investigations, the increase in soil EC caused by the extended use of saline groundwater irrigation disperses the clay, resulting in uncovered stable enzymes that are more susceptible to denaturalization through proteolysis (Nannipieri *et al.,* 2012). The decrease in soil osmotic potential, which decreased protein solubility through drying out and consequently altered the binding affinity of the enzyme protein, may only explain one such result (Siddikee *et al.,* 2011). Similarly, due to ionic mobility and reduced OM availability, salinity has a direct effect on microbial enzyme synthesis and structural alterations (Singh, 2016). Rietz and Haynes (2003) found that irrigation-induced salinity lowered microbial enzyme activity due to a decrease in substrate availability and microbial proliferation.

Effect of water quality on soil properties

The irrigation water quality resulted in significant effects on soil pH, EC and available N, P, K in soil after crop harvest (Fig. 3). Significantly higher soil pH, EC, P and K were observed in in saline groundwater irrigated plots in both the years. While, soil OC and P content were higher in canal water irrigated plots. Saline groundwater irrigation increased the soil pH by 10.26% and 9.62%, soil EC by168.37% and 116% and soil K by 3.40% and 3.11% during 2018 and 2019, respectively as compared to canal water irrigation. Whereas 4.70% and 7.69%, 6.52% and 4.73% increase in soil OC and P was reported during 2018 and 2019, respectively with canal water irrigation compared to saline groundwater irrigation. Higher soil pH of saline groundwater irrigated soils may be due to higher accumulation of cations (Ca^{+2} and Mg^{+2}) present in saline groundwater compared to canal water. Furthermore, high level of CO_3^{2-} and HCO_3^- ions combined with Ca^{2+} and Mg^{2+} may have precipitated as calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) which in turn caused an alkalizing effect and increased the soil pH (Table 1). Slightly higher soil pH of saline groundwater irrigated soils of Bathinda district compared to canal water irrigated soil has earlier been reported by Yadav (2020). Saline groundwater irrigated soils showed higher EC which may be due to higher amount of soluble salts (Yadav *et al.,* 2022). The findings of Kim *et al.* (2016), Tan and Thanh (2021) and Yadav (2021), who reported that when the salt content in the water increased by 4 to 25%, the salt content in the soil also increased, supported this conclusion. Similarly, higher K was reported in saline groundwater irrigated soils, as due to higher addition of K^+ ions. The ground water of Bathinda district has substantial amount of dissolved K

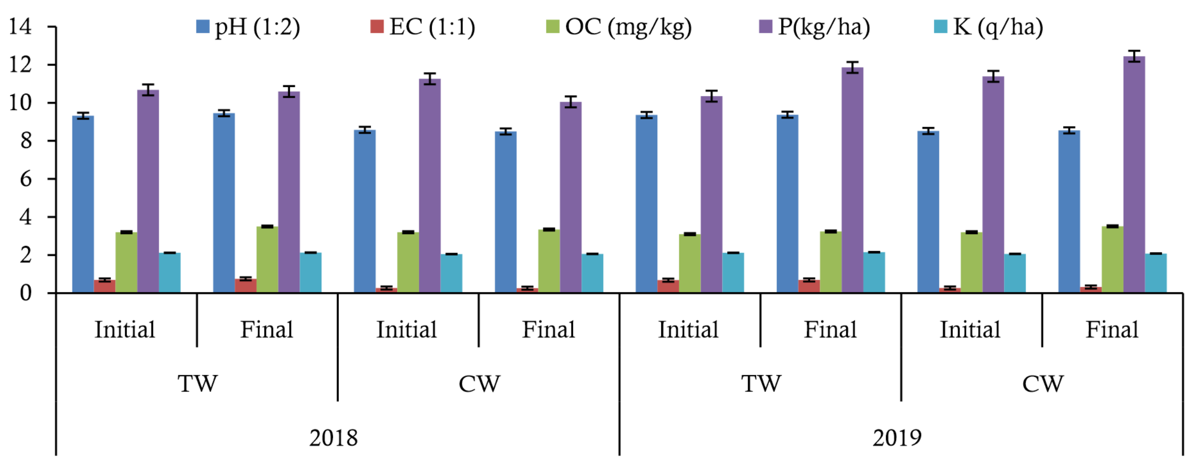


Fig. 3 Initial and after crop harvest (final) chemical properties of soil under different water quality (Bars represent ±SEM), TW-Tubewell Water, CW-Canal Water

(Yadav, 2021; Yadav and Thaman, 2021) and irrigation with such waters results into higher amounts of available K in these soils.

The soil OC content was decreased under saline groundwater irrigation, which might be due to the enhancement of the activity of carbon-degrading extracellular enzymes and microbial decomposition rates (Morrissey *et al.*, 2014). Further, Setia *et al.* (2013) demonstrated that lower organic matter in saline soil is more likely to be due to the decreased plant input than the increased decomposition. However, low soil P in saline groundwater irrigated plots may be due to low P solubility under saline condition (Bruland and DeMent, 2010). low nutrient ion activity of macro and micro-nutrients due to extreme ratios of Na^+/Ca^{2+}, Na^+/K^+, Ca^{2+}/Mg^{2+}, and Cl^+/NO_3^+ in the soil solution was reported by Bidalia *et al.* (2019). Specifically, the P availability was reduced due to the ionic strength effect, a high sorption capacity to soil particles and a low solubility of minerals in saline soil (Grattan and Grieve, 1999).

Effect of water quality on plant growth attributes and yield

The significant differences ($P \leq 0.05$) of water quality on number of fruits per plant, fruit weight and yield per plant of the brinjal were observed in both years (Fig. 4). Similarly, significant differences ($P \leq 0.05$) were also reported among the brinjal genotypes during both the years. The number of fruits plant^{-1} were reported from 3.53 to 23.27 and 3.23 to 21.80 in 2018 and 3.40 to 22.73 and 2.10 to 21.27 in 2019 with saline and canal groundwater irrigation, respectively. Irrespective of water quality genotypes PBL 215 contain maximum number of fruits plant^{-1} in respective years of testing. However, the fruit weight varied from 18.70 to 122.30 g in 2018 and 37.73 to 281.93 g in 2019 with saline groundwater, and ranged from 19.67 to 85.27 g in 2018 and 39.27 to 294.53 g in 2019 with canal groundwater irrigation. Maximum fruit weight was recorded with genotype PBR 26 and KBSR-343-1 in their respective year.

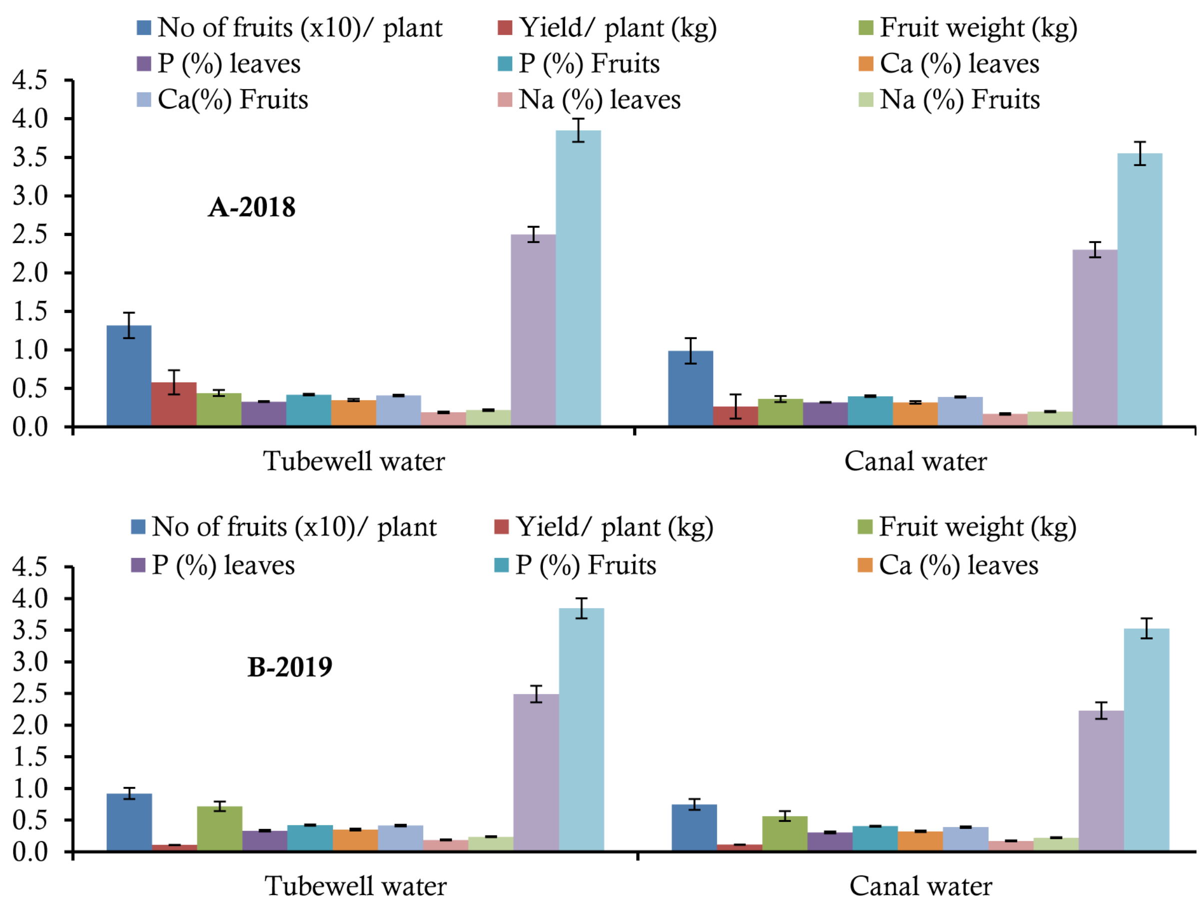


Fig. 4 Yield attributes, yield and nutrient content in leaves and fruits under different water quality (Bars represent ± SEM)

The fruit yield per plant was reported from 255 to 580 g in 2018 and 378 to 1217g in 2019 with saline groundwater irrigation. While in canal groundwater irrigation the yield per plant varied from 202-431 g in 2018 and 230-874 g in 2019. Maximum fruit yield was recorded with genotype PBS followed by PBL 234 and PBR 26 with saline groundwater and PBL 234 followed by PBR 27 and PBR 26 with canal groundwater in 2018. Whereas, highest yield was recorded with genotype KBSR-343-1 followed by BL-2013-4-3-1 and PBL 215 with saline groundwater and PBL 215 followed by BL-2013-4-3-1 and PBR 27 with canal groundwater in 2019. It was also observed that saline groundwater increased 28% number of fruits per plant, 24% fruit weight and 18% fruit yield per plant. In general, salinity can reduce plant growth by causing water deficit (osmotic effect), toxic effects of ions and imbalance of the uptake of essential nutrients (Grattan and Grieve, 1999). Heuer *et al*. (1986) in a field experiment determined that fruit yield of eggplant decreased above EC_e = 1.1 dS m^{-1}. Akinci *et al*. (2004) determined that NaCl salinity decreased germination and seedling dry weight of three eggplant cultivars. However, in this study the saline groundwater irrigation increased the number of fruits per plant, fruit weight and yield per plant, might be due to salt tolerance efficiency of genotypes. Phogat *et al.* (2010) stated that brinjal is relatively tolerant, as 50% reduction in yield takes place at a high ECe of 10 dS m^{-1}, hence, the vegetable crops which are semi-tolerant to tolerant should be preferred with saline/alkali water. Similarly, Hannachi and Van Labeke (2018) measured differences in salt tolerance among different egg plant cultivars. Moreover, the salinity hazards caused by irrigation depend on the type of salt, soil, and climatic conditions, crop species, and the amount, quality, and frequency of water applications (Hanson *et al.,* 2006). The soil of the present study is loamy sand in texture with 80.1% sand with good leaching fractions; therefore, the soil salinity was not built-up up to critical limits and the yield of brinjal didn't vary significantly. Water of high salt concentration as an EC of 12 dS m^{-1} can be used for growing tolerant and semi-tolerant crops in coarse textured soils, provided the annual rainfall is not less than 400 mm (Phogat *et al.,* 2010). Furthermore, since the brinjal was also grown during rainy season, the irrigation schedules got disturbed with rainfall events occurring at irregular intervals. Thus, the effects of different schedules of irrigation in general remained insignificant.

The water quality significantly ($P \leq 0.05$) influenced the nutrient content in leaves and fruits. In general, higher nutrient content was recorded with saline groundwater as compared to canal groundwater irrigation during the both year and fruits contained more nutrients than leaves. Further, 6.2 and 5.0% higher P, 9.5 and 6.3% higher Ca, 8.8 and 12.1% higher Na, 10.0 and 8.7% higher K was observed in leaves and fruits, respectively under saline groundwater irrigation compared to canal groundwater irrigation. The higher nutrients content was found in fruits than leaves, because of higher mobility of these nutrients in plants. The brinjal genotypes grown under saline contain higher nutrient content as soluble salts are present in all soils and irrigation water, and saline groundwater contain higher nutrient than canal water, which are responsible for higher nutrient content. The ground water of the district has substantial amount of dissolved cations/ anions and irrigation with such water results into higher amounts of available nutrients (Yadav and Kumar, 2021; Yadav and Thaman, 2021).

Conclusion

The decrease in dehydrogenase, acid phosphatase and alkaline phosphatase activity, and increase in the soil $pH_{1:2}$, $EC_{1:2}$, available P and K was observed due to application of saline water of 4.35 dS m^{-1} electrical conductivity. Moreover, positive effect on plant growth, yield and its contributing traits of most of the brinjal genotypes was observed in a well-drained and low fertility loamy sand alluvial soil due to higher nutrient availability under saline groundwater irrigation. However, this effect can vary with soil types and climatic conditions and region-specific studies needs to be undertaken before using saline groundwater for irrigation as secondary soil salinization can have adverse effect on crop production.

Acknowledgements

The authors are thankful to PC unit, SAS & USW, CSSRI, Karnal, Haryana for financial assistance and Director, PAU, Regional Research Station, Bathinda for providing all necessary facilities for this study.

References

Akinci I, Akinci S, Yilmaz K and Dikici H (2004) Response of eggplant varieties (*Solanum melongnea*) to salinity in germination and seedling stages. *New Zealand Journal of Crop and Horticultural Science* **32**: 193–200.

Andronov EE, Petrova SN, Pinaev AG, Pershina EV, Rakhimgalieva SZ, Akhmedenov KM and Sergaliev NK (2012) Analysis of the structure of microbial community in soils with different degrees of salinization using T-RFL Pandreal-time PCR techniques. *Eurasian Soilless Science* **45**: 147–156.

Anonymous (2018) *Package of practices for cultivation of vegetables*. Punjab Agricultural University, Ludhiana. pp 192.

Bidalia A, Vikram K, Yamal G and Rao KS (2019) Effect of Salinity on Soil Nutrients and Plant Health. In: Akhtar, M. (eds) *Salt Stress, Microbes, and Plant Interactions: Causes and Solution*. Springer, Singapore. https://doi.org/10.1007/978-981-13-8801-9_13.

Bohme L, Langer U and Bohme F (2005) Microbial biomass enzyme activities and microbial community structure in two European long-term field experiments. *Agriculture, Ecosystems and Environment* **109**: 141-152.

Bruland GL and DeMent G (2009) Phosphorus sorption dynamics of Hawaiis coastal wetlads. *Estuaries Coasts* **32**: 844-854.

Colla G, Rouphael Y, Leonardi C and Bie Z (2010) Role of grafting in vegetable crops grown under saline conditions. *Scientia Horticulture* **127**: 147-155.

Grattan SR and Grieve CM (1999) Salinity - Mineral nutrient relations in horticultural crops. *Scientia Horticulture* **78**: 127–157.

Hannachi S and Van Labeke M (2018) Salt stress affects germination, seedling growth and physiological responses differentially in eggplant cultivars (*Solanum melongia* L.). *Scientia Horticulture* **228**: 56-65.

Hanson BR, Grattan SR and Fulton A (2006) Agricultural salinity and drainage. Division of Agriculture and Natural Resources, Publication 3375, University of California Irrigation Program University of California, Davis. pp 164.

Heuer B, Meiri A and Shalhevet J (1986) Salt tolerance of eggplant. *Plant and Soil* **95**: 9–13.

Inalpulat M, Genc L, Kizil U and Aksu S (2014) Responses of eggplant to pruning under irrigation deficiency. International Conference on Biological, Civil and Environmental Engineering (BCEE-2014) March 17-18, Dubai (UAE): 176-181.

Jackson ML (1973) *Soil Chemical Analysis*. Prentice-Hall of India Pvt. Ltd., New Delhi, pp. 1-498.

Kim H, Jeong H, Jeon J and Bae S (2016) Effects of irrigation with saline groundwater on crop growth and yield in greenhouse cultivation. *Water* **8**: 127-136.

Levitt J (1972) Responses of plants to environmental stresses. Academic Press, New York, pp: 697.

Morrissey EM, Gillespie JL, Morina JC and Franklin RB (2014) Salinity affects microbial activity and soil organic matter content in tidal wetlands. *Global Change Biology* **20**: 1351–1362.

Nannipieri P, Giagnoni L, Renella G, Puglisi E, Ceccanti B, Masciandaro G, Fornasier F, Moscatelli MC and Marinari S (2012) Soil enzymology: classical and molecular approaches. *Biology and Fertility of Soils* **48**: 743-762.

Oren A (2001) The bioenergetic basis for the decrease in metabolic diversity at increasing salt concentrations: implications for the functioning of salt lake ecosystems. *Hydrobiologia* **466**: 61-72.

Osawa T (1963) Studies on the salt tolerance of vegetable crops with special reference to osmotic effects and specific ion effects. *Journal of the Japanese Society for Horticultural Science* **162**: 825-831.

Passioura J (2007) The drought environment: physical, biological and agricultural perspectives *Journal of Experimental Botany* **58**: 113-117.

Phogat V, Sharma SK, Kumar S, Satyavan and Gupta SK (2010) Vegetable cultivation with poor quality water, Tech. Bull., pp. 72. Department of Soil Science, CCS Haryana Agricultural University, Hisar-125 004, India.

Rana RS (1985) Breeding for salt resistance: concept and strategy. *International Journal of Tropical Agriculture* **3**: 236-254.

Rangaswamy R (2014) A textbook of agricultural statistics. New Age International Publishers, New Delhi, India, pp. 333–364.

Rietz DN and Haynes RJ (2003) Effect of irrigation-induced salinity and sodicity on soil microbial activity. *Soil Biology and Biochemistry* **35**: 845-854.

Rousk J, Elyaagubi FK, Jones DL and Godbold DL (2011) Bacterial salt tolerance is unrelated to soil salinity across an arid agroecosystem salinity gradient. *Soil Biology and Biochemistry* **43**: 1881–1887.

Sardinha M, Müller T, Schmeisky H and Joergensen RG (2003) Microbial performance in soils along a salinity gradient under acidic conditions. *Applied Soil Ecology* **23**: 237-244.

Setia R, Gottschalk P, Smith P, Marschner P, Baldock J, Setia D and Smith J (2013) Soil salinity decreases global soil organic carbon stocks. *Science of the Total Environment* **465**: 267-272.

Siddikee MA, Tipayno S, Kim K and Chung JB (2011) Influence of varying degree of salinity-sodicity stress on enzyme activities and bacterial populations of coastal soils of Yellow Sea, South Korea. *Journal of Microbiology and Biotechnology* **21**: 341-346.

Singh D, Chhonkar PK and Pandey RN **(**1999) *Soil plant water analysis – a methods manual*. New Delhi, Indian Agricultural Research Institute.

Singh K (2016) Microbial and enzyme activities of saline and sodic soils. *Land Degradation and Development* **27**: 706-718.

Singh P, Choudhary OP and Mavi MS (2018) Irrigation induced salinization effects on soil chemical and biological properties under cotton-wheat rotation in loamy sand soil in Northwest India. *Journal of the Indian Society of Soil Science* **66**: 386-391.

Tabatabai MA (1982) Soil enzymes. In: Page AL, Miller RH and Keeney DR (Eds.) Methods of Soil Analysis Part 2, Agronomy 9, *American Society of Agronomy*. Madison Wis. pp. 903-947.

Tabatabai MA and Bremner JM (1969) Use of p-nitrophenol phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry* **1**: 301-307.

Tan LV and Thanh T (2021) The effects of salinity on changes in characteristics of soils collected in a saline region of the Mekong Delta, Vietnam. *Open Chemistry* **19**: 471-480.

Tripathi S, Kumari S, Chakraborty A, Gupta A, Chakrabarti K and Bandyapadhyay BK (2006) Microbial biomass and its activities in salt-affected coastal soils. *Biology and Fertility of Soils* **42**: 273–277.

Yadav BK, Garg Naveen, Pandove Gulab and Kalia Anu (2022) Effect of irrigation water quality, nitrogen doses and microbial inoculants on soil enzyme activity and green pod yield of cowpea (*Vignaunguiculata*) in loamy sand alluvial soil of semi-arid region of Punjab, India. *Journal of Soil Salinity and Water Quality* **14**: 53-62.

Yadav BK (2020) Effect of poor-quality water on soil enzyme activities in arid soils of Punjab. *Journal of Soil Salinity and Water Quality***12**: 80-88.

Yadav BK (2021) Assessment of RO water-purifier wastewater quality for vegetable production. *Journal of Soil Salinity and Water Quality* **13**: 261-267.

Yadav BK and Kumar D (2021) Assessment of ground water quality for irrigation and drinking purposes in Bathinda and Mansa districts of Southwest Punjab, India. *Journal of Environmental Biology* **42**: 388-395.

Yadav BK and Thaman S (2021) Water quality and potassium and sulphur contribution through groundwater irrigation in Bathinda district of Punjab. *Agricultural Research Journal* **58**: 1014-1119.

Received: April 15, 2024; Accepted: June 21, 2024

Journal of Soil Salinity and Water Quality 16(1), 25-30, 2024

Long-term Effect of Sodic Water for Irrigation on Soil Quality and Wheat Yield in Rice-Wheat Cropping System

Kirti Yadav[1], Neeraj K Aggarwal[1]*, Awtar Singh[2], Gajender Yadav[2] and Rajender Kumar Yadav[2]

[1]Department of Microbiology, Kurukshetra University, Kurukshetra-136119, Haryana, India
[2]ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India
**Corresponding author's Email: nkumar@kuk.ac.in*

Abstract

Increasing scarcity of good quality water in many arid and semi-arid regions necessitates the use of poor quality groundwater for irrigation. Soil degradation resulting from alkali water irrigation has become a serious threat to soil health. In the present study, we conducted an investigation (2021-22) on the physicochemical properties (soil organic carbon, available Na, and available K) of sandy loam soil under a semi-controlled lysimeter. Wheat was grown as an experimental crop, which was irrigated with synthetic alkali waters having similar salts (total electrolyte concentration, TEC = 30 me L^{-1}) and sodium adsorption ratio (SAR_{iw} 10 mmol L^{-1}) but varying in residual sodium carbonate (RSC) are being continuously applied since 2004 (20 years). Five types of irrigation water having different levels of residual sodium carbonate comprised. (T_1) best available groundwater, (T_2) residual sodium carbonate water 1 (RSC- 5 me L^{-1}), (T_3) RSC water 2 (RSC 10 me L^{-1}), (T_4) RSC water 3 [RSC 10 treated with gypsum (RSC 10 neutralized to RSC 5 me L^{-1} with gypsum)] and (T_5) RSC water 4 [RSC 10 treated with sulphur (RSC 10 neutralized to RSC 5 me L^{-1} with sulphur)]. Soil samples were collected after harvesting two wheat varieties (KRL 210 and HD 3226). Long-term irrigations with alkali water increased the available Na and K in the soil. Furthermore, soil organic carbon (SOC) decreased significantly with increasing alkalinity of irrigation water. Continuous irrigation with alkali water reduced grain yield of wheat by 31.7% over BAW. Moreover, the addition of gypsum and sulphuric acid has shown some capacity to partially restore soil properties, although not to the level of BAW. The majority of soil parameters under both crop cultivars showed a similar trend. The study's findings led to the conclusion that continuous applications of alkali water drastically degrade soil physicochemical properties. Partial neutralization of alkali water did not allow for the sustained existence of soil physicochemical properties. Consequently, it is recommended that the rate at which amendments are added to alkali water be adjusted to restore the decline in soil physicochemical properties.

Keywords: Sodic water, Irrigation, Soil properties, Wheat yield

Introduction

Poor quality aquifers have been utilized for irrigation to maintain food production and retain the nutritional and economic security of humankind all over the world (Singh *et al.*, 2022a; Minhas *et al.*, 2021). Global agricultural productivity is severely constrained by the lack of fresh water available for irrigation (Makarana *et al.*, 2023). One-fourth of the world's groundwater is consumed by India, one of the countries with the highest per capita consumption (230 km^3 per year) (Fagodiya *et al.*, 2023). Alkalinity has an adverse effect on groundwater quality in many Indian states, including Punjab, Haryana, Uttar Pradesh, Rajasthan, Andhra Pradesh, and Tamil Nadu (Choudhary and Bajwa, 2012). In arid and semi-arid regions, many farmers use poor quality ground water to meet the crop water requirements due to inadequate availability of good quality water and insufficient rainfall. India is by far no different from other countries with 6.74 million hectares (m ha) of salt affected lands (Mandal *et al.*, 2009), losing 16.8 million tonnes of farm production valued approximately US$ 3.5 billion per annum (Sharma *et al.*, 2015). The problem would be more acute in the north-western India where ~2.7 m ha of barren sodic soils area is underlain with saline/alkali water (32–84%) in different states.

Wheat is the most common field crop grown in winter on 6 m ha of Indo-Gangetic Plain (Chhuneja *et al.*, 2005). Continuous and indiscriminate use of sodic water, however, poses a serious threat to soil health and crop productivity, mainly through increased pH, sodium saturation of soil, and associated deterioration of soil physical properties (Choudhary and Bajwa, 2021; Minhas *et al.*, 2021; Sheoran *et al.*, 2021b, c). Since microbial activities in soils regulate ecological function and soil fertility, salinity has a significant impact on soil microbial populations and their activity (Rietz and Haynes, 2003; Chowdhury *et al.*, 2011). Soil microflora contributes greatly to maintaining or improving soil quality by regulating degradation of organic matter, nutrient availability, and promoting the development of macro-aggregates (Singh *et al.*, 2018). Microbial parameters are sensitive indicators of soil quality changes in response to management strategies or environmental stress, (Wang *et al.*, 2008; Setia *et al.*, 2010) such as soil type, amendment application, crop cultivars as well as different growth stages. The effects of irrigation with alkali water and amendments on soil microbial activity, as well as the mechanisms behind these altered activities, are consequently of major interest (Singh *et al.*, 2015).

Therefore, in order to understand the impacts of long-term irrigation of poor quality water with high RSC on soil quality parameters and yields of wheat (*Triticum aestivum*) the current study was aimed to ascertain the impact of alkali water irrigation on soil quality parameters (available potassium, sodium, and soil organic carbon) as well as wheat grain yield. Additionally, the study sought to ascertain the correlation between soil properties and microbial biomass carbon and dehydrogenase activity, as well as the relationship between wheat yield and soil quality parameters.

Material and Methods

This investigation was carried out at ICAR–Central Soil Salinity Research Institute, Karnal (Haryana) India in 20 lysimeters of 2 m^3 size. The initial soils belonged to sandy loam texture having exchangeable sodium percentage value of 5.3, soil pH (1:2) 7.8 and electrical conductivity of saturation extract 0.7 dS m^{-1}. Factor one had five treatments of irrigation water quality which included T_1: best available water (BAW), T_2: RSC 5, T_3: RSC 10, T_4: RSC 10 (T3) neutralized to RSC 5 with application of gypsum (RSC 10 + gypsum), and T_5: RSC 10 (T3) neutralized to RSC 5 with application of sulphuric acid (RSC 10+ sulfuric acid). RSC was calculated by the equation:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}).$$

Five quality of irrigation water were applied in respective plots and two different wheat varieties namely KRL 210 and HD 3226 were sown (2021-22) in each plot adopting the recommended agronomic packages of practices. First irrigation was applied @ 100 L per plot before sowing, using respective RSC water. Afterward, five irrigations of 200 L (each plot) per plot were applied according to the critical growth stages of wheat.

After wheat harvest, soil samples were collected from 0-15 cm soil depth and fresh samples were sieved using a 2 mm sieve and kept at 4°C for analysis of microbial parameters. Soil organic carbon, available Na and K, exchangeable sodium percentage, sodium adsorption ratio, pHs, were estimated and their correlation with microbial properties and wheat yield was determined. Both varieties of wheat were harvested in the first fortnight of April, 2022. The grain yield of wheat was determined by weighing and expressing the harvested wheat grains from each plot in terms of metric tons per hectare (t ha^{-1}) after the threshing and sorting processes. The analysis of variance (ANOVA) was done for treatment comparison in randomized complete block design using SAS (9.4) (SAS, 2013) at $P \leq 0.05$ significance.

Results and Discussion

Changes in Soil Organic Carbon, Available Na and K

A significant decline in soil organic carbon was observed due to irrigation with alkali water as compared to BAW (Fig.1a). The reduction in SOC values was greater in the treatments having higher RSC. The lowest OC (3.23 g kg^{-1}) was recorded in RSC 10 applied irrigation water followed by BAW,

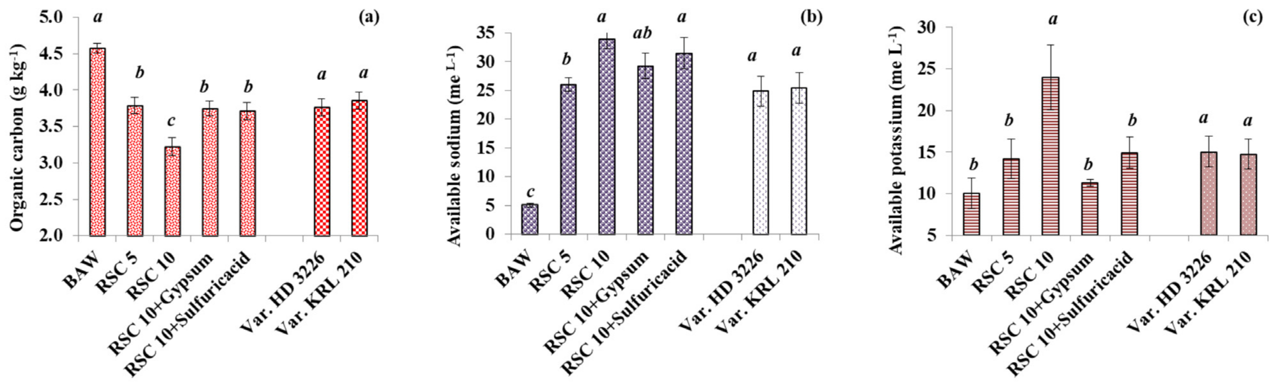


Fig. 1 Effect of alkali water irrigation and wheat varieties on (a) Organic carbon (OC), (b) Available sodium, (c) Available potassium

RSC 5, RSC 10 + gypsum, RSC 10 + sulphuric acid (4.58, 3.79, 3.75, and 3.71 g kg^{-1}). There was no significant difference in OC under two different wheat varieties. The depletion of organic matter under alkali water irrigation may be attributed to lower inputs of organic matter from plants due to severe reduction in crop growth, especially the stunted root growth caused by sodicity stress that was the main source of organic biomass in root zone (Singh *et al.*, 2022 a).

Irrigation with RSC 10 water increased available K (23.95 me L^{-1}) by 138% over BAW, although available K was comparable among RSC 5 me L^{-1} treatments, viz. RSC 5, RSC 10 + Sulfuric acid and RSC 10 + Gypsum (14.16, 14.91, and 11.32 me L^{-1}) (Fig.1c). It might be the result of lower removal of potassium through restricted growth and lesser bioass reduction (Singh *et al.*, 2022a). As a result, inadequate root growth and development hindered their ability to explore a larger area of soil in search of nutrients to be absorbed (Bhardwaj, 2021).

Available Na exhibited significant variation (ranging from 5.06 to 33.96 me L^{-1}) among the different treatments (Fig.1b). Higher concentration of Na^+ ions (33.96 me L^{-1}) was recorded in soils irrigated with ALKW2 (Alkali water type 2 having RSC 10), while soils irrigated with good quality water showed the lowest available Na concentration (5.06 me L^{-1}), followed by RSC 5 (25.99 me L^{-1}), RSC 10+Gypsum (29.27 me L^{-1}), and RSC 10+Sulfuric acid (31.45 me L^{-1}). Although there was no significant difference in available Na concentrations between the two wheat varieties. The HD 3226 had 24.90 me L^{-1} and KRL 210 had 25.40 me L^{-1} Na concentrations.

Correlations of Soil Biological Properties with Soil Alkalinity Parameters

Dehydrogenase and microbial biomass carbon were negatively associated with soil pH, ESP and SAR (Fig.2 a-f). It indicated the adverse effect of soil alkalinity on the microbial activities of soil. Higher coefficient of determination (R^2 = 0.49-0.85) was observed for DHA than MBC (R^2 = 0.54-0.68) indicating that DHA is one of the most important indicators of overall soil microbial activity (Singh *et al.*, 2018), because these occur intracellular in all living microbial cells.

Correlation among Wheat Grain Yield, Soil Biological and Alkalinity Parameters

Pearson's correlation statistic ($p \leq 0.05$) (Fig. 3) among grain yield, soil biological and alkalinity parameters of wheat crop, showed that grain yield had a strong and positive relationship with OC (r = 0.92), DHA (r = 0.91), MBC (r = 0.75); and moderate positive correlation with Ca+Mg (r = 0.25). However, ESP (r = -0.98), Na (r = -0.96), SAR (r = -0.93) and pHs (r = -0.92) exhibited negative association with wheat grain yield. A relationship study among different parameters of wheat crop revealed that organic carbon (OC) had a strong and positive correlation with DHA (r = 0.97), MBC (r = 0.95) and negatively interacted with ESP (r = -0.98). ESP showed a strong negative relationship with microbial enzyme activity, i.e., DHA (r = -0.96), MBC (r = -0.86). The effect of soil biological attributes on grain was determined by performing principal component analysis (PCA) (Fig.4). The first two principal components (PC1: 87.28%, PC2: 10.29%) accounted for nearly 97% of the cumulative

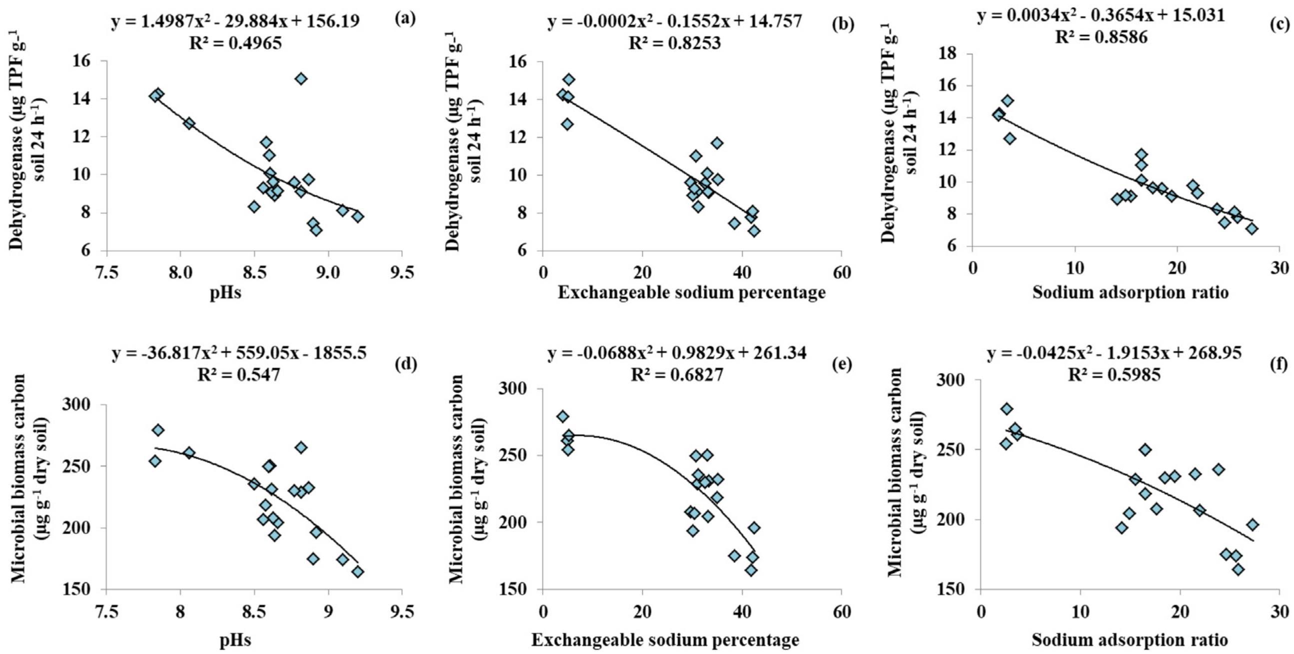


Fig. 2 Relationship of microbial biomass carbon (MBC) and dehydrogenase activity (DHA) with some soil properties. (a), (b) and (c) show relationships of DHA with soil pHs, exchangeable sodium percentage and sodium adsorption ratio, respectively; (d), (e) and (f) show relationships of MBC with soil pHs, exchangeable sodium percentage and sodium adsorption ratio.

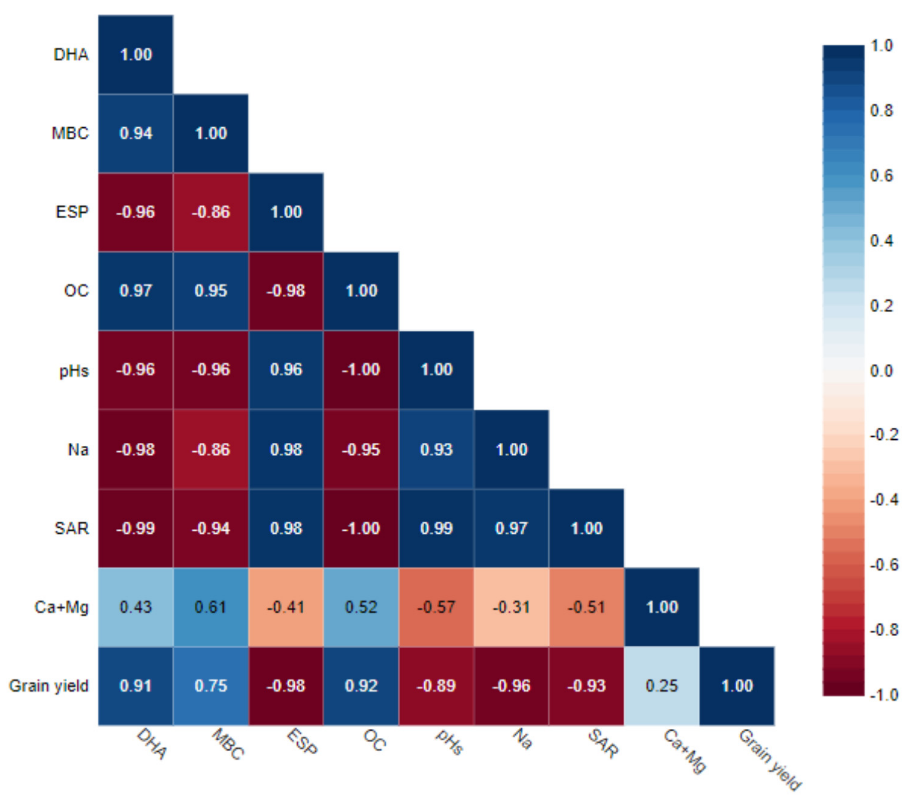


Fig. 3 Pearson's correlation coefficients among grain yield, soil biological and alkalinity parameters under different quality of irrigation water. The color of the boxes reflects the strength of the correlation. The correlation coefficients represent mean value of pooled measurements of soil parameters and microbial activities. DHA; dehydrogenase, MBC; microbial biomass carbon, ESP; exchangeable sodium percentage, OC; organic carbon, pHs; negative logarithm of hydrogen ion activity in saturated soil, Na; available sodium, Ca+Mg; available calcium and magnesium, SAR; sodium adsorption ratio, grain yield

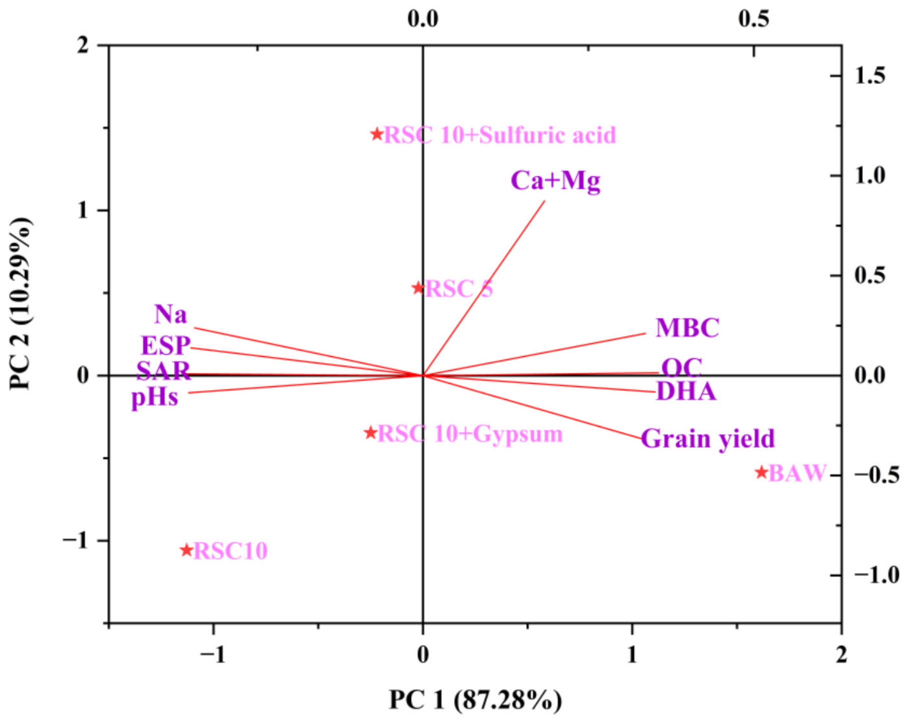


Fig. 4 Biplot showing variable loadings on first two principal components on wheat grain yield, soil biological attributes and soil alkalinity parameters. DHA, dehydrogenase; MBC, microbial biomass carbon; OC, organic carbon; SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage; pHs, negative logarithm of hydrogen ion activity in saturated soil; Na, available sodium; Ca+Mg, available calcium and magnesium

variation. Treatments with BAW (control) irrigation water clustered in the first quadrant. Na and grain yield showed unique separation and laid on the opposite quadrant in the PCA biplot. Grain yield along with DHA, MBC, OC and Ca+Mg laid in one quadrant while Na and alkalinity parameters (ESP, SAR and pHs) laid in the opposite quadrant.

Conclusion

The long-term effects of residual irrigation water alkalinity resulted in decreased organic carbon content of the soil, increased available Na and K content, soil chemical & biological properties, and significantly decreased wheat grain yield. The effect was increased with the increment in the alkalinity of the applied irrigation water and highest in the RSC 10 water. The neutralization alkalinity (5RSC units) of irrigation water with gypsum or sulfuric acid was marginally better than the pure RSC 5 alkalinity water in terms of wheat yield and alkalinity buildup in the soil. The dehydrogenase and microbial biomass carbon were found negatively correlated with the soil alkalinity parameters pHs, ESP and SAR. The pearson's correlation coefficients and PCA validated the positive association of OC and DHA MBC with wheat yield and negative association with soil alkalinity with the increased RSC of irrigation water. The study concluded that the irrigation water alkalinity had a negative effect on soil biological properties and OC, hence wheat yield. The neutralization of RSC with gypsum or sulfuric acid is an effective technique to utilize high RSC water for wheat production and reverting the alkalinity buildup in the soil.

References

Bhardwaj AK, Rajwar D, Nagaraja MS (2021) Soil fertility problems and management. In: Minhas PS, Yadav RK, Sharma PC (eds) Managing salt-afected soils for sustainable agriculture. ICAR, New Delhi. pp 386–407.

Chhuneja PS, Kaur Y, Vikal NSB and Dhaliwal HS (2005) Development of 'PBW 343' near isogenic lines for leaf rust resistance genes Lr 24 and Lr 28. *Crop Improvement* **32**: 7–13.

Choudhary OP and Bajwa MS (2021) Sodic water irrigations and their management. In: Minhas PS, Yadav RK, Sharma PC (eds) Managing salt-affected soils for sustainable agriculture. ICAR, New Delhi. pp 485–513.

Chowdhury N, Marschner P and Burns RG (2011a) Soil microbial activity and community composition: impact of changes in matric and osmotic potential. *Soil Biology & Biochemistry* **43**: 1229–1236.

Fagodiya RK, Singh A, Singh R, Rani S, Kumar S, Rai AK and Chaudhari SK (2023) The food-energy-water-carbon nexus of the rice-wheat production system in the western Indo-Gangetic Plain of India: An impact of irrigation system, conservational tillage and residue management. *Science of The Total Environment* **860**: 160428.

Makarana G, Yadav RK, Sheoran P, Kumar R, Kumar A, Ram H and Rajput VD (2023) Effects of sodic water irrigation and neutralizing amendments on physiological, biochemical, and nutritional quality traits of fodder sorghum. *Agronomy* **13(4)**: 1128.

Mandal AK, Sharma RC and Singh G (2009) Assessment of salt affected soils in India using GIS. *Geocarto International* **24**: 437–456.

Minhas PS, Bali A, Bhardwaj AK, Singh A and Yadav RK (2021) Structural stability and hydraulic characteristics of soils irrigated for two decades with waters having residual alkalinity and its neutralization with gypsum and sulfuric acid. *Agricultural Water Management* **244**: 106609.

Reitz DN and Haynes RJ (2003) Effects of irrigation induced salinity and sodicity on soil microbial activity. *Soil Biology and Biochemistry* **35**: 845-854.

SAS (2013) Statistical Analysis Software. Users' Guide Statistics Version 9.4. SAS Institute Inc., Cary.

Setia R, Marschner P, Baldock J and Chittleborough D (2010) Is CO_2 evolution in saline soils affected by an osmotic effect and calcium carbonate? *Biology and Fertility of Soils* **46**: 781-792.

Sharma DK, Thimmappa K, Chinchmalatpure AR, Mandal AK, Yadav RK, Chaudhari SK, Kumar S and Sikka AK (2015) Assessment of production and monetary losses from salt affected soils in India. Technical Bulletin. ICAR-CSSRI, Karnal, India. pp. 1–99.

Sheoran P, Basak N, Kumar A, Yadav RK, Singh R, Sharma R, Kumar S, Singh RK and Sharma PC (2021b) Ameliorants and salt tolerant varieties improve rice-wheat production in soils undergoing sodification with alkali water irrigation in Indo-Gangetic Plains of India. *Agricultural Water Management* **243**: 106492.

Sheoran P, Kumar A, Sharma R, Barman A, Parjapat K, Singh RK, Kumar S, Sharma PC, Ismail AM and Singh RK (2021c) Managing sodic soils for better productivity and farmers' income by integrating use of salt tolerant rice varieties and matching agronomic practices. *Field Crops Research* **270**: 108192.

Singh Y and Singh B (2015) Soil and fertilizer nitrogen. In: Rattan RK, Katyal JC, Dwivedi BS, Sarkar AK, Bhattacharyya T, Tarafdar JC, Kukal SS (eds) Soil science: an introduction. Indian Society of Soil Science, New Delhi. pp 541–569.

Singh A, Kumar A, Yadav RK, Minhas PS and Saini U (2022a) Long-term effect of alkali and partially neutralized irrigation water on soil quality. *Journal of Soil Science and Plant Nutrition* **22(2)**: 1252-1266.

Singh P, Choudhary OP and Mavi MS (2018) Irrigation-induced salinization effects on soil chemical and biological properties under cotton-wheat rotation on loamy sand soil in northwest India. *Journal of the Indian Society of Soil Science* **66**: 386-391.

Wong VNL, Dalal RC and Greene RSB (2009) Carbon dynamics of sodic and saline soil following gypsum and organic material additions: a laboratory incubation. *Applied Soil Ecology* **41**: 29–40.

Received: May 29, 2024; Accepted: June 11, 2024

Journal of Soil Salinity and Water Quality 16(1), 31-40, 2024

Effect of Treated Sewage Water and Organic Manure Application on Soil Fertility, Nutrient Composition, Quality and Yield of Maize (*Zea mays* L.)

Raj Kumar[1], Uma Devi[2], Preetam Kumar[3] and Satender Kumar[4]*

[1]*Department of Agronomy, CCS Haryana Agricultural University (CCSHAU), Hisar-125004, Haryana, India*
[2]*Pulses Section, Department of G&PB, CCSHAU, Hisar-125004, Haryana, India*
[3]*Indian Bank, Gohana-131301, Haryana, India*
[4]*ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India*
**Corresponding author's E-mail: Satender2144@hau.ac.in*

Abstract

Now-a-days, water resources are steadily declining due to over-exploitation of ground water. In most Indian cities, a sewage system is used, which includes an underground pipe system that collects wastewater from home and transport it to treatment plant. A field experiment was conducted during 2020 on maize crop. Treatments consisted of 2 maize single cross hybrids (HQPM-5 and HQPM-1); two sources of irrigation (canal water and treated sewage water) and four levels of organics (No manure or fertilizer, 100% recommended dose of nitrogen (RDN) though FYM, 100% RDN through vermicompost and 50% of RDN through FYM and 50% of RDN through vermicompost). Use of the treated sewage water resulted in improvement of yield and yield attributes, nutrient content and quality of maize and improved soil NPK status as compared to canal water. Among the two hybrids, HQPM-1 was observed superior based on yield and yield parameters. Application of 100% RDN by vermicompost increased the maize yield significantly over the other sources, while remaining statistically at par with 50-50% both.

Key words: Canal water, Farm yard manure, Irrigation, Maize, Sewage water, Vermicompost

Introduction

Maize, also known as corn, holds significant importance in India and the state of Haryana due to its versatility, economic value and role in food security. It is a staple food for many communities and provides essential nutrients. It is used in various forms including corn flour, cornmeal and as a direct food source (boiled and roasted). Maize is a major contributor to the agricultural economy, cultivated widely and supports the livelihood of millions of farmers. It is used in various industries including food processing, animal feed and biofuel production, enhancing its economic significance. It can be used for multiple purposes - as food, fodder and industrial raw material. India produced about 34.6 million tonnes from 11 million hectares area of maize in 2022-23 (Anonymous, 2024). Haryana is one of the important maize-producing states in India. Maize can be grown in all the three seasons, *viz. kharif*, *rabi* and summer; providing flexibility and reducing dependency on a single season. It plays a vital role in crop rotation practices in Haryana helping maintain soil fertility and reducing pest and disease cycles. It is often rotated with crop like wheat and rice, which helps in sustainable agricultural practices. In Haryana, maize is an important feed crop for livestock, especially dairy cattle, supporting the state's robust dairy industry. It is used as silage, green fodder, and grain feed, contributing to improved milk production.

Due to the rising population and industrial expansion, global resources are consistently dwindling. This has prompted individuals to embrace practices such as recycling, reusing, and reducing the strain on existing resources, in place of polluting them through environmental discharge. Employing sewage water for agricultural irrigation can diminish the quantity of water required to be drawn from natural water sources. Such sewage water contains the majority of nutrients and might be used for irrigating crops. In agriculture, irrigation water have an effect on crop production, quality and soil properties.

After green revolution in India, overuse of chemical fertilizers in crops have resulted in multi-nutrient deficiencies and fertility imbalances. The addition of organic manures in the soil contributes to the conservation of soil fertility and enhances productivity. Vermicompost (VC) and farmyard manure (FYM) hold particular significance for utilization in this context. FYM application in maize results in increased growth and yield of maize (Chaudhari *et al.*, 2017); vermicompost is a good substitute for synthetic fertilizers since it contains more nitrogen, phosphorous and potassium than normal heap manure (Nasab *et al.*, 2015). Therefore, it has more concern to the farmers for adopting irrigation source and organic manure application to achieve higher yield with improved soil health. Considering these facts, the current study was aimed to investigate the impact of organic manure application, irrigation sources and two hybrids on maize yield attributes, yield, nutrient content, quality and soil characteristics.

Material and Methods

Site description and treatments

A field experiment was carried out at Student Farm of CCS Haryana Agricultural University Hisar during spring 2020. The meteorology of study area indicated that the temperature ranges from freezing point in winter to 48^{0}C in summer with annual average rainfall of 429 mm. The soil of experimental site had textural class of sandy loam (55% sand, 35% silt and 10% clay). Initial soil characteristics of the experimental field are presented in Table 1.

Table 1. Soil characteristics of experimental site before sowing of the maize crop

Characteristic	0-15 cm
Texture	Sandy loam
EC	0.39 dS m^{-1}
pH	8.01
Walkley-Black C	0.34 %
$KMnO_4$ oxidizable N	105 kg ha^{-1}
0.5 M $NaHCO_3$ extractable P	15.4 kg ha^{-1}
1 N NH_4OAC extractable K	302 kg ha^{-1}

The experiment was arranged in split-plot design, replicated thrice. Main-plot treatment comprised of maize single cross hybrids (HQPM-1 and HQPM-5) and sources of irrigation (Canal water and treated sewage water) while organic manures were allocated to sub-plots (No manure; 100% FYM: 100% recommended dose of nitrogen (RDN) through FYM; 100% VC: 100% RDN through vermicompost and 50-50% both: 50% of RDN through FYM and 50% of RDN through vermicompost). Each treatment was replicated thrice. The sub-plots measuring 6.0 m × 5.0 m. Following recommended spatial arrangement of 60 cm × 20 cm, seeds of both the hybrids were sown 5 cm deep by hand dibbling on 26 February 2020 in respective treatments. The crop was cultivated as per package of practises of the university. Upon reaching maturity, the crop was manually harvested by removing all the cobs from respective plots. The harvested cob are than threshed to assess the grain yield. Yield calculations were performed for both straw and grain from each plot and the results were converted to tonnes per hectare (t ha^{-1}). For calculating number of kernels per cob, number of grains/row were multiplied with the number of rows/cob. Seed index as the weight of hundred seeds, counted from the grains of ten cobs from each plot, recorded by electronic weighing machine. Cob yield with husk was recorded by harvesting all the cobs of each plot and weighing the cobs with husk, which then converted to (t ha^{-1}).

Irrigation treatment

According to treatments, canal water and treated sewage water was applied to respective plots. The crop was given irrigation through check basin method of irrigation to ensure optimum growth and development of maize throughout the crop life span. The frequency of application was adhered to in accordance with the crop water requirement. The treated sewage water used for irrigation was obtained from sewage treatment plant located at CCS HAU farm, Hisar. The characteristics of treated sewage water used for irrigating the experimental crop is presented in Table 2.

Table 2. Characteristic of treated sewage water used

Characteristics	Value
EC	1.45 dS m^{-1}
pH	7.86
CO_3^-	Nil
HCO_3^-	4.5
Cl^-	5.0 m. eq. $litre^{-1}$
Ca^{++}	2.0
$Ca^{++} + Mg^{++}$	5.5
Cd	0.005 ppm
Pb	Nil
Co	Nil
Ni	Nil
Cr	Nil
Cu	Nil
Zn	0.242 ppm

Organic manure

The nutrient status of organic manure (FYM and vermicompost) used for application to the crop was analyzed and presented in Table 3. The recommended dose of fertilizers (RDF) for spring maize is 180-60-60 N-P-K kg ha^{-1} respectively. According to the amount of nutrient concentration in the organic manures, the required dose of organic manure equivalent to RDN to respective treatments, applied to soil prior to sowing of maize. The organic manures used in the experiment were obtained from Department of Agronomy, CCS HAU Hisar.

Soil analysis

Soil samples were randomly collected from the experimental field (0-15 cm depth) before sowing to determine the initial soil properties. The composite soil sample was air dried, ground and passed through a 2 mm sieve and then placed in the plastic bags before analysis. The pre-sowing and post-harvest soil sample were examined for various soil property following standard procedures. The international pipette method (Piper, 1950) was used to ascertain the individual soil fraction, namely clay, silt and sand. The pH of soil was determined by pH meter with glass electrode in 1:2 soil water suspension (Jackson, 1973). Electrical conductivity (EC) was measured using conductivity bridge method as described by Richards (1954). Soil organic carbon was estimated by Walkley and Black method (1934), available nitrogen was determined by Alkaline Permanganate method (Subbiah and Asija, 1956), available phosphorous by Olsen's method (Olsen *et al.*, 1954), while available potassium was determined by flame photometric method (Richards, 1954).

Table 3. Characteristics of organic manure used for the crop

Characteristic	N (%)	P (%)	K (%)
FYM	0.62	0.2	0.5
Vermicompost	2.5	1.0	1.5

Plant analysis

Nitrogen content in maize grain and straw was determined using the Nessler reagent method (Lindner, 1944), phosphorous by vanado-molybdophosphoric acid yellow color method (Koening and Johnson, 1942) and potassium by flame photometric method (Richards, 1954). The protein content in grain was determined by multiplying the nitrogen content (%) in grain with a factor of 6.25. Protein yield was calculated using the following formula:

$$\text{Protein yield (t ha}^{-1}) = [\text{Protein content in grain (\%)} \times \text{grain yield (t ha}^{-1})]$$

The shelling (%) was computed using formula:

$$\text{Shelling (\%)} = \frac{\text{Grain yield}}{\text{Cob yield without husk}} \times 100$$

Statistical analysis

All recorded data were analysed using standard statistical technique of ANOVA. The significance of difference in treatment means was assessed by employing the critical difference (CD) at 0.05 level of significance.

Results and Discussion

Nutrient content in maize

Data pertaining to nitrogen, phosphorous and potassium content in maize grain and straw are depicted in Figure 1 and Figure 2. It was observed that the nitrogen and phosphorous content was higher in grain of maize than in the straw while potassium content was more in straw of maize than in the grains. HQPM-1 exhibited significantly

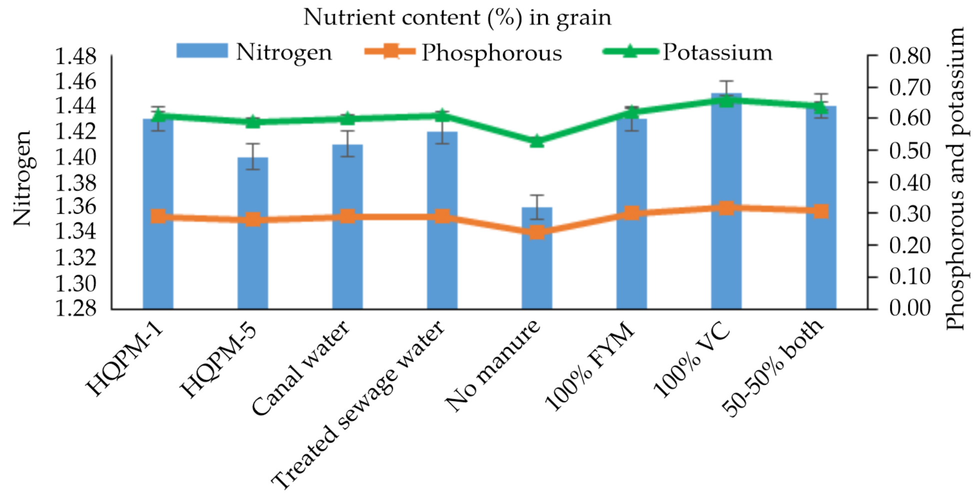


Fig. 1 Effect of organic manure and treated sewage water on NPK content in grain of maize

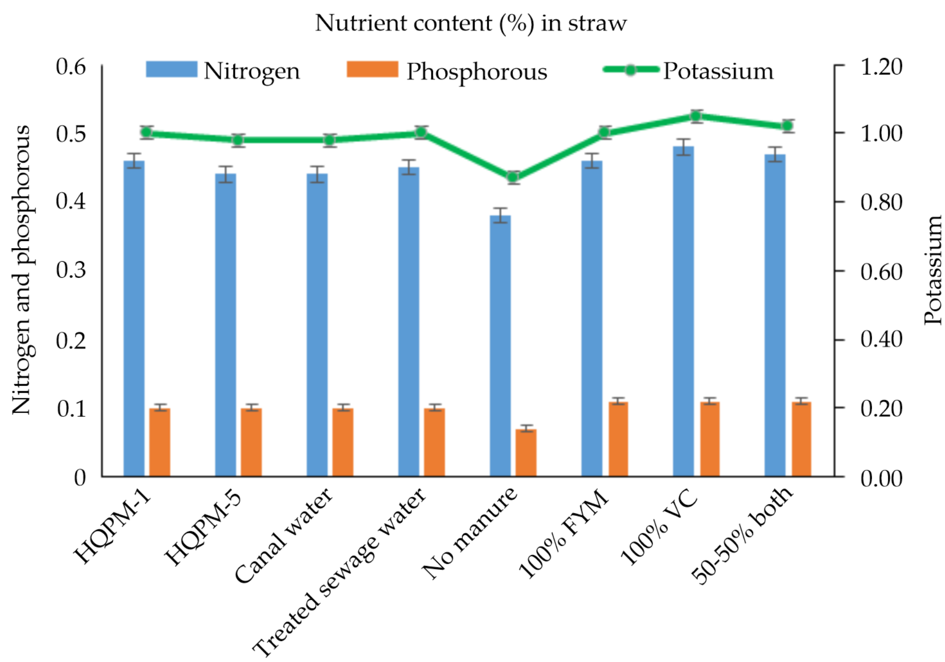


Fig. 2 Effect of organic manure and treated sewage water on NPK content in straw of maize

higher NPK content in straw and grain than HQPM-5. However, phosphorous content in straw was found to be statistically at par with HQPM-1 over HQPM-5. This might be due to difference in their genetic makeup (Nagy, 2009 and Kumar, 2016). The use of treated sewage water irrigation significantly increased NPK content in grain as well as in straw of maize over canal water irrigation. But, phosphorous content was found to be similar in grain and straw of maize with canal water preceding to treated sewage. The observed phenomenon could be due to higher nutrient input and availability of nutrients into treated sewage water plots as evident by the results reported by Alghobar and Suresha (2016), Mhaske and Nikam (2017) and Alawsy *et al.* (2018).

Application of organic manure significantly increased the NPK content in maize grain. Highest nitrogen content in grain as well as in straw and phosphorous content in straw were achieved under 100% VC treatment which was significantly higher than no manure but was statistically at par with 50-50% both and 100% FYM. Highest potassium content in grain as well as in straw and phosphorous content in grain was recorded under 100% VC which was significantly higher over other treatments. The observed effect could be ascribed to the rapid nutrient availability in plots treated with vermicompost and improved root proliferation due to organic manure application. The results were consistent with previous studies as reported by Kumar *et al*. (2015) and Prasad (2019).

Yield attributes, cob yield and shelling

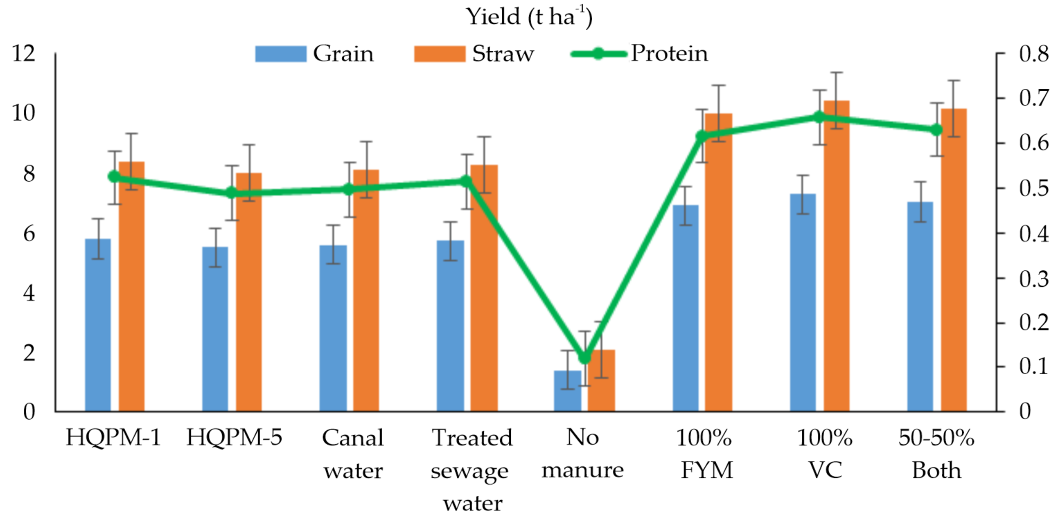
Data pertaining to number of kernels per cob, seed index (g), shelling (%), cob yield with and without husk (t ha^{-1}) are presented in Table 4. Irrigation source and single cross hybrids showed no significant effect on number of kernels per cob. However, HQPM-1 recorded numerically higher number of kernels per cob than HQPM-5. The application of treated sewage water resulted in a numerically higher number of kernels per cob than canal water. Similar trend was also observed for seed index and shelling with respect to single cross hybrids and irrigation source.

Application of organic manure had significant effect on the number of kernels per cob. Maximum number of kernels per cob and shelling was obtained under 100% VC, which was statistically at par with 50-50% both and 100% FYM, but significantly higher than no manure application. Highest seed index was observed under 100% VC which was significantly higher than rest of the treatments. This might be due to increased nutrient availability by application of organic manure, which increased the growth of maize plants ultimately increasing the interception and utilization of solar energy leading to accumulation of more dry matter by better source-sink relation that enhanced the yield attributes of maize. These results are concomitant with the findings of Meena *et al*. (2012), Afe *et al*. (2015) and Prasad (2019).

The critical examinations of data presented in Table 4 indicated that HQPM-1 recorded significantly higher cob yield (both with and without husk) than HQPM-5. The percentage increment was 4.85 and 5.12 for cob yield with husk and without husk respectively in HQPM-1 over HQPM-5. Application of treated sewage water produced significantly higher cob yield (with and without husk) over canal water. The percentage increment was 2.00 and 1.98 for cob yield with husk and without husk respectively by application of treated sewage water over canal water. Maximum cob yield with husk was recorded under 100% VC which was statistically at par with 50-50% both and 100% FYM, while

Table 4. Effect of organic manure and treated sewage water on no. of kernels per cob, seed index (g), cob yield with and without husk (t ha^{-1}) and shelling (%) of maize.

Treatment	No. of kernels per cob	Seed index	Cob yield with husk	Cob yield without husk	Shelling (%)
Single cross hybrid					
HQPM-1	382.87	18.91	8.612	7.460	74.73
HQPM-5	377.44	18.61	8.218	7.096	74.40
S.E.(m)±	3.40	0.11	0.033	0.035	0.28
C.D. at 0.05	NS	NS	0.116	0.123	NS
Irrigation source					
Canal water	378.14	18.69	8.331	7.206	74.45
Treated sewage water	382.17	18.83	8.498	7.349	74.67
S.E.(m)±	3.40	0.11	0.033	0.035	0.28
C.D. at 0.05	NS	NS	0.116	0.123	NS
Organic manure source					
No manure	219.81	11.56	3.170	2.373	59.60
100% FYM	429.13	20.52	9.951	8.826	78.48
100% VC	437.69	21.99	10.435	9.048	80.69
50-50% both	433.98	20.97	10.101	8.863	79.47
S.E.(m)±	2.97	0.16	0.215	0.214	0.76
C.D. at 0.05	8.68	0.48	0.628	0.625	2.23



*C.D. at 0.05 for grain, straw and protein yield respectively: (0.120, 0.153 and 0.011 for single cross hybrids and irrigation source) and (0.389, 0.573 and 0.033 for organic manure source).

Fig. 3 Effect of organic manure and treated sewage water on grain, straw and protein yield (t ha^{-1}) of maize.

significantly higher than no manure. But in case of cob yield without husk highest values were observed under 100% VC being statistically at par with 50-50% both, while significantly higher over 100% FYM and no manure.

Yield and quality

Grain, straw and protein yield (t ha^{-1}) of maize as influenced by different single cross hybrids, irrigation source and organic manure are depicted in Figure 3. It revealed that maize yield (grain, straw and protein) was significantly higher under HQPM-1 (5.81, 8.38 and 0.52 t ha^{-1}, respectively) than HQPM-5 (5.52, 7.99 and 0.49 t ha^{-1}, respectively). The higher cob (with and without husk), grain and straw yield might be ascribed to genetic yield potential and higher yield attributes. Higher protein yield with HQPM-1 might be due to higher grain yield and nitrogen content in HQPM-1.

The utilization of treated sewage water had favourable impact on the maize yield and quality. Grain, straw and protein yield of maize were significantly higher with the application of treated sewage water (5.73, 8.26 and 0.52 t ha^{-1}, respectively) over canal water (5.605, 8.103 and 0.497 t ha^{-1}, respectively). The interaction effect of single cross hybrids and irrigation source were recorded significant on maize grain yield (Table 5). HQPM-1 exhibited a higher grain yield when treated sewage water was used as irrigation. Higher yields could be attributed to increased nutrient input in plots applied with treated sewage water irrigation as well as higher yield attributes. Similar results were also recorded by Yaryan (2000), Galavi *et al.* (2009) Nahhal *et al.* (2013) and Chandrikapure *et al.* (2017). Higher protein yield in treated sewage water plots might be due to higher grain yield and increased nutrient input in these plots, which increased the nitrogen content in plants thus increased protein content.

Application of organic manure significantly improved the protein, grain and straw yield of maize. Highest maize yield (grain and straw) was achieved under 100% VC (7.29 and 10.45 t ha^{-1}, respectively) which was statistically similar to 50-50% both (7.04 and 10.17 t ha^{-1}, respectively) and 100% FYM (6.92 and 10.03 t ha^{-1}, respectively), while significantly superior over no manure application. This could be attributed to the increased supply of nutrients through organic manure, a higher no. of kernels per cob and increased grain weight.

The application of organic manures had favourable effect on the soil chemical, biological and physical, properties, leading to improved nutrient uptake and ultimately resulting in a higher yield. These results are in conformation with

Table 5. Interaction effect of different treatments on grain yield (t ha^{-1}) of maize

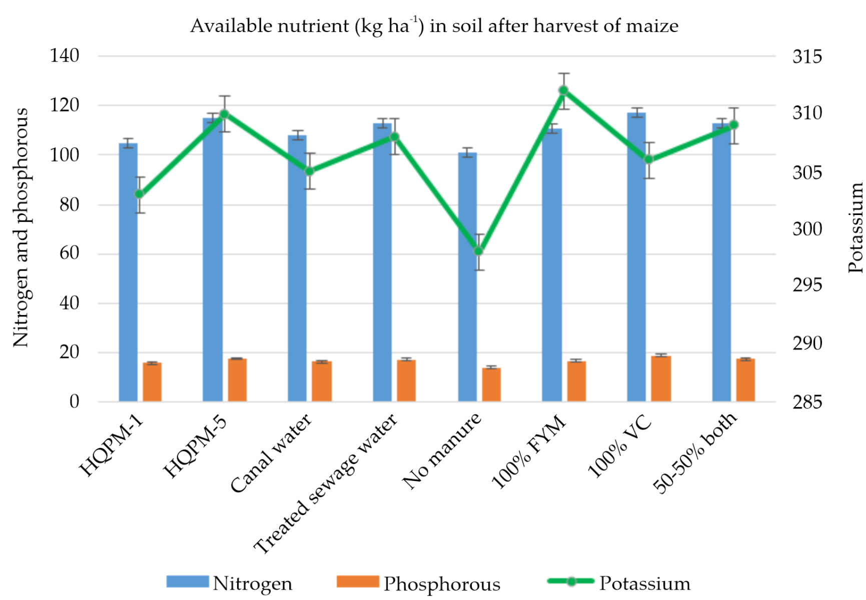
	Interactive effect of single cross hybrids and irrigation source	
	Canal water	Treated sewage water
HQPM-1	5.748	5.868
HQPM-5	5.462	5.584
S.E.(m)±	0.049	
C.D. at 0.05	0.170	

	Interactive effect of single cross hybrids and organic manure source			
	No manure	100% FYM	100% VC	50-50% both
HQPM-1	1.558	7.063	7.429	7.183
HQPM-5	1.271	6.780	7.147	6.893
S.E.(m)±	0.188			
C.D. at 0.05	0.551			

Jayaprakash *et al*. (2003), Pathan (2005), Gunjal and Chitodkar (2017) and Prasad (2019). Protein yield of maize was recorded significantly higher under 100% VC (0.66 t ha^{-1}) over 100% FYM and no manure, but it was statistically at par with 50-50% both (0.63 t ha^{-1}). The interaction between single cross hybrids and organic manure had significant impact on maize grain yield (Table 5). Maize hybrid HQPM-1 grown with 100% VC recorded the highest grain yield. Higher protein yield might be ascribed to better soil properties which increased the nutrient availability through application of organic manure especially vermicompost; continuous supply of nitrogen increased the nitrogen content in plant which ultimately increased the protein content. These findings are in line with those of reported by Prasad (2019), Jat *et al*. (2012) and Pravinbhai (2004).

Fertility status of soil post-maize harvest

The data regarding available nitrogen, phosphorous and potassium (kg ha^{-1}) in soil after harvest of maize crop are depicted in Figure 4. Available N, P and K in soil was significantly affected by single cross hybrids. Significantly



*C.D. at 0.05 for available nitrogen, phosphorous and potassium respectively: (3, 0.68 and 3 for single cross hybrids), (3, 0.68 and NS for irrigation source) and (9, 1.93 and 6 for organic manure source).

Fig. 4 Effect of organic manure and treated sewage water on available NPK (kg ha^{-1}) status after harvest of maize higher available nitrogen, phosphorous and potassium in soil after harvesting of maize was recorded under HQPM-5 (115, 17.42 and 310 kg ha^{-1} respectively) over HQPM-1 (105, 15.73 and 303 kg ha^{-1} respectively). It might be due to higher utilization of nutrients in soil by HQPM-1 due to higher yield and uptake resulted in comparatively higher NPK status in HQPM-5 plots after harvest.

The perusal of data depicted in Figure 4 indicates that treated sewage water irrigation helped in improving fertility status of soil after harvest of maize. Available nitrogen and phosphorous in soil after harvest of maize was recorded significantly higher under application of treated sewage water (113 and 17.00 kg ha^{-1} respectively) than canal water (108 and 16.15 kg ha^{-1} respectively). But available potassium in soil was found to be statistically similar with application of treated sewage water and canal water. This might be ascribed to the addition input of nutrients through treated sewage water irrigation causing increase in available soil nutrients status. Similar findings have been documented by Kharche *et al*. (2011), Singh *et al*. (2012) and Alghobar and Suresha (2016).

Organic manure application significantly improved the status of available nitrogen, phosphorous and potassium in soil after maize crop harvest. Highest available nitrogen in soil after harvest of maize was recorded under 100% VC which was significantly higher over no manure, but statistically at par with 50-50% both and 100% FYM. Increment in available nitrogen in soil might be due to direct addition of nitrogen through organic manure and improvement in microbial count converting the organic nitrogen into inorganic form. Highest available P in post-maize harvest soil was recorded under 100% VC which was significantly higher over 100% FYM and no manure, but statistically at par with 50-50% both. It might be due to the fact that organic manure reduces the phosphate fixing capacity of soil and increasing the solubilization native soil pool as revealed by Kumar *et al*. (2005). Highest available potassium in soil after harvest of maize was recorded under the application of 100% FYM being statistically at par with 50-50% both and 100% VC. It might be due to increased application of potassium through FYM before sowing of crop as compared to vermicompost for same amount of nitrogen, organic manure also releases organic acid onto decomposition which mobilize the non-exchangeable forms of potassium and charge the solution with K^{+}, making it readily available. These results are in similarity with the findings of Bunker *et al*. (2013), Afe *et al*. (2015) and Prasad (2019).

Conclusion

Treated sewage water is rich in organic matter and nutrients. The utilization of treated sewage water for irrigation has become crucial worldwide, given the constraints imposed by limited and diminishing water resources. Usage of treated sewage water resulted in a higher yield and its attributes, NPK content and quality of maize in comparison to irrigating with canal water; and it also improved the status of available N, P and K in soil. Throughout the research, application of either 100% RDN through vermicompost or 50-50% both, HQPM-1 produced higher yield and improved soil fertility. The study indicates that treated sewage water could augment water resources for crop irrigation, potentially providing benefits for agricultural production.

Acknowledgement

The authors express gratitude to Professor & Head, Department of Agronomy, CCS Haryana Agricultural University, Hisar for facilitating the research. Authors declare no conflict of interest. This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

References

Anonymous (2024) India needs a new maize revolution. Business line, The Hindu. https://www.thehindubusinessline.com/economy/agri-business/india-needs-a-new-maize-revolution/article67974954.ece

Afe AI, Atanda S, Aduloju MO, Ogundare SK and Talabi AA (2015) Response of maize (*Zea mays* L.) to combined application of organic and inorganic (soil and foliar applied) fertilizers. *African Journal of Biotechnology* **14**(44): 3006-3010.

Alawsy WSA, Alabadi LAS and Khaeim HM (2018) Effect of sewage water irrigation on growth performance, biomass and nutrient accumulation in maize and barley. *International Journal of Agricultural and Statistical Sciences* **14**(2): 519-524.

Alghobar MA and Suresha S (2016) Effect of wastewater irrigation on growth and yield of rice crop and uptake and accumulation of nutrient and heavy Metals in Soil. *Applied Ecology and Environmental Sciences* **4**(3): 53-60.

Bunker MC, Patel AM, Man MK and Ali S (2013) Influence of integrated nutrient management on productivity and quality of single cross hybrid maize (*Zea mays* L.) cv. HQPM-1. *Advance Research Journal of Crop Improvement* **4**(1): 54-58.

Chandrikapure VM, Khawale VS, Gajnhiye UN and Uikey KN (2017) Effect of sewage water treatments on growth and yield of maize. *Trends in Biosciences* **10**(33): 7143-7145.

Chaudhari BH, Parmar JK, Mali RH and Bumbadiya NH (2017) Effect of Co level and FYM on growth and yield of fodder maize. *International Journal of Chemical Studies* **5**(1): 327-329.

Galavi M, Jalali A, Mousavi SR and Galavi H (2009) Effect of treated municipal wastewater on forage yield, quantitative and qualitative properties of sorghum (*S. bicolor* Speed feed). *Asian Journal of Plant Sciences* **8**(7): 489-494.

Gunjal BS and Chitodkar SS (2017) Direct and residual fertility of varying sources and levels of nutrients on growth and yield behaviour of sweet corn (*Zea mays ver*. L.)-potato (*Solanum tuberosum* L.) cropping system. *International Journal of Chemical Studies* **5**(6): 1336-1342.

Jackson ML (1973) Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, pp. 468.

Jat NK, Kumar A, Meena SR, Rana DS, Meena BP and Rana KS (2012) Influence of integrated nutrient management on the productivity, quality and soil health of maize (*Zea mays*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **57**(4): 327-332.

Jayaprakash TC, Nagalikar VP, Pujari BT and Shetty RA (2003) Effect of organics and inorganics on yield and yield attributes of maize under irrigation. *Karnataka Journal of Agricultural Sciences* **16**(3): 451-453.

Kharche VK, Desai VN, Pharande AL **(**2011) Effect of sewage irrigation on soil properties, essential nutrient and pollutant element status of soils and plants in a vegetable growing area around Ahmednagar city in Maharashtra. *Journal of Indian Society of Soil Science*, **59**(2): 177-184.

Koening R and Johnson C (1942) Colorimetric determination of phosphorus in biological materials.

Kumar A (2016) *Studies on performance of maize hybrids under different planting methods in spring season.* M.Sc. Thesis, CCS HAU Hisar.

Kumar A, Gautam RC, Singh R and Rana KS (2005) Growth, yield and economics of maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.) cropping sequences as influenced by integrated nutrient management. *Indian Journal of Agricultural Sciences* **75**(11): 709-711.

Kumar R, Bohra JS, Singh AK and Kumawat N (2015) Productivity and nutrient-use efficiency of baby corn (*Zea mays*) as influenced of varying fertility levels. *Indian Journal of Agronomy* **60**(2): 285-290.

Lindner RC (1944) Rapid analytical methods for some of the more common inorganic constituents of plant tissues. *Plant Physiol* **19:** 76-86.

Meena SR, Kumar A, Jat NK, Meena BP, Rana DS and Idnani LK (2012) Influence of nutrient sources on growth, productivity and economics of baby corn (*Zea mays*)-potato (*Solanum tuberosum*)-mungbean (*Vigna radiata*) cropping system. *Indian Journal of Agronomy* **57**(3): 217-221.

Mhaske A and Nikam P (2017) Impact of Treated Domestic Sewage Irrigation on Crop Yield, Plant Uptake and Soil Properties in Central India. *Proceedings of the International Conference on Science and Engineering for Sustainable Development*. pp. 79-92.

Nagy J (2009) Effect of sowing date on the yield and quality of maize hybrids with different growing seasons. *Acta Agronomica Hungarica* **57**: 389-399.

Nahhal Y E, Tubail K, Safi M, Safi J (2013) Effect of treated waste water irrigation on plant growth and soil properties in Gaza Strip, Palestine. *American Journal of Plant Sciences* **4**: 1736-1743.

Nasab MV, Mobasser HR and Ganjali HR (2015) Effect of different levels of vermicompost on yield and quality of maize varieties. *In Biological Forum* **7**: 856.

Olsen SR, Cole CV, Watanable FS and Dean LA (1954) *Estimation of available phosphorus in soil by extraction with sodium bicarbonate* (p 19) In: Circular, Washington DC, US Department of Agriculture, **939**: 1-24.

Pathan AK (2005) *Integrated nutrient management in rabi maize (Zea mays L.) under middle Gujarat conditions*. M.Sc. Thesis, Anand Agriculture University, Anand.

Piper CS (1950) Soil and plant analysis. *Hans Publisher*, Bombay.

Prasad G (2019) *Response of organic and inorganic nutrient sources in spring maize and their residual effects on succeeding basmati rice*. Ph.D. Thesis. CCS HAU, Hisar.

Pravinbhai MM (2004) *Effect of organic manures and varying leaves of nitrogen on yield and quality of rabi maize* (*Zea* *mays* L.). M.Sc. Thesis, Anand Agricultural University, Gujrat, pp 87.

Richards LA and Weaver LR (1954) Fifteen atmosphere percentage as related to permanent wilting percentage. *Soil Science* **46**: 331-339.

Singh PK, Deshbhratar PB and Ramteke DS (2012) Effects of sewage wastewater irrigation on soil properties, crop yield and environment. *Agricultural Water Management* **103**: 100-104.

Subbiah BV and Asija, GL (1956) A rapid procedure for the estimation of nitrogen in soils. *Current Science* **25**: 259-260.

Walkley AJ and Black CA (1934) Estimation of soil organic carbon by the chromic acid titration method. *Soil Science* **37**: 29-38.

Yaryan KM (2000) *The effect of treated wastewater and irrigation systems on yield of some field crops.* M.Sc. Thesis, Isfahan University Technology College of Agriculture Iran.

Received: February 01, 2024; Accepted: June 10, 2024

Journal of Soil Salinity and Water Quality 16(1), 41-47, 2024

Physiological Studies and Yield of Different Mustard Genotypes under Saline Water Irrigation in Semi-arid Region of Haryana

Ram Prakash[1]*, Sarita Devi[2], Sarita Rani[1], Mukesh Kumar Jat[1], Ankush Dhanda[1] and RL Meena[3]

[1]*Department of Soil Science, College of Agriculture, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*

[2]*Department of Botany & Plant Physiology, College of Basic Sciences & Humanities, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*

[3]*Project Coordination Unit, ICAR-CSSRI, Karnal-132001, Haryana, India*

**Corresponding author's E-mail: ramsansanwal@gmail.com*

Abstract

This study was conducted to identify salt-tolerant mustard genotypes suitable for the saline soils and waters of the semi-arid region. This particular region faces a significant challenge due to abundance of poor-quality water for crop irrigation. The accumulation of nutrients in a saline environment represents the primary hindrance to achieve sustainable crop production. Three different water qualities EC_{iw} (Canal, 2.5, and 7.5 dS m^{-1}) were applied to evaluate the eleven mustard varieties. Among the eleven mustard genotypes CSCN 220-10 gave the maximumt seed yield (23.7q ha^{-1}) and the minimum seed yield (15.0 q ha^{-1}) was obtained in variety Kranti at EC_{iw} 7.5 dS m^{-1}. Overall mean reduction in yield at 2.5, 5.0 and 7.5 dS m^{-1} was 3.31, 14.12 and 23.34%, respectively compared with the canal water. The entire range of characteristics i.e. seed yield, plant height, number of branches and siliqua per plant, chlorophyll content (SPAD units) and photochemical quantum yield (Fv/Fm) exhibited a consistent decline as salinity levels increased from canal to 7.5 dS m^{-1}. The salinity susceptibility index (SSI) indicates the varietal tolerance when values <1 under salinity stress. Notably, genotypes CS 60, CS 2020-4, NPJ-231 and CS 2009-234 demonstrated the highest salt tolerance (from the canal to 7.5 dS m^{-1}) among the tested genotypes.

Keywords: Photochemical quantum, Chlorophyll, Mustard, Genotypes, Water quality, Yield

Introduction

Mustard (*Brassica juncea*) is an oilseed crop that belongs to the *Brassicaceae* (Synonym- *Cruciferae*) family. In India, the mustard crop is grown in the *rabi* season and is amenable to growth in cooler climates. A variety of *Brassica* species are accepted for their significant nutritional value. These are cultivated for their oil, flavoring, vegetables, and fodder value. *Brassica* species cultivated for commercial purposes are rapeseeds (*Brassica campestris* L. and *B. napus* L.), mustards (*B. juncea* L.) and *B. carinata* (Ashraf and Mc Neilly 2004). Besides the use of mustard oil for industrial and edible purposes, its cake is a healthful feed for livestock because it has up to 40% protein. India is ranked fourth in terms of production (9.5 percent) and second in terms of area (15.2 percent) for rapeseed. With a cultivated area of roughly 8.74 million hectares and a yield of 1270 kg/ha on average, it produces 10.95 MT. After cereal crops, it is also one of Haryana's main crops. Presently, the state of Haryana has 7.1 lakh hectares planted with mustard, producing 7.9 million tons with an average yield of 1117 kg/ha. The North-West agroclimatic zone is home to the bulk of the mustard production area. Here, the majority of groundwater is very saline and has medium to high sodicity issues, which negatively impacts the germination, growth, and yield of mustard seeds (Shanker *et al.,* 2016). Mustard is grown widely in the arid and semi-arid regions of the world which often experiences salt stress. High salinity levels reduce seed germination and seedling growth. Hence, there is a need to improve crop productivity under saline conditions. The selection of salt-tolerant mustard varieties holds great promise in this respect. The use of salty groundwater is expected to grow crops in arid and semi-arid climatic regions due to the limited availability of good-quality water for irrigation (Singh *et al.,* 2018). High cocentration of salts slowdown the plant growth through the more negative osmotic potential of the soil solution, specific ion toxicity, and ion imbalance (Ankush *et al.,* 2020), which reduce uptake of nutrients and affect quality and yield of mustrad. Chlorophyll biosynthesis and the inefficiency of photosynthesis are affected by salinity (Priyanka *et al.,* 2022). However, unsuitable and regular use of saline water irrigation has resulted in increasing groundwater levels, which can activate salt accumulation in the soil profile and negatively affect crop production (Priyanka *et al.,* 2022).

Therefore, it is need to develop salt-tolerant genotypes of Indian mustard. In this quest, a Indian mustard, variety CS 60 not only performed better in the All India Salinity Alkalinity Tolerant Variety Trials (AISATVT) in different salinity and alkalinity stress locations in the states of Haryana, Punjab, and Uttar Pradesh but was also widely adopted by farmers in these states. Indian mustard (*Brassica juncea*) is mainly grown in Rajasthan, Haryana, Uttar Pradesh, Gujarat, and Madhya Pradesh. It is grown in both rainfed and irrigated areas in south-western Haryana. It is capable of utilizing the residual soil moisture efficiently under rainfed conditions due to the deep tap root system. However, there is a major constraint of poor quality water supply for irrigation in south-western Haryana under irrigated conditions. Oilseeds are foremost in terms of area, production and value after food grains in the agricultural economy of India. The productivity of mustard very less than its maximum yield potential in Haryana. It is a fact that among the oilseed crops, mustard is a salinity tolerant crop but its productivity is affected by the salinity of soil as well as irrigation water. Hence, the mustard yield under saline conditions water irrigation can be increased by growing of salt tolerant varieties with efficient and balanced use of poor-quality water. One form of stress caused by salinity is osmotic stress, while the other is ionic stress. Osmotic stress causes dehydration and poor leaf growth. Salt stress has also been attached to increment in respiration rates, ion toxicity, changes in C and N metabolism, mineral distribution, and reduced biosynthesis of chlorophyll and photosynthesis inefficiency all of which contribute to low economic productivity (Bhardwaj *et al.,* 2020).

The information available on salt tolerance of recently developed mustard genotypes is meager; therefore present experiment was undertaken to evaluate eleven mustard genotypes at different salinity levels that showed variations in relation to phenology, growth and yield.

Material and Methods

The study was conducted in permanent (continues using for same quality of water) pucca plots of 2 m x 2 m in size during *Rabi* season 2021-22, at the Soil Science Department, research farm area of Chaudhary Charan Singh Haryana Agricultural University, Hisar. The research area located in semi-arid, sub-tropics region is cool in winters (1.5 and 4°C) and hot in summers (40 and 46°C) at latitude 29°10' N, longitude of 75°46' E and at an altitude of 215.2 m above from mean sea level in Haryana State of India with average rainfall around 429 mm. The research was planed with four quality of irrigation water EC_{iw} (Canal (0.3), 2.5, 5.0 and 7.5 dS m^{-1}) and eleven mustard varieties RH 1927, CS-54, Kranti (NC), CS-60, NPJ 256, CS 2009-234, CS 2020-4, NPJ- 231, CS 2013-64, CS 2020-10 and RH 1928 in Completely Randomised Design (CRD) with three replications in sandy loam soil with the recommended dose of chemical fertilizers for mustard crop N, P, and K @ (60,20 and 20kg/ ha). A calculated dose of phosphorous and potash and half doses of nitrogen were applied at the time of crop sowing and a second half dose of nitrogen through urea was applied after the first irrigation. Different quality of irrigation water of desired EC_{iw} Canal (0.36), 2.5, 5.0 and 7.5 dSm^{-1} was prepared by mixing of saline water of saline tube well with canal water in a tank. The texture of the soil is sandy loam with pH (8.12), EC (0.38 dS $m^{-1)}$ low in organic carbon (0.31%) and N (104.10 kg ha^{-1}) and medium in P (16.09 kg ha^{-1}) and K (239.32 kg ha^{-1}). Different mustard varieties were grown under the different quality of irrigation water *i.e.* EC_{iw} (canal 0.3 dS m^{-1}, 2.5 dS m^{-1}, 5.0 dS $m^{-1}$and 7.5 dS m^{-1}).

Table 1. Seasonal agro-metrological data of the crop growth period

Month	Temperature (°C)		Relative humidity (%)		Pan evaporation	Total rainfall
	Max.	Min.	M	E	(mm)	(mm)
October, 2021	32.0	19.6	88.0	47.0	3.2	0.2
November	27.9	10.0	89.0	34.0	1.8	0.0
December	21.3	6.3	95.0	50.0	1.3	0.0
January, 2022	16.4	7.2	98	70	1.2	2.1
February	23.2	8.1	94	51	2.0	0.0
March	39.4	19.5	87	35	3.6	0.0

The agro-metrological data (Table 1) of the experimental site during *rabi* season 2021-22 showed that the mean monthly rainfall ranges from 0 to 2.1 mm, lowest temperature ranges from 6.3 to 19.6 °C and highest temperature ranges from 16.4 to 39.4°C and relative humidity of morning range from 87-98% and relative humidity of evening range from 34-71%.

Chlorophyll content (SPAD units)

Chlorophyll content was determined by SPAD 502 plus instrument by measuring the absorbance of the leaf in two wavelength regions (Blue: 400-500nm and Red: 600-700nm). Measurements are noted by simply inserting a leaf and closing the measuring head. The meter calculates a numerical SPAD value which is proportional to the amount of chlorophyll present in leaf. It is not necessary to cut the leaf, so the same leaf can be measured throughout the growing process.

Photochemical quantum yield (Fv/Fm)

Chlorophyll fluorescence in plants was measured on a sunny day using a chlorophyll fluorometer (OS-30p, Opti-Science, Inc., Hudson, USA). For two minutes, a fully expanded leaf was acclimated to darkness using a clip, and the leaf adapted darkness was then continuously irradiated for one second (1500 mol $m^{-2}s^{-1}$) by an array of three light emitted diodes in the sensor. F0 and Fm fluorescence levels were measured, and variable fluorescence (Fv) was calculated by subtracting F0 from Fm. The Fv/Fm ratio was used to determine photochemical quantum yield.

Salinity Susceptibility Index (SSI %)

The salinity susceptibility index was calculated by the formula given by Fischer and Maurer, 1978.

$$SSI = (1- Y_s / Y_p) / SI$$

Where, $SI = (1- \bar{Y}_s / \bar{Y}_p)$

Statistical analysis

Experimental data of growth and yield parameters were statistically analyzed by the method of analysis of variance (ANOVA) prescribed for the design to test the significance of overall difference among treatments by the F-test and conclusions were drawn at 5% probability level.

Result and Discussion

The data showed that the seed yield of different genotypes of mustard decreased with an increase in EC_{iw} of the irrigation water (Table 2). The mustard genotype CSCN 220-10 gave the highest seed yield (23.7qha^{-1}) which is significantly higher than genotype CS-60 (21.2 q ha^{-1}) and at par with CS2009-234 (22.8 q ha^{-1}) at EC_{iw} 7.5 dS m^{-1} and the lowest seed yield (15.0 q ha^{-1}) was obtained in Kranti. The overall mean reduction in yield at 2.5, 5.0 and 7.5 dS m^{-1} was 3.31, 14.12 and 23.34%, respectively as compared to canal. The entire genotype showed a decreasing trend with increasing levels of salinity (canal to 7.5 dS m^{-1}). The data showed that the plant height, number of branches, and siliqua per plant of different genotypes of mustard decreased with an increase in the EC of the irrigation water (Tables 2 and 3). The mustard genotype CSCN-2020-10 gave the highest plant height (200.2 cm) which is significantly at par with genotypes CS2009-234 (193.4 cm), and CS60 (196.1 cm) at EC_{iw} 7.5 dS/m (Table 2). The mean reduction in plant height at EC_{iw} 2.5, 5.0 and 7.5 dS/m was 2.7, 7.4, and 11.8%, respectively as compared to canal. The number of branches and siliqua per plant also

Table 2. Seed yield and plant height of mustard genotypes as affected by waters of different salinities

Genotypes	Seed yield (qha^{-1})					Plant height (cm)				
	EC_{iw} (dS m^{-1})									
	Canal	2.5	5.0	7.5	Mean	Canal	2.5	5.0	7.5	Mean
RH 1927	24.5	23.7	21.3	19.0	22.1	203.0	196.6	188.3	179.2	191.8
CS-54	22.1	21.4	18.8	16.8	19.8	195.3	191.4	181.3	179.0	187.3
Kranti (NC)	20.1	19.3	17.6	15.0	18.0	184.0	177.6	168.3	148.3	169.6
CS-60	27.5	26.8	23.6	21.2	24.8	210.8	206.3	195.3	190.6	200.8
NPJ 256	20.8	20.1	18.0	16.0	18.7	193.6	189.4	180.0	169.1	183.0
CS 2009-234	28.9	28.0	24.6	22.8	26.1	215.7	209.3	202.7	193.4	205.3
CS 2020-4	20.4	19.5	17.3	15.2	18.1	193.5	189.1	174.2	157.8	178.6
NPJ- 231	23.3	22.6	19.8	17.7	20.8	198.9	192.0	185.1	179.4	188.9
CS 2013-64	21.6	20.9	18.2	16.1	19.2	194.0	190.8	183.0	171.1	184.7
CS 2020-10	29.8	29.0	26.1	23.7	27.1	222.2	215.1	204.8	200.2	210.6
RH 1928	26.1	25.2	22.3	19.9	23.4	206.7	199.8	188.6	186.7	195.4
Mean	24.1	23.3	20.7	18.5		201.6	196.1	186.7	177.7	
CD (p = 0.05)	Salinity (S) = 0.95, Variety (V) = 1.58, S × V = NS					Salinity (S) = 0.75, Variety (V) = 1.25, S × V = NS				

Table 3. Number of branches and number of siliqua per plant of mustard as affected by waters of different salinities

Genotypes	Number of branches					Number of siliqua per plant				
	Canal	2.5	5.0	7.5	Mean	Canal(03)	2.5	5.0	7.5	Mean
	EC_{iw} (dS m^{-1})									
RH 1927	18.2	17.9	16.2	15.74	17.01	323.8	314.4	272.3	260.5	292.8
CS-54	17.5	17.3	15.8	15.36	16.51	311.7	300.2	260.8	247.6	280.1
Kranti (NC)	14.8	14.4	13.2	12.78	13.79	287.6	279.7	235.1	222.7	256.3
CS-60	18.8	18.4	17.1	16.48	17.67	337.9	325.2	288.7	272.1	305.9
NPJ 256	16.9	16.5	15.1	14.41	15.73	303.33	293.8	250.0	237.9	271.3
CS 2009-234	19.3	19.1	17.3	16.51	18.1	343.6	339.1	296.2	280.1	314.7
CS 2020-4	15.2	15.0	13.6	13.3	14.3	294.2	289.0	246.2	231.8	265.3
NPJ- 231	17.9	17.5	16.1	15.6	16.8	319.3	308.6	265.7	252.5	286.5
CS 2013-64	17.5	16.7	15.3	15.0	16.0	308.2	296.4	255.0	241.2	275.2
CS 2020-10	19.9	19.4	18.0	16.6	18.5	356.3	344.4	306.0	285.2	323.2
RH 1928	18.3	18.0	16.1	16.1	17.26	331.2	321.0	280.8	264.3	299.3
Mean	17.6	17.1	15.4	15.3		319.7	310.2	268.8	254.3	
CD (p = 0.05)	Salinity (S) = 1.07, Variety (V) = 1.77, S × V = NS					Salinity (S) = 14.91, Variety (V) = 24.72, S × V = NS				

showed a decreasing trend with increasing levels of salinity (canal to 7.5 dS /m) (Table 3). The maximum number of branches (19.9) and number of siliquae per plant (356.3) was observed in genotype CS2020-10 where canal water was applied while minimum (12.78 and 22.7) counts of the above traits were observed in Kranti where saline water of 7.5 dS m^{-1} was applied.

Mean Chlorophyll content (SPAD units) of mustard genotypes decreased from 27.59 to 18.90 with increasing salinity levels *i.e.* control to 7.5 dS m^{-1}. Maximum chlorophyll content was observed in CS54 (24.97) followed by RH 1927 (22.00) and minimum in NPJ 256 (15.40) at 7.5 dS m^{-1} of salinity (Fig. 1). Mean photochemical quantum yield (Fv/Fm) also showed declining trend from 0.759 to 0.702 at EC_{iw} canal to 7.5 dSm^{-1} (Fig. 2). The salinity susceptibility index (SSI) serves as a measure to assess the sensitivity of different varieties to salinity-induced stress. The values less than one indicated the tolerance of varieties towards salt stress. Notably, values <1

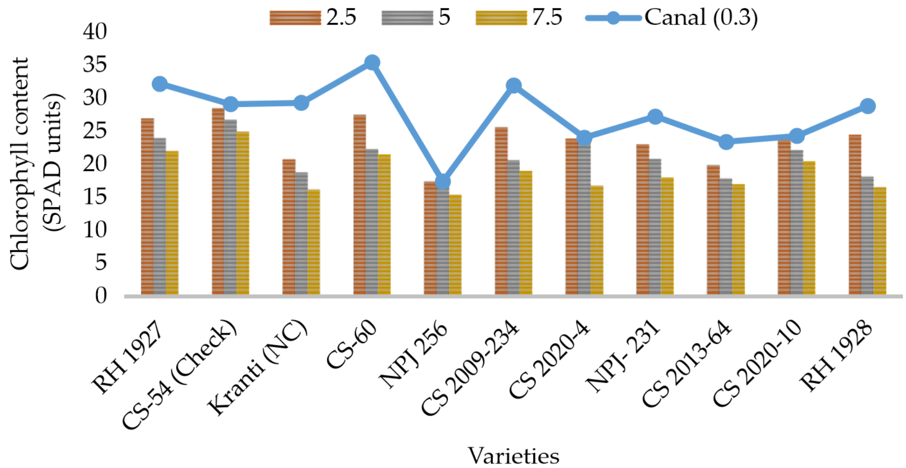


Fig. 1 Chlorophyll content (SPAD units) of mustard genotypes as affected by waters of different salinities

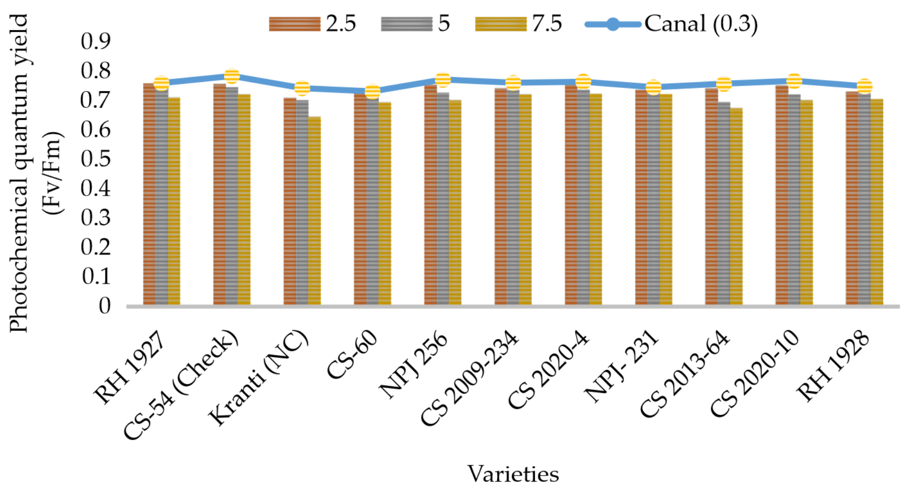


Fig. 2 Photochemical quantum yield (Fv/Fm) of mustard genotypes as affected by waters of different salinities

were recorded at higher salinity levels of 7.5 dS m^{-1} for several mustard varieties, including RH 1927 (0.97), CS60 (0.78), CS 2009-234 (0.77), CS 2020-4 (0.79), NPJ- 231 (0.47) and RH 1928 (0.88) in the tested mustard varieties, exhibited higher salt tolerance when compared to others (Fig 3). Leaf chlorophyll is a key indicator of leaf greenness and is frequently used to investigate leaf nutrient deficiencies and changes in chlorophyll (Ali *et al.,* 2020). Chlorophyll content (SPAD units) and photochemical quantum yield (Fv/Fm) were decreased with the increasing levels of salt stress from control (canal) to 7.5 dS m^{-1} in mustard varieties. The downfall in total chlorophyll and quantum yield under salt stress might be attributed to chlorophyll and other chloroplast pigment oxidation, which are associated with pigment protein complex instability (Majeed *et al.,* 2016). The Fv/Fm ratio is useful for the efficiency of excitation energy that captured by the Photosystem II (PSII) reaction centre representing the maximum capacity of light-dependent charge separation. At highest salt concentration chlorophyll content in leaves of sorghum varied from 1.98 mg/g to 1.40 mg/g in SSG 59-3 and COFS 29, respectively (Kumari *et al.,* 2015). Similar results in tomato, *Zygophyllum xanthoxylum*, and *Phaseolus vulgaris* (Yang *et al.,* 2022). The decrease in photochemical quantum yield with increasing salt stress in barley (*Hordeum vulgare* L.) genotypes (Akhter *et al.,* 2021). The work under saline conditions in the semi-arid region of Northwestern Haryana with four mustard varieties in main plots (Kranti, Giriraj, CS54, and CS58) and three fertilizer doses in sub-plots (100, 125 and 150% RDF). During the experimentation, saline water irrigation was applied at a rate of 7.5 dS/m and notable changes

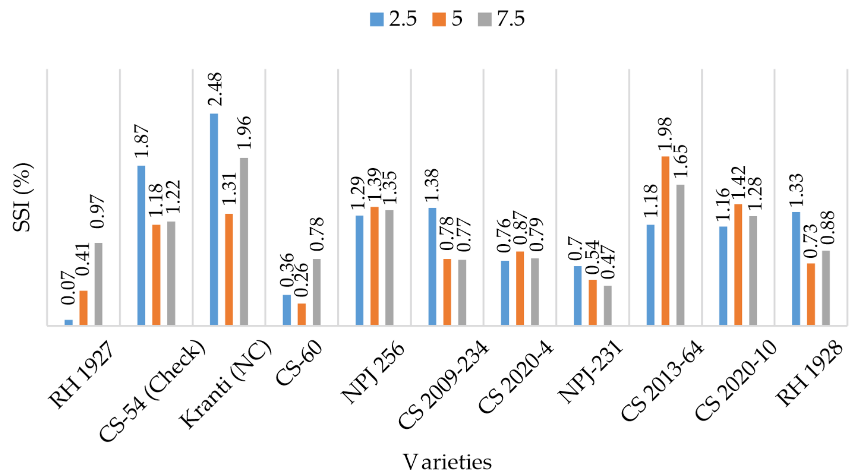


Fig. 3 Salinity susceptibility index (SSI) of mustard genotypes as affected by waters of different salinities

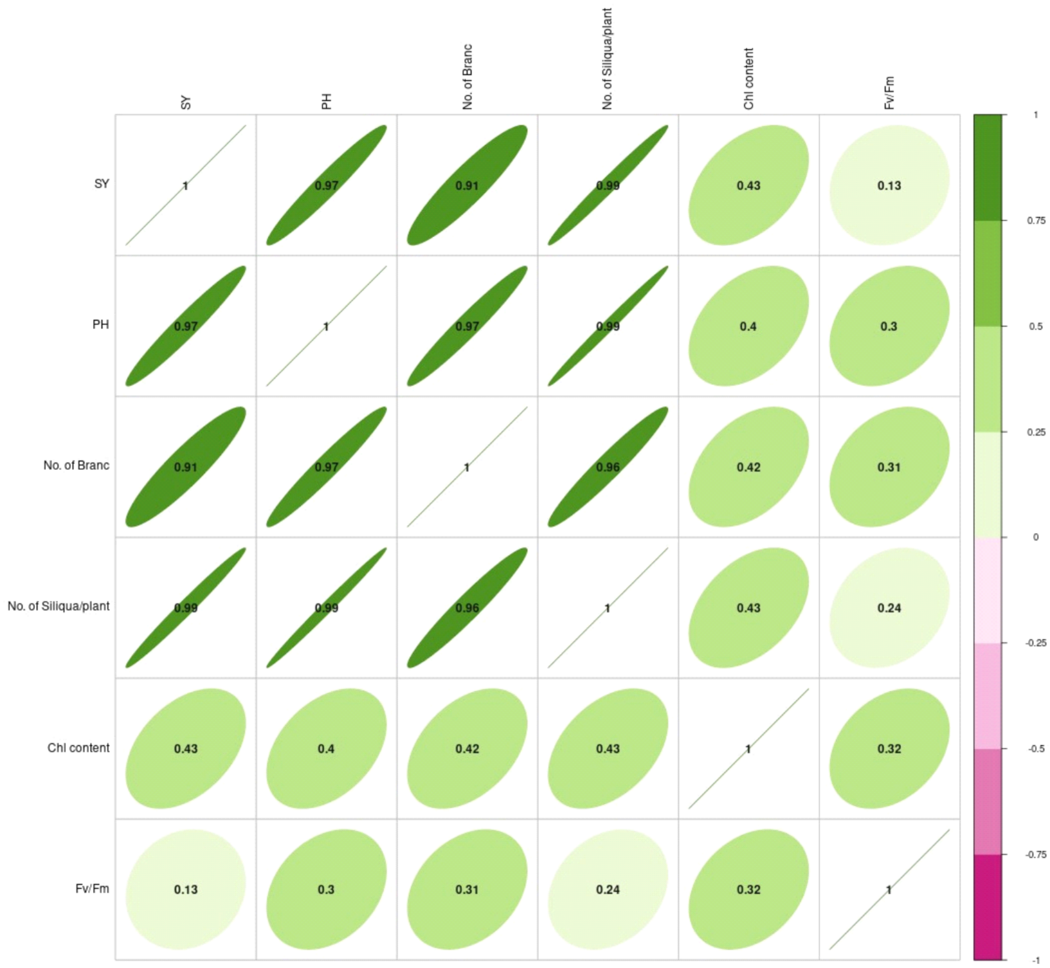


Fig. 4 Correlogram of different traits of mustard genotypes as affected by waters of different salinities

in various physiological parameters were observed. Specifically, as the fertilizer dosage increased, parameters such as relative water content (RWC %), total chlorophyll content, and photosynthetic rate exhibited significant improvements. Conversely, these parameters experienced a decline with the application of saline water irrigation (Priyanka *et al.,* 2022). Concomitant results were also noticed by (Lohar *et al.,* 2022) in *Brassica juncea.* Fig. 4 represents the correlation of different traits for seed yield. The mean salinity in the soil profile at the time of

Table 4. Salinity at different soil depths after the mustard harvest

Depth	EC_e (dS/m)			
(cm)	Canal	2.5	5.0	7.5
0-15	1.99	4.52	7.85	10.41
15-30	1.84	4.14	7.09	10.21
Mean	1.92	4.33	7.47	10.31

mustard harvest varied from 1.92 dS/m in canal water irrigated plots to 10.31 dS m^{-1} in plots irrigated with saline water of ECiw 7.5 dS m^{-1} (Table 4).

Conclusions

Among the eleven mustard genotypes CSCN 220-10 gave the highest seed yield (23.7q ha^{-1}) under salt stress. The. seed yield, plant height, number of branches and siliqua per plant, chlorophyll content (SPAD units), and photochemical quantum yield (Fv/Fm) exhibited a consistent decline as salinity levels increased from the canal to 7.5 dS m^{-1}. The genotypes CS 60, CS 2020-4, NPJ-231, and CS 2009-234 were found with highest salt tolerance (from the canal to 7.5 dS m^{-1}).

References

Akhter MS, Noreen S, Mahmood S, Ashraf M, Alsahli AA and Ahmad P (2021) Influence of salinity stress on PSII in barley (*Hordeum vulgare* L.) genotypes, probed by chlorophyll-A fluorescence. *Journal of King Saud University – Science* **33**: 1-11.

Ali AYA, Ibrahim MEH, Zhou, Nimir G, Jiao NEA, Zhu X, Elsiddig G, Suliman AMI, Elradi MSE, SBM and Yue W (2020) Exogenous jasmonic acid and humic acid increased salinity tolerance of sorghum. *Agronomy Journal* **112** (2): 871-878.

Ankush, Ram Prakash, Kumar R, Singh V, Harender & Singh VK (2020) Soil microbial and nutrients dynamics influenced by irrigation-induced salinity and sewage sludge incorporation in sandy-loam textured soil. *International Agrophysics* **34**: 451-462.

Ashraf M and Mc Neilly T (2004) Salinity tolerance in brassica oilseeds. *Critical Reviews in Plant Sciences* **23**(2):157-174.

Bhardwaj S and Kumar P (2020) Salinity stress, its physiological response and mitigating effects of microbial bioinoculants and organic compounds. *Journal of Pharmacognosy and Phytochemistry* **9**(4): 1297-1303.

Fischer RA & Maurer R (1978) Drought resistance in spring wheat cultivars. I. Grain yield responses. *Australian Journal of Agricultural Research* **29**: 897-912.

Kumari S, Yadav BL, Verma HP, Meena JS, Pancholi P (2015) Effect of sodic water, biofertilizer and phosphorus on physical properties of soil, yield attributes and yield of mungbean. *Annals of Agricultural Research* **36**(4): 394-399.

Lohar M, Kumari S, Ram Prakash, Devi S and Kumar V (2022) Effect of Water Quality on Biochemical and Physiological Parameters in Different Mustard (*Brassica juncea*) Genotypes. *Journal of Soil Salinity and Water Quality* **14**(2): 236244.

Majeed S, Akram M, Latif M, Ijaz M and Hussain M (2016) Mitigation of drought stress by foliar application of salicylic acid and potassium in mungbean (*Vigna radiata* L.). *Legume Research* **39**(2): 208-214.

Priyanka, Prakash R, Yadav R, Kumar N and Dhillon A (2020) Performance of different Indian mustard (*Brassica juncea*) varieties with saline water and graded fertilizer doses under semi-arid conditions of Haryana. *Journal of Environmental Biology* **41**: 1599-1604.

Priyanka, Prakash R, Ankush, Devi S, Rajpaul and Singh R (2022) Physiological studies and nutrient accumulation in mustard varieties in response to fertilizer doses under saline condition in semi-arid region of northwestern Haryana. *Indian Journal of Experimental Biology* **60**(8): 628-634.

Rahman M, Khatun A, Liu L and Barkla BJ (2018) Brassicaceae Mustards: Traditional and Agronomic Uses in Australia and New Zealand. *Molecules* **23**(1): 231-249.

Sewhag M, Ahlawat DS, Ramparkash, Pawar N and Sangwan M (2022) Performance of salt tolerant mustard varieties under different fertility levels. *Journal of Plant Development Sciences* **14**(3): 331-336.

Shanker K, Parihar SK, Kuldeep KK and Kumar A (2016) Relative salt tolerance of Indian mustard (*Brassica juncea*) genotypes in relation to germination, growth and seed yield. *Journal of Oilseed Brassica* **2**(2): 76-82.

Singh RB, Kaledhonkar MJ, Chaudhari SK, Shishodia PK and Meena BL (2018) Effect of saline and alkaline water on mustard yield under sprinkler irrigation. *Journal of Soil Salinity and Water Quality* **10**(2): 246-253.

Yang QQ, Farha AK, Cheng LZ, Kim G, Zhang T and Corke H (2020) Phenolic content and in vitro antioxidant activity in common beans (*Phaseolus vulgaris* L.) are not directly related to anti-proliferative activity. *Food Bioscience* **36**: 100662.

Received: January 04, 2024; Accepted: June 12, 2024

Journal of Soil Salinity and Water Quality 16(1), 48-55, 2024

Spatial and Temporal Analysis of Sodic Soils in Sharda Sahayak Canal Command of Amethi District using Sentinel-2A/2B MSI Data

RH Rizvi*, Sanjay Arora, Chhedi Lal Verma, Anil Kumar Dubey and RK Yadav

ICAR-CSSRI Regional Research Station, Lucknow-226002, Uttar Pradesh, India
**Corresponding author's Email: Raza.Rizvi@icar.gov.in*

Abstract

In Sharda Canal Command of Uttar Pradesh, about 2,60,000 ha area is waterlogged and 2,53,300 ha area is salt affected. Therefore, this command area having problems of waterlogging and salinity needs to be properly and regularly monitored for site-specific reclamation and managment. Geospatial technologies have potential to analyse spatially and temporally a geographical area say district for desired feature. 48 soil samples at 12 locations and four depths with their GPS locations were collected from Sharda Canal Command in Amethi district. These samples were analyzed in laboratory for different soil parameters like pH_2, EC_2, OC, Na, K, pH_e, EC_e, etc. Most of the soil samples have pH more than 10 indicating that soils in the Sharda Command is highly sodic. Soil EC varied from 1.55 to 13.32 dS/m at 0-15 cm depth and ESP of the samples ranged from 81-93%. Soil pH_2 and EC_2 varied from 10.13 to 10.67 and dS/m, respectively at 15-30 cm depth. Organic carbon varied from 0.20 to 0.43% at 0-15 cm depth and from 0.11 to 0.40% at 15-30 cm depth. Sentinel-2A/2B MSI remote sensing images (spatial resolution 10-20m) for pre-monsoon period (May 2022 & May 2023) were downloaded and pre-processed. Land use land cover (LULC) analysis for Amethi district was done using an open source software QGIS (v. 3.24.0). Unsupervised classification method (ISODATA) was applied on district's images and the output image was reclassified for five LULC classes mainly water/water bodies, built-ups/sandy areas, vegetation/plantation, bare/fallow land and sodic soils. Area under plantation/vegetation and bare/fallow land accounted for more than 27 percent in both the years. Estimated area under sodic soils increased from 5.50 percent in May 2022 to 6.39 percent in May 2023 in Amethi district.

Key words: LULC, Sharda Canal, Sentinel-2, sodic soils, unsupervised

Introduction

Soil salinization caused by natural and anthropogenic factors is a serious environmental hazard especially in arid and semi-arid regions of the world. Accumulation of salts in the soils is a major threat to crop production and global agriculture. Its accumulation is controlled and aggravated by a combination of several factors such as human activities, climatic conditions, land form variability and water table depths. Rapid and precise detection of salt-affected lands is highly critical for planning soil sustainability for supporting food production. In Sharda Canal Command of Uttar Pradesh, about 2,60,000 ha area is waterlogged and 2,53,300 ha area is salt affected. Therefore, this command area having problems of waterlogging and salinity needs to be properly and regularly monitored. Mandal *et al*. (2009) prepared salt affected soil maps at 1:250000 scale for 14 states and a Union Territory. An area of 6.73 million ha was estimated to salt affected in the entire country. State wise estimates showed that this extensive area is distributed over the Gangetic plains of Uttar Pradesh, the arid and semi-arid regions of Gujarat and the peninsular plains of Maharashtra state.

Elhag (2016) investigated several salinity indices using Landsat-8 MSS data for mapping soil salinity in arid ecosystem of Saudi Arabia. Out of 11 indices, salinity index-9 was found to be the best and then estimated values of index were used to map and classify soil salinity in the whole study area. Soil salinity in irrigated paddy fields was assesses using Sentinel-2 time series data (Moussa *et al*. 2020). Two complementary approaches were tested: salinity assessment of bare soils using salinity index (SI) and monitoring of indirect effect of salinity on rice growth using temporal series of vegetation index (NDVI). Results showed that since there were few periods of bare soil, SI could not differentiate salinity classes.

Suleymanov *et al*. (2021) analysed relationships between the level of soil salinity and key spectral indices based on Sentinel-2A satellite data. Salinity index III = (G x R)/ B showed the best correlation values with salinity level (r = 0.89). In general, it was found that highest correlation values were observed with indices based on three visible bands (B-blue, G-green, R-red).

Al-Gaadi *et al*. (2021) developed soil salinity prediction model using Sentinel-2A satellite data. Soil saturation extract parameter ECe was used for estimating soil salinity. A combination of Short Wave Infrared-1 FULL FORM? and the simplified brightness index was found to be the most appropriate (R^2=0.65) for prediction of soil salinity.

Wang *et al*. (2020) estimated soil salinity using four predictive modelling approaches: partial Least Square Regression (PLSR), Convolution Neural Network (CNN), Support Vector Machine (SVM) and Random Forest (RF). Among these, the RF model was the best model (R^2=0.75) and was most effective in revealing the spatial characteristics of Salt distribution.

Zarai *et al*. (2021) investigated potential of Sentinel-2 imagery for mapping and monitoring soil salinity for several spectral features based on satellite band reflectance, salinity indices and vegetation indices. Three regression models including Gradient Boost Machine (GBM), Extreme Gradient Boost (XGBoost) and RF were built to estimate soil salinity. The XGBoost method outperformed GBM and RF.

Suleymanov *et al*. (2023) predicted soil properties using machine learning techniques and Sentinel-2A satellite imageries. They found bands B8A, B8 and B7 were the most effective covariates in predicting soil organic matter (SOM), whereas spectral indices Green Normalised Difference Vegetation Index (GNDVI) and Soil Adjusted Vegetation Index (SAVI) explained most of the spatial distribution of soil pH.

Aksoy *et al*. (2021) analysed the performance of three machine learning algorithms to map soil salinity using Landsat-8 OLI, Sentinel-2A satellite images and ground based electrical conductivity (EC) measurements with the aid of Google Earth Engine platform. They employed Classification and Regression Trees (CART), Support Vector Regression (SVR) methods and RF to establish correlation between ground measurements and satellite derived spectral indices. The output map of RF model estimated more reliable salinity levels.

Sahna *et al*. (2021) assessed the degree of soil salinity and its spatial distribution in the Sunderbans using remote sensing and field measured datasets. Eight salinity indices extracted from satellite images were statistically correlated with measured electric conductivity values. They found that Salinity Index (SI-3) and Normalized Difference Salinity Index (NDSI) were determined as the most suitable indices to map soil salinity of the Sunderbans.

Geospatial technologies have potential to analyse spatially and temporally a geographical area say district for desired feature. Advantage of remote sensing techniques and machine learning algorithms has started to contribute to large-scale monitoring of salt-affected soils (SAS). The present study aimed at mapping sodic soils in Sharda Canal Command of Amethi district using Sentinel-2 MSI remote sensing data. Besides this, temporal change in sodic soils area for two periods was also assessed in the district.

Materials and Methods

Sentinel-2A/2B multispectral remote sensing images (spatial resolution 10-20m) for Nov. 2021, May 2022 and May 2023 were downloaded from Earth Explorer. Downloaded images were pre-processed for rectification, mosaicking and then clipping from district boundary. Boundary shape file obtained from Survey of India, Dehradun was used for clipping purpose. The clipped images were subjected to land use land cover (LULC) classification using an open source software QGIS (v. 3.24.0). Unsupervised classification methods (ISODATA/ kMeans) were applied to obtain LULC classes. Accuracy for sodic soils class was

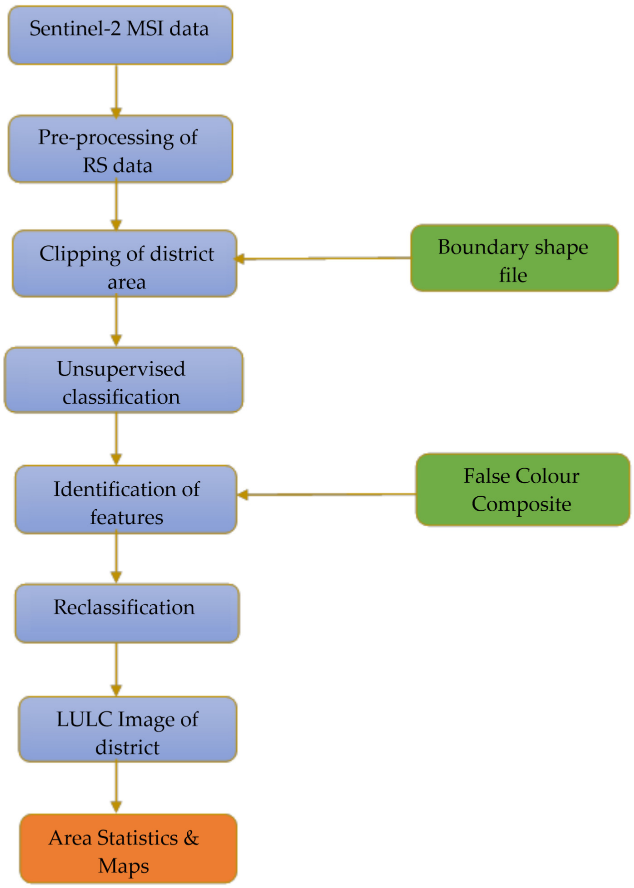


Fig. 1 Methodology for mapping sodic soils using Sentinel-2 data

judged with the help of GPS points. Methodology for LULC and sodic soils mapping is depicted in Figure 1. Total 48 soil samples with GPS points were collected from Sharda Canal Command in Amethi district (Figure 2).

Results and Discussion

Soil analysis

The geo-referenced soil samples (depth-wise) were collected from 12 sites in the Sharda Sahayak Canal command from Amethi district of UP. These samples were analysed in laboratory for soil parameters viz. pH_2, EC_2, OC, pH_e, EC_e, Na and K. It was observed that in surface soil, the pH_2 ranged from 10.31 to 10.76 and generally showed decreasing trend with soil depth in all the sampled locations. Soil EC_2 varied from 1.55 to 13.32 dS/m with five sites having EC of more than 4 dS/m indicating occurrence of salinity along with sodicity in the area. ESP of the samples ranged from 81-93%, Na ranged from 39.09 to 292.39 meq/l and soil K ranged from 0.08 to 0.39 meq/l.

Similarly, pH_e of saturation extract ranged from 9.09 to 10.42 in surface soil, which decreased with soil depth upto 60 cm where its value ranged from 7.32 to 9.16. Irrespective of the soil depth, the relationship between pH_2 and pH_e was found to follow the polynomial of 2^{nd} order with R^2 of 0.83 in comparison to linear relation (R^2=0.77) (Figure 3). The EC_2 (0.37-13.32) and EC_e

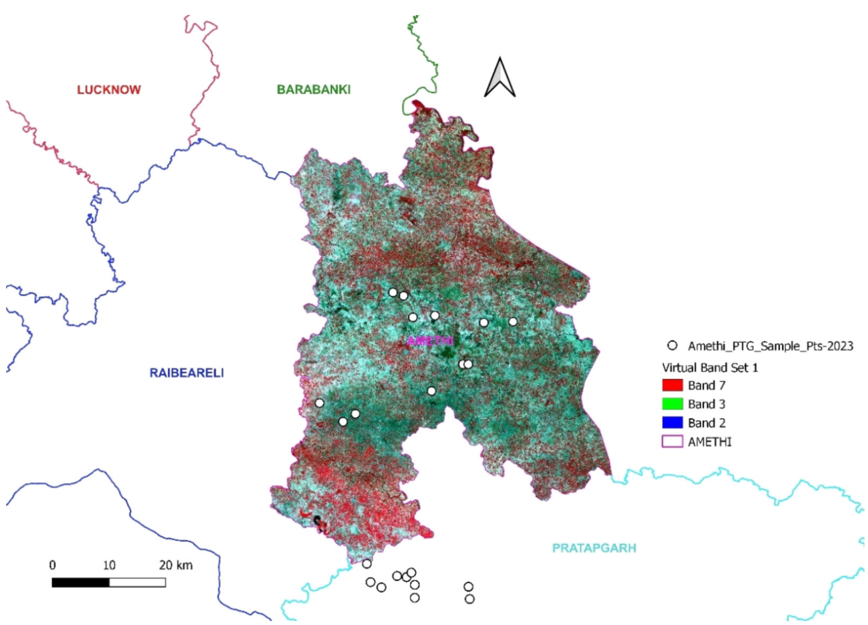


Fig. 2 Soil sampling sites in Amethi district of Uttar Pradesh

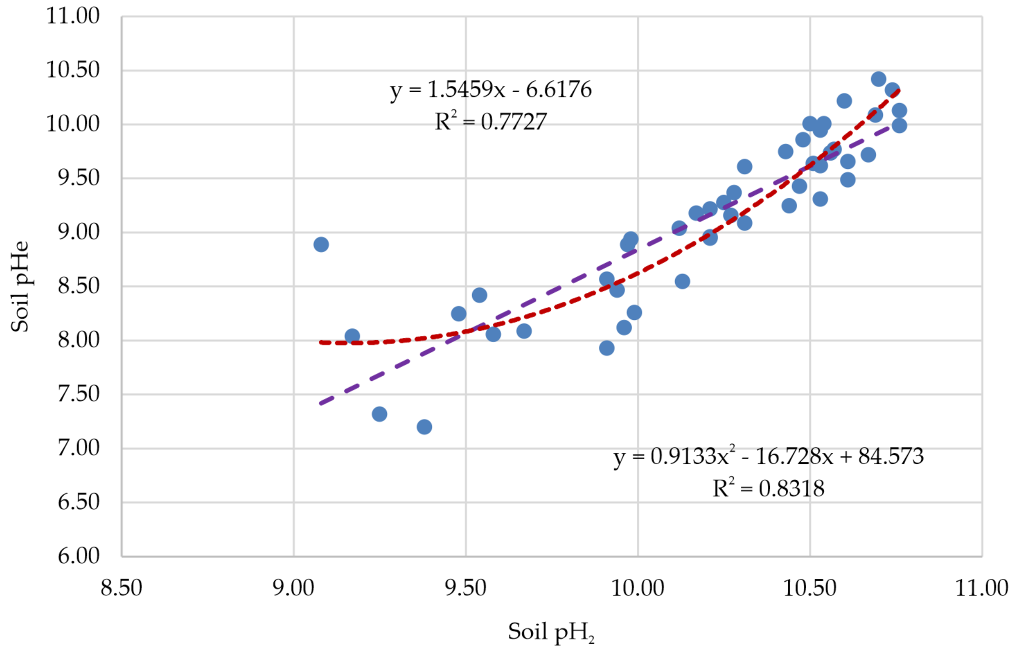


Fig. 3 Relationship between pH_2 and pH_e of canal command soils in Amethi district

(0.97-84.13) showed logarithmic relation with R^2 of 0.37 compared with linear relation (R^2=0.30).

Soil organic C content in surface soil, ranged between 0.20 to 0.43% that declined with soil depth. It declined to minimum value of 0.03 to 0.29% at the depth of 60 cm. Sodium content in saturation extract ranged from 39.1 to 292 meq /l (Figure 4). The sodium content also generally decreases with increase in soil depth with decline percent ranging from 70.6 to 94.2%. Decrement of soluble sodium with soil depth is indicative of movement of salt to the lower depths with the influence of canal water seepage. Similar observation for decrease in potassium content from 0.08 to 0.39 meq /l in surface soil was observed with decrement of 11.4 to 86.8% in lower depth over the surface content in all the locations.

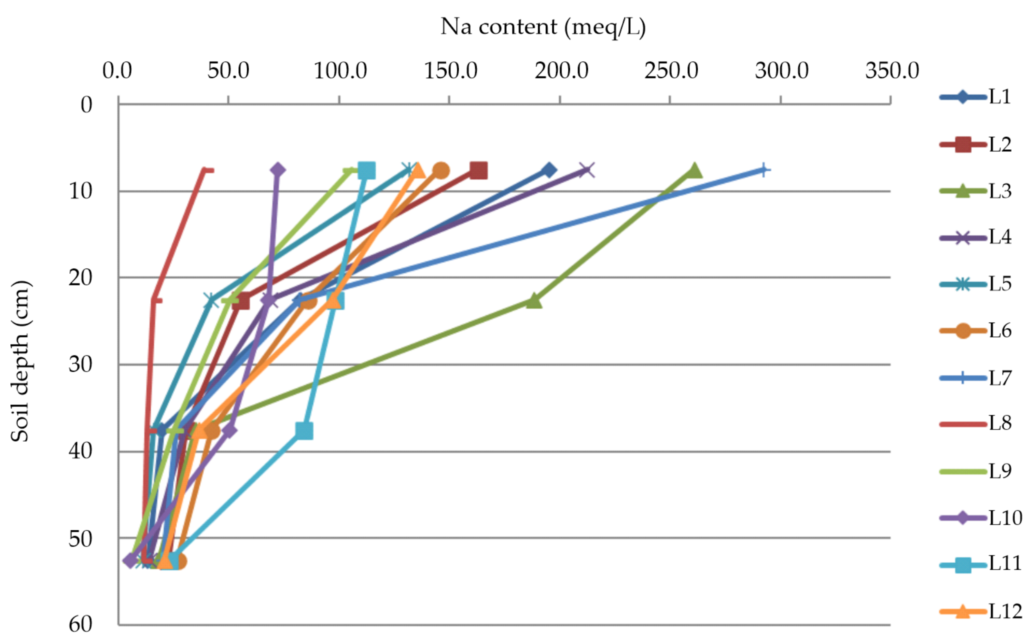


Fig. 4 Depth-wise distribution of sodium in canal command soils of Amethi

Table 1. Classification of soil samples according to soil pH and EC in Amethi district

pH class	No. of samples	Category	ECe class	No. of samples	Category
< 8.5	00	Non-sodic	<= 4.0	38	Non-saline
8.5 – 9.0	00	Slightly sodic	> 4.0	10	Saline
9.0 – 9.5	05	Moderately			
9.5 – 10.0	10	Sodic			
> 10	33	Highly sodic			

Table 2. Land use land cover of Amethi district in Uttar Pradesh (Nov. 2021)

Class	LULC classes	Area (m^2)	Area (ha)	Area (%)
1	Sodic soils	23219700	2321.97	0.84
2	Water/ water bodies	34680600	3468.06	1.26
3	Built-ups/ sandy area	617744100	61774.41	22.45
4	Vegetation/ plantation	789703500	78970.35	28.70
5	Agricultural crops	237286800	23728.68	8.62
6	Bare/ fallow land	1048961700	104896.17	38.12
		2751596400	275159.64	

Remote Sensing Analysis

Land use land cover analysis (LULC) analysis of Sentinel-2A/2B images for Nov. 2021, May 2022 and May 2023 was done using an open source software QGIS (v. 3.24.0). Remote sensing images were classified by applying unsupervised method of ISODATA. Five classes viz. Water, built-ups, vegetation, bare land and sodic soils were obtained after reclassification of images. According to this LULC classification, an estimated area of sodic soils in Nov. 2021 and May 2022 was 2321.97 ha and 15131.01 ha, respectively (Tables 2 & 3). Area in Nov. 2021 was found lesser than that in May 2022 because soluble salt leached belowground during rainy season from the soils having EC values. Area under sodic soils increased from 5.50 percent in May 2022 to 6.39 percent in May 2023.

Some studies were conducted for mapping salinity level or its distribution using salinity indices (Elhag 2016; Moussa *et al*. 2020; Sahna *et*

Table 3. Land use land cover of Amethi district in Uttar Pradesh (May 2022)

Class	LULC classes	Area [m^2]	Area (ha)	Area (%)
1	Sodic soils	151310100	15131.01	5.50
2	Builtups/ sandy areas	683797400	68379.74	24.85
3	Water/ water bodies	40009900	4000.99	1.45
4	Vegetation/ plantation	1030998700	103099.87	37.47
5	Bare/ fallow land	844528600	84452.86	30.69
		2750644700	275064.47	

Table 4. Land use land cover of Amethi district in Uttar Pradesh (May 2023)

Class	LULC Class	Area [m^2]	Area [ha]	Area (%)
1	Sodic soils	175636700	17563.67	6.39
2	Water/ water bodies	69060200	6906.02	2.51
3	Builtups/ Sandy area	710281200	71028.12	25.82
4	Vegetation/ plantation	1036853700	103685.37	37.69
5	Bare/ fallow land	758812900	75881.29	27.59
		2750644700	275064.47	

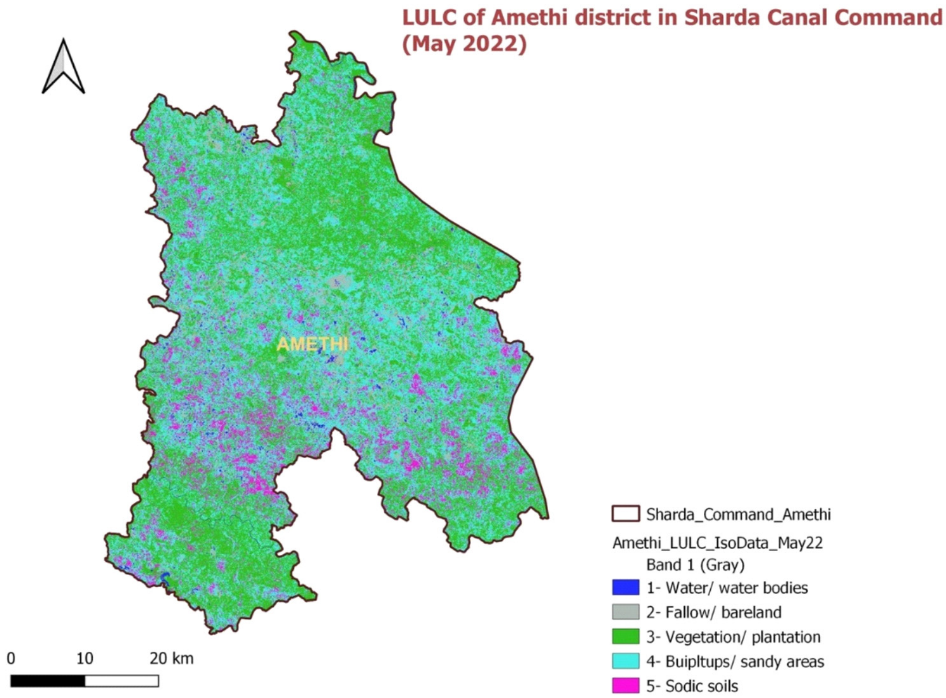


Fig. 5(a) LULC map of Amethi district (May 2022) in Sharda Canal Command

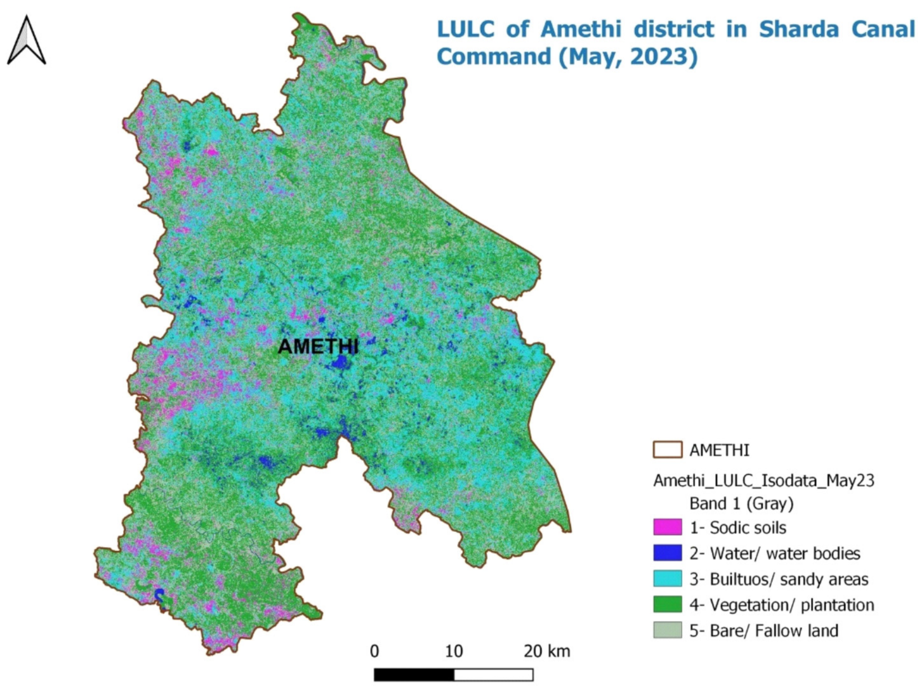


Fig. 5(b) LULC map of Amethi district (May 2023) in Sharda Canal Command

al. 2021; Suleymanov *et al*. 2021). Predictive modelling approach for assessing soil salinity was adopted in some studies (Wang *et al*. 2020; Zarai *et al*. 2021). In most of these studies Sentinel-2 remote sensing data was used for salinity mapping. Some studies found Random Forest model as suitable model for prediction of salinity level or its distribution (Aksoy *et al*. 2021; Wang *et al*. 2020). Soil properties like soil organic matter was predicted by combining machine learning technique and spectral bands of Sentinel-2A (Suleymanov *et al*. 2023).

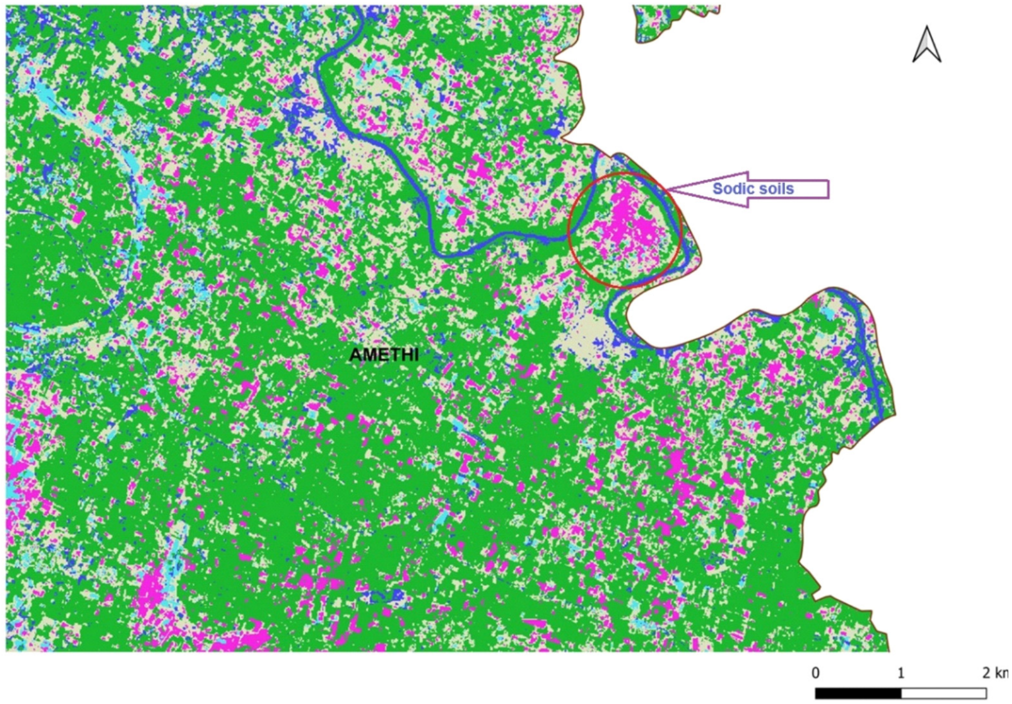


Fig. 5(c) Spatial distribution of sodic soils in part of Amethi district

In the present study, sodic soils in Sharda Canal Command of Amethi district have been identified and mapped with the help of remote sensing data, field GPS points and raster clustering method. However, salinity indices or machine learning techniques may examined for mapping sodicity levels in the study area.

Conclusions

Analysis of soil samples from Sharda Canal Command in Amethi district revealed that mostly soils is highly sodic (pH>10). For mapping of the waterlogged sodic soils, high resolution remote sensing data (Sentinel-2) together with ground check points (GPS) was taken. LULC classification of the district was done and sodic soils were mapped for pre-monsoon periods (May 2022 & May 2023). Although remote sensing analysis for post-monsoon period (Nov. 2021) was also done, but estimated area under sodic soils was only 0.84 percent, which does not seem realistic figure. This is because most of the salts on surface soils might have leached during rains. Therefore for accurate spatial and temporal mapping of sodic soils, remote sensing images for pre-monsoon period would give better results.

References

Aksoy S, Yildrim A, Gorji T *et al.* (2021) Assessing the performance of machine learning algorithms for soil salinity mapping in Google Earth Engine Platform using Sentinel-2A and Landsat-8 OLI data. *Advance in Space Research*, doi: 10.1016/j.asr.2021.10.024.

Al-Gaadi KA, Tola EK, Mudugundu R and Fulleros RB (2021) Sentinel-2 images for effective mapping of soil salinity in agricultural fields. *Current Science* **121 (3)**: 384-390.

Elhag M (2016) Evaluation of different soil salinity mapping using remote sensing techniques in arid ecosystems, Saudi Arabia. *Journal of Sensors*, doi: 10.1155/2016/7596175.

Mandal AK and Sharma RC (2011) Delineation and characterization of waterlogged salt-affected soils in IGNP using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing* **39(1)**: 39-50.

Mandal AK, Sharma RC and Singh G (2009) Assessment of salt-affected soils in India using GIS. *Geocarto International* **24**:437-456.

Moussa I, Walter C, Michot D, Boukary IA, Nicholas H, Pichelin P and Guero Y (2020) Soil salinity assessment in irrigated paddy fields of the Niger valley using a four year time series of Sentinel-2 images. *Remote Sensing* **12**, 3399 (doi: 3390/rs12203399).

Sahana M, Rehman S, Patel PP, Dou Jie, Hong H and Sajjad H (2021) Assessing the degree of soil salinity in the

Indian Sunderban Biosphere Reserve using measured soil electric conductivity and remote sensing data driven salinity indices. *Arabian Journal of Geosciences* **13,** 1289.

Suleymanov A, Gabbasova I, Abakumov E and Kostecki J (2021) Soil salinity assessment from satellite data in the Trans-Ural steppe zone (Southern Ural, Russia). *Soil Science Annual*, **72(1)**:132233 (doi: 10.37501/soilsa/132233).

Suleymanov A, Tuktarova I, Belan L, Suleymanov R, Gabbasova I and Arastanova L (2023) Spatial prediction of soil properties using Random forest, k-nearest neighbourhood and cubist approaches in the foothills of the Ural Mountains, Russia. *Modelling Earth Systems and Environment* **9**: 3461-3471 (doi: 10.1007/s40808-023-01723-4).

Wang N, Xue J, Biswas A, He Young and Shi Zhou (2020) Integrating remote sensing and landscape characteristics to estimate soil salinity using machine learning methods: A case study from southern Xinjiang, China. *Remote Sensing* **12**, 4118 (doi: 10.3990/rs12244118).

Zarei A, Hassanlou M and Mahdianpari M (2021) A comparison of machine learning models for soil salinity estimation using multispectral earth observation data. *ISPRS Annals of the Photogrammetry Remote Sensing and Spatial Information Sciences* (doi: 10.5194/isprs-annals-V-3-2021-257-2021).

Received: May 27, 2024; Accepted: June 29, 2024

Journal of Soil Salinity and Water Quality 16(1), 56-68, 2024

Impact of Organic and Inorganic Amendments on Microbiological and Chemical Properties and Their Relationship with Rice Productivity in an Alkali Soil of Southern India

Hari Mohan Meena[1]* and HC Prakasha[2]

[1]*Department of Soil Science, Punjab Agricultural University, Ludhiana, Punjab, India*
[2]*Department of Soil Science and Agricultural Chemistry,*
University of Agricultural Sciences, Bengaluru, Karnataka, India
**Corresponding author's Email: harimohanmeena46@gmail.com*

Abstract

Soil alkalinity has a detrimental effect on agricultural sustainability and soil health. This experiment was carried out in order to evaluate the impact of both organic and inorganic amendments on reclamations and the enhancement of the alkali soil health in Karnataka, India. A randomized complete block design with seven treatments and three replications was used to set up the experiment. When pressmud was used in conjunction with soil test value-based fertilizer application (STV) + farmyard manure (FYM) + $ZnSO_4$ instead of other integrated treatments, rice grain yield was significantly improved. The use of pressmud and gypsum in conjunction with STV + FYM + $ZnSO_4$ decreased the soil pH values to 7.78 and 7.88, respectively compared to RDF + FYM + $ZnSO_4$ (8.36) and increased soil organic carbon, and available nitrogen, phosphorus, and potassium ($p \leq 0.05$). Exchangeable Na and ESP decreased by 20.2 and 43.5% in STV + pressmud + FYM + $ZnSO_4$ than RDF + FYM + $ZnSO_4$. When comparing STV + pressmud + FYM + $ZnSO_4$ to RDF + FYM + $ZnSO_4$, the increases in soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), dehydrogenase, urease, and alkaline phosphatase activity were 7.1, 28.1, 19.3, 18.5, and 25.3%, respectively. The pH, exchangeable Na and exchangeable sodium percent (ESP) were negatively correlated with SMBC, SMBN, alkaline phosphatase and available nutrients after the harvest of rice and residual dhaincha crop. The results suggested that the addition of pressmud in combination with FYM significantly decreased the pH, exchangeable Na and ESP, and improved soil biological properties.

Keywords: Alkali soil, Enzyme activity, Gypsum, Pressmud, Microbial biomass carbon and nitrogen, Soil test value–based fertilizers application, Yield

Introduction

Soil alkalinity has a detrimental effect on agricultural sustainability. Globally, about 1.5 billion hectares of land are affected by salt (Jun-Feng *et al.*, 2010). In India, alkalinity affects over 3.7 million hectares of land (Mandal *et al.*, 2009). In arid and semi-arid areas, salinity and sodicity cause unfavorable soil physical, chemical, and biological properties limiting plant growth (Mane 2012). Furthermore, soil organic carbon decreases substantially over time due to soil salinization (Wong *et al.*, 2010). As a result, developing the best reclamation technology or combining technologies to enhance the chemical and physical characteristics of salt-affected soils. Use of inorganic amendments such as gypsum and organic amendments such as farmyard manure, press mud to remediate salt-affected soils is a successful, low-cost, and convenient solution (Tejada *et al.*, 2006; Ahmad *et al.*, 2013; Rai *et al.*, 2021; Basak *et al.,* 2022; Rashmi *et al.*, 2024a).

The physicochemical properties of alkali soils are enhanced by use of farmyard manure along with gypsum (Ullah and Bhatti, 2011). Gypsum is a common source of calcium that replaces Na^+ from the exchange site (Amezketa *et al.,* 2005); it is widely used as an amendment to mitigate the harmful effects of high sodium, which result in a significant reduction in soil pH and sodium adsorption ratios. As farmyard manure decays, it raises CO_2 levels in the soil and releases hydrogen ion (H^+) as it dissolves in water. $CaCO_3$ dissolution is helped by the released H^+, which frees up more Ca^{2+} for Na^+ exchange (Ghafoor *et al.*, 2008). Additionally, the physicochemical properties of soil are enhanced by organic components, which accelerate the exchange of cations on soil solids, and the draining of salt from the root zone (Clark *et al.*, 2007). This helps to reduce root salt injuries and promotes more smoothly expanding roots.

Pressmud is a byproduct of sugar factories that can be applied to horticultural and agricultural crops as an organic fertilizer that is rich in nutrients. The application of pressmud on alkali soils improves the chemical, biological, and physical properties, resulting in increased growth and yield of crop (Sheoran *et al.*, 2021). Alkali soils have poor structural stability due to low organic matter (Wang *et al.*, 2014). The application of organic amendments in alkali soils binds the tiny soil particles together into large–water stable aggregates, increases porosity and thus improves the soil physical properties (Wang *et al.*, 2023). Organic amendments, on the other hand, lower down the pH and exchangeable sodium percentage (ESP) of the alkali soils by producing organic acids and increasing the availability of Ca^{2+} (Mahmoodabadi *et al.*, 2013; Yazdanpanah *et al.*, 2013), that exchange with the Na^+ in the clay complex, resulting in a more favorable environment for microbial activity. Consequently, the goal of the current study is to examine how fertilizer application and amendments based on soil test values affect the chemical and biological properties of alkali soils.

Material and Methods

Experiment details

A field experiment using rice (*Oryza sativa* L.) as the test crop was conducted in *Kharif* 2016 at Zonal Agricultural Research Station (ZARS), Vishweshwaraiah Canal Farm, Mandya (Karnataka), 12°57′ N latitude, 76°82′ E longitude, 705 meters above mean sea level. Using the dhaincha crop (*Sesbania aculeata* L.), a residual study was conducted in the *Summer* session 2017 using the same treatments applied without disturbing the plots. The texture of the soil at the experiment site was sandy clay loam. During the cropping period (June 2016 to May 2017), the mean maximum air temperature varied between 26.2 and 32.2 °C. In contrast, during the cropping period, the mean minimum air temperature ranged from 11.4 to 20.3 °C. The actual rainfall received during the cropping period (June 2016 to May 2017) was 539.5 mm in the experimental site.

The soil pH was 8.60 at the start of the field experiment. The soil organic carbon was 3.20 g kg^{-1}. There were 228.6, 22.5 and 159.9 kg ha^{-1} of available nitrogen, available phosphorus, and available potassium, respectively. With seven treatments and three replications, the experiment was set up using randomized complete block design (RCBD). 10.8 m^2 (3.6 m × 3 m) was the net plot size. Surface drainage channels of 30 cm depth and 30 cm width between each replication were provided to leach out salts. The following were the seven treatments: T_1: Farmer's practice (NPK only), T_2: Recommended dose of fertilizer (RDF) + farmyard manure (FYM) + $ZnSO_4$, T_3: T_2 + gypsum, T_4: T_2 + pressmud, T_5: Soil test value–based fertilizer application (STV) + FYM + $ZnSO_4$, T_6: T_5 + gypsum and T_7: T_5 + press mud. According to the University of Agricultural Sciences, Bengaluru package of practice, recommended dose of fertilizer for rice was applied @ 125, 65.5, and 65.5 kg N, P_2O_5, and K_2O ha^{-1}, respectively in alkali soil, and farmyard manure and $ZnSO_4$ were at the rate 10 t ha^{-1} and 40 kg ha^{-1}, respectively, for all the treatments, with exception of treatment T_1 (Farmer's practice). A total of 150, 40, and 35 kg N, P_2O_5, and K_2O ha^{-1}, respectively were applied in farmer's practice treatment (T_1). The experimental soil had low levels of accessible N and P at the beginning, so 25% more nitrogen and phosphatic fertilizer than the required dosage was added to treatments T_5, T_6, and T_7 based on soil test results. Calculated amounts of fertilizers were applied to each plot, with 50% of the recommended dose of N and K_2O, and 100% recommended dose of P_2O_5 were the basal doses used at the time of transplanting of rice through urea, single superphosphate (SSP), and muriate of potash (MOP), respectively. After 30 and 60 days of rice transplanting, the remaining half of the nitrogen and potassium were top dressed in two equal portions. In accordance with

Table 1. The chemical characteristics of the pressmud, gypsum, and FYM

Parameters	Pressmud	Gypsum	FYM
$pH_{1:2}$	6.74	4.21	7.14
$EC_{1:2}$ (dS m^{-1})	4.19	2.58	1.22
Organic carbon (%)	27.5	ND	17.8
N (%)	1.12	0.03	0.67
P (%)	0.55	0.02	0.20
K (%)	1.61	0.14	0.63
Ca (%)	5.70	20.71	0.78
Mg (%)	3.24	3.76	0.35
S (%)	4.10	18.00	0.28

Schoonover's (1952) gypsum requirement, 5.4 t ha^{-1} of gypsum was applied. Pressmud was applied @ 10.0 t ha^{-1} based on equal to FYM recommendation dose. One month prior to planting, each amendment was added to the corresponding experimental plots and mixed by plowing. Table 1 lists the chemical properties of the pressmud, FYM, and gypsum.

Soil sample analysis

After the crops were harvested, soil samples were taken at a depth of 0 to 15 cm, passed through a 100-mesh screen, and stored in refrigerator at 4 degrees C to determine various biological parameters (dehydrogenase activity, urease activity, alkaline phosphatase activity, SMBC and SMBN). The chemical properties such as pH, organic carbon, exchangeable Na, ESP, available N, P, and K, as well as the microbiological parameters, including soil enzyme activities (dehydrogenase, urease, alkaline phosphatase), SMBC, and SMBN, were analyzed in the processed soil samples. Soil pH was determined by using a digital pH meter with a glass electrode in 1:2 soil: water suspension as Jackson (1973) described. Soil organic carbon was ascertained using the method of Walkley and Black (1934). Available N by alkaline $KMnO_4$ distillation method as given by Subbiah and Asija (1956). Olsen's extractant was used to extract phosphorus from the soil, and concentration of phosphorus was measured using the ascorbic acid method outlined by Jackson (1973). Neutral normal ammonium acetate extractant was used to extract available K from the soil, and concentration of K in the extract was measured using a flame photometer, as outlined by Jackson in 1973. Exchangeable Na was identified using a flame photometer model Elico CL–361, following the procedure described by Jackson (1973). Soil cation exchange capacity (CEC) was assessed by leaching the soil with sodium acetate buffer adjusted to pH 8.5. After removing unadsorbed Na with ethyl alcohol, the sodium-saturated soils were then leached with neutral normal ammonium acetate to replace Na with ammonium. Exchangeable Na in the leachate was analyzed using the Elico CL 361 digital flame photometer, following the procedure outlined by Richards (1954). The results were reported in cmol (p^+) kg^{-1} soil. The ESP was calculated by using cation exchange capacity and exchangeable Na values of soils.

ESP (%) = (Exchangeable sodium) / Cation exchange capacity) × 100

The activity of dehydrogenase was assessed following the procedure outlined in Casida *et al.* (1964). The activity of urease and alkaline phosphatase in soil was determined using the method outlined by Tabatabai and Bremner (1969). The SMBC and SMBN were assessed using the chloroform fumigation method determined. SMBC was computed using a K_C value of 2.26 (Vance *et al.*, 1987), and SMBN by the method as given by Brookes *et al.* (1985) using K_N value of 2.22.

Statistical analysis

The data collected underwent statistical analysis using the complete randomized block design for variance analysis (ANOVA) following the method recommended by Gomez and Gomez (1984). The correlation among various parameters was established using the OPSTAT of Hisar Agricultural University in Hisar, India (Sheoran *et al.*, 1998). All figures were created using Microsoft Office Excel 2013.

Results and Discussion

Effect of amendments on grain yield of rice

Grain yield of rice significantly increased in pressmud and gypsum amended plots compared to without amended plots (Fig. 1). The use of gypsum in conjunction with STV + FYM +

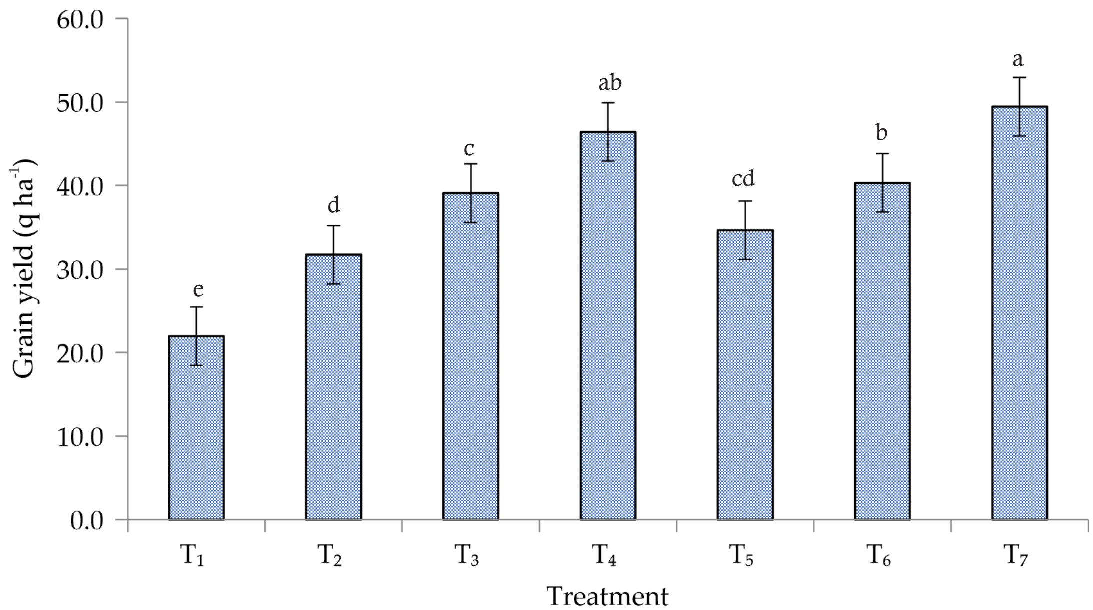


Fig. 1 Effect of organic and inorganic amendments on yield of rice; error bars represent the standard error; bars with similar lowercase letters within a particular soil size fraction are not significant at p< 0.05; (T_1: Farmer's practice (NPK only), T_2: Recommended dose of fertilizer + farmyard manure (FYM) + $ZnSO_4$, T_3: T_2 + gypsum, T_4: T_2 + pressmud, T_5: Soil test value-based fertilizer application (STV) + FYM + $ZnSO_4$, T_6: T_5 + gypsum and T_7: T_5 + pressmud)

$ZnSO_4$ resulted in a considerable increase in grain yield of rice (49.4 q ha^{-1}) followed by RDF + pressmud + FYM + $ZnSO_4$ (46.41 q ha^{-1}) compared to other treatments. It is clearly indicated that application of organic amendments with 25 per cent more nitrogen and phosphate fertilizers based on soil test result over the recommended dose of fertilizer. Additionally, nutrient mineralization and continuous nutrient supply from pressmud may have adequately fulfilled the needs of the nutrient of the crop, particularly during critical stages of crop growth. Kumar et al. (2014) similarly observed similar findings. The increase in grain yield by 27.2% with STV + gypsum + FYM + $ZnSO_4$ compared to RDF + FYM + $ZnSO_4$ may be due to the enhancement of soil pH and reduction of ESP in sodic soil resulting from the application of gypsum. This led to improved nutrient utilization by rice and also contributed to the enhancement of soil physical properties. Consequently, the leaching of excessive ions to deeper layers reduced the salt concentration on the root surface, promoting plant growth and ultimately resulting in a significant increase in rice yield. Similar results also reported by Bahadur *et al.* (2013). The farmer's practices resulted in the lowest rice yield compared to all other treatments possibly because of the imbalanced use of chemical fertilizer and inefficient utilization of available plant nutrients by rice due to a poor root environment caused by higher ESP. Similarly, low yield of rice grown in unamended sodic soils also reported by Suwiphaporn *et al.* (2014).

Effect of amendments on soil chemical properties

The pH of alkali soil significantly decreased under pressmud and gypsum amended plots compared to without amended plots after the rice harvest (Fig. 2). The use of pressmud and gypsum in conjunction with STV + FYM + $ZnSO_4$ significantly decreased the soil pH values to 7.78 and 7.88, respectively, as compared to RDF + FYM + $ZnSO_4$ (8.36) and farmer's practice (NPK only) (8.61), which revealed ameliorative effect of pressmud and gypsum on soil alkalinity. Likewise, after the harvest of residual dhaincha crop, the treatment consisting of STV + FYM + $ZnSO_4$ in conjunction with pressmud and gypsum decreased the soil pH values to 7.82 and 7.94, respectively compared to the farmer's practice (NPK only) (8.61) (Fig. 3).

The value of soil pH was decreased in pressmud treated plots because release of organic

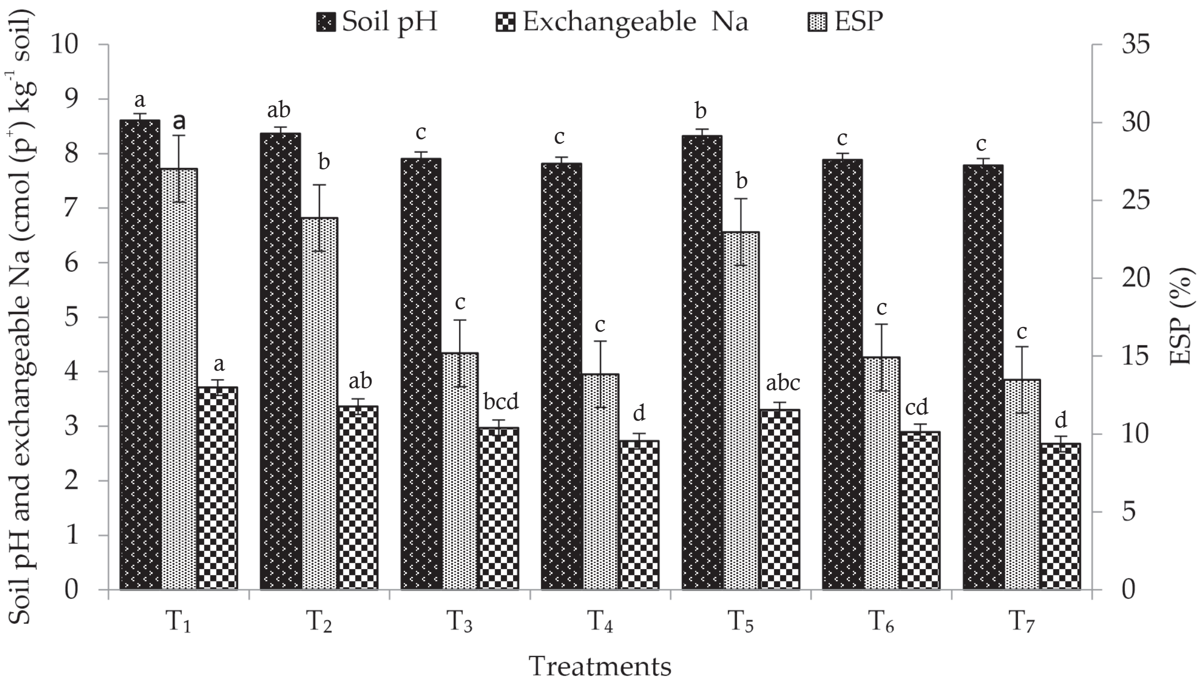


Fig. 2 Effect of organic and inorganic amendments on soil pH, exchangeable Na, and exchangeable sodium percentage (ESP) after rice harvest; error bars represent the standard error. Bars with similar lowercase letters within a particular soil size fraction are not significant at $p < 0.05$. (T_1: Farmer's practice (NPK only), T_2: Recommended dose of fertilizer (RDF) + farmyard manure (FYM) + $ZnSO_4$, T_3: T_2 + gypsum, T_4: T_2 + pressmud, T_5: Soil test value-based fertilizer application (STV) + FYM + $ZnSO_4$, T_6: T_5 + gypsum and T_7: T_5 + press mud).

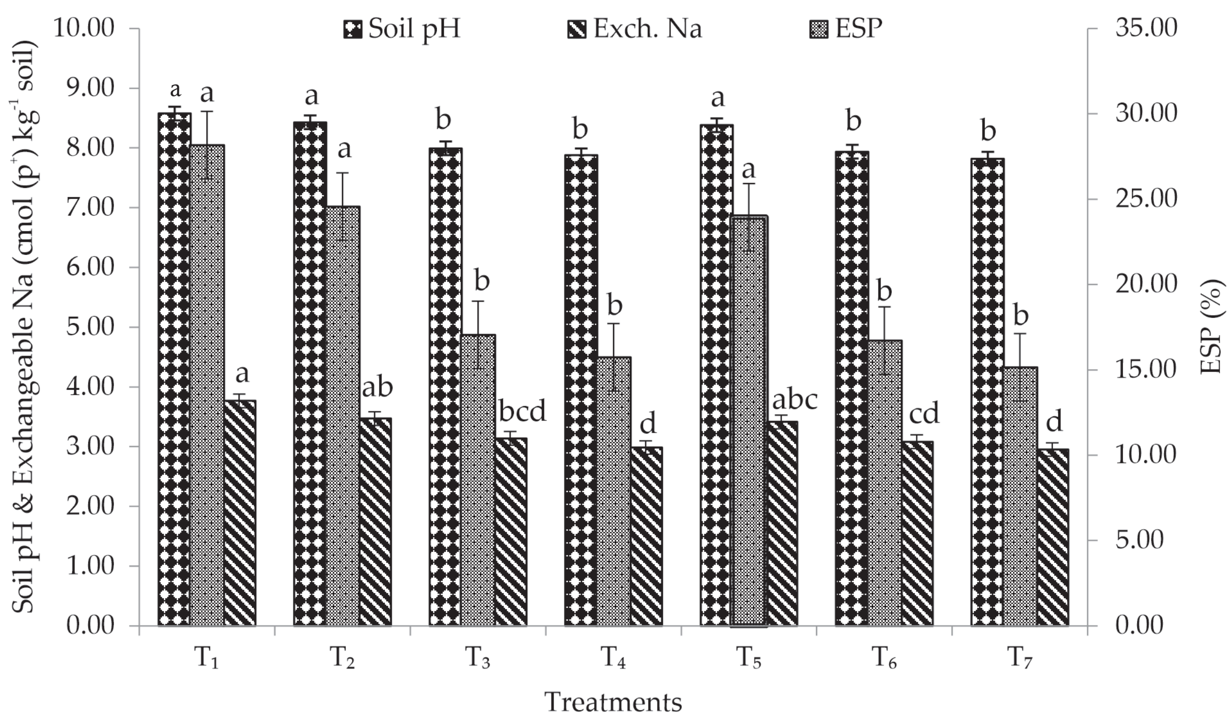


Fig. 3 Effect of organic and inorganic amendments on soil pH, exchangeable Na, and exchangeable sodium percentage (ESP) after dhaincha harvest; error bars represent the standard error; bars with similar lowercase letters within a particular soil size fraction are not significant at $p < 0.05$; (T_1: Farmer's practice (NPK only), T_2: Recommended dose of fertilizer (RDF) + farmyard manure (FYM) + $ZnSO_4$, T_3: T_2 + gypsum, T_4: T_2 + pressmud, T_5: Soil test value-based fertilizer application (STV) + FYM + $ZnSO_4$, T_6: T_5 + gypsum and T_7: T_5 + pressmud).

acids during decomposition of pressmud, which helped reduce the soil pH. Sundhari *et al.* (2018) also observed that reducing soil pH (9.20 to 7.86) by applying the recommended fertilizer dose and 10 t pressmud ha^{-1}. The reduction in pH of alkali soil of gypsum amended plots could be ascribed to the displacement of exchangeable Na^+ by Ca^{2+} ions, which are present in the amendments resulting from the formation of sodium sulfate, which gets leached out through the drainage process (Sheoran *et al.*, 2021). Yadav and Chhipa (2007) also reported that soil pH reduced from 9.30 to 8.63 by applying gypsum at 5.3 t ha^{-1}. A significant reduction in soil pH with the combined use of gypsum with FYM was also reported by Ravinder *et al.* (2017). Negim and Mustafa (2016) have also documented similar results.

After the rice harvest, there was a significant decrease in exchangeable Na and ESP in soils amended with pressmud and gypsum compared to soils with no amendments (Fig. 2). Relative to RDF + FYM + $ZnSO_4$, exchangeable Na and ESP were decreased by 20.2 and 43.5%, respectively in STV + press mud + FYM + $ZnSO_4$ and decreased by 18.8 and 42.1%, respectively in RDF + pressmud + FYM + $ZnSO_4$. Likewise, exchangeable Na and ESP significantly decreased by 21.8 and 44.8%, respectively in STV + gypsum + FYM + $ZnSO_4$ treatment followed by 20.0 and 43.8%, respectively in RDF + gypsum + FYM + $ZnSO_4$ than farmer's practice (NPK only). However, exchangeable Na and ESP in the plots where fertilizer was applied based on STV were statistically at par with exchangeable Na and ESP in the plots where RDF was applied. Similarly, the exchangeable Na and ESP followed an nearly identical pattern after the harvest of residual dhaincha crop (Fig. 3). Among all the treatments, STV + pressmud + FYM + $ZnSO_4$ treated plots contained the lowest exchangeable Na and ESP. That value was 21.8 and 46.3% lower compared with farmer's practice (NPK only) plots, respectively (Fig. 2).

The decrease in exchangeable Na and ESP in gypsum amended plots could be ascribed to replacing Na^+ ions on exchange complex by Ca^{2+} ions in solution and formation of sulfate salts, and consequently washed out during subsequent leaching. Similarly, the decline in exchangeable sodium percentage of soil because of use of gypsum in conjunction with FYM + Zn has been reported by Shaimaa *et al.* (2012). The significant decrease in exchangeable Na and ESP in pressmud treated plots could be ascribed to the buildup of CO_2, which encourages the dissolution of Ca and thus replaces the Na from the exchange complex sites. It's subsequently leached out through drainage (Shivalingaiah 2006). Sundha *et al.* (2020) have observed similar results.

Effect of amendments on soil organic carbon (SOC) and available nutrients

Soil organic carbon content after rice harvest varied from 3.17 g kg^{-1} in farmer's practice (NPK only) to 3.89 g kg^{-1} in STV + pressmud + FYM + $ZnSO_4$ (Table 2). The treatments which comprising pressmud with STV + FYM + $ZnSO_4$ and RDF + FYM + $ZnSO_4$ had 14.1 and 11.1% higher SOC content compared with the treatment comprising RDF + FYM + $ZnSO_4$ (Table 2). Similarly, Singh *et al.* (2009) also observed that the addition of pressmud increased SOC content due to increased yield and root biomass. Likewise, STV + gypsum + FYM + $ZnSO_4$ and RDF + gypsum + FYM + $ZnSO_4$ treated plots contained 13.1 and 10.4% higher SOC than farmer's practice (NPK only). Similarly, after the harvest of residual dhaincha crop, SOC content in soil also followed similar trend. Among the treatments, STV + pressmud + FYM + $ZnSO_4$ treated plots had highest SOC content followed by RDF + pressmud + FYM + $ZnSO_4$ plots which was 14.6 and 11.0% greater compared with RDF + FYM + $ZnSO_4$ plots, respectively (Table 2). Seth *et al.* (2005) reported that soil organic carbon significantly increased up to 6.90 percent by applying pressmud. Similar effects have been reported by Basak *et al.* (2021). In farmers' practice plots, the use of only NPK led to the lowest soil organic carbon content, probably as a result of inadequate crop growth and the consequent insufficient input of root biomass to the soil. Generally, SOC content slightly decreased after the dhaincha crop harvest when compared to the rice harvest, possibly because of the higher rate of organic matter decomposition anticipated during the summer due to greater temperatures.

Table 2. Effect of organic and inorganic amendments on soil organic carbon and available nutrient

Treatment	After rice harvest				After dhaincha harvest			
	Organic carbon (g kg^{-1})	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (g kg^{-1})	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
T_1 : Farmer's practice (NPK only)	3.2^{c}	281.7^{d}	27.5^{e}	156.4^{d}	3.2^{d}	225.5^{c}	20.0^{d}	154.8^{f}
T_2 : RDF + FYM + $ZnSO_4$	3.4^{b}	311.0^{c}	35.1^{d}	164.9^{c}	3.4^{cd}	233.0^{c}	29.1^{c}	161.8^{e}
T_3 : T_2 + Gypsum	3.5^{b}	321. 7^{c}	41.7^{bc}	172.6^{b}	3.4^{bcd}	243.0^{b}	35.6^{bc}	166.6^{bc}
T_4 : T_2 + Pressmud	3.8^{a}	335.3^{b}	48.4^{a}	181.4^{a}	3.7^{ab}	251.4^{ab}	42.4^{ab}	170.1^{ab}
T_5 : STV + FYM + $ZnSO_4$	3.4^{b}	317.3^{c}	37.2^{cd}	165.2^{c}	3.4^{cd}	233.8^{c}	32.9^{c}	162.9^{de}
T_6 : T_5 + Gypsum	3.6^{b}	334.0^{b}	45.2^{ab}	173.9^{b}	3.5^{bc}	250.9^{b}	39.9^{b}	165.6^{cd}
T_7 : T_5 + Pressmud	3. 9^{a}	349.3^{a}	51.6^{a}	186.3^{a}	3.8^{a}	260.2^{a}	47. 5^{a}	172.4^{a}

Means with similar lowercase letters within a column are not significantly different at $p \leq 0.05$.

In case of available N, P, and K, plots treated with STV + pressmud + FYM + $ZnSO_4$ and RDF + pressmud + FYM + $ZnSO_4$ had 12.3 and 7.8% higher available N, 46.9 and 37.9% higher available P, and 13.0 and 10.0% higher available K, respectively than RDF + FYM + $ZnSO_4$ plots. According to Seth et al. (2005), pressmud treatment raised available K and nitrogen by 11.8 to 59.2 percent and 41.4 to 74.8 percent, respectively, over control. The highest available P was registered in the plots, which received STV + pressmud + FYM + $ZnSO_4$. The reasons are: a.) high solubilization of native soil P and applied 25 per cent more phosphate fertilizer based on soil test value; b.) higher P availability may have resulted from lower soil binding energy and P sorption capacity due to organic acids produced during pressmud breakdown, which created stable complexes chelates with cations responsible for P fixation and pressmud decomposition processes. A similar effect of pressmud on available phosphorus has been reported earlier report Swarup and Yaduvanshi (2004); and Venkatakrishnan and Ravichandran (2007).

Available N, P and K in STV + gypsum + FYM + $ZnSO_4$ were 18.6, 64.4 and 11.2%, respectively higher than farmer's practice (NPK only) plots, respectively could be attributed to the application of gypsum, neutralization of alkalinity, and slow down the volatilization losses of soil N and wasteful transformation of applied N (Sundha *et al.,* 2017). Thus, it increases the mineralization of native and applied nutrients, increasing the available N, P and K content in the soil. The least content of available N, P, and K were obtained in farmer's practice (NPK only) plots, and that values were 10.4, 27.6 and 5.2%, respectively less than RDF + FYM + $ZnSO_4$ plots. In general, plots receiving soil test value based fertilizers (STV) had comparatively higher available N than plots receiving recommended dose fertilizers (RDF) may result from applying 25% more nitrogen fertilizer based on soil test results than RDF might have resulted in eliciting microbial activity and nutrient availability. Similarly, following the harvest of the leftover dhaincha crop, the available N, P, and K content of alkali soil exhibited a nearly identical pattern to that noted following the harvest of rice. In contrast to the main crop, the available N, P, and K levels decreased following the harvest of dhaincha because the crop removed these nutrients, as described by Prakash and Ali (1994). Among the treatments, the residual effect of pressmud recorded significantly higher available nitrogen content, which might be attributed to biological nitrogen fixation by the increased activity of N fixers and from NO_3^-–N formed in the soil during the aerobic phase in summer. Maurya *et al*. (2009) have noted comparable results.

The residual effect of pressmud maintained available phosphorus might be due to the beneficial impact of pressmud and FYM in the next season due to the slow decomposition rate. The magnitude of increase in available P content in soil from the main crop to residual dhaincha crop is low. This might be due to only 20–25 per cent of applied phosphorus becoming available to the immediate crop. The rest adds to the soil pool, which increased the functional P status of soil after the rice harvest. The succeeding residual crop dhaincha efficiently utilized the pooled P. Hence, there was a decline in available P in soils after harvest of dhaincha compared to post-harvest soils of rice.

Effect of amendments on microbiological properties

In comparison to farmer's practice (NPK only) plots, the microbial biomass carbon (SMBC) of the organic and inorganic amendment-treated plots was substantially higher (Table 3). In the STV + pressmud + FYM + $ZnSO_4$ plot, SMBC and SMBN considerably increased by 7.1 and 28.1%, respectively, compared to RDF + FYM + $ZnSO_4$ plot, and by 6.2 and 23.6%, respectively, in RDF + pressmud + FYM + $ZnSO_4$ plots. This might be due to the higher carbon and nitrogen contents in pressmud treated soil, which acted as an energy source for the autochthonous microorganisms (Perucci, 1992), significantly increasing the microbial numbers and acting as a suitable substratum for microbial activity. An increase in microbial population by integrated use of pressmud, FYM, and chemical fertilizer compared to inorganic fertilizer alone was observed by Biswas *et al.* (2007) and Kundu *et al.* (2016). Similarly, in comparison to the farmer's practice (NPK only) plot, the SMBN and SMBC considerably increased by 9.2 and 33.2%, respectively, in the STV + gypsum + FYM + ZnSO4 plot and by 8.2 and 27.7%, respectively, in the RDF + gypsum + FYM + ZnSO4 plot. The application of FYM and gypsum enhanced SMBC and SMBN, according to Rao *et al*. (2004). This could be because the soil became more fertile by lowering pH and ESP, which created an environment that was better for microbial and biological activity. Jat and Singh (2017) and Pawar *et al*. (2018) have reported a similar impact. The findings also showed that the trend observed after rice harvest was repeated in the SMBC and SMBN following the harvest of residual dhaincha crop (Table 4). The SMBC and SMBN varied from 291.1 and 47.6 mg kg^{-1} to 330.4 and 30.9 mg kg^{-1}, respectively with the highest value under STV + pressmud + FYM + $ZnSO_4$ and the lowest under farmer's practice treatment (NPK only). The marginal decrease in SMBC and SMBN under farmers' practice could be ascribed to a reduction in microbial populations and their activity due to high exchangeable sodium percentage (ESP) and pH and deterioration in physical properties of the soil (Batra and Manna 1997). Similar results were reported by Choudhary and Gill (2013).

Effect of organic and inorganic amendments on the activity of enzymes

The activity of dehydrogenase under the STV + pressmud + FYM + $ZnSO_4$ plots was significantly higher than those obtained using NPK fertilizer alone (farmer's practice) (Table 4). Plots under STV + pressmud + FYM + $ZnSO_4$ had 19.3, 25.3 and 18.5% higher dehydrogenase, alkaline phosphatase and urease activity, respectively than RDF + FYM + $ZnSO_4$ could be ascribed to decreased soil pH, which might have increased

Table 3. Effect of organic and inorganic amendments on soil microbial biomass nitrogen (SMBN) and soil microbial biomass carbon (SMBC)

Treatment	After harvest of rice		After harvest of dhaincha	
	SMBC (mg kg^{-1})	SMBN (mg kg^{-1})	SMBC (mg kg^{-1})	SMBN (mg kg^{-1})
T_1 : Farmer's practice (NPK only)	293.1^{d}	32.4^{d}	291.1^{d}	30.9^{e}
T_2 : RDF + FYM + $ZnSO_4$	310.0^{c}	38.1^{c}	308.0^{c}	37.4^{d}
T_3 : T_2 + Gypsum	317.0^{bc}	41.4^{c}	315.2^{bc}	40.1^{cd}
T_4 : T_2 + Pressmud	329.1^{ab}	47.1^{ab}	328.1^{a}	46.2^{ab}
T_5 : STV + FYM + $ZnSO_4$	311.5^{c}	39.2^{c}	310.6^{c}	37.8^{d}
T_6 : T_5 + Gypsum	319.9^{abc}	43.2^{bc}	318.3^{b}	42.5^{bc}
T_7 : T_5 + Pressmud	332.0^{a}	48.8^{a}	330.4^{a}	47.6^{a}

Means with similar lowercase letters within a column are not significantly different at $p \leq 0.05$.

Table 4. Effect of organic and inorganic amendments on enzymes activity

Treatment	After harvest of rice			After harvest of dhaincha		
	Dehydrogenase activity (μg of TPF g^{-1} hr^{-1})	Urease activity (μg NH_4^+-N g^{-1} hr^{-1})	Alkaline phosphatase activity (μg PNP g^{-1} hr^{-1})	Dehydrogenase activity (μg of TPF g^{-1} hr^{-1})	Urease activity (μg NH_4^+-N g^{-1} hr^{-1})	Alkaline phosphatase activity (μg PNP g^{-1} hr^{-1})
T_1 : Farmer's practice (NPK only)	42.14^{d}	53.29^{d}	24.11^{d}	39.13^{d}	50.92^{d}	22.68^{d}
T_2 : RDF + FYM + $ZnSO_4$	48.72^{c}	65.71^{c}	31.05^{c}	45.39^{cd}	63.64^{c}	29.39^{c}
T_3 : T_2 + Gypsum	50.25^{c}	67.15^{bc}	32.90^{bc}	48.25^{c}	66.05^{bc}	31.90^{bc}
T_4 : T_2 + Pressmud	57.22^{ab}	75.53^{ab}	37.89^{ab}	56.22^{ab}	74.20^{ab}	36.53^{ab}
T_5 : STV + FYM + $ZnSO_4$	48.63^{c}	65.64^{c}	31.19^{c}	46.96^{c}	63.97^{c}	29.86^{c}
T_6 : T_5 + Gypsum	51.21^{bc}	68.37^{abc}	33.46^{bc}	50.11^{bc}	67.67^{abc}	32.80^{bc}
T_7 : T_5 + Pressmud	58.10^{a}	77.87^{a}	38.90^{a}	57.63^{a}	76.54^{a}	37.90^{a}

Means with similar lowercase letters within a column are not significantly different at $p \leq 0.05$

nitrogen content in the soil, therefore increasing microbial mineralization. Singh and Kaushik (2017) reported that the application of pressmud increased the dehydrogenase activity by applying pressmud in alkali soil. Plots treated with pressmud showed enhanced alkaline phosphatase activity, which may have resulted from the faster breakdown of organic matter in the presence of phosphorus and nitrogen minerals, which increased the release of phosphorus that was bonded to organic matter. These minerals stimulate the synthesis of the enzyme, as reported by Mohammadi *et al*. (2012). Likewise urease activity also increased might be attributed to the soil substrate enrichment with higher organic carbon and enhanced biological activity upon organic manure. The favorable effect of the combined application of organic amendments and NPK fertilizer on urease activity in alkali soil might be attributed to the increased mineralization of nutrients from microbial decomposition of organic matter. Jat and Singh (2017) also reported that the highest phosphatase and urease activity were recorded by the combined application of FYM and pressmud along with chemical fertilizers over control. Likewise, application of gypsum in conjunction with STV + FYM + $ZnSO_4$ increased dehydrogenase, alkaline phosphatase, and urease activity by 21.5, 38.8 and 28.3%, respectively, in comparison to farmer's practice (NPK only). This may have been caused by the gypsum application improving the soil alkalinity. Therefore, a decrease in pH of amended soil favored microbial growth and microbial activity. The plots that were fertilized based on soil test value (STV) showed slightly higher dehydrogenase, alkaline phosphatase, and urease activity compared to the plots that received the recommended dose of fertilizer (RDF). This could be due to the balanced nutrient application and the 25% increase in fertilizer based on soil test value over RDF, which boosted the activity of hydrolytic enzymes and stimulated heterotrophic microbial activity (Masto *et al.*, 2006). Similarly, the residual effect of organic and inorganic amendments on dehydrogenase, alkaline phosphatase and urease activity after the harvest of residual dhaincha crops followed the same trend (Table 4). Plots under STV + pressmud + FYM + $ZnSO_4$ and RDF + pressmud + FYM + $ZnSO_4$ had 27.0 and 23.9% higher dehydrogenase activity than RDF + FYM + $ZnSO_4$ plots, respectively. The alkaline phosphatase and urease activity was greater in STV + pressmud + FYM + $ZnSO_4$ (37.9 μg PNP g^{-1} hr^{-1} and 76.54 μg NH_4^+–N g^{-1} hr^{-1}) and lower in in farmer's practice (NPK only) (22.7 μg PNP g^{-1} hr^{-1} and 50.9 μg NH_4^+–N g^{-1} hr^{-1}).

Organic manures and chemical fertilizers applied together resulted in greater urease activity compared to the use of chemical fertilizers alone, according to findings by Meena et al. (2014) and Lakshmi *et al*. (2011). In addition, the findings of the current study align with the discoveries of Heidari and colleagues (2016), who found that organic fertilizer positively influenced the activity of urease. A similar effect has been observed by earlier reported (Pawar *et al.*, 2018; Jat and Singh, 2017; Shirale *et al.*, 2017).

Correlation study

An examination of the data showed that soil organic carbon, available nutrients (N, P and K), SMBC (r= 0.88**), SMBN (r= 0.88**), dehydrogenase (r= 0.92**), urease (r= 0.95**), and alkaline phosphatase (r= 0.93**) were positively and significantly correlated with yield of rice (Table 5). Soil pH (r= –065) and exchangeable sodium percentage (r= –136) was negativity correlated with yield of rice.

Conclusions

Table 5. Relationship of chemical and microbiological properties of soil with grain yield of rice

Soil chemical and microbiological properties	Grain yield
Soil pH	-0.07^{NS}
Exchangeable Na	0.14^{NS}
Exchangeable sodium percentage (ESP)	-0.13^{NS}
Soil organic carbon	0.94**
Available N	0.91**
Available P	0.89**
Available K	0.95**
SMBC	0.88**
SMBN	0.88**
Dehydrogenase activity	0.92**
Urease activity	0.95**
Alkaline phosphatase activity	0.93**

**Correlation is significant at $p \leq 0.01$; * Correlation is significant at $p \leq 0.05$; NS = Non-significant

The application of organic and inorganic amendments significantly improved the soil pH, organic carbon, and available nutrients (N, P, and K) compared to other treatments. The addition of pressmud in combination with fertilizer based on soil test values (STV), farmyard manure (FYM), and zinc sulfate ($ZnSO_4$) led to a significant enhancement in soil microbial biomass carbon, soil microbial biomass nitrogen, as well as the activities of dehydrogenase, urease, and phosphatase enzymes. The application of pressmud and gypsum significantly reduced exchangeable Na and ESP compared to without amended soil. The pH and ESP showed a negative correlation, whereas the soil microbiological properties exhibited a positive and significant correlation with the rice grain yield.

Disclosure statement

The authors did not report any potential conflict of interest.

Acknowledgment

The University of Agricultural Sciences in Bengaluru (India) is greatly appreciated by the authors for providing all the essential resources for conducting this research.

References

Ahmad S, Ghafoor A, Akhtar ME and Khan MZ (2013) Ionic displacement and reclamation of saline sodic soils using chemical amendments and crop rotation. *Land Degradation & Development* **24**(2): 170-178.

Amezketa E, Aragüés R and Gazol R (2005) Efficiency of sulfuric acid, mined gypsum, and two gypsum by products in soil crusting prevention and sodic soil reclamation. *Agronomy Journal* **97**(3): 983-989.

Bahadur L, Tiwari DD, Mishra J and Gupta BR (2013) Nutrient management in rice-wheat sequence under sodic soil. *Journal of Indian Society of Soil Science* **61**(4): 341-346.

Basak N, Rai AK, Sundha P, Meena RL, Bedwal S, Yadav RK and Sharma PC (2022) Assessing soil quality for rehabilitation of salt-affected agroecosystem: A comprehensive review. *Frontiers in Environmental Science* **10**: 935785. doi: 10.3389/fenvs.2022.935785.

Basak N, Sheoran P, Sharma R, Yadav RK, Singh RK, Kumar S, Krishnamurthy T and Sharma PC (2021) Gypsum and pressmud amelioration improve soil organic carbon storage and stability in sodic agroecosystems. *Land Degradation & Development* **32**(15): 4430–4444. https://doi.org/10.1002/ldr.4047.

Batra L and Manna MC (1997) Dehydrogenase activity and microbial biomass carbon in salt-affected soils of semi-arid and arid regions. *Arid Land and Research Management* **11**: 295-303.

Biswas H, Rattan RK and Singh AK (2007) Effect of soil manipulation and resource management on carbon and nitrogen turnover under rice-wheat cropping system. *Journal of the Indian Society of Soil Science* **55**(3): 276-284.

Brookes PC, Landman A, Pruden G and Jenkinson DS (1985) Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. *Soil biology and* *biochemistry* **17**(6): 837-842.

Casida Jr LE, Donald A Klein and Thomas Santoro (1964) Soil dehydrogenase activity. *Soil science* **98**(6): 371-376.

Choudhary OP and Gill JK (2013) Water-extractable carbon pools and microbial biomass carbon in sodic water-irrigated soils amended with gypsum and organic manures. *Pedosphere* **23**(1): 88-97.

Clark GJ, Dodgshun N, Sale PWG and Tang C (2007) Changes in chemical and biological properties of a sodic clay subsoil with addition of organic amendments. *Soil Biology and Biochemistry* **39**(11): 2806-2817.

Ghafoor A, Murtaza G, Ahmad B and Boers TM (2008) Evaluation of amelioration treatments and economic aspects of using saline–sodic water for rice and wheat production on salt affected soils under arid land conditions. *Irrigation and Drainage*: *The journal of the International Commission on Irrigation and Drainage* **57**(4): 424-434.

Gomez KA and Gomez AA (1984) Statistical procedures for agricultural research. 2nd Ed. John Wiley & Sons, New York.

Heidari G, Mohammadi K and Yousef Sohrabi (2016) Responses of soil microbial biomass and enzyme activities to tillage and fertilization systems in soybean (*Glycine max* L.) production. *Frontiers in Plant Science* **7**: 207995.

Jackson ML (1973) Soil chemical analysis. Practice Hall of India (Pvt.) Ltd., New Delhi.

Jalali V, Kapourchal SA and Homaee M (2017) Evaluating performance of macroscopic water uptake models at productive growth stages of durum wheat under saline conditions. *Agricultural water management* **180**: 13-21.

Jat LK and Singh YV (2017) Short-term effects of organic and inorganic fertilizers on soil properties and enzyme activities in rice production. *International Journal of Current Microbiology and Applied Science* **6**:185-194.

Jun-Feng Y, Gu F, Hai-Yan MA and Chang-Yan T (2010) Effect of nitrate on root development and nitrogen uptake of *Suaeda physophora* under NaCl salinity. *Pedosphere* **20**: 536-544.

Kumar A, Meena RN, Lalji Yadav and Gilotia YK (2014) Effect of organic and inorganic sources of nutrient on yield, yield attributes and nutrient uptake of rice cv. PRH-10. *The Bioscan* **9**(2): 595-597.

Kundu DK, Mazumdar SP, Ghosh D, Saha AR, Majumdar B, Ghorai AK and Behera MS (2016) Long-term effects of fertilizer and manure application on soil quality and sustainability of jute-rice-wheat production system in Indo-Gangetic plain. *Journal of Applied and Natural Science* **8**: 1793-1800.

Lakshmi Ch S Rama, Sreelatha T, Usha Rani T, Rao SRK and Naidu NV (2011) Effect of organic manures on soil fertility and productivity of sugarcane in north coastal zone of Andhra Pradesh. *Indian Journal of Agricultural Research* **45**: 307-313.

Mahmoodabadi M, Yazdanpanah N, Sinobas, LR, Pazira E and Neshat A (2013) Reclamation of calcareous saline sodic soil with different amendments (I): Redistribution of soluble cations within the soil profile. *Agricultural water management* **120**: 30-38.

Mandal AK, Sharma RC and Singh G (2009) Assessment of salt affected soils in India using GIS. *Geocarto International* **24**: 437-456.

Mane D (2012) Biological properties of soils of Purna valley [*MSc thesis*]. Akola, Maharashtra (India): Panjabrao Deshmukh Agriculture University.

Masto RE, Chhonkar PK, Singh D and Patra AK (2006) Changes in soil biological and biochemical characteristics in a long-term field trial on a sub-tropical Inceptisol. *Soil Biology and Biochemistry* **38**: 1577-1582.

Maurya BR, Ram H and Prasad SS (2009) Impact of soil amendments on properties of the salt-affected rice soil. *Journal of the Indian Society of Soil Science* **57**: 385-388.

Meena VS, Maurya BR, Meena RS, Meena SK, Singh NP, Malik VK, Kumar V and Jat LK (2014) Microbial dynamics as influenced by concentrate manure and inorganic fertilizer in alluvium soil of Varanasi, India. *African Journal of Microbiology Research* **8**: 257-263.

Mohammadi K, Heidari G, Nezhad MTK, Ghamari S and Sohrabi Y (2012) Contrasting soil microbial responses to fertilization and tillage systems in canola rhizosphere. *Saudi journal of biological sciences* **19**: 377-383.

Negim O and Mustafa A (2016) Remediation of a highly calcareous saline sodic soil using some soil amendments. *International Journal of Plant & Soil Science* pp. 1-13.

Pawar SK, Kumbhar GA and Dahiphale SB (2018) The effect of crop residues, green manuring and gypsum on sequestration of carbon in soils of purna valley. *International Journal of Science and Research* **7**:1549-1553.

Perucci P (1992) Enzyme activity and microbial biomass in a field soil amended with municipal refuse. *Biology and Fertility of Soils* **14**: 54-60.

Prakash TR and Ali MK (1994) Relative efficiency of different phosphorus sources as influenced by liming on the yield and P uptake by rice on an Oxisol. *Journal of the Indian Society of Soil Science* **42**: 271-273.

Rai AK, Basak N and Sundha P (2021) Alternate amendments for reclamation of alkali soils, In: managing salt-affected soil for sustainable agriculture. Editors Minhas PCSPS and Yadav RK (New Delhi, India: New Delhi: Indian Council of Agricultural Research ICAR), 332–345.

Rao DLN, Gupta BR and Batra L (2004) Biological indicators of soil sodication and ameliorative measures. *In Proceedings of the International Conference on Sustainable Management of Sodic Lands*, 9-14 February 2004, Extended Summaries. Uttar Pradesh Council of Agricultural Research, Lucknow, India. pp. 31-33.

Rashmi, Meena BP, Rajendiran S, Jayaraman S, Joshy CG, Ali S, Mina BL, Kumar K, Kumar A, Kumawat Kala AS (2024a) Can gypsum and organic amendments achieve sustainability, productivity and maintain soil health under soybean-mustard cropping in sodic soils of western India. *Soil and Tillage Research* **240**: 106075. https://doi.org/10.1016/j.still.2024.106075.

Ravinder J, Lokya T, Konde NM and Thakur P (2017) Potentiality of BFF and soil amendments in degraded Purna Valley soils reclamation and soybean yield. *International Journal of Current Microbiology and Applied Science* **6**: 2540-2548.

Richards LA (1954) *Diagnosis and Improvement of Saline Alkali Soils*, Agriculture, 160, Handbook 60. US Department of Agriculture, Washington DC.

Schoonover WR (1952) "*Examination of soil for alkali*", University of California Extension services, Berkeley, USA.

Seth R, Chandra R, Kumar N and Tyagi AK (2005) Utilization of composted sugar industry waste (pressmud) to improve properties of sodic soil for rice cultivation. *Journal of Environmental Science and Engineering* **47**: 212-217.

Shaimaa H, El Rahman ABD, Mostafa MAM, Taha TA, Elsharawy MAO and Eid MA (2012) Effect of different amendments on soil chemical characteristics, grain yield and elemental content of wheat plants grown on salt-affected soil irrigated with low quality water. *Annals of Agricultural Sciences* **57**(2): 175-182.

Sheoran OP, Tonk DS, Kaushik LS, Hasija RC and Pannu RS (1998) Statistical software package for agricultural research workers. *Recent advances in information theory, statistics & computer applications by DS Hooda & RC Hasija Department of Mathematics Statistics, CCS HAU, Hisar,* pp. 139-143.

Sheoran P, Basak N, Kumar A, Yadav RK, Singh R, Sharma R, *et al*. (2021) Ameliorants and salt tolerant varieties improve rice-wheat production in soils undergoing sodification with alkali water irrigation in Indo–Gangetic Plains of India. *Agricultural Water Management* **243**: 106492. doi:10.1016/j.agwat.2020.106492.

Shirale AO, Kharche VK, Zadode RS, Meena BP and Rajendiran S (2017) Soil biological properties and carbon dynamics subsequent to organic amendments addition in sodic black soils. *Archives of Agronomy and Soil Science* **63**: 2023-2034.

Shivalingaiah (2006) Effect of different amendments on changes in soil properties and growth of rice crop. *M. Sc. (Agri.) Thesis*, University of Agricultural Sciences, Bangalore.

Singh K and Kaushik A (2017) Impact of fly ash and pressmud amendment on properties and heavy metal concentration of an alkali soil and their impact on plant growth. *International Journal of Engineering Science and Research Technology*, pp. 42-45.

Singh R, Singh YP, Yaduvanshi NPS and Sharma DK (2009) Effect of irrigation scheduling and integrated nutrient management on yield of rice-wheat system and properties of a reclaimed sodic soil. *Journal of the Indian Society of Soil Science* **57**: 280-286.

Subbiah BV and Asija GL (1956) Rapid procedure for the estimation of the available nitrogen in soil. *Current Science* **25**: 259-260.

Sundha P, Basak N, Rai A, Yadav RK, Sharma DK and Sharma PC. (2017). N and P Release pattern in saline-sodic soil amended with gypsum and municipal solid waste compost. *Journal of Soil Salinity and Water Quality* **9**: 145-155.

Sundha P, Basak N, Rai AK, Yadav RK, Sharma PC, Sharma DK (2020) Can conjunctive use of gypsum, city waste composts and marginal quality water rehabilitate saline-sodic soils? *Soil and Tillage Research* **200**: 104608. https://doi.org/ 10.1016/j.still.2020.104608.

Sundhari T, Thilagavathi T, Baskar M, Thuvasan T and Eazhilkrishna N (2018) Effect of gypsum incubated organics used as an amendment for sodic soil in green gram. *International Journal of Chemical Studies* **6**: 304-308.

Suwiphaporn J, Rhanachit S, Somchai, Anusontpornperm and Wiriyakitnateekul W (2014) Soil amendments effect on yield and quality of jasmine rice grown on typic natraqualfs, northeast Thailand. *International Journal of Soil Science* **9**(2): 37-54.

Swarup A and Yaduvanshi NPS (2004) Response of rice and wheat to organic and inorganic fertilizers and soil under sodic water irrigated conditions. *International Rice Research Notes* **29**: 3-5.

Tabatabai MA and Bremner JM (1969) Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biology and Biochemistry* **1**: 301-307.

Tejada M, Garcia C, Gonzalez JL and Hernandez MT (2006) Use of organic amendment as a strategy for saline soil remediation: influence on the physical, chemical and biological properties of soil. *Soil Biology and Biochemistry* **38**: 1413-1421.

Ullah W and Bhatti AU (2011) Physico-chemical properties of soils of Kohat and Bannu districts NWFP Pakistan. *Journal of the Chemical Society of Pakistan* **29**: 20.

Vance ED, Brookes PC and Jenkinson DS (1987) An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry* **19**: 703-707.

Venkatakrishnan D and Ravichandran M (2007) Effect of integrated nutrient management on growth and yield of sugarcane. *International Journal of Tropical Agriculture* **25**: 163-168.

Walkley A and Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29-38.

Wang L, Sun X, Li S, Zhang T, Zhang W and Zhai P (2014) Application of organic amendments to a coastal saline soil in north China: effects on soil physical and chemical properties and tree growth. *PloS one* **9**: e89185.

Wang Y, Gao M, Chen H, Chen Y, Wang L and Wang R (2023) Organic amendments promote saline-alkali soil desalinization and enhance maize growth. *Frontiers in Plant Science* **14**: 1177209.

Wong VNL, Greene RSB, Dalal RC and Murphy BW (2010) Soil carbon dynamics in saline and sodic soils: a review. *Soil Use and Management* **26**: 2-11.

Yadav KK and Chhipa BR (2007) Effect of FYM, gypsum and iron pyrites on fertility status of soil and yield of wheat irrigated with high RSC water. *Journal of the Indian Society of Soil Science* **55**: 324-329.

Yazdanpanah N, Pazira E, Neshat A, Mahmoodabadi M and Sinobas LR (2013) Reclamation of calcareous saline sodic soil with different amendments (II): Impact on nitrogen, phosphorous and potassium redistribution and on microbial respiration. *Agricultural Water Management* **120**: 39-45.

Received: March 17, 2024; Accepted: June 21, 2024

Journal of Soil Salinity and Water Quality 16(1), 69-75, 2024

Effect of Irrigation Water Salinity, Sowing Techniques and Mulching on Physio-Biochemical Traits of Fodder Sorghum

Kailash Prajapat*, RK Yadav and Ashwani Kumar

ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India
**Corresponding author's E-mail: kp.agron@gmail.com*

Abstract

A lysimetric experiment comprising irrigation water salinity, sowing techniques and mulching was conducted to evaluate the physico-biochemical and quality traits of fodder sorghum. Results revealed that dry matter accumulation (DMA) and green fodder yield (GFY) in the fodder part of sorghum reduced significantly by 20.24% and 8.9%, respectively with the irrigation water salinity of 6.0 dSm^{-1} as compared to good quality water irrigation. Fodder sorghum grown on two row raised beds recorded significantly highest DMA and GFY. Among physiological traits membrane injury (MI, %), total soluble carbohydrates (TSC), proline content and lipid peroxidation (LPO) increased with saline water irrigation while relative water content decreased significantly. Application of 5 t ha^{-1} residues as mulch showed beneficial effects by lowering the values of MI, TSC, proline and LPO. The values of proline and LPO were significantly lower under two row raided bed sowing at 20 DAS, whereas, ridge and furrow planted sorghum showed lowest values at 60 DAS. Fodder sorghum grown under best available water, two row raided bed sowing and residue mulching showed highest crude protein. Fibre of acid and neutral detergent portion in fodder significantly reduced under mulched plots as compared to non-mulched plots.

Key words: Fodder sorghum, Mulch, Raised bed, Ridge and furrow, Water salinity

Introduction

India is primarily an agricultural nation with the world's largest livestock population. The rural livestock sector significantly contributes to the livelihood security and well-being of India's rural populace. The livestock sector constitutes approximately 4% of the national GDP and serves as a significant source of employment and essential livelihood for 70% of the rural population in recent years, deficiency of feed and fodder for livestock is the main limiting factor in achieving desired level of their productivity. At the national level, there exists a substantial disparity between the demand for and the supply of feed and fodder. According to IGFRI (2015), projections indicate that by 2050, the country will experience a deficit of 18.4% in green fodder and 13.2% in dry crop fodder. Arid and semi-arid agro-ecological region faces the main constraint of irrigation water availability and quality in green fodder production especially during summer months.

Sorghum (*Sorghum bicolor* (L.) Moench) is a rapidly growing annual plant ideally cultivated during the summer season, particularly valued for its ability to yield abundant feed when fodder is scarce in mid-summer. It thrives best in warm, fertile soils but faces growth limitations in cool, wet conditions. While sorghum shows good tolerance to drought, optimal yields are achieved with adequate soil fertility and moisture.

The early 21st century is characterized by a worldwide shortage of water resources, environmental contamination, and rising salinity in both soil and water. The growing human population and diminishing arable land pose dual challenges to agricultural sustainability. Salinity is one of the major environmental stresses that adversely impact soil health, environmental quality and agricultural production. With intensification of agricultural practices and global climate change, problems of soil and water salinity are assuming serious dimensions (Sheoran *et al.*, 2020). Although tremendous success of different salinity mitigation technologies is evident in India and elsewhere, a range of social, policy and monetary constraints have restricted the scope of these techniques in the soil restoration projects. Abiotic stresses particularly salinity stress could exert specific ion toxicity, osmotic stress, nutrient deficiencies etc. which adversely affect plants' photosynthetic, biochemical and physiological processes thus limit crop yield (Krishnamurthy *et al.,* 2007; Kumar *et al*., 2018, 2019). In response to the limited availability of high-quality irrigation water, we must employ sustainable and efficient practices of these resources to maximize their productivity. By suitable agronomic manipulations like adjustment in sowing technique, mulching with crop residues etc., we could minimize the effects of salt stress while using poor quality waters. So, the present study was performed to assess the effects of sowing techniques and mulching on physico-biochemical and quality traits of sorghum using saline irrigation water.

Materials and Methods

Experimental details

The effect of saline irrigation water under different planting techniques and mulch on physico-biochemical and quality traits experiment was carried out in the lysimeter facilities at the ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana. The initial $EC_{1:2}$ and $pH_{1:2}$ of the experimental soil were 0.32 dSm^{-1} and 7.53, respectively. The experiment consisted of two levels of irrigation water salinity (Best available water (BAW) having 0.6 dSm^{-1} EC_{iw} and irrigation water of 6.0 dSm^{-1} EC_{iw}), three sowing methods (flat bed, raised bed and ridge, and furrows with alternate furrow irrigation) and mulching (without mulch and rice residue mulch @ 5 t ha^{-1}). The study was followed in Factorial Randomized Block Design with three replications. The saline water of 6.0 dSm^{-1} was prepared by suitable dilution of naturally available saline under-ground water (~16.0 dSm^{-1} EC) brought from ICAR-CSSRI, Nain Farm, Panipat (Haryana) with the BAW available at ICAR-CSSRI, Karnal. The quality parameters of irrigation water used may be referred from Prajapat *et al.* (2018).

The raised beds were prepared freshly with 30 cm wide raised beds and 15 cm furrows, and two rows of sorghum were sown on both the shoulders of beds keeping row to row distance of 20 cm. Under ridge and furrow method, ridge and furrows were prepared keeping centre to centre distance of 30 cm between furrows or ridges and the crop was sown in furrows. Under flat bed, crop was sown at 30 cm row spacing. Rice straw mulch @ 5t ha^{-1} was used as mulch in respective plots after germination of fodder sorghum. The fodder sorghum *cv.* Hybrid Mayur was sown on 08th May 2015 and harvested at 65 days after sowing (DAS). The crop was fertilized with 100 and 40 kg ha^{-1} of N and P_2O_5, respectively. Full dose of P_2O_5 as single super phosphate applied as basal. Nitrogen through urea was applied in three equal splits as basal and top dressings after first and third irrigation. Based on pre-determined IW/CPE ratio of 1.2, total 6.0 cm depth of water was irrigated to the crop as per salinity treatments. Under two row raised bed, ridge and furrow treatment plots, 6.0 cm depth of water was given based on irrigation area available in furrows.

Physico-biochemical and quality traits

Five plants from each treatment were tagged for observation, focusing on physio-biochemical and quality traits. Relative water content (RWC) was estimated in the third from the top expanded leaf following Weatherley's method (1950). Membrane stability, total soluble carbohydrates, proline content were assessed using the procedure outlined by Dionisio-Sese and Tobita (1998), Yemm and Willis method (1954) and Bates *et al.* (1973), respectively. Lipid peroxidation, indicated by malondialdehyde (MDA) levels in leaf tissues, was measured using a modified method from Heath and Packer (1968). Approximately one kilogram of representative samples was used for the analysis of forage quality. Samples were air-dried in shade followed by overnight drying in a hot air oven at 80°C for dry matter estimation. Plant samples were digested with concentrated sulfuric acid, and nitrogen content was measured using the Micro-Kjeldahl procedure. Percentage crude protein content was derived by multiplying nitrogen content by a factor of 6.25. The HCN content was determined using the method developed by Hogg and Anlg (1942). Neutral detergent fiber (NDF) and acid detergent fiber

(ADF) were estimated using the Van Soet (1963) method for forage analysis.

Statistical analysis

Data obtained in the experiment were statistically analysed using 3-way ANOVA in Factorial Randomized Block Design (Gomez and Gomeze, 1984). Least significant difference was applied at 0.05 (LSD=5%) probability level to compare the differences in treatments means. The data were analysed using the general linear model procedure in SPSS software version 20.0.

Results and Discussion

Growth and yield

Data pertaining to DMA and GFY of sorghum as influenced by salinity, planting methods and mulching are presented in Figure 1. Increasing salinity levels in irrigation water significantly reduced (20.24%) dry matter accumulation at harvest stage of fodder sorghum. Sorghum grown on raised beds recorded significantly highest DMA. DMA plant^{-1} did not differ under mulching and no mulching treatments (Figure 1).

The green fodder yield reduced (8.9%) significantly as the levels of irrigation water salinity increased to 6.0 dSm^{-1} as compared to irrigation with best available water (BAW, 0.6 dSm^{-1} ECiw) (Figure 1). The negative effect of salinity on physiological parameters (Table 1) retarded the growth and ultimately biomass production by fodder sorghum. Among the methods of planting, fodder sorghum grown on raised beds recorded significantly highest green fodder yield which was at par with flatbed planting and significantly higher over ridge and furrow planting. However, later two treatments also remained statistically at par with each other. Under raised beds, the movement of salts took place towards centre of beds and furrow and side of beds remained less affected and conserve more moisture (Prajapat *et al.*, 2018), congenial for better growth and productivity of crop (Devkota *et al.*, 2015). Though, there was numerical increase in green fodder yield with mulching than without mulching but the difference between two remained non-significant.

Physiological traits of fodder sorghum

Sorghum grown with the application of saline water exhibited significant differences for relative water content (RWC) and membrane injury (MI). RWC depicts the water status of plants and results showed the non-significant effect of salinity at 20 DAS. But at 40 and 60 DAS, salinity showed significant effects by decreasing RWC i.e. 8.42% and 8.63%, respectively in comparison to BAW (Table 1). Osmotic stress due to salinity or water deficit mainly restricts water intake by the crops,

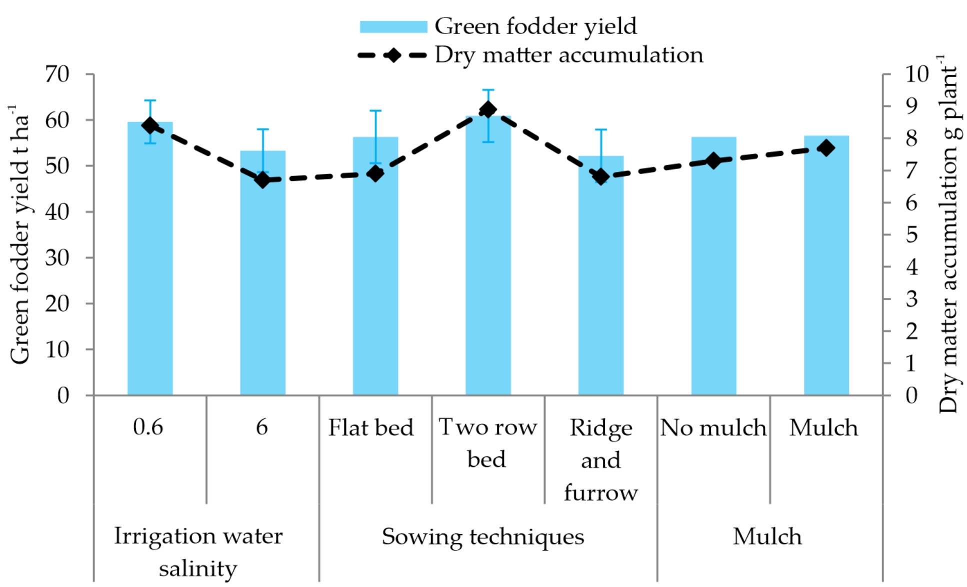


Fig. 1 Effect of irrigation water salinity, sowing techniques and mulching on DMA and green fodder yield of sorghum. Error bars represent LSD value at 5% (p≤0.05)

Table 1. Effect of irrigation water salinity, sowing techniques and mulching on physio-biochemical parameters of fodder sorghum

Treatment	RWC (%)			MI			TSC (mg g^{-1} FW)			Proline (mg g^{-1} FW)		LPO (µmols MDA g^{-1} FW)	
	20DAS	40 DAS	60 DAS	20DAS	40 DAS	60 DAS	20DAS	40 DAS	60DAS	20DAS	40 DAS	20DAS	40 DAS
Irrigation water salinity (EC_{iw}, dSm^{-1})													
BAW	60.5^a	76.0^b	75.3^b	12.2^a	14.8^a	21.5^a	0.60^a	0.31^a	0.071^a	0.088^a	0.673^a	0.122^a	0.231^a
6.0	60.1^a	69.6^a	68.8^a	14.4^b	15.5^b	26.5^b	0.66^a	0.35^b	0.084^b	0.101^b	0.937^b	0.160^b	0.267^b
Sowing techniques													
Flat bed	61.3^a	73.7^a	72.0^a	12.8^a	15.9^b	23.5^a	0.62^a	0.34^a	0.081^a	0.100^a	0.831^a	0.146^b	0.273^c
Row raised bed	59.1^a	71.8^a	72.8^a	13.4^a	14.4^a	22.1^a	0.64^a	0.32^a	0.075^a	0.087^a	0.794^a	0.131^a	0.245^b
Ridge and furrow	60.5^a	72.9^a	71.3^a	13.6^a	15.1^b	21.3^a	0.62^a	0.33^a	0.077^a	0.096^a	0.791^a	0.146^b	0.228^a
Mulching													
No mulch	59.0^a	72.0^a	68.9^a	13.8^a	16.8^b	24.9^b	0.62^a	0.35^b	0.08^b	0.097^b	0.835^b	0.148^b	0.276^b
Mulch	61.6^a	73.6^a	75.2^b	12.7^a	13.5^a	23.0^a	0.64^a	0.31^a	0.074^a	0.091^a	0.776^a	0.133^a	0.221^a

Means with different alphabets within same column are significantly ($p \leq 0.05$) different using least significant difference (LSD). RWC: relative water content; MI: membrane injury; TSC: total soluble carbohydrate; LPO: lipid peroxidation; FW: fresh weight.

leads to cellular dehydration. This dehydration is mainly responsible for the reduction in RWC (Kumar *et al.,* 2016; 2017, Pooja *et al.,* 2019) under saline condition. The per cent membrane injury in fresh leaves of fodder sorghum was significantly higher (18.04, 4.73 and 23.27%) with saline water irrigation as compared to normal irrigation water at 20, 40 and 60 DAS stages of crop, respectively (Table 2). Abiotic stresses such as drought and salinity increase the saturation of membrane fatty acids by altering the properties of proteins, which ultimately raises the permeability of the plasma membrane (Chinnusamy and Zhu, 2003; Pooja *et al.,* 2019, 2020). This increased permeability is responsible for the heightened membrane injury in cells.

Data pertaining to effect of salinity, planting methods and mulching on total soluble sugars (TSC) content in fodder sorghum are presented in Table 1. TSC consistently decreased with increase of crop growth stages. Crop irrigated with saline water had significantly higher TSC content at 20 and 40 DAS than BAW. Sugars serve as a source of energy and carbon required for adaptive or defensive responses to stress (Kumar *et al.,* 2015). They play a crucial role in carbon storage, radical scavenging, osmotic adjustment and osmo-protection (Lata *et al.,* 2017). Proline content and lipid peroxidation in fresh leaves of fodder sorghum increased with advancement of crop growth stages from 20 DAS to 60 DAS (Table 1). Proline is thought to act as a compatible solute, helping to balance the water potentials between the cytoplasm and vacuole (Hassine *et al.*, 2008; Lata *et al.*, 2017). The stress arising due to application of saline water leads to significant rise in proline content and more peroxidation of lipids in leaves of fodder sorghum at 20, 40 and 60 DAS than BAW. Results show high proline accumulation in sorghum leaves which might counteract the harmful effects of toxic salt ions in cell vacuoles. Lipid peroxidation, an important indicator of oxidative damage increased due to more leakage of electrolytes from cells and increased H_2O_2 accumulation (Kukreja *et al.*, 2006; Rani *et al.,* 2018; Pooja *et al.,* 2020).

Manipulation in sowing techniques didn't show any significant effect on RWC, TSC and

Table 2. Effect of irrigation water salinity, sowing techniques and mulching on fodder quality of sorghum

Treatment	ADF (%)			NDF (%)			Crude protein (%)		
	20DAS	40 DAS	60 DAS	20DAS	40 DAS	60 DAS	20DAS	40 DAS	60 DAS
Irrigation water salinity (EC_{iw} dSm^{-1})									
BAW	35.5[a]	35.8[a]	43.7[a]	35.5[a]	68.0[a]	69.7[a]	17.36[a]	14.95[b]	11.31[b]
6.0	33.8[a]	37.0[a]	44.8[a]	33.8[a]	68.8[a]	72.6[a]	16.71[a]	13.73[a]	10.05[a]
Sowing techniques									
Flat bed	35.1[a]	38.3[a]	45.0[a]	35.1[a]	65.8[a]	71.1[a]	17.03[a]	14.12[a]	10.33[a]
Row raised bed	33.4[a]	34.2[a]	43.3[a]	33.4[a]	70.8[a]	70.5[a]	17.14[a]	14.78[a]	11.05[a]
Ridge and furrow	35.5[a]	36.6[a]	44.4[a]	35.5[a]	68.5[a]	71.9[a]	16.94[a]	14.11[a]	10.67[a]
Mulching									
No mulch	37.0[b]	38.1[b]	45.7[b]	37.0[a]	69.4[a]	72.2[a]	16.78[a]	14.12[a]	10.11[a]
Mulch	32.3[a]	34.6[a]	42.8[a]	32.3[a]	67.4[a]	70.1[a]	17.29[a]	14.55[a]	11.25[b]

Means with different alphabets within same column are significantly ($p \leq 0.05$) different using least significant difference. ADF: acid detergent fibre; NDF: neutral detergent fibre.

proline content at all the growth stages and MI at 24 and 60 DAS. However, MI at 40 DAS and lipid peroxidation at 20 DAS were significantly lower under raised bed sowing than flat bed and ridge and furrow planting. Conservation of more moisture and lesser salt load in root zone of crop under raised beds sowing in present experiment (Prajapat *et al*., 2018) might resulted in MI and peroxidation of lipids under raised bed.

RWC (20 and 40 DAS), MI (20 DAS), and TSC (20 DAS) were not varied significantly under mulching than no mulch (Table 1). The membrane injury in sorghum leaves at 40 and 60 DAS was significantly lower by 19.64% and 7.63% in mulching as compared to without mulch plots (Table 1). Rice residues mulching significantly reduced TSC content at 40 and 60 DAS stages of fodder sorghum compared to no mulch. Mulching with crop straw resulted in significant reduction in proline content and per-oxidation of lipids than crop grown without mulching at both the growth stages of crop. Mulching with rice residues resulted in more soil moisture as well as lower salt concentration in upper soil layers (Prajapat *et al*., 2018), therefore mulched plots faced lower level of salt stress than no mulch plots and thereby better plant water status and physiological activity was associated with mulching than without mulching plots. Residue mulching on soil surface also reduces the evaporation losses from soil, maintains the residual soil moisture for longer period (Jat *et al*., 2018; Meena *et al*., 2020) and moderates the soil temperature (Ram *et al.,* 2012) which is more important during hot summer months. All these factors also led to improvement of physiological processes in the plant growing under mulched plots.

Fodder quality

The quality parameters of fodder sorghum as influenced by different treatments are presented in Table 2 and Figure 2. In general, ADF and NDF increased with the crop age, while crude protein content showed reverse trend with crop stage. Though ADF and NDF at 20, 40 and 60 DAS in fodder sorghum did not vary by salinity levels in irrigation water, but crude protein content at 40 and 60 DAS reduced significantly due to salinity over normal water irrigation. The decrease in leaf nitrogen content (Data not shown) under salinity stress resultant in concomitant reduction in crude protein content. Decreased synthesis of protein and increased protein hydrolysing enzymes activities under salt stressed leaves also reported to reduce the status of crude protein level in leaves (Kumari *et al*., 2017).

There was no marked difference in ADF, NDF and protein content in fodder sorghum grown under different methods of planting. The values of ADF were significantly lower in sorghum at 20, 40 and 60 DAS under mulching as compared to non-mulched crop (Table 2). NDF content remained unaffected due to mulching at all the growth stages. Mulching with rice residues significantly increased the crude protein content at 60 DAS stage of crop. Mulching with residues helps in improvement in soil hydrothermal regime and better root growth, which enhances the nutrient uptake (Chakraborty *et al.,* 2008; Balwinder-Singh *et al*., 2011) by the crop plants. Therefore, increase in uptake of higher N by plants might resulted in improved crude protein content under mulching in present study.

Conclusions

Irrigation with saline water significantly affected the physiological parameters (RWC, MI, TSC, Proline content and lipid peroxidation) but no marked effect was evidenced on quality parameters of fodder sorghum except crude protein. Raised bed sowing of sorghum improved the MI and lipid peroxidation in fodder sorghum. Mulching also had positive effect on all the above parameters and quality (ADF, NDF and crude protein) at various growth stages of sorghum plants. This indicated that fodder sorghum can be grown with moderate saline water without any harmful effect on quality. Further the effect of salinity can be mitigated through sowing on raised bed and mulching with crop residues.

Acknowledgements

The first author is sincerely thankful to the Director, ICAR-IIWBR, Karnal and Director ICAR-CSSRI, Karnal for permitting the present investigation and providing necessary facilities during professional attachment training.

References

Balwinder-Singh, Humphreys E, Eberbach PL, Katupitiya A, Yadvinder-Singh and Kukkal SS (2011) Growth yield and water productivity of zero till wheat as affected by rice straw mulch and irrigation schedule. *Field Crops Research* **121**: 209-225.

Bates L, Waldren RP and Teare ID (1973) Rapid determination of free proline for water-stress studies. *Plant and Soil* **39**: 205-207.

Chakraborty D, Nagarajan S, Aggarwal P, Gupta VK, Tomar RK, Garg RN, Sahoo RN, Sarkar A, Chopra UK, Sarma, KSS and Kalra N (2008) Effect of mulching on soil and plant water status and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management* **95**: 1323-1334.

Chinnusamy V and Zhu JK (2003) Plant salt tolerance. In: Hirt H and Shinozaki K (eds) *Plant Responses to Abiotic Stress.* Topics in Current Genetics, vol. 4. Springer, Berlin, Heidelberg, pp 241-270.

Devkota M, Gupta RK, Martius C, Lamer JPA, Devkota KP, Sayre KD and Vlek, PLG (2015) Soil salinity management on raised beds with different furrow irrigation modes in salt-affected lands. *Agricultural Water Management* **152**: 243-250.

Dionisio-Sese ML and Tobita S (1998) Antioxidant responses of rice seedlings to salinity stress. *Plant Science* **135:** 1-9.

Gomez KA and Gomez AA (1984) *Procedures for Agricultural Research*. John Willley and Sons, NewYork.

Ram H, Singh Y, Saini KS, Kler DS, Timsina J and Humphreys EJ (2012) Agronomic and economic evaluation of permanent raised beds, no tillage and straw mulching for an irrigated maize-wheat system in North-West India. *Experimental Agriculture* **48(1)**: 21-38.

Hassine AB, Ghanem ME, Bouzid S and Lutts S (2008) An inland and a coastal population of the Mediterranean xero-halophyte species Atriplex halimus L. differ in their ability to accumulate proline and glycinebetaine in response to salinity and water stress. *Journal of Experimental Botany* **59(6)**: 1315-1326.

Heath RL and Packer L (1968) Photoperoxidation in isolated chloroplast I. Kinetics and stoichiometry of fatty acid peroxidation. *Archives of Biochemistry and Biophysics* **125**: 189-198.

Hogg PG and Ahlgren HC (1942) A rapid method of determining hydrocyanic acid content of single plant of Sudan grass. *Journal of American Society of Agronomy* **43**: 199-200.

IGFRI (2015) *Vision 2050*: ICAR-Indian Grassland and Fodder Research Institute, Jhansi (UP), India.

Jat HS, Singh G, Singh R and Madhu C (2018) Effect of planting and ex-situ mulching on growth, productivity, profitability and nutrient uptake in maize-wheat cropping sequence. *Journal of soil Salinity and Water Quality* **10(1)**: 95-103.

Krishnamurthy L, Serraj R, Hash CT, Dakheel AJ and Reddy BVS (2007) Screening sorghum genotypes for salinity tolerant biomass production. *Euphytica* **156**: 15-24.

Kukreja, S, Nandwal, AS, Kumar, N, Sharma, SK, Sharma, SK, Kundu, BS, Unvi, V and Sharma, PK (2006) Response of chickpea roots to short-term salinization and desalinization: Plant water status, ethylene evolution, antioxidant activity and membrane integrity. *Physiology and Molecular Biology of Plants* **12(1)**: 67-73.

Kumar A, Charu Lata, Krishnamurthy SL, Kumar A, Prasad KRK and Kulshreshtha N (2017) Physiological and Biochemical Characterization of Rice Varieties under Salt and Drought Stresses. *Journal of Soil Salinity and Water Quality* **9(2)**: 167-177.

Kumar A, Krishnamurthy SL, Charu Lata, Kumar P, Ritu Devi, Kulshrestha N, Yadav RK and Sharma SK (2016) Salinity and drought induced changes in gas exchange attributes and chlorophyll fluorescence characteristics of rice (*Oryza sativa*) varieties. *Indian Journal of Agricultural Sciences* **86(6)**: 718-726.

Kumar A, Mann A, Kumar A, Devi S and Sharma PC (2018) Potential and role of halophyte crops in saline environments. In: Gupta S K, Goyal M R and Singh A. (eds) *Engineering Practices for Management of Soil Salinity*. Apple Academic Press Inc., Canada, pp 329-365.

Kumar A, Mann A, Lata C, Kumar N, and Sharma PC (2019) Salinity-induced Physiological and Molecular Responses of Halophytes. In: Dagar JC, Yadav RK and Sharma PC (eds) *Research Developments in Saline Agriculture*. Springer Nature, Singapore Pte Ltd., pp 331-356.

Kumar A, Sharma SK, Lata C, Sheokand S and Kulshreshta N (2015) Combined effect of boron and salt on polypeptide resolutions in wheat (*Triticum aestivum*) varieties differing in their tolerance *Indian Journal of Agricultural Sciences* **85**: 1626-1632.

Kumari Pummy, Pahuja SK, Sheoran RS, Arya S and Joshi UN (2017) Effect of varying levels of salinity on growth, yield and quality of forage sorghum genotypes. *Forage Research* **43(1)**: 64-66.

Lata C, Kumar A, Sharma SK, Singh J, Shital Sheokand, Pooja, Mann A and Babita Rani (2017) Tolerance to combined boron and salt stress in wheat varieties: Biochemical and molecular characterization. *Indian Journal of Experimental Biology* **55**: 321-328.

Meena RP, Venkatesh K, Khobra Rinki, Tripathi SC, Prajapat K, Sharma RK and Singh GP (2020) Effect of rice residue retention and foliar application of K on water productivity and profitability of wheat in North West India. *Agronomy* **10**: 434.

Pooja, Nandwal AS, Chand M, Kumari A, Rani B, Goel V and Kulshreshtha N (2020) Soil moisture deficit induced changes in antioxidative defense mechanism of four sugarcane varieties differing in their maturity. *Indian Journal of Agricultural Sciences* **90(3)**: 56-61.

Pooja, Nandwal, AS, Chand M, Singh K, Mishra AK, Kumar A, Kumari A and Rani B (2019) Varietal variation in physiological and biochemical attributes of sugarcane varieties under different soil moisture regimes. *Indian Journal of Experimental Biology* **57(10)**: 721-732.

Prajapat K, Yadav RK, Kumar A and Charu Lata (2018) Influence of sowing methods and mulching on soil salt dynamics and performance of fodder sorghum irrigated with saline water. *Journal of Soil Salinity and Water Quality* **10(2)**: 225-233.

Rani B, Madan S, Sharma KD, Pooja and Kumar A (2018) Influence of arbuscular mycorrhizal fungi on antioxidative system of wheat (*Triticum aestivum* L.) under drought stress. *Indian Journal of Agricultural Sciences* **88(2)**: 289-297.

Sheoran P, Kumar A, Ashwani Kumar, Raju R, Sharma R, Parjapat K, Barman A, Singh R K, Kumar S, Sharma PC, Chahal VP, Singh A K (2020) Impact of pressmud application in reclamation of high RSC irrigation water induced soil sodification and sustaining rice - wheat production in Indo-Gangetic Plains. *Indian Journal of Agricultural Sciences* **90(1)**: 53-62.

Van Soest PJ (1963) Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. *Journal of the Association of Official Analytical Chemistry* **46**: 829-435.

Weatherley PE (1950) Studies in the water relations of the cotton plant I. The field measurements of water deficit in leaves. *New Phytologist* **49**: 81-97.

Yemm, E and Willis AJ (1954) The estimation of carbohydrate in plant extracts by Anthrone. *Biochemical Journal* **57**: 508-514.

Received: January 06, 2024; Accepted: June 19, 2024

Journal of Soil Salinity and Water Quality 16(1), 76-84, 2024

Seasonal Assessment of Physico-chemical Parameters of Untreated Wastewater from District Ludhiana, Punjab, India

Vibhu Vaid[1]* and Nisha Vashishat[1]

[1]Punjab Agricultural University, Ludhiana-141004, Punjab, India
**Corresponding author's E-mail: vibhuvaid30@gmail.com*

Abstract

Water pollution has become a major environmental challenge globally. The aim of the study was to assess water quality of untreated wastewater collected from Sewage treatment plant, Bhattian in district Ludhiana, Punjab (India). Laboratory analysis of collected samples was performed for analysing various physico-chemical water parameters such as water temperature (WT), hydrogen ion concentration (pH), Biological Oxygen Demand (BOD), alkalinity and free carbon dioxide (FCO_2) by using standard methods recommended by APHA. Significant ($p \leq 0.05$) differences were observed in the values of different variables (WT, FCO_2, BOD and alkalinity) during different seasons.

Key words: Ludhiana, Wastewater, Water pollution, Water quality

Introduction

Fresh water is an essential natural resource for survival of living beings and provides habitat to millions of aquatic organisms (Bhat *et al.,* 2018). Fresh water bodies of India are very diverse and include rivers, streams, ponds, lakes, dams and impoundments. About 0.036% of the total water is accessible to human beings through rivers and lakes (Dwivedi, 2017). Over the last few decades, water pollution has become a major environmental challenge worldwide, especially in developing countries including India. According to Annual report of National Rural Drinking Water Programme data for the year 2014-15, 163 million Indians are not having access to clean water (Ministry of drinking water and sanitation, 2015). Around 37.7 million Indians got affected by water borne diseases costing $600 million annually (Kaur *et al.*, 2022).

With the advent of human civilization, rapid urbanization, industrialization, population growth and modern agricultural methods; quality of water assets are deteriorating with industrial, sewage and domestic discharge having various chemical pollutants such as pesticides, heavy metals along with other compounds that can encourage rapid and excessive microbial growth (Singh *et al.*, 2016; Kaur *et al.*, 2022). The pollution constitutes microbes, organic matter, untreated or partly treated sewage, pesticide, dead body dumping, cattle washing, heavy metals, biocides, chemicals and industrial discharge which eventually deteriorates aquatic environment (Sharma and Kansal, 2011). According to the Central Pollution Control Board, 70% of the accessible water is contaminated in India (CPCB, 2000), out of which, 84-92% is polluted with sewage discharge and remaining is affected with disposal of improperly treated industrial effluents (Khapekar *et al.*, 2008).

In India, the sewage production rate in cities and metropolitan cities was assessed to be 60 L day^{-1} and 120 L day^{-1} per person, respectively (Subashini *et al.*, 2017). About 40×10^6 L of wastewater enters groundwater, surface water and other aquatic bodies daily (Bhutiani *et al.*, 2021). In addition, Punjab is one of the most urbanized states in North India, with total population of 27.7×10^6 out of which 10.3×10^6 belongs to urban areas. According to 2011 Census, Punjab accounts for about 1.53% of land area and represents 2.37% of the India's population. Ludhiana, the metropolitan centre of Punjab, has emerged as the most important industrial centre. Around 57% Ludhiana's population is having sewage network and produces approximately 432 million L wastewater per day (Singh, 2015). Nature has a fascinating endowment to confront little amount of wastewater and aquatic pollution but could not tackle with huge amount of untreated wastewater discharge (Bhatia *et al.*, 2017).

Raw sewage has deteriorated water ecology by the presence of nutrients (nitrogen and phosphorous) which stimulates the growth of microorganisms and aquatic plants by increasing biological and chemical oxygen demands. Along with this, pathogenic microbes in sewage water such as bacteria, viruses and fungus make it unfit for human consumption (Maurya *et al.*, 2020). Recently, the United Nations (UN) General Assembly stated that clean and safe drinking water and sanitation is a human right necessary to enjoy life as well as other human rights (WHO, 2011). Various aquatic organisms such as fish accumulate contaminants into their living cells at concentrations much higher than those present in their environment changing biota's diversity and ecosystems in aquatic environments (Akankali *et al.*, 2022). Along with this, aquatic pollution causes alterations in the physiology and biochemical mechanisms of biota impairing functions including respiration, reproduction, osmoregulation and mortality (Rawat *et al.*, 2016; Ruhela *et al.*, 2022).

The physico-chemical water quality is described by physical, chemical and biological characteristics. Estimation of physicochemical water quality parameters is essential to protect biodiversity and to revive aquatic resources (Das *et al.*, 2021). Monitoring of water quality parameters is a crucial step in assessment of hydrochemistry, ecosystem, ecology, management, conservation and restoring of water quality within acceptable levels (Feisal *et al.*, 2023). Hence, the present study was designed to study the physico-chemical parameters of untreated wastewater.

Materials and Methods

Study area

The sample site i.e., Sewage water treatment plant (STP) (lat 30°96 N; long 75°8 E), Bhattian Punjab (India) was within the municipal limits of Ludhiana located at the distance of 12.10 km from Punjab Agricultural University, Ludhiana, Punjab, India. The location map of the study area is shown in Fig. 1.

Collection and analysis of water samples

Untreated wastewater was collected every month from September, 2022 to August, 2023 in pre-treated plastic and BOD bottles from STP located

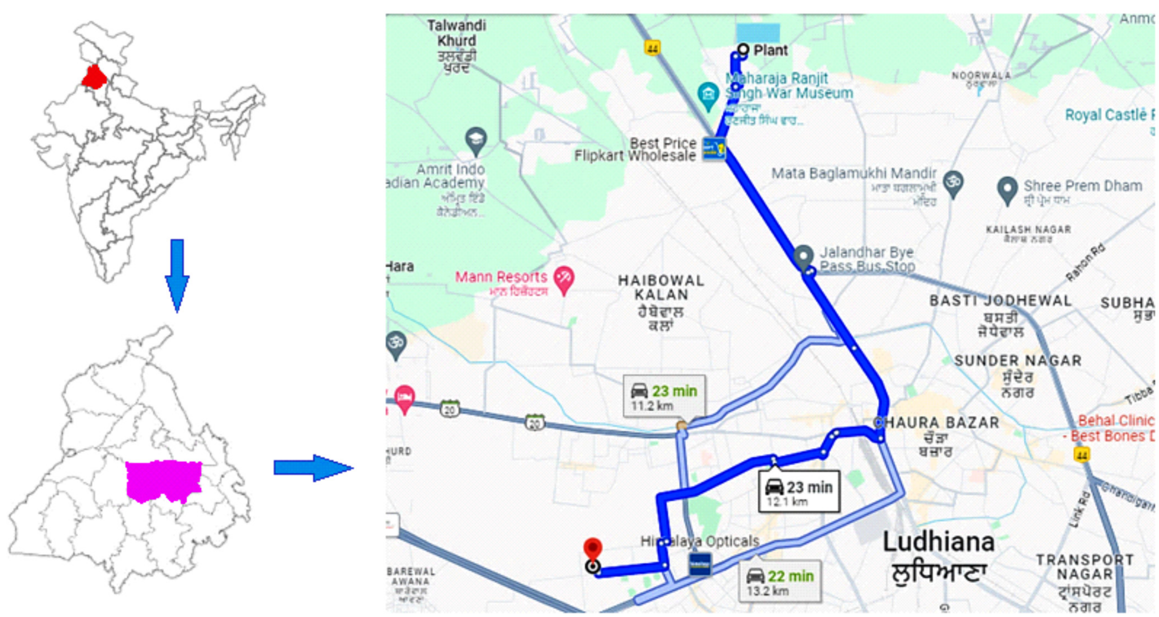


Fig. 1 Location map of study area

at Bhattian in Ludhiana, an industrial hub of Punjab (India). The water samples were instantly preserved in ice packs and carried to the laboratory without any further delay. The water samples were analysed for a period of 12 months from September, 2022 to August, 2023 on a seasonal basis (Autumn, winter, summer and monsoon) for various physico-chemical parameters viz. water temperature (WT), hydrogen ion concentration (pH), alkalinity and free carbon-dioxide (FCO_2) within a day of collection. The water samples were analysed using standardized methods given by American Public Health Association (APHA, 2005). WT was measured at the time of collection using glass thermometer; pH was estimated using pH meter; FCO_2 was estimated by titrimetric method; and Biochemical Oxygen Demand (BOD) was estimated after 5 days incubation at 20°C in BOD incubator using titrimetric method.

Statistical analysis

The experiments were performed in triplicate and the data was depicted as mean±standard error (S.E.). Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) version 16.00. One way analysis of variance (ANOVA) followed by Tukey HSD was used to compare significant difference among different seasons. A 'p' value of 0.05 was used as a standard for statistically significant differences.

Results and Discussion

The trends of physico-chemical parameters of samples of influent of STP receiving wastewater from Ludhiana are presented in the Table 1. The variations in different physico-chemical variables might be due to seasonal variations (Adeogun *et al.*, 2013; Olaniran *et al.*, 2019). In addition, untreated wastewater samples collected from STP during different seasons ranged from dark brown to black in colour. Similarly, Sarker *et al.* (2016) noticed that wastewater collected from 12 stations of Industrial water environment in Habirbari union of Bhaluka upazila (Bangladesh) ranged from brown, dark brown to black colour.

Water temperature (WT)

The variations in WT of wastewater during seasons ranged from 21 to 43°C as shown in table

Table 1. Seasonal variations of selected physico-chemical parameters of untreated wastewater, Bhattian, Punjab (India) during different seasons

Parameters	Water temperature (WT) (°C)		Hydrogen ion concentration (pH)		Free carbon dioxide (FCO_2) (mg/L)		Biochemical Oxygen Demand (BOD) (mg/L)		Alkalinity (mg/L)	
Seasons	Mean±S.E.	Range	Mean±S.E.	Range	Mean±S.E.	Range	Mean±S.E.	Range	Mean±S.E.	Range
Autumn	34.33 ± 1.45^{b}	32.00-37.00	7.42 ± 0.11^{a}	7.27-7.63	74.67 ± 2.91^{a}	70.00-80.00	130.00 ± 1.15^{b}	128-132	78.67 ± 4.06^{b}	72.00-86.00
Winter	23.33 ± 1.45^{c}	21.00-26.00	7.59 ± 0.12^{a}	7.42-7.81	36.00 ± 6.93^{b}	24.00-48.00	112.67 ± 3.71^{b}	108-120	104.00 ± 3.46^{a}	98.00-110.00
Summer	40.00 ± 1.15^{ab}	38.00-42.00	7.41 ± 0.03^{a}	7.37-7.48	73.33 ± 2.40^{a}	70.00-78.00	156.00 ± 8.08^{a}	140-166	92.67 ± 4.81^{ab}	86.00-102.00
Monsoon	40.67 ± 1.20^{a}	39.00-43.00	7.48 ± 0.10^{a}	7.30-7.64	78.67 ± 1.76^{a}	76.00-82.00	167.33 ± 4.67^{a}	160-176	75.33 ± 3.53^{b}	70.00-82.00

Values are Mean±S.E. (n=3)

2. WT was observed significantly lower ($p \leq 0.05$) in winter season while significantly higher ($p \leq 0.05$) in monsoon season (Table 1). High fluctuation of WT recorded during different seasons might be due to variations in intensity of solar radiation. The observed WT values of wastewater were above the permissible levels (40.00 °C) during monsoon season as depicted in Table 2. The observations are in accordance with the investigations done by Bhatia *et al.* (2018), in Buddha Nullah during the study period of 2014. The scientists observed maximum mean temperature in rainy season (40.83±2.42°C) and minimum in autumn (37.66±2.58°C). Similarly, temperature in summer (41.16±4.99 °C) was recorded more than winter (39.25±2.25°C) at site 2. The authors suggested that the effect of temperature is related to season and sampling time (Bhatia *et al.*, 2018). Kalyani *et al.* (2018) also recorded maximum WT (29°C) during summer season and minimum (7°C) during winter season in January (Palampur, Himachal Pradesh). The authors suggested rise in temperature lead to increase in biochemical reactions and decrease the solubility of gases. The higher temperature of discharged effluents affects the land and water properties (Kolhe *et al.*, 2009). Additionally, WT also affects chemical activities and rate of reactions within water samples, thereby influencing its suitability for irrigation practices (Metcalf and Eddy, 2003). Similarly, Bhanot (2019) also studied that WT of wastewater collected from Bhattian (Punjab) was within permissible limits (40.00°C).

Hydrogen ion concentration (pH)

The value of pH of collected wastewater samples during different seasons showed non-significant difference ($p > 0.05$) ranging from 7.41±0.03 to 7.59±0.12. Maximum pH was recorded in winter season while minimum value was observed in summer season (Table 1). Observed pH values were within permissible limits set by World Health Organization (WHO, 2011), Indian Standard Institute (ISI, 1973), Indian Council of Medical Research (ICMR, 1975) and Bureau of Indian Standards (BIS) (Sudarshan *et al.*, 2019) as shown in Table 2. Low or high pH values are indication of presence of chemical constituents or heavy metal concentration. In addition, seasonal variations in WT might be responsible for seasonal alterations in pH due to its ability to decrease viscosity, increase mobility and number of ions due to dissociation of molecules (weak acids and bases) (Mandal, 2014). Matta *et al.* (2017) also observed variations in pH values of river Ganga seasonally and suggested that seasonal variability might due to industrial discharge. Paul *et al.* (2012) investigated high pH in industrial effluent and that slight alkalinity might be due to bleaching and scouring agents along with chemicals such as sodium hydroxide, surfactants, sodium hypochlorite and sodium phosphate used in mercerization of fabric. pH higher than

Table 2. Values of selected physico-chemical parameters of untreated wastewater, Bhattian, Punjab (India) from September 2022 to August 2023 compared to permissible limits prescribed by WHO (2011), ISI (1973), ICMR (1975) and BIS (Sudarshan *et al.*, 2019)

Parameters	Untreated wastewater		Permissible limits			
	Mean±S.E.	Ranges	WHO (2011)	ISI (1973)	ICMR (1975)	BIS (Sudarshan *et al.*, 2019)
Water temperature (WT) (°C)	34.58±2.17	21.00-43.00	-	-	-	40.00 (°C) (Bhatia *et al.*, 2018)
Hydrogen ion concentration (pH)	7.48±0.05	7.27-7.81	6.50-8.50	6.50-8.50	7.74	6.50-8.50
Free carbon dioxide (FCO_2) (mg/L)	65.67±5.48	24.00-80.00	22.00 (Lkr *et al.*, 2022)	-	-	10.00
Biochemical Oxygen Demand (BOD) (mg/L)	141.50±6.82	108.00-176.00	30.00	-	-	10.00
Alkalinity (mg/L)	87.67±3.85	70.00-110.00	120.00	200.00	120.00	200.00

permissible limits was observed by Desai and Kore (2011) in water samples collected from effluent treatment plant of textile industry in Kolhapur of Maharashtra (India). Similar interpretations were also witnessed by Tiwari and Chauhan (2006) in Kitham lake (Sur Sarovar), Agra (India).

Bhat *et al*. (2018) also noted maximum pH at station 2 during the winter and minimum at station 2 (river Yamuna) during the summer. The authors suggested that high pH value at station 2 might be due to amplified influx of carbonates and bicarbonates of calcium (Ca) and magnesium (Mg) in wastewater from industrial and anthropogenic discharge. In addition, lower pH value was observed in summer which could be due to accumulation of FCO_2 and high rate of respiration of organisms with increase in temperature. Lower pH value observed in monsoon season might also be due to accumulated FCO_2 and enhanced rate of respiration of organisms due to increase in temperature. Higher pH values in wastewater might enhance solubilisation of essential elements which could further affect aquatic biota (Younas *et al.* 2017). In contrast, pH values (5 to 8) of water samples collected from Nalasopara (Maharashtra) were recorded minimum in winter while highest pH was recorded in monsoon season (Sangeeta and Neha, 2015). Similarly, analysis of physicochemical water variables of Buddha Nullah also revealed higher pH value of different sites in summer (6.09-7.18) than winter (6.1-6.96) season (Kaur *et al*., 2022).

Biochemical Oxygen Demand (BOD)

The value of BOD during different seasons ranged from 108 to 176 mg/L with the mean value 141.50±6.82 mg/L as indicated in Table 2. BOD was found significantly lesser ($p \leq 0.05$) during winter season while significantly higher ($p \leq 0.05$) values were recorded during summer and monsoon seasons. The untreated wastewater showed BOD levels above the permissible limits prescribed by WHO, 2011 (30 mg/L) and BIS (10 mg/L) (Sudarshan *et al*., 2019) (Table 2). Similarly, BOD values higher than permissible limits were observed in domestic wastewater collected from drainage at Vishnupuri, Nanded (India) by Sonune *et al*. (2015). Kaur *et al*. (2022) also observed increase in BOD values in summer season. The rise in BOD during summer season might be due to higher microbial activities for decomposing organic matter under aerobic conditions (Yisa and Jimoh, 2010). Similar findings were reported by Sharma *et al*. (2020) in Yamuna River (India) and Mena-Rivera *et al.* (2017) in river Burio (Costa Rica). The BOD showed a significant positive correlation with temperature. Kamboj *et al*. (2021) also observed higher average BOD during monsoon particularly and comparatively lesser BOD in post monsoon in water samples collected from river Beas in Punjab (India). Higher BOD values lead to stress, suffocation and eventually death in aquatic (Dhinamala *et al*., 2015). Decline in BOD during winter might be due to inhibition of microbial activity (Shiddamallayya and Pratima, 2008).

Alkalinity

Alkalinity values act as pH reservoir for inorganic carbon and indicate the carbonate level in water. In addition, it also reflects the ability of wastewater to support algal growth and water to neutralize the soil acidity (Manahan, 1994). Alkalinity ranged from 70.00 to 110.00 mg/L with the mean value 87.67±3.85 mg/L during different seasons and values were within the permissible limits prescribed by different organizations including WHO (2011) (120 mg/L), ISI (1973) (200 mg/L), ICMR (1975) (120 mg/L) and BIS (Sudarshan *et al*., 2019) (200 mg/L) as shown in Table 2. Significantly (p d" 0.05) higher alkalinity was observed in winter season while significantly ($p \leq 0.05$) lower alkalinity values were recorded during monsoon and autumn seasons. Similar findings were reported by Dhanalakshmi *et al.* (2013) where total alkalinity was higher during winter season and lower in autumn season at Krishnan Anaikattu Kulam pond in Pollachi town in Tamil Nadu (India), which might be due to decline in photosynthetic rate in aquatic plants and increase in organic impurities input brought by domestic sewage. Durrani (1993) suggested that CO_2 withdrawal from bicarbonates by algae for photosynthesis might lead to elevation in total alkalinity. Higher levels of alkalinity in water samples indicate the presence of carbonate, bicarbonate and hydroxide in the water body (Jain, 2000). In addition, degradation of organic waste, flora and fauna in the water resource might be the reasons for elevated levels of bicarbonate and carbonate, thereby increasing alkalinity levels (Deepa *et al*., 2016). Dissolution of CO_2 led to high alkalinity in natural water systems. However, alkalinity values higher than permissible limits directed the existence of strongly alkaline sewage discharge and industrial wastewater (Patil *et al*., 2018). Additionally, variations in alkalinity values also occur due to changes in salt concentration, rock, soils and floral activities altering pH values of wastewater which further affect the livelihood of aquatic organisms (Soni *et al*., 2022).

Free carbon dioxide (FCO_2)

FCO_2 concentrations ranged from 24.00 to 80.00 mg/L with the mean value 65.67±5.48 mg/L over the period of 12 months which were above the prescribed limits as depicted in Table 2. Significantly higher ($p \leq 0.05$) value of FCO_2 was recorded in monsoon season while minimum was found in winter season (Table 1). In the studied water samples, pH showed an inverse relation with FCO_2. The relationship between pH and FCO_2 concentration in wastewater is depicted in the Fig. 2. The recorded R^2 was 0.27. Similarly, negative relation between FCO_2 and pH was also reported by (Jindal and Rumana, 2000) in water samples from river Yamuna. The results of current findings are in conformity with the findings of Joshi *et al.* (2009) who also observed annual fluctuations in FCO_2 levels in water samples collected from river Ganga in different seasons. The authors also reported highest FCO_2 levels in rainy season and least values of FCO_2 were reported in winter season. Slathia *et al*. (2023) also observed maximum FCO_2 concentration during monsoon season at Chadwal stream and minimum during post-monsoon season at Nagri stream. The authors also observed significant ($p > 0.01$) alterations in mean values of FCO_2 during different seasons. Enhanced FCO_2 during monsoon might be due to accumulation and decomposition of dumped sewage and declined rate of photosynthesis (Surana *et al*., 2010).

Higher level of FCO_2 in wastewater indicates increased rate of oxidation of organic and inorganic compounds along with oxygen depletion which could further impact aquatic fauna (Benit and Roslin, 2015). Jindal and Sharma (2011) also recorded relatively higher FCO_2 levels during late summer (May-June, 2007) in river Sultej, Ludhiana (India). The authors suggested that rise in temperature might be responsible for accelerating the process of decaying organic matter and accelerating respiratory activities of biota, leading to rise in FCO_2 values of water samples. In addition, FCO_2 also leads to increase

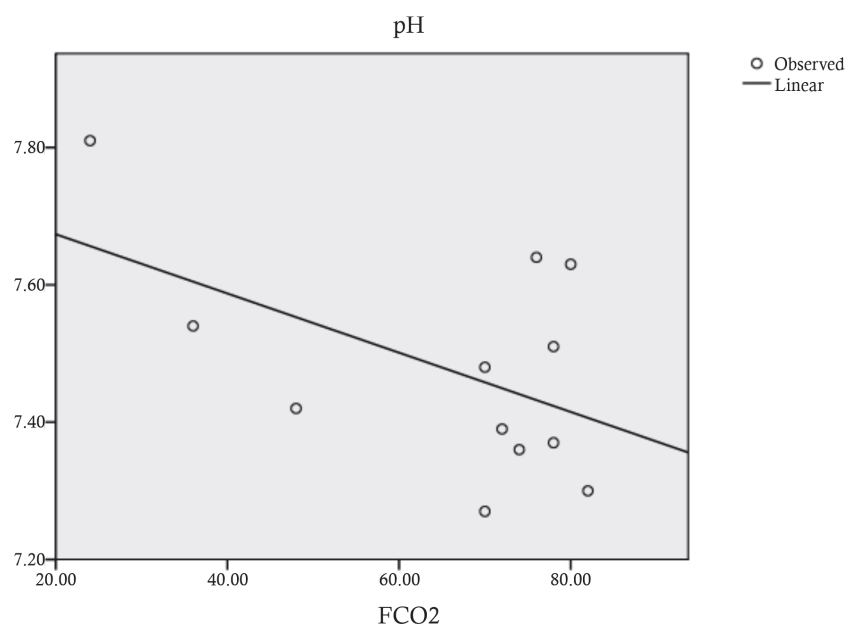


Fig. 2 Relationship between hydrogen ion concentration (pH) and free carbon dioxide (FCO_2) (mg/L) concentration in wastewater

in hydrogen ion and bicarbonate concentrations while hydroxyl ion and carbonate concentrations decrease, which leads to inverse relation between FCO_2 and pH (Raven *et al*., 2020). Similar observations were recorded by Nath and Srivastava (2001) and Gurumayum *et al*. (2002) who also investigated higher levels of FCO_2 during summer and monsoon seasons in water samples collected from Narmada (Madhya Pradesh) and selected rivers in Meghalaya, respectively.

Shortcomings and future research

The present study analysed physicochemical parameters of untreated wastewater. Further work can be done to analyse nutrient levels (nitrate, phosphate), pesticide and heavy metal concentrations. In addition, effect of wastewater on aquatic fauna can be studied.

Conclusions

The present study analysed physicochemical water parameters of collected untreated wastewater. There was evident water quality deterioration as the average values of parameters (FCO_2 and BOD) were higher than maximum prescribed limits set by different organizations. The values of physicochemical water parameters such as WT, FCO_2, BOD and alkalinity of collected untreated wastewater also showed significant ($p \leq 0.05$) seasonal variability while the values of pH varied non-significantly ($p > 0.05$) during different seasons. Higher values of BOD indicated pollution which further increases the content of organic waste leading to deterioration of water quality and aquatic biodiversity loss. It was evident that untreated effluents from various sectors of district Ludhiana were directly discharged into water without proper treatment. The fluctuations in parameters highlighted the requirement of implementation of stringent legislation and guidelines to prevent direct discharge of pollutants into water bodies. The water quality of the study area could be restored by various measures such as restriction on inflow of raw sewage and effluent discharge from industrial and residential areas, desilting and prevention of dumping of solid waste by communities residing near the study area.

Acknowledgements

The authors would like to thank the Head of the Department of Zoology, Punjab Agricultural University, Ludhiana district, Punjab (India) for providing all the necessary facilities to carry out this research work and Department of Science and Technology (DST), Government of India, New Delhi, for providing infrastructural facilities under FIST grant. The authors received financial support from the Department of Science and Technology (DST) for INSPIRE Fellowship under INSPIRE Program.

References

Adeogun AO, Ibor OR and Chukwuka AV (2013) Acute toxicity of abattoir and saw-mill effluents to juvenile-sized *Clarias gariepinus*. *Zoology and Ecology* **23(1)**: 53-57.

Akankali JA, Davies IC and Tambari-Tebere A (2022) Pollution impacts of abattoir and associated activities wastes on the water quality of Eagle Island creek, Niger delta, Nigeria. *International Journal of Contemporary Applied Researches* **9(2)**: 63-85.

APHA (2005) Standard methods for the examination of water and wastewater 21st edition. Washington DC, USA.

Benit N and Roslin AS (2015) Physicochemical properties of wastewater collected from different sewage sources. *International Journal of Innovative Science, Engineering and Technology* **2(11)**: 691-696.

Bhanot R (2019) *Assessment of Cytotoxicity in Flesh, Gills and Liver of Fish (Labeo rohita) Reared in Untreated and Treated Sewage Water*. Ph.D. Thesis, Punjab Agricultural University, Punjab, India.

Bhat BN, Parveen S and Hassan T (2018) Seasonal assessment of physicochemical parameters and evaluation of water quality of river Yamuna, India. *Advances in Environmental Technology* **1**: 41-49.

Bhatia D, Sharma NR, Kanwar R and Singh J (2018) Physicochemical assessment of industrial textile effluents of Punjab (India). *Applied Water Science* **8**: 83.

Bhatia D, Sharma NR, Singh J and Kanwar RS (2017) Biological methods for textile dye removal from wastewater: a review. *Critical Reviews in Environmental Science and Technology* **47**(19): 1836-1876.

Bhutiani R, Ahamad F and Ruhela M (2021) Effect of composition and depth of filter-bed on the efficiency of sand-intermittent-filter treating the industrial wastewater at Haridwar, India. *Journal of Applied and Natural Sciences* **13(1)**: 88-94.

CPCB (2000) Water quality status of Yamuna River, Central Pollution Control Board, Parivesh Bhawan, Delhi India.

Das S, Kaur S and Jutla A (2021) Earth observations based assessment of impact of COVID-19 lockdown on surface water quality of Buddha Nala, Punjab, India. *Water* **13(10)**: 1363.

Deepa P, Raveen R, Venkatesan P, Arivoli S and Samuel T (2016) Seasonal variations of physicochemical parameters of Korattur lake, Chennai, Tamil Nadu, India. *International Journal of Chemical Studies* **4(3)**: 116-123.

Desai PA and Kore VS (2011) Performance evaluation of effluent treatment plant for textile industry in Kolhapur of Maharashtra. *Universal Journal of Environmental Research and Technology* **1(4)**: 560-565.

Dhanalakshmi V, Shanthi K and Remia KM (2013) Physicochemical study of eutrophic pond in Pollachi town, Tamil Nadu, India. *International Journal of Current Microbiology and Applied Sciences* **2(12)**: 219-227.

Dhinamala K, Pushpalatha M, Samuel T, Raveen R (2015) Spatial and temporal variations in the water quality parameters of Pulicat Lake, Tamil Nadu, India. *International Journal of Fisheries and Aquatic Studies* **3(2)**: 255-259.

Durrani IA (1993) *Oxidative mineralization of plankton with its impact on eutrophication of Bhopal*. Ph.D. Thesis, Barkatullah University, Bhopal, India.

Dwivedi AK (2017) Researches in water pollution: A review. *International Research Journal of Natural and Applied Sciences* **4(1)**: 118-142.

Feisal NAS, Kamaludin NH, Sani MFA, Ahmad DKA, Ahmad MA, Razak NFA and Ibrahim TNBT (2023) Anthropogenic disturbance of aquatic biodiversity and water quality of an urban river in Penang, Malaysia. *Water Science and Engineering* **16(3)**: 234-242.

Gurumayum SD, Daimari P, Goswami BSJ, Sarkar A and Chaudhury M (2002) Physico-chemical qualities of water and plankton of selected rivers in Meghalaya. *Journal of the Inland Fishries Society of India* **34(2)**: 36-42.

ICMR (1975) In: Manual of standards of quality for drinking water supplies New Delhi: ICMR.

ISI (1973) In: Indian standards methods for sampling and test (physical and chemical) for water used in industry. Indian Standard Institute, Mank Bhawan.

Jain C (2000) Groundwater quality in sugar districts Madhya Pradesh, India. *Journal of Environmental Health* **42(4)**: 151-158.

Jindal R and Rumana HS (2000) Biomonitoring of water pollution in Western Yamuna Canal at Yamunanagar, Haryana. *Journal Punjab Academy of Sciences* **2(1)**: 177-182.

Jindal R and Sharma C (2011) Studies on water quality of Sutlej River around Ludhiana with reference to physicochemical parameters. *Environmental Monitoring and Assessment* **174**: 417-425.

Joshi DM, Kumar A and Agrawal N (2009) Studies on physicochemical parameters to assess the water quality of river Ganga for drinking purpose in Haridwar district. *RASÂYAN Journal of Chemistry* **2(1)**: 195-203.

Kalyani S, Chauhan RC and Singh B (2018) Water quality of fresh water pond ecosystem under sub-temperate conditions of Palampur, Himachal Pradesh. *Indian Journal of Ecology* **45(4)**: 774-777.

Kamboj S, Datta SN, Tyagi A and Tewari G (2021) Assessment of water quality and microbial load in the selected stretches of river Beas in Punjab, India. *Journal of Experimental Zoology India* **24**: 435-440.

Kaur H, Katyal P and Chandel S (2022) Assessment of water quality using different physicochemical and biological parameters: a case study of Buddha nallah, Punjab, India. *Environment Conservation Journal* **23(3)**: 145-59.

Khapekar RR, Chaudhary PR and Nandkar PB (2008) Impact of industrial effluents on freshwater bodies: a review. In: Gupta KR, Maiti P (eds.) Global environment: problems and policies, Atlantic Publishers and Distributors, New Delhi **4**: 84-105.

Kolhe AS, Ingale SR and Bhole RV (2009) Effluent of dairy technology. *Shodh, Samiksha aur Mulyankan (International Research Journal)* **2(5)**: 459-461.

Lkr A, Singh MR and Puro N (2021) Spatio temporal infuence on river water chemistry of Doyang river, Nagaland, India, using multivariate techniques. *International Journal of Environmental Science and Technology* **20**: 625-638.

Manahan SE (1994) Environmental Chemistry. Lewis Publication/CRC Press, USA. Pp. 161-173.

Mandal (2014) Effect of temperature on pH of wastewater of Phagwara. *International Journal of Applied Engineering Research* **9(10)**: 1219-1229.

Matta G, Srivastava S, Pandey RR and Saini KK (2017) Assessment of physicochemical characteristics of Ganga canal water quality in Uttarakhand. *Environment, Development and Sustainability* **19(2)**: 419-431.

Maurya A, Singh MK and Kumar S (2020) Biofiltration technique for removal of waterborne pathogens. In: Waterborne Pathogens, pp. 123-141.

Mena-Rivera L, Salgado-Silva V, Benavides-Benavides C, Coto-Campos JM and Swinscoe THA (2017) Spatial and seasonal surface water quality assessment in a tropical urban catchment: Burío River, Costa Rica. *Water* **9(8)**: 558.

Metcalf and Eddy (2003) Wastewater engineering treatment and reuse, fourth edition, New York, USA: McGraw Hill. (https://www.academia.edu/35811755/Wastewater_Engineering_Treatment_ and_Reuse_Fourth_Edition)

Ministry of Drinking Water and Sanitation (2015) Annual report 2014-15. (http://www.india.gov.in/ ministry-drinking-water-and-sanitation-annualreports)

Nath D and Srivastava NP (2001) Physico-chemical characteristics of Narmada for the stretch Sandia to Mola in M.P. state in the context of construction of reservoirs on the river or its tributaries. *Journal of the Inland Fisheries Society of India* **33(1)**: 17-24.

Olaniran EI, Sogbanmu TO and Saliu JK (2019) Biomonitoring, physico-chemical and biomarker evaluations of abattoir effluent discharges into the Ogun River from Kara Market, Ogun State, Nigeria using *Clarias gariepinus*. *Environmental Monitoring and Assessment* **191**: 44.

Patil A, Patil S and Sathe S (2018) Water quality index of Belawale Khurd Reservoir of Kolhapur district (MH) (India). *The Journal of Indian Botanical Society* **97 (1&2)**: 131-135.

Paul SA, Chavan SK and Khambe SD (2012) Studies on characterization of textile industrial waste water in Solapur city. *International Journal of Chemical Science* **10(2)**: 635-642.

Raven JA, Gobler CJ and Hansen PJ (2020) Dynamic CO_2 and pH levels in coastal, estuarine, and inland waters: Theoretical and observed effects on harmful algal blooms. *Harmful Algae* **91**: 101594.

Rawat D, Mishra V and Sharma RS (2016) Detoxifcation of azo dyes in the context of environmental processes. *Chemosphere* **155**: 591-605.

Ruhela M, Sharma K, Bhutiani R, Chandniha SK, Kumar V, Tyagi K, Ahamad F and Tyagi I (2022) GIS-based impact assessment and spatial distribution of air and water pollutants in mining area. *Environmental Science and Pollution Research* **29(21)**: 31486-31500.

Sangeeta P and Neha P (2015) Monitoring of seasonal variation in physicochemical water parameters in Nalasopara Region. *Journal of Ecosystem and Ecography* **5**: 1.

Sarker BC, Baten MA, Haque ME, Hossain A, Hasan MZ and Sarker S (2016) Physico-chemical quality and efficiency study of textile and garments effluent. *Oriental Journal of Chemistry* **31(1)**: 283-290.

Sharma D and Kansal A (2011) Water quality analysis of river Yamuna using water quality index in the national capital territory, India (2000–2009). *Applied Water Science* **1(3&4)**: 147-157.

Sharma R, Kumar R, Satapathy SC, Al-Ansari N, Singh KK, Mahapatra RP, Agarwal AK, Le HV and Pham BT (2020) Analysis of water pollution using different physicochemical parameters: A study of Yamuna River. *Frontiers in Environmental Science* **8**: 581591.

Shiddamallayya N and Pratima M (2008) Impact of domestic sewage on fresh water body. *Journal of Environmental Biology* **29(3)**: 303-308.

Singh S (2015) India: Support strategic assessment for innovative and transformative change in delivering urban environment services in Amritsar and Ludhiana (English). Vol (1st), AUS7971.

Singh S, Singh N, Kumar V, Datta S, Wani AB, Singh D, Singh K and Singh J (2016) Toxicity, monitoring and biodegradation of the fungicide carbendazim. *Environmental Chemistry Letters* **14**: 317-329.

Slathia N, Langer S and Jasrotia R (2023) Assessment of water quality and its effect on prawn abundance in three tributaries of Shiwalik rivers: Chenab and Ravi of Jammu, India—A case study. *Applied Water Science* **13**: 77.

Soni R, Pal AK, Tripathi P, Jha PK and Tripathi V (2022) Physicochemical analysis of wastewater discharge and impact on Ganges River of major cities of North India. *Water Supply* **22(6)**: 6157-6178.

Sonune NA, Mungal NA and Kamble SP (2015) Study of physico-chemical characteristics of domestic wastewater in Vishnupuri, Nanded, India. *Internatinal Journal of Current Microbiology and Applied Sciences* **4(1)**: 533-536.

Subashini ML, Asarudin and Pradeep R (2017) Waste water characterization of dairy industry. *International Journal of Pure and Applied Mathematics* **116(13)**: 465-471.

Sudarshan P, Mahesh MK and Ramachandra TV (2019) Assessment of seasonal variation in water quality and water quality index (WQI) of Hebbal Lake, Bangalore, India. *Environment and Ecology* **37(1B)**: 309-317.

Surana R, Subba BR and Limbu KP (2010) Physico-chemical studies on Chimdi Lake of Sunsari district during its restoration stage. *Our Nature* **8**: 258-269.

Tiwari A and Chauhan SV (2006) Seasonal phytoplanktonic diversity of Kitham lake, Agra. *Magnesium* **7(17.5)**: 8-15.

WHO (2011) Guidelines for drinking water quality, 4th edition. WHO Press, World Health Organization, Geneva. (https://www.who.int/publications/i/item/ 9789241549950).

Yisa J and Jimoh T (2010) Analytical studies on water quality index of river Landzu. *American Journal of Applied Sciences* **7(4)**: 453-445.

Younas U, Iqbal S, Saleem A, Iqbal M, Nazir A, Noureen S and Nisar N (2017) Fertilizer industrial effluents: physico-chemical characterization and water quality parameters evaluation. *Acta Ecologica Sinica* **37(4)**: 236-239.

Received: February 07, 2024; Accepted: June 20, 2024

Journal of Soil Salinity and Water Quality 16(1), 85-93, 2024

Variation among *Eucalyptus* Species for Morphological, Physiological and Biochemical Traits under Simulated Salt Stress Conditions

Asani Anis Kholi, Gurvinder Pal Singh Dhillon and Baljit Singh*

Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana, India
**Corresponding author's E-mail: singh-baljit@pau.edu*

Abstract

The investigation was conducted on five-month-old seedlings of *Eucalyptus camaldulensis, E. pellita, E. tereticornis* and *E. citriodora* in earthen pots. Four levels of NaCl concentration *i.e.,* 0, 40, 80 and 120 mM were applied through irrigation to these *Eucalyptus* species arranged in completely randomized design (CRD) in three replications. Significant differences among the species were found for morphological (plant height, collar diameter, root length and total plant length), physiological (relative water content, electrolyte leakage, chlorophyll and carotenoid content) and biochemical (proline, sugar and reducing sugar content) parameters. *E. camaldulensis* registered the highest average values (height 160.07 cm and collar diameter 10.65 mm) for morphological traits whereas the lowest average values (height 100.04 cm and collar diameter 6.82 mm) were in case of *E. citriodora.* Increase in salinity level ultimately led to significant decrease in all the traits indicating a reverse trend between these traits and salinity treatments. Significant reduction in total chlorophyll, carotenoids and relative water content was observed with increase in salinity level. Electrolytes leakage increased as the salinity increased indicating the damage caused by salt stress. Salinity stress raised the content of osmoprotectants such as proline, total soluble sugar and reducing sugar. *E. camaldulensis* was the most tolerant species which performed better than other species even at the highest salinity level and the salinity tolerance of species varied as *E. camaldulensis* > *E. pellita* > *E. tereticornis* > *E. citriodora*. These findings indicate more research into morphological, physiological and biochemical understanding of *Eucalyptus* species for salt tolerance mechanism.

Key words: *Eucalyptus* species, Growth response, Osmoprotectants, Photosynthetic pigments, Salinity tolerance

Introduction

Depending on market demand and site conditions, plantation forestry makes use of a variety of tree species especially *Eucalyptus*, *Populus*, *Pinus*, and *Acacia* (FAO, 2009). Plantation forests continue to meet the growing global demand for timber products (FAO, 2016). Expansion of *Eucalyptus* plantations is expected to continue owing primarily to global demand for pulp in paper industry (Phillips, 2013). The pulp and paper industry are capable of producing products that go beyond paper (Christie, 2008). Furthermore, the unfavorable conflict that occurs when food and biomass production compete for land can be avoided by planting short rotation trees on marginal lands, particularly salt-affected and barren land (Scarlat *et al*., 2015; Madiwalar *et al*., 2023).

Factors leading to abiotic stress such as temperature, heat, drought, chemical toxicity, heavy metals and salinity result in oxidative stress which ultimately affects plant development and growth. Like many other abiotic stresses, salinity also inhibits the plant growth and it is expanding rapidly as a result of different irrigation practices around the world (Munns and Gilliham, 2015). However, tolerance level of different plant species may vary (Marschner, 1995; Singh *et al.*, 2020). Around 6.71 percent of inland areas (areas far away from ocean) are affected universally and this issue is rampant in the semi-arid and arid lands of Asia, Africa and Australia. It is approximated that about 20 million hectare of such land is in Southeast Asia alone (FAO, 2015). Soil salinity affects 8.31 billion ha of land, making it an ecological problem worldwide (Munns and Tester, 2008). In India, around 6.75 million ha land is salt affected (Mandal *et al.*, 2010) and is likely to increase up to 20 million ha by the end of 21st century (CSSRI, 2013).

Eucalyptus is native to Australia and has become an important tree species in India. It has high level of growth rate as compared to other tree species under salt affected conditions, which can be interconnected to its inherent salt-tolerant ability due to some physiological advantages while linking between salt and drought response (Munns, 2002). Saline conditions up to 18 dS m^{-1} or even more than 31 dS m^{-1} can be tolerated by *Eucalyptus* spp. (Akhtar *et al.*, 2008). Presently, even though various salt tolerant cultivars of several agricultural crops are accessible to grow in relatively moderate salt affected soils, still these cultivars sink to harvest the expected yields on high saline soils. With high possibility to grow in saline soils under arid climatic conditions, *Eucalyptus* species are considered as one of the vital bio-economic tree species (Bennett *et al.*, 2009; Singh *et al.*, 2019). In *Eucalyptus* spp. biosynthesis of osmoprotectants i.e. soluble sugars, reducing sugars, proline and glycine betaine increased under increasing salt concentrations in order to cope up with salinity stress (Shariat and Assareh, 2016).

The present investigation was conducted to identify *Eucalyptus* spp. that are tolerant to salinity stress with a holistic approach highlighting differences in plant morphological, physiological and biochemical traits. The study would help in determining salt tolerance ability of four different *Eucalyptus* species and identify potential mechanisms to enhance their growth and productivity under salt stress.

Materials and Methods

Site description and experimental details

The experiment was conducted at the Research Area of Department of Forestry and Natural Resources, Punjab Agricultural University, Ludhiana. It is located at 75°78′E longitude and 30°54′ N latitude with an elevation of 247 m above the mean sea level. The region's climate is subtropical to tropical, with scorching summers (May-June) and freezing winters. The region gets majority of its rainfall (700-800 mm) from July to September, with only a few light showers in the winters. The experimental soil had sandy loam texture. The pH, EC, organic carbon, available N, P and K were 7.62, 0.28 dS m^{-1}, 0.32 %, 121.8 kg ha^{-1}, 9.2 kg ha^{-1} and 178.1 kg ha^{-1}, respectively.

Four different *Eucalyptus* species were used namely *Eucalyptus camaldulensis*, *E. pellita*, *E. tereticornis* and *E. citriodora* {Syn *Corymbia citriodora*}. Seedlings of these different *Eucalyptus* spp. were planted in earthen pots filled with 4 kg soil and 2 kg FYM (in the ratio of 2:1) in the pots having 30 cm height and 30 cm top diameter. All the plants were irrigated regularly with tap water for first two weeks for initial establishment of seedlings. For better acclimatization of plants, the T_1, T_2, T_3 and T_4 pots were irrigated with 0, 20 mM, 40 mM and 60 mM NaCl, respectively for 4 weeks. Later on, the salinity treatments were enhanced to 0, 40 mM, 80 mM and 120 mM NaCl, respectively. The other cultural and management conditions in all the treatments were similar. Irrigation water having these different salt concentrations was applied to the plants of different *Eucalyptus* spp. under study on every alternate day. The irrigation water volume was determined by adding the leaching amount to the water consumed by the plants i.e., half liter pot^{-1}. Saline water treatments were applied till the harvest of the plants. The pH of the soil increased with an increase in the concentration of NaCl which was 7.70, 8.10, 8.23 and 8.33 at 0, 40, 80 and 120 mM NaCl concentrations, respectively. The EC of soil at 0, 40, 80 and 120 mM NaCl was 0.33, 1.0, 1.54 and 2.53 dS m^{-1} respectively, at the end of experiment i.e., 7 months after initiation of salinity treatments. The average initial value soil EC was 0.28 dS m^{-1}.

Observations

Growth parameters like plant height (cm) and collar diameter (mm) were measured using a measuring scale and digital Vernier caliper (to the nearest of 0.02 mm), respectively 7 months after planting. At the end of the experiment, plants were harvested and partitioned into four components i.e., leaves, branches, stem and roots. Total plant height and root length were measured using measuring scale. Subsequently, the survival percentage of the plants was calculated. The physiological parameters viz. relative water content (RWC), electrolyte leakage, total chlorophyll content and carotenoids were determined at the end of the experiment. In the leaves, the RWC was determined by the method developed by Silveira *et al*. (2003) and the electrolyte leakage (EL) by the method suggested by Fletcher and Drexlure (1980). The method given by Hiscox and Israelstam (1979) was followed for estimation of total chlorophyll content and carotenoid. Osmolyte concentrations, viz. proline, total soluble sugars and reducing sugars content were determined in the treated plants. Proline content in the leaf samples was measured according to the method described by Bates *et al*. (1973). Total soluble sugars content was determined by the method suggested by Dubois *et al*. (1956) and the reducing sugars content by the method suggested by Sumners (1935).

Statistical analysis

The experiment was arranged in completely randomized design (CRD) with three replications. Therefore, the data collected were tabulated and analyzed by analysis of variance technique in CRD (Panse and Sukhatme, 1985). The least significant differences (LSD) at 5% level of significance were worked out to separate the means of the treatments.

Results and Discussion

Morphological parameters

Salinity stress had a significant negative impact on plant growth parameters. The seedlings grown under irrigation with high NaCl concentration (120 mM) had the lowest average plant height of 104.75 cm followed by that of those grown at 80 mM (116.82 cm) and at 40 mM (130.32 cm) and finally highest growth (160.07 cm) was attained when the seedlings were irrigated with tap water (control) (Table 1). These results indicate the existence of a reverse relationship between the salinity level and the height of plants. The average plant height differed significantly among *Eucalyptus* species with different treatments. The mean height (160.07 cm) of *E. camaldulensis* was significantly greater than other three *Eucalyptus* species whereas the lowest mean plant height was that of *E. citriodora* (100.04 cm). The interactions effects indicate that *E. pellita* had the highest percent reduction (44%) in height at 120 mM and *E. camaldulensis* the lowest (30%) from control. Increasing salinity in irrigation water significantly decreased the collar diameter of the plants. At 7 months after initiation of salinity treatments, collar diameter of plants was 9.7 mm in control, whereas with increased treatment of NaCl concentrations (40, 80 and 120 mM), there was successive decrease in collar diameter, i.e. 9.35, 8.59 and 7.81 mm, respectively (Table 1). Among *Eucalyptus* species, *E. camaldulensis* recorded the highest collar diameter (10.65 mm) and lowest (6.82 mm) was in case of *E. citriodora*. Average root length was the highest (47.14 cm) in control and the lowest (22 cm) at 120 mM concentration. The interaction effects indicate that root length was highest in control in *E. camaldulensis* (45.56 cm) whereas it was lowest (16.33 cm) in *E. citriodora* at 120 mM salinity level. Total plant length was found significantly different among the species. *E. camaldulensis* was found to be significantly superior to other species. Variations were found among treatments. In control, greatest (207.21 cm) total plant length was observed and lowest (126.75 cm) was in case of 120 mM NaCl concentration treatment (Table 1). Highest per cent reduction (49%) was recorded for *E. pellita* at 120 mM and lowest (32%) for *E. camaldulensis* from control. The highest average survival per cent (80.6%) was recorded for *E. camaldulensis* and lowest (38.3%) for *E. citriodora*. Among treatments, the highest average survival was recorded in control (94.4%) which decreased to 31.3% at 120 mM of salinity treatment.

Trees productivity is hampered by salinity stress, which is a major abiotic component. Salinity stress is a complex phenomenon that involves osmotic stress, specific ion impact, nutritional deprivation and other factors, affecting several morphological, physiological and biochemical parameters involved in plant growth and development. Plants have developed a variety of mechanisms to deal with the harmful effects of salts. The analysis of variance for different parameters was significant in the current

Table 1. Growth parameters and survival of *Eucalyptus* spp. subjected to various salinity levels

Treatments (NaCl, mM)	Species *E. camaldulensis*	*E. pellita*	*E. tereticornis*	*E. citriodora*	Mean
		Plant height (cm)			
0	195.78	167.44	151.56	125.50	160.07[a]
40	162.50	138.33	122.78	97.67	130.32[b]
80	144.67	117.00	115.28	90.33	116.82[c]
120	137.33	94.00	101.00	86.67	104.75[d]
Mean	*160.07[a]	129.19[b]	122.65[b]	100.04[c]	
LSD (P= 0.05): Species × treatments=NS					
		Collar diameter (mm)			
0	11.44	11.16	8.64	7.54	9.70[a]
40	11.08	10.74	8.22	7.35	9.35[b]
80	10.24	9.92	7.69	6.50	8.59[c]
120	9.83	8.33	7.20	5.87	7.81[d]
Mean	10.65[a]	10.04[b]	7.94[c]	6.82[d]	
LSD (P= 0.05): Species × treatments=NS					
		Root length (cm)			
0	45.56	55.11	54.89	33.00	47.14[a]
40	36.00	32.83	32.67	23.83	31.33[b]
80	35.67	29.67	28.89	20.67	28.72[c]
120	27.00	20.00	24.67	16.33	22.00[d]
Mean	36.06[a]	34.40[a]	35.28[a]	23.46[b]	
LSD (P= 0.05): Species × treatments=6.04					
		Total plant length (cm)			
0	241.33	222.56	206.44	158.50	207.21[a]
40	198.05	171.17	155.44	121.50	161.07[b]
80	180.33	146.67	144.17	111.00	145.54[c]
120	164.33	114.00	125.67	103.00	126.75[d]
Mean	195.54[a]	163.60[b]	157.93[c]	123.50[d]	
LSD (P= 0.05): Species × treatments=16.97					
		Survival (%)			
0	100.0	100.0	100.0	77.8	94.4[a]
40	88.9	66.7	79.2	44.4	69.8[b]
80	77.8	33.3	58.3	20.1	47.4[c]
120	55.6	16.3	42.1	11.0	31.3[d]
Mean	80.6[a]	54.1[c]	69.9[b]	38.3[d]	
LSD (P= 0.05): Species × treatments=NS					

*Means followed by different superscript letters are significantly different according to L.S.D. test at P=0.05

experiment, indicating the existence of genetic variability among *Eucalyptus* species and differential response of the species to different salt stress levels. Survival at higher salt concentrations with accumulation of sodium shows significant salt tolerance in *Eucalyptus* spp. The stress effect on growth parameters became more pronounced at 120 mM after 7 months of NaCl treatments. Comparably, earlier studies in *Casuarina* (Bassi *et al.*, 2020) and *Eucalyptus* (Nasim *et al.*, 2009; Singh *et al.*, 2023b) reported that with the increase of salinity, the growth of plant height was drastically reduced. This might be due to application of higher concentration of sodium chloride solution in all species which might have led to effect on photosynthetic rate, carbohydrates formation and their accumulation. Both of these factors might cause plant development to be stifled (Mazher *et al.*, 2007). The decrease in collar diameter of salt-stressed plants could be attributed to the formation of excessive salts and the resulting osmotic variations in the cellular level, causing negative effects (Silva *et al.*, 2011; Singh *et al.*, 2023a). The present study is in accordance with Alotaibi *et al.* (2013), in which stem diameter growth was significantly reduced under the highest levels of salt treatment. Increasing the concentration of NaCl in irrigation water reduced root length of *Eucalyptus* spp. which could be attributed to the fact that salinity reduced plants ability to utilize water transport due to higher osmotic stress, resulting in a decrease in growth rate as well as changes in plant metabolic processes (Munns, 2002). The results are in conformity with findings of El-Juhany *et al*. (2008) who noticed significant reduction of root length of three *Eucalyptus* species under saline irrigation conditions. Pulavarty *et al*. (2016) have reported remarkable reduction in root length in *Eucalyptus citriodora* as compared to control as the salinity increased (75 mM NaCl). Decreasing total plant length of the *Eucalyptus* spp. with increasing salinity levels concurs with findings of Gama *et al*. (2007) and Houimli *et al*. (2008) who indicated that increasing the concentration of NaCl was accompanied by proportional reductions in plant length. As the salt content increases around the root zone, osmotic stress has a direct impact on plant growth factors (Munns and Tester, 2008).

Physiological parameters

The relative water content (RWC) of the salt treated plants vary significantly at 7 months after initiation of salinity treatments with respect to increase in NaCl concentrations. Its average values among treatments ranged between 77.27% in control to 48.38% in 120 mM NaCl treated plants (Table 2). Among *Eucalyptus* species, the mean RWC was highest (71.29%) in *E. tereticornis* and the lowest in *E. citriodora* (49.65%). Electrolytes leakage (EL) was found to be significant among the species with different treatments. *E. pellita* had the highest value (53.20%) which was statistically at par with *E. citriodora* and *E. camaldulensis* (Table 2). Variations were also found among treatments. In control, lowest value (22.99%) was recorded and the highest value (76.42%) was at 120 mM NaCl concentration. Chlorophyll content was significantly affected with increasing concentration of NaCl (Table 2). The overall chlorophyll content decreased significantly as the salt level increased. *E. tereticornis* had the highest mean total chlorophyll content (19.17 mg g^{-1} fresh weight) which was at par with *E. camaldulensis* whereas the lowest value was found in *E. pellita* (9.64 mg g^{-1} fresh weight). Significant differences were also found among treatments. Plants irrigated with normal water had the highest (21.37 mg g^{-1} fresh weight) chlorophyll content and those irrigated with 120 mM NaCl had the lowest (9.07 mg g^{-1} fresh weight). Carotenoid values significantly decreased as the NaCl concentrations increased (Table 2). Among treatments, the highest carotenoid content was recorded when plants were irrigated with normal water and the lowest at 120 mM. *E. camaldulensis* had the highest value (1.074 mg g^{-1} fresh weight) which was statistically at par with *E. tereticornis*.

Table 2. Physiological parameters of *Eucalyptus* species subjected to various salinity levels

Treatments	Relative water content (%)	Electrolyte leakage (%)	Chlorophyll content (mg g^{-1} fresh weight)	Carotenoid content (mg g^{-1} fresh weight)
***Eucalyptus* species**				
E. camaldulensis	65.53^{b}	50.38^{a}	17.96^{a}	1.074^{a}
E. pellita	62.21^{b}	53.20^{a}	9.64^{c}	0.528^{c}
E. tereticornis	71.29^{a}	41.42^{b}	19.17^{a}	1.043^{a}
E. citriodora	49.65^{c}	51.07^{a}	11.87^{b}	0.692^{b}
Salinity levels (NaCl, mM)				
0	77.27^{a}	22.99^{d}	21.37^{a}	1.113^{a}
40	65.84$_{b}$	40.47^{c}	15.79^{b}	0.928^{b}
80	57.20^{c}	56.19^{b}	12.41^{c}	0.723^{c}
120	48.38^{d}	76.42^{a}	9.07^{d}	0.572^{d}

*Means followed by different superscript letters are significantly different for *Eucalyptus* species and salinity levels separately according to L.S.D. test at P=0.05

In the present study, decreased RWC with increasing concentration of NaCl in irrigation water corroborate with the results reported by Singh *et al*. (2011) and El-Juhany *et al*. (2008). According to Siddique *et al*. (2000), the ability of tolerant cultivars to absorb more water from the soil and adjust for transpiration is the reason of greater RWC. The exterior solutions of high salt content generated osmotic stress and dehydration at the cellular level, resulting in a drop in RWC (Grennway and Munns, 1980). Pulavarty *et al.* (2016) reported that increased RWC reflected salt tolerance mechanism in *E. citriodora* thereby mitigating the toxic ions with an overall contribution in preventing the plant mortality. Increasing NaCl concentration in irrigation water increased EL. The cell membrane is a thin layer of phospholipids that serves as a semi-permeable barrier to solutes. Any stress, particularly ionic stress, damages the cell membrane and allows ions to flow out (Nisha, 2015). In different crops, electrolyte leakage has been described as a useful selection criterion for salt tolerance (Tiwari *et al.,* 2010). The effect of salt tolerance on electrolyte leakage varies greatly between species and cultivars. When salt concentrations are increased, electrolyte leakage is found to increase greater in salt sensitive cultivars than in salt tolerant cultivars (Mansour and Salama, 2004). Total chlorophyll content was severely affected as the salinity level increased from control (21.37 mg g^{-1} fresh weight) to 120 mM NaCl (9.07 mg g^{-1} fresh weight) concentrations. In salt-stressed eucalyptus, chlorophyll pigment was reported to be rigorously damaged (Cha-um *et al.,* 2013). Similarly, Pulavarty *et al*. (2016) reported that chlorophyll content was significantly affected with increasing concentration of NaCl both at 2 and 6 months of treatments duration in *E. citriodora*. At high salt concentrations, Kumari *et al*. (2012) also found decrease in total chlorophyll content in *Azadirachta indica* leaves. Salinity may be causing the degradation of chlorophyll and chlorophyll protein complexes, resulting in a decrease in total chlorophyll (Sheng *et al.*, 2008). Pulavarty *et al.* (2016) stated that there was no significant variation in carotenoids content under salt treated seedlings and control after 2 months, whereas it significantly decreased in case of salt treated seedlings after 6 months. Reduction of carotenoid content with increased salinity of the soil in *Eucalyptus* clones, indicating the higher stability of maximum photosystem II (PSII) efficiency at noon in the clones may be due to the photo protection promoted by carotenoids (Andrade *et al.*, 2019). Santos and Silva (2015) emphasized that the degradation of carotenoid pigments interfered in the photo protection exerted by the plants which increased the chances of photo-oxidation under stress conditions.

Biochemical parameters

The average proline content of leaves increased at higher salt stress level of 120 mM NaCl concentration (20.73 µmole g^{-1} dry weight) as compared to the control treatment (7.0 µmole g^{-1} dry weight) (Table 3). *E. camaldulensis* had accumulated the highest proline content (16.2 µmole g^{-1} dry weight) which was statistically at par with *E. citriodora* while the lowest was recorded in *E. tereticornis* which was at par with *E. pellita* under salt stress. Increase in proline content was highest (253%) in *E. camaldulensis* at 120 mM NaCl concentration over control whereas it was lowest (169%) in *E. pellita* over control. There was significant increase in total soluble sugar content in the NaCl treated plants with increase in NaCl concentration. Total soluble sugar content was highest at 120 mM after 7 months of treatment and minimum in case of control. *E. citriodora* had accumulated highest total soluble sugar content and lowest for *E. tereticornis* which was statistically at par with *E. pellita* and *E. camaldulensis* (Table 3). The reducing sugar level increased under salt stress in all the *Eucalyptus* spp. Under salt stress, highest reducing sugar content was in *E. citriodora* followed by *E. pellita* which was statistically at par with *E. tereticornis* and *E. camaldulensis*.

E. camaldulensis has high salt tolerance ability due to maximum proline accumulation that allows it to withstand high salt concentration in irrigation water. Cha-um *et al.* (2013) reported that proline levels significantly increased in all *Eucalyptus* genotypes when plants were exposed to 200 mM NaCl for 14 days. Similar increase in proline concentration in *Pistacia atlantica* Desf. was found by Benhassaini *et al*. (2012). Under salt stress,

Table 3. Proline, total soluble sugar and reducing sugars content of *Eucalypts* spp. subjected to various salinity levels

Treatment (NaCl, mM)	Species				Mean
	E. camaldulensis	*E. pellita*	*E. tereticornis*	*E. citriodora*	
		Proline content (μmole g^{-1} dry weight)			
0	7.27	6.70	6.17	7.86	7.00[d]
40	12.88	10.55	10.88	13.30	11.90[c]
80	18.97	13.48	13.51	18.00	15.99[b]
120	25.65	18.00	16.95	22.33	20.73[a]
Mean	*16.20[a]	12.18[b]	11.88[b]	15.37[a]	
LSD (P= 0.05): Species × treatments=2.55					
		Total soluble sugars content (mg g^{-1} dry weight)			
0	16.52	16.18	13.59	27.56	18.46[d]
40	22.33	19.47	21.73	34.13	24.42[c]
80	30.40	31.32	32.53	38.00	33.06[b]
120	44.03	45.33	39.62	47.00	44.00[a]
	28.32[b]	28.08[b]	26.86[b]	36.67[a]	
LSD (P= 0.05): Species × treatments=3.96					
		Reducing sugars content (mg g^{-1} dry weight)			
0	2.69	3.54	3.14	3.95	3.33[d]
40	4.09	3.91	4.19	5.61	4.45[c]
80	5.30	5.89	5.26	6.67	5.78[b]
120	6.32	7.00	6.19	7.23	6.68[a]
	4.60[b]	5.08[b]	4.69[b]	5.86[a]	
LSD (P= 0.05): Species × treatments=NS					

*Means followed by different superscript letters are significantly different according to L.S.D. test at P=0.05

proline content in the roots of salt tolerant alfalfa plants quickly doubled, however in salt sensitive plants the response was sluggish (Fougere *et al.*, 1991). Proline is one of the most important osmolytes in salt stressed plants, controlling osmotic potential at the cellular level (Szabados and Savoure, 2009). Plants that are stressed, such as those that are exposed to salt, accumulate proline. In salt tolerant genotypes, the build-up of high levels of proline may be attributed to both higher rate of proline synthesis and a lower magnitude of proline oxidation (Kumar *et al.*, 2003). Salt stress increased the content of soluble sugars in the leaves of all *Eucalyptus* spp. as salinity levels increased. Shariat and Assareh (2016) also concluded that soluble sugars content increased progressively by increasing the intensity of salt stress. Plants try to mitigate the negative effects of salt stress by accumulating more soluble sugars, which results in an increase in total soluble sugars. Similar findings were reported in a study conducted by Hasegawa *et al.* (2000) who reported that plants normally cope with salinity stress in a variety of ways. Accumulation of total soluble sugars being the important ones that function as osmolytes. The reducing sugar content under this study increased as salinity increased. One of the mechanisms established by plants to overcome salt stress is a large category of organic osmotic solutes comprised of sugars (Gupta and Huang, 2014). The role of reducing sugars (glucose and fructose) in the adaptive mechanism is more debatable, and their accumulation can be harmful from several perspectives (Kerepesi and Galiba, 2000).

Conclusions

The study showed that the growth traits of *E. camaldulensis, E. pellita, E. tereticornis* and *E. citriodora* were drastically reduced under salt stress. The relative water content, chlorophyll and carotenoids decreased significantly under salinity stress. Consequently, electrolytes leakage increased significantly under high salt stress treatment. Furthermore, an increase in proline, total soluble sugar and reducing sugar synthesis reflects a salt tolerance mechanism, mitigating the effect of toxic ions and contributing to plant mortality prevention. Results indicate that *E.*

camaldulensis was the most tolerant species which had optimum growth even at 120 mM but *E. citriodora* was the most sensitive species to salinity stress. Thus, *E. camaldulensis* could have a significant impact on breeding approaches and species selection for salt-affected lands.

References

Akhtar J, Saqib ZB and Qureshi RH (2008) The effect of spacing on the growth of *Eucalyptus camaldulensis* on salt-affected soils of the Punjab, Pakistan. *Canadian Journal of Forest Research* **38**: 2434-2444.

Alotaibi MO, Mahammed AE, Hamid MM, Abdalla MS and Elobeid MM (2013) Physiological behavior and growth responses of *Eucalyptus camaldulensis* Dehn. seedlings to salt stress conditions. *International Journal of Scientific Research* **4**: 2434-2438.

Andrade JR, Maia S, Santos AFS, Silva VM, Bezeoca LT, Silva JRR, Santos CM, Ferreira VM and Endres L (2019). Photosynthetic performance in *Eucalyptus* clones cultivated in saline soil. *Emirates Journal of Food and Agriculture* **31**: 368-379.

Bassi P, Garg RK, Choudhary OP and Kaur N (2020) Effect of salinity stress on growth related physiological and biochemical traits of *Casuarina* clones in nursery. *Indian Journal of Agroforestry* **22**: 90-96.

Bates LS, Waldren RP and Tears ID (1973) Rapid determination of free proline for water stress studies. *Plant and Soil* **39**: 205-207.

Benhassaini H, Fetati A, Hocine AK and Belkhodja M (2012) Effect of salt stress on growth and accumulation of proline and soluble sugars on plantlets of *Pistacia atlantica* Desf. used as rootstocks. *Biotechnology, Agronomy, Society and Environment* **16**: 159-165.

Bennett SJ, Barrett-Lennard EG and Colmer TD (2009) Salinity and waterlogging as constraints to salt and pasture production: a review. *Agriculture, Ecosystem and Environment* **129**: 349–360.

Cha-um S, Somsueb S, Samphumphuang T and Kirdmanee C (2013) Salt tolerant screening in eucalypt genotypes (*Eucalyptus* spp.) using photosynthetic abilities, proline accumulation, and growth characteristics as effective indices. *In Vitro Cellular and Developmental Biology* **l49**: 611-619.

Christie S (2008) Energy, chemicals and carbon: future options for the Eucalyptus value chain. *Southern Forests* **70**: 175–182.

CSSRI (2013) *Annual Report ICAR-Central Soil Salinity Research Institute*, Karnal, Haryana-132 001, India.

Dubois M, Giles KA, Hamilton JK, Reters PA and Smith F (1956) Calorimetric method for the determination of sugars and related substances. *Analytical Chemistry* **28**: 350-356.

El-Juhany L, Aref IM and Ahmed AIM (2008) Response of *Eucalyptus camaldulensis, Eucalyptus microtheca* and *Eucalyptus intertexta* seedlings to irrigation with saline water. *World Journal of Agricultural Sciences* **4**: 825-834.

Fletcher RA and Drexlure DM (1980) Interactions of dichloro-methyl and 2, 4-D in cultivated oats (*Avena sativa*). *Weed Science* **28**: 363–366.

Food and Agricultural Organization of the United Nations (2009) *Proceedings FAO advisory committee on paper and wood products*. Fiftieth session, Rome, Italy.http://www.fao.org/3/k6183e/k6183e00.htm.

Food and Agricultural Organization of the United Nations (2015) *Status of the world's soil resources-main report*. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy. ISBN 978-92-5-109004-6.

Food and Agricultural Organization of the United Nations (2016) *Global forest resources assessment 2015. How are the world's forests changing*? Second Edition, Food and Agricultural Organization of the United Nations, Rome, Italy, p 56. http://www.fao.org/3/a-i4793e.pdf.

Fougere FL, Rudulier D and Streeter JG (1991) Effects of salt stress on amino acid, organic acid, and carbohydrate composition of roots, bacteroids, and cytosol of alfalfa (*Medicago sativa* L.). *Plant Physiology* **96**:1228-1236.

Gama PBS, Inanaga S, Tanaka K and Nakazawa R (2007) Physiological response of common bean (*Phaseolus vulgaris* L) seedlings to salinity stress. *African Journal of Biotechnology* **6**: 79-88.

Greenway H and Munns R (1980) Mechanism of salt tolerance in non-halophytes. *Annual Review of Plant Physiology* **31**: 149-190.

Gupta B and Huang B (2014) Mechanism of salinity tolerance in plants: Physiological, biochemical and molecular characterization. *International Journal of Genomics* 2014: 701596 https://doi:10.1155/2014/701596.

Hiscox JD and Israelstam GF (1979) A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**: 1332-1334.

Houimli SIM, Denden M and Elhadj SB (2008) Induction of salt tolerance to pepper (B or Hbt 1mmtt1) by 24-epibrassinolide. *Eurasian Journal of Biosciences* **2**: 83-90.

Kerepesi H and Galiba G (2000) Osmotic and salt stress-induced alternation in soluble carbohydrate content in wheat seedlings. *Crop Science* **40**:482-487.

Kumar SG, Reddy AM and Sudhakar C (2003) NaCl effects on proline metabolism in two high yielding genotypes of mulberry (*Morus alba* L.) with contrasting salt tolerance. *Plant Science* **165**: 1245-1251.

Kumari SPK, Sridevi V and Lakshmi MVVC (2012) Studies on effect of salt stress on some medicinal plants. *International Journal of Computational Engineering Research* **2**:143-149.

Madiwalar AF, Dhillon GPS, Singh A, Singh P and Singh B (2023). *Eucalyptus* clones respond differentially for heavy-metals phytoextraction and carbon sequestration in tree biomass and soil with distillery effluents irrigation in north-western India. *Proceedings of Indian Science Academy* **89**: 77-100.

Mandal AK, Sharma RC, Singh G and Dagar JC (2010) *Computerized Database on Salt Affected Soils in India*. Technical Bulletin: ICAR-CSSRI/Karnal/2010 Karnal, Pp-28.

Mansour MMF and Salama KH (2004) Cellular basis of salinity tolerance in plants. *Environmental and Experimental Botany* **52**:113-122.

Marschner H (1995) *Mineral Nutrition of Higher Plants*. Pp. 889, Academic press, London.

Mazher AMA, El-Quesni EMF and Farahat MM (2007) Responses of ornamental and woody trees to salinity. *World Journal of Agricultural Sciences* **3**: 386–395.

Munns R (2002) Comparative physiology of salt and water stress. *Plant, Cell and Environment* **25**: 239–250.

Munns R and Gilliham M (2015) Salinity tolerance of crop what is the cost? *New Phytologist* **208**: 668-673.

Munns R and Tester M (2008) Mechanisms of salinity tolerance. *Annual Review of Plant Biology* **59**: 651–681.

Nasim M, Qureshi HQ, Aziz T and Saqib M (2009) Different *Eucalyptus* species show different mechanism to tolerance to salinity and salinity x hypoxia. *Journal of Plant Nutrition* **32**: 1427-1439.

Nisha S (2015) *Effect of salinity on morphological characteristics of* Dalbergia sissoo *Roxb.* M.Sc. Thesis, CCS Haryana Agricultural University, Hisar, Haryana, India.

Phillips RB (2013) Global dynamics of the pulp and paper industry. *New Zealand Journal of Forestry Science* **58**: 34–42.

Pulavarty A, Kukde S, Shinde V M and Sarangi BK (2016) Morphological, physiological and biochemical adaptations of *Eucalyptus citriodora* seedlings under NaCl stress in hydroponic conditions. *Acta Physiologiae Plantarum* **38**: 1–12.

Santos CM and Silva MA (2015) Physiological and biochemical responses of sugarcane to oxidative stress induced by water deficit and paraquat. *Acta Physiologiae Plantarum* **37**: 1-14.

Scarlat N, Dallemand JF, Monforti-Ferrario F and Nita V (2015) The role of biomass and bioenergy in a future bioeconomy: Policies and facts. *Environmental Development* **15**: 3-34.

Silva PHM, Poggiani F and Laclau JP (2011) Applying sewage sludge to *Eucalyptus grandis* plantations: Effects on biomass production and nutrient cycling through litterfall. *Applied and Environmental Soil Science* https://doi:10.1155/2011/710614.

Silveira JAG, Viegas RA, Rocha IMA, Moreira ACDM, Moreira RA and Oliveira JTA (2003) Proline accumulation and glutamine synthetase activity are increased by salt-induced proteolysis in cashew leaves. *Journal of Plant Physiology* **160**:115–123.

Shariat A and Assareh MH (2016) Physiological and biochemical responses of eight *Eucalyptus* species to salinity stress. *Ecopersia* **4**: 1269-1282.

Sheng M, Tang M, Chen H, Yang B, Zhang F and Huang Y (2008) Influence of arbuscula rmycorrhizae on photosynthesis and water status of maize plants under salt stress. *Mycorrhiza* **18**: 287-296.

Siddique MRB, Hamid AIMS and Islam MS (2000) Drought stress effects on water relations of wheat. *Botanical Bulletin of Academia Sinica* **41**: 35-39.

Singh A, Singh P, Dhillon GPS, Sharma S, Singh B and Gill RIS (2023a) Differential impacts of soil salinity and water logging on Eucalyptus growth and carbon sequestration under mulched vs. unmulched soils in south-western Punjab, India. *Plant and Soil* **482**: 401-425.

Singh A, Toky OP, Singh B and Dhillon GPS (2011) Influence of salinity on biomass and plant water relations of *Eucalyptus tereticornis* and *E. camaldulensis*. *Indian Journal of Ecology* **38**: 180–183.

Singh B, Dhillon GPS, Singh A and Singh P (2023b) Soil salinity and variable moisture regimes impacts on growth attributes of *Eucalyptus* in north-western Punjab, India. *Journal of Soil Salinity and Water Quality* **15**: 15-24.

Singh B, Kaur N and Gill RIS (2019) Saline agroforestry: a hanging fruit for saline waterlogged ecologies. *In: Research Developments in Saline Agriculture*. Pp 705-727, Dagar JC, Yadav RK and Sharma PC (Eds.). Springer Nature, Singapore Pvt Ltd, Singapore.

Singh B, Kaur B and Singh D (2020) Assessment of different multipurpose tree species for phytoextraction of lead from lead-contaminated soils. *Bioremediation Journal* **24**: 215-230.

Sumner JB (1935) A more specific reagent for the determination of sugars in urine. *Biological Chemistry* **36**: 393-407.

Szabados L and Savoure A (2009) Proline: a multifunctional amino acids. *Trends in Plant Science* **15**: 89-97.

Tiwari JK, Munshi AD, Kumar R, Pandey RN, Arora A and Bhat JS (2010) Effect of salt stress on cucumber Na^+, K^+ ratio, osmolyte concentration, phenols, chlorophyll content. *Acta Physiologiae Plantarum* **32**: 103-114.

Received: March 20, 2024; Accepted : June 26, 2024

Journal of Soil Salinity and Water Quality 16(1), 94-102, 2024

Wetted Front Advance under Surface Vertical Line Segment Source for Designing Drip Irrigation for Deep Rooted Crops

Chhedi Lal Verma[1]*, Ravi Kant Pandey[2], Sushrut Richa[3] and Shyam Ji Mishra[4]

[1, 4]Central Soil Salinity Research Institute-Regional Research Station,
PO. Dilkusha,Lucknow-226002, Uttar Pradesh, India
[2]Ph.D. Scholar, SHUATS, Prayagraj, Uttar Pradesh, India
[3]M. Tech. Research Scholar, Deptt. Mechanical Engineering, HBTU, Kanpur, Uttar Pradesh, India
**Corresponding author's E-mail: lalc_verma@yahoo.com*

ABSTRACT

Surface vertical line segment source is suitable for applying irrigation water to deep rooted plantations. Wetted front advance in horizontal and vertical direction are required for deciding the spacing between emitters, drip laterals and depth of water application. Shape of wetted soil mass in combination of average change in volumetric moisture content as single soil input parameter has led to develop simple models for predicting wetted front advance. Two mathematical models namely Moving Cylinder Model and Cylinder with Hemispheroid Model were developed to describe wetted front advance under surface vertical line segment source water flow geometry. The developed models were tested with sand tank model data especially for lateral and vertical advances of wetted fronts. The values of predicted wetted front radii and depths compared closely with the observed wetted front radii and depths with average percent deviations of 2.47% and 4.84% for Moving Cylinder Model and 2.78% and 7.44% for Cylinder with Hemispheroid Model once the flow geometry is fully developed. Advantage of the models is that they require average change in volumetric moisture content as basic soil input parameter, which is quite easy to determine under field conditions. The developed model may be satisfactorily used for field application in normal as well as salt affected soils.

Key words: Drip irrigation, Hydraulic conductivity, Line source, Surface irrigation, Wetting pattern

Introduction

Drip irrigation is becoming popular day by day in developing nations due to increasing water scarcity and government support subsidy for its adaption. Surface drip irrigation system is being used by cultivators for irrigating all types of crops. It is becoming popular because of its associated advantages and installation ease. Surface drip irrigation system has been used for all type of crops but not very effective for deep rooted orchard crops. In sodic soils surface drip irrigation system is not suitable for plantation crops. Surface vertical line segment source would be quite effective under sodic condition. Use of surface drip irrigation for deep rooted crops has limitations due to deep rooting pattern and limited nutrient and moisture availability from limited soil. Losses of moisture from surface and hindrance in agricultural operations while irrigations are other problems associated with surface drip irrigation system. For deep rooted plantation there is need to develop special type of drip system which overcomes all associated problems of drip for irrigation in irrigating deep rooted plantation crops. Surface line segment source seems to be quite useful for developing a new drip irrigation system for crops and orchard plantation efficient irrigation. Geometrical complexity and unsaturated hydraulic conductivity function all together makes the analytical solutions complex and further soluble analytically. Numerical solutions are complex for field application and understanding water front movement pattern behavior from the sets of equations. Sodic soils are available in the country for deep rooted salt tolerant plantation crops and vertical line segment source a special variant of drip irrigation system would be quite useful.

Knowledge of soil wetting pattern and its advancement with time plays an important in deciding spacing between emitters and pipes. It is also required for designing of irrigation scheduling and improving the efficiency of drip irrigation (Subbaiah, 2013). The soil wetting pattern can be directly measured in the field or can be obtained by using analytical or numerical models. Most of the models use Richards' (1931) equation for estimation of water flow under unsaturated conditions to simulate the soil water potential or water content distribution in the wetted soil. Surface drip irrigation with point and/or line water source systems is quite common for variety of crops (Raats, 1970; Philip 1971; Zachman and Adrian, 1973; Gilley and Allred, 1974; Philip, 1972; Raats, 1972; Warrick and Lomen, 1977; Philip and Forrester, 1975; Thomas *et al*., 1977; and Raats, 1977). Chhedi Lal (2000) developed a series of solutions for wetted front advance against various possible water flow geometries using average change in soil moisture content as basic soil input parameter. Root activity pattern is affected by soil wetting pattern of drip irrigation (Ma *et al.,* 2022) and researchers are still working on geometry of wetted soil volume (Cristobal-Munoz *et al.,* 2022).

Basic input to these models is unsaturated hydraulic conductivity function. A good number of unsaturated hydraulic conductivity functions are reported (Burdine, 1953; Gardener, 1958; Brook and Corey, 1966; Maulem, 1976 and van Genuchten, 1980) but the Gardener's (1958) exponential unsaturated hydraulic conductivity function had been used extensively to linearize Richards water flow equation. Gardener's conductivity function does not represent whole range of soil matric suction and hydraulic conductivity. The constant "a", which is relative measure of capillary over gravity, is assumed constant in Gardener's conductivity function, which is not a real case. Determination of unsaturated hydraulic conductivity function itself is a tedious job in the laboratory and requires a lot of efforts and time to get a reliable representative value. A number of researchers are trying to develop techniques for the measurement of unsaturated hydraulic conductivity function with field test data (drip discharge, wetted front advance with time and moisture pattern) but they are yet to be standardized for field application. Singh and Verma (2010) developed a model to calculate unsaturated hydraulic conductivity from particle size distribution curve but failed to give a functional relationship which can linearize the moisture flow equation for water front movement. Kumari *et al.* (2012) studied wetted front advance under point source and formation of line source with passage of time. Ismail *et al.* (2006) developed and studied Drip Chartist using Microsoft Visual Basic for single and bilateral tubing with and without physical barriers for surface and subsurface drip. The model is fast and stable for all soil textures and suitable to monitor the effect of several design parameters, soil properties, and solution techniques on the wetting pattern shape.

Semi empirical model are simple and convenient for system design than the dynamic models. Schwartzman and Zur (1986) developed simplified semi-empirical models of wetted soil geometry with surface trickle irrigation and Singh *et al*. (2006) developed similar models for Surface drip irrigation system. For better understanding and application of analytical model simple soil parameter need to be employed to reduce the complexity of the solution. Smart irrigation systems are being integrated with smart IOT devices to automate the irrigation process (Drashti *et al.,* 2023).

Ben Asher *et al*. (1986) first derived a transient water flow model to describe water flow under surface point source conditions using average change in volumetric moisture content as basic input soil parameter to the model. He concluded that experimental data were in close agreement with values calculated by the model over a sufficiently long period of time. An approximate spheroidal model is proposed for explaining the wetting front advance under Surface vertical line segment drip source using average change in volumetric moisture content as single soil parameter under gravity dominant flow conditions.

Materials and Method

Theoretical Development

Water application from closely spaced emitters behaves like line source for all practical purposes.

Actually uniform emission of water from a porous lateral line is an ideal example of line source. A line source segment may be created horizontally or vertically for applying water to specific soil geometry. A vertically placed horizontal line segment drip source would be a good design of drip irrigation system for irrigating deep rooted horticultural crops. Design and development of such systems are still missing in the literature and field. When water starts seeping out from surface vertical line segment source a saturated cylinder of very small diameter develops initially, with hemi spheroidal cap on the bottom ends of the segment and a circle on the soil surface. With the passage of time wetted front geometry grows as a combination of wetted cylinder and hemi-spherical caps at the ends under capillarity dominant flow and with hemi spheroidal caps under gravity dominant flow conditions. Water flow geometry for surface vertical line segment source as shown in Fig. 1. The volume of wetted soil mass having unit length along lateral can be calculated as follows.

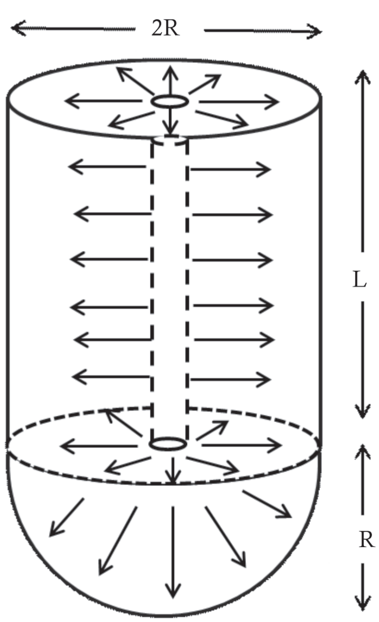


Fig. 1 Wetted front geometry under surface vertical line segment drip source

Evaporation is the major loss from wetted soil surface directly exposed to atmosphere. Uptake of water from wetted soil volume is in the form of transpiration. There is almost no water loss as the wetted front is below the soil surface. If the wetted soil volume is more the root development will be more and consequently transpiration rate will be high. When gravity is dominant under vertical line segment source a spheroidal wetted front geometry develops. The symmetry of wetted front against horizontal mid section of vertical line segment starts deteriorating. Wetted front can be considered of two hemispheroid with a common radius but two different height or depths. The volume of wetted soil mass can be worked out by summing up of upper and lower hemi-spheroids as below.

$$V_w = \pi r^2 (L + \frac{2}{3} y) \Delta\theta \qquad \ldots(1)$$

where,

V_w = Vs. Δθ, volume of water in wetted soil, [L^3]

Vs = volume of wetted soil, [L^3]

R_t = wetted front radius, [L]

L = height or length of cylinder (length of line segment) [L]

y = depth of spheroid, [L]

Δθ = average change in volumetric moisture content [L^3L^{-3}]

Volume of water present in wetted soil can be also calculated from emitter discharge rate, q and time of irrigation, t (V_w=qt).

Differentiating equation (1) and changing it to water balance equation as under.

$$\pi L \Delta\theta . 2r \frac{dr}{dt} + \frac{2}{3} \pi \Delta\theta (r^2 \frac{dy}{dt} + 2yr \frac{dr}{dt}) = qL - \pi r^2 E - \pi r^2 (L + \frac{2}{3} y) T \qquad \ldots(2)$$

Substituting y=ar, in the above water balance equation, the following governing equation can be obtained.

$$V_w = 2\pi\Delta\theta \left[L \int_0^{R_t} \frac{rdr}{qL - \pi r^2 E - \pi r^2 (L + \frac{2}{3} ar) T} + 2a \int_0^{R_t} \frac{r^{2dr}}{qL - \pi r^2 E - \pi r^2 (L + \frac{2}{3} ar) T} \right] \qquad \ldots(3)$$

the solutions of the above governing equation for different cases can be worked out as under.

Case 1: When E=0 and T=0, the governing equation, then, reduces to,

$$t = 2\pi\Delta\theta\left[L\int_0^{R_t}\frac{rdr}{qL} + 2a\int_0^{R_t}\frac{r^{2dr}}{qL}\Big|\right] \qquad \ldots(4)$$

And the solution obtained can be written as.

$$t = \frac{2\pi\Delta\theta}{qL}\left[L\frac{R_t^2}{2} + a\frac{R_t^3}{3}\Big|\right] \qquad \ldots(5)$$

When a=1, the wetted soil mass becomes, a combination of the cylinder and the hemisphere and the final solution becomes,

$$t = \frac{2\pi\Delta\theta}{qL}\left[L\frac{R_t^2}{2} + \frac{R_t^3}{3}\Big|\right] \qquad \ldots(6)$$

When L>0 and T=0,the governing equation, then, reduces to,

$$t = 2\pi\Delta\theta\left[L\int_0^{R_t}\frac{rdr}{qL - \pi r^2 E} + 2a\int_0^{R_t}\frac{r^{2dr}}{qL - \pi r^2 E}\Big|\right] \qquad \ldots(7)$$

And the solution obtained is presented below,

$$t = \frac{\Delta\theta}{E}\left[\ln\frac{qL}{\frac{qL}{\pi E} - r_T^2} + a\left(\sqrt{\frac{qL}{\pi E}}\ln\frac{\sqrt{\frac{qL}{\pi E}} + R_t}{\sqrt{\frac{qL}{\pi E}} - R_t}\right) - 2R_t\Big|\right]$$

When a=1, the solution reduces to,

$$\ldots(8)$$

$$t = \frac{\Delta\theta}{E}\left[\ln\frac{qL}{\frac{qL}{\pi E} - r_T^2} + \left(\sqrt{\frac{qL}{\pi E}}\ln\frac{\sqrt{\frac{qL}{\pi E}} + R_t}{\sqrt{\frac{qL}{\pi E}} - R_t}\right) - 2R_t\Big|\right] \qquad \ldots(9)$$

Case 3: When E=0 and T>0, the governing equation, then, reduces to,

$$t = 2\pi\Delta\theta\left[L\int_0^{R_t}\frac{rdr}{qL - \pi r^2(L + \frac{2}{3}ar)T} + 2a\int_0^{R_t}\frac{r^{2dr}}{qL - \pi r^2(L + \frac{2}{3}ar)T}\Big|\right] \qquad \ldots(10)$$

And the approximate solution is given below.

$$t = \frac{2\pi\Delta\theta}{qL}\left[\begin{array}{l} L\left\{\frac{R_t^2}{2} + \frac{\pi T}{qL}\left(\frac{LR_t^4}{4} + \frac{2}{3}a\frac{R_t^5}{5}\right) + \frac{\pi^2T^2}{q^2L^2}\left(\frac{LR_t^4}{4} + \frac{2}{3}a\frac{R_t^5}{5}\right)\right\} + \\ a\left\{\frac{R_t^3}{3} + \frac{\pi T}{qL}.\left(L\frac{R_t^5}{5} + \frac{2}{3}\frac{R_t^6}{6}\right) + \frac{\pi^2T^2}{q^2L^2}\left(L\frac{R_t^5}{5} + \frac{2}{3}a\frac{R_t^6}{6}\right)\right\} \end{array}\Big|\right] \qquad \ldots(11)$$

Experimental Verification

An experiment was conducted in a sand tank model (0.95 m × 0.95 m × 1.08 m) by creating a 15 cm long surface vertical line segment source at the corner by puncturing a drip tube closely to develop gravity dominant quarter wetted front advance pattern (Fig. 2). The study was conducted in the laboratory of Irrigation and Drainage Engineering Department, Pantnagar University during year 2000. Sun dried, cleaned coarse sand was filled in the sand tank model uniformly in layers and the wetted front advances under surface vertical line segment source were outlines against time and measured in laboratory. The sand tank model was made of angular mild steel frame having transparent Perspex sheets from two sides of the tank. The discharge of line source segment was measured to be 3.5 lph. Wetted front radius and depths from the centre of the source were measured at 2 cm regular interval and plotted later to depict the wetted front profiles. Water was applied for 150 minutes and wetted fronts advance

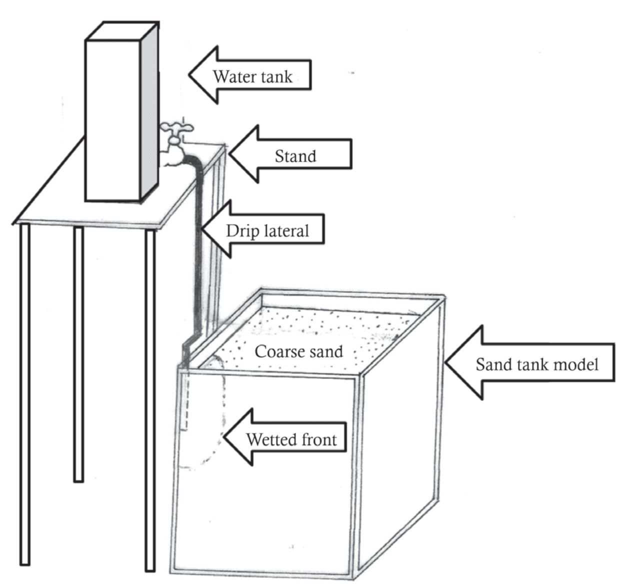


Fig. 2 Experimental set up

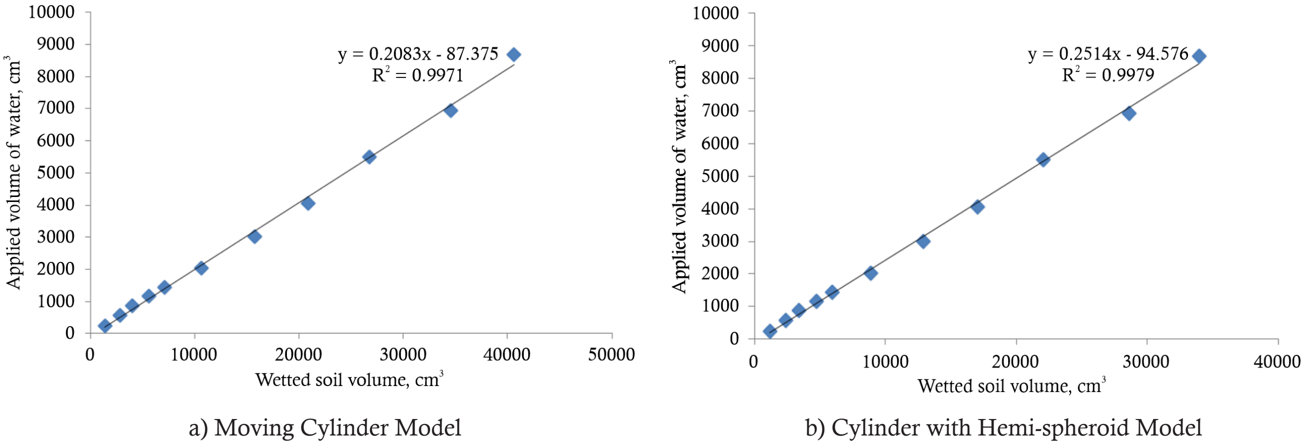


Fig. 3 Variation of wetted soil volume against applied volume of water under surface vertical line segment source in course sand

were measured after 4, 10, 15, 20, 25, 35, 52, 70, 95, 120 and 150 minutes of water application times by outlining boundary of wetted front with the help of color pencil. Volumetric moisture contents were worked out by measuring slope of plotted line between applied volumes of water against wetted soil volumes for cylinder with hemi-spheroid and moving cylinder as shown in Fig. 3. Volumetric moisture contents for both the model were also directly calculated and averaged out (Table 1 and 2). Average change in volumetric moisture content was considered as a basic soil input parameter to the model to predict wetted front advance with respect to time. Wetted front radii and total length of spheroid were calculated using a=b=1 and Eqn. (6). Calculated and observed values wetted fronts and their % deviations are presented in Table 1 and 2 for moving cylinder model and cylinder with hemi-spheroid model, respectively.

RESULTS AND DISCUSSION

Surface vertical line segment source is suitable to deep rooted orchard/plantations crops such as guava, mango, litchi, and ber etc. with effective root zone as 1.0 to 1.5 m from irrigation point of view in normal and sodic soils. Traditional surface drip irrigation is being used to apply water to these orchard crops. To ensure water application to root zone depth surface line segment source may an effective method in normal as well as sodic soil conditions. Study of wetted front geometry under surface line segment source is needed for designing of the system. Two new models namely Moving Cylinder Model and Cylinder with Hemi-spheroid Model were studied.

Assessment of Volumetric Moisture Content

Variations of applied volume of water and wetted soil volumes by Moving Cylinder Model and Cylinder with Hemi-Spheroid for 15 cm long surface vertical line segment source against 3.5 lph discharge rate as shown in Fig. 3. Advance of wetted front positions in the horizontal (radii) and vertically downwards below the source (depths) against time as shown in Fig. 4. It may be seen from Fig. 3 and 4 that the advance of wetted front positions has a U shape with almost a flat bottom initially, but with increased in time, the flat bottom acquired a semi-circular/ ellipsoidal shape. The wetted front on soil surface advanced in a circular shape with time. Surface wetted front radii advanced 14 cm after 10 minutes and 28 cm after 150 minutes of water application time. The wetted front depth below the source advanced to a distance of 3.6 cm after 10 minutes and 41 cm after 150 minutes from the source. The shape of wetted soil mass appeared to be a combination of Moving Cylinder and Cylinder with hemi-spheroid. Two models namely Moving Cylinder and Cylinder with Hemi-Spheroid were proposed for describing wetted front advance under vertical line segment source with one end on soil surface. Moving cylinder model ignores curvilinear portion of wetted front but signifies wetted front radius and depth which is useful for designing the system. In order to work out average change in volumetric moisture content (Δθ) the applied

Table 1. Predicted wetted front radii and depths by Moving Cylinder model for surface vertical line segment source with a discharge of 3.5 lph.

Time min	Observed wetted front positions		Wetted soil volume cm^3	Applied volume of water cm^3	Volumetric moisture content cm^3	Predicted wetted front		Percent deviation	
	Radius cm	Height cm				Radius cm	Height cm	Radius cm	Height cm
4	10.4	16.4	1393.2	231.5	0.1662	9.40	13.41	+9.62	+18.23
10	14.0	18.6	2863.3	578.7	0.2021	13.96	18.50	+0.29	+0.54
15	16.0	20.0	4021.2	868.0	0.2158	16.49	21.25	-3.06	-6.25
20	18.0	22.0	5598.3	1157.3	0.2067	18.16	22.38	-0.89	-1.73
25	19.2	24.6	7122.4	1446.7	0.2031	19.44	24.59	-1.25	-2.46
35	22.0	28.0	10643.7	2025.3	0.1903	21.29	26.52	+3.23	+6.36
52	23.2	37.2	15726.7	3009.1	0.1914	22.51	35.03	+2.97	+5.83
70	24.4	44.6	20854.7	4050.7	0.1942	23.86	42.63	+2.21	+4.42
95	25.6	52.0	26765.4	5497.3	0.2054	25.74	52.56	-0.55	-1.08
120	27.0	60.4	34582.3	6944.0	0.2008	26.84	59.69	+0.59	+1.18
150	28.0	66.0	40639.6	8680.0	0.2136	28.71	69.37	-2.54	-5.11
					0.1991			2.47	4.84

Table 2. Predicted wetted front radii and depths by cylinder with hemispheroid model in coarse sand for surface vertical line segment source with a discharge of 3.47 lph

Time min	Observed wetted front positions				Wetted soil volume water cm^3	Applied volume of water cm^3	Volumetric moisture content cm^3/cm^3	Predicted wetted front		Percent deviation	
	Radii cm	Depth of cylinder cm	Depth of spheroidal cm	Total depth cm				Radii cm	Total depth cm	Radii	Total depth
4	10.4	9.6	7.4	16.4	1183.6	231.5	0.1956	9.21	11.9	+11.44	+27.44
10	14.0	10.0	8.6	18.6	2422.0	578.7	0.2389	13.70	17.6	+2.14	+5.38
15	16.0	10.8	9.2	20.0	3404.7	868.0	0.2550	16.18	20.6	-1.13	-3.00
20	18.0	12.0	10.0	22.0	4750.1	1157.3	0.2436	17.79	21.4	+1.17	+2.73
25	19.2	12.6	12.0	24.6	5964.3	1446.7	0.2426	18.93	23.8	+1.41	+3.25
35	22.0	14.4	13.6	28.0	8920.5	2025.3	0.2270	20.99	24.9	+4.69	+11.07
52	23.2	17.4	19.8	37.2	12935.6	3009.1	0.2326	22.41	34.9	+3.41	+8.33
70	24.4	20.4	24.2	44.6	17082.8	4050.7	0.2371	23.79	41.9	+2.50	+6.05
95	25.6	24.8	27.2	52.0	22098.6	5497.3	0.2488	25.56	51.8	+0.16	+0.39
120	27.0	29.2	31.2	60.4	28627.8	6944.0	0.2426	26.63	58.3	+1.37	+3.48
150	28.0	29.4	32.6	66.0	33948.5	8680.0	0.2557	28.35	73.1	-1.25	-10.76
Average							0.2381			2.78	7.44

volume of water was plotted against wetted soil volume and slopes of the straight lines were worked out. The values of $\Delta\theta$ for Moving Cylinder were worked out as 0.2514 cm^3 cm^{-3}and for Cylinder with Hemi-spheroid was 0.2083 cm^3 cm^{-3} (Fig. 3).

1. Moving Cylinder Model

Wetted soil volume by vertical line segment source with one end on soil surface was considered as an approximate cylinder having radius of wetted front on soil surface and heights of wetted front at the vertical line segment source. Applied volume of water and calculated wetted volume of soil as presented in Table 1 and their corresponding variations as shown in Fig. 3a. It may be seen from Fig. 3a and Table 1 that the applied volume of water varies linearly with wetted soil volume. Applied volume of water ranged 231.5 to 8680.0 cm^3 and respective wetted soil volume ranged

1393.2 to 40639.6 cm^3 over a time period of 150 minute. Average change in volumetric moisture content ranged from 0.1662 to 0.2158 cm^3cm^{-3} with an average value of 0.1991 cm^3cm^{-3}. A representative average change in volumetric moisture content estimated from the slope of plotted line was 0.2083 cm^3cm^{-3}. Predicted value of radius of cylinder ranged from 9.40 to 28.71 cm and height of cylinder 13.41 to 69.37 cm. Percent deviation of predicted values of wetted front radii of cylinder deviated in the range of -3.06 to +9.62 and heights in the range of -5.11 to +18.23 (Fig. 4 and 5). Except for a few values all the predicted values of wetted front radii and heights were within 10 percent over a time period of 150 minutes in coarse sand. Moving cylinder model gave reasonably close values of wetted front radii and heights which is good enough for designing of drip irrigation system supporting deep rooted horticultural crops. The model is quite simple for field application.

2. Cylinder with Hemispheroid Model

Applied volume of water and calculated wetted volume of soil as presented in Table 2 and their corresponding variations as shown in Fig. 3. Applied volume of water ranged 231.5 to 8680.0 cm^3 and respective wetted soil volume ranged 1183.6 to 33948.5 cm^3 over a time period of 150 minute. Average change in volumetric moisture content ranged from 0.1956 to 0.2557 cm^3cm^{-3} with an average value of 0.2381 cm^3cm^{-3}. A representative average change in volumetric moisture content estimated from the slope of plotted line was 0.2514 cm^3cm^{-3}. Representative value of average change in soil moisture content for Cylinder with Hemispheroid Model was 1.2069 times higher than the values obtain for Moving Cylinder Model. Predicted value of radii of cylinder ranged from 9.21 to 28.35 cm and total height (cylinder height + spheroid height) from 11.9 to 73.1 cm over a time period of 150 minute. Percent deviation of predicted values of wetted front radii of cylinder deviated in the range of -1.25 to +11.44 and heights in the range of -10.76 to +27.44 (Fig. 4 and 5). Except for a few values of wetted front radii and heights all the predicted values of wetted front radii and heights were within 10 percent over a time period of 150 minutes in coarse sand. Cylinder with Hemispheroid Model gave quite close values of wetted front radii and heights which is sufficient for designing of drip irrigation system for deep rooted horticultural crops. Cylinder with Hemispheroid Model was found superior over Moving Cylinder Model due to consideration of actual wetted front geometries below the cylinder which was ignored in case of Moving Cylinder Model.

Individual estimate of volumetric moisture content increased slightly with respect to time and ranged from 0.1662- 0.2158 cm^3cm^{-3}. Initial variations of average change in volumetric moisture content are high due to deviation of developed wetted front geometry with proposed cylinder with spheroidal model and moving cylinder model. After about 15 minutes wetted front geometry is fully developed and variation in

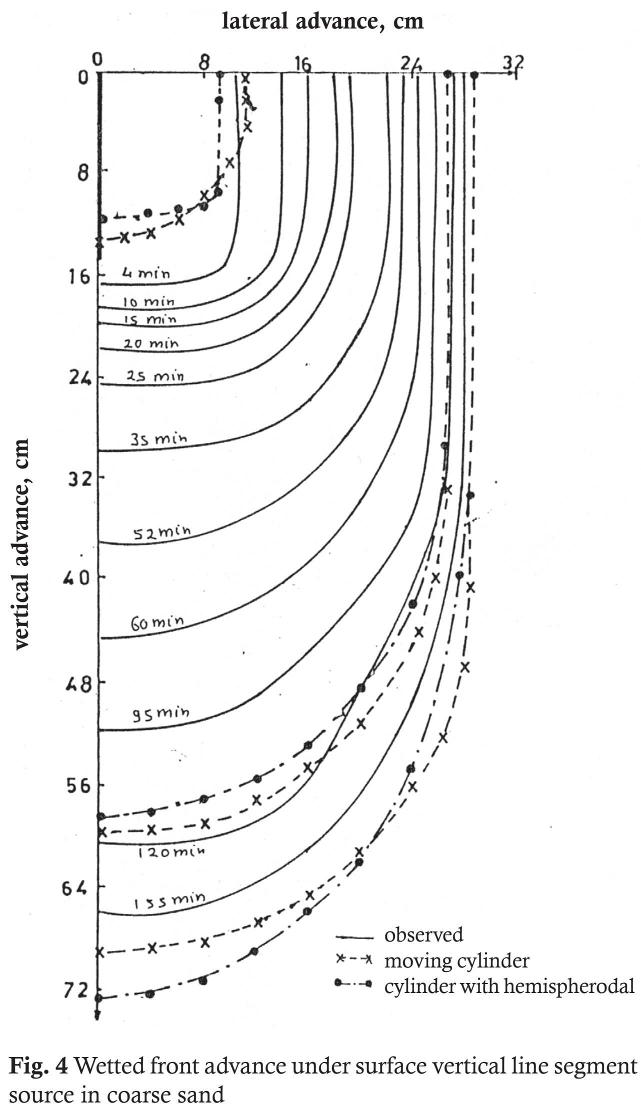
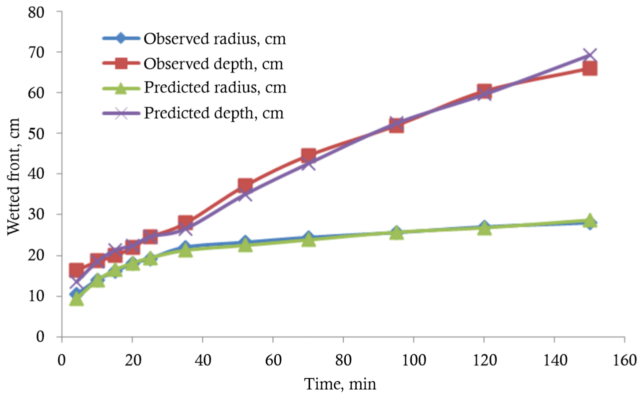
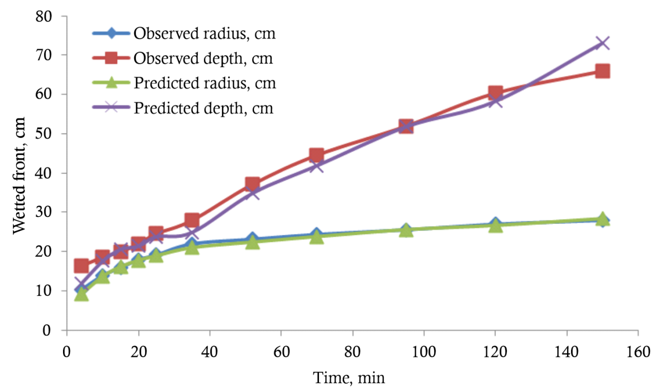


Fig. 4 Wetted front advance under surface vertical line segment source in coarse sand



a) Moving Cylinder Model



b) Cylinder with Hemi-spheroid Model

Fig. 5 Advance of wetted front radii and depths with time under surface vertical line segment source in coarse sand

average volumetric moisture content narrowed down drastically. Initially 10-15 minutes may be taken as stabilization period for proposed flow geometry and not of much importance from practical point of view.

Conclusions

Determination of a reliable representative unsaturated hydraulic conductivity function under laboratory conditions is a tedious and time-consuming process. Determination of in-situ unsaturated hydraulic conductivity function from field observations is yet to be standardized. There was need for developing simple mathematical model for describing wetted fronts advance under surface vertical line segment source with one end on soil surface using simple soil input parameter. An attempt is made to develop two simple models namely Moving Cylinder Model and a Cylinder with Hemi-spheroid Model. These models use an average change in volumetric moisture content of soil as input parameter to the models. The soil input parameter is quite easy to work out in the field with the measurement of wetted front advance in horizontal and vertical directions. The model was verified using the laboratory experimental data generated in a sand tank model of size 0.95 m × 0.95 m × 1.08 m. A 15 cm long surface vertical line segment source was created in the sand tank model and wetted fronts were measured for a period of 150 minutes against a discharge rate of 3.5 lph. Maximum wetted front radii and wetted front heights were measured. Average change in soil moisture content was worked out from the slope of a line plotted between applied volume of water through surface vertical line segment source and wetted soil volume for both the models. The maximum wetted radii and heights were observed to be 28.71 cm and 69.37 cm for Moving Cylinder Model and 28.35 cm and 73.1 cm for Cylinder with Hemispheroid Model after 150 minutes of water application. Both the models predicted quite close values of wetted front radii and wetted front heights. Both the models predicted wetted front positions quite well in coarse sand and can be used for developing new drip irrigation system for orchard crops and developing design protocols for such drip irrigation system.

References

Ben-Asher J, Charach Ch and Zemel A (1986) Infiltration and water extraction from trickle irrigation source: The effective hemispherical model. *Soil Science Society of America Journal* **50**:882-887.

Brooks RH and Corey AT (1966) Properties of porous media affecting fluid flow. *Journal of Irrigation and Drainage Engineering. American Society of Civil Engineers* **92(IR-2)**:61-88.

Burdine and HT (1953) Relative permeability calculation from pore size distribution data. *Transactions of the American Institute of Mining and Metallurgical Engineers* **198**: 71-77.

Chhedi Lal (2000) Wetted front advance and design of trickle system under different water flow geometries. Ph.D. Thesis submitted to G.B. Pant University of Agriculture and Technology, Pantnagar (India) in partial fulfilment of the degree requirement.

Cristóbal-Muñoz I, Prado-Hernández JV, Martínez-Ruiz A, Pascual-Ramírez F, Cristóbal-Acevedo D, Cristóbal-

Muñoz D (2022) An Improved Empirical Model for Estimating the Geometry of the Soil Wetting Front with Surface Drip Irrigation. *Water* **14(11)**:1827. https://doi.org/10.3390/w14111827

Dasberg S and Or D (1999) Applied Agriculture: Drip Irrigation. Springer-Verlag, New York, NY.

Elmaloglou S and Diamantopoulos E (2007) Wetting front advance patterns and water losses by deep percolation under the root zone as influenced by pulsed drip irrigation. *Agricultural Water Management* **90(1–2)**:160–163.

Gardener and WR (1958) Some steady state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. *Soil Science*. **85**:228-232.

Gilley JR and Allred ER (1974) Infiltration and root extraction from irrigation laterals. *Transactions of the American Society of Agricultural Engineers* **17(5)**:927-933.

Ismail SM, Zien El-Abedin TK, Wassif MA and El-Nesr MN (2006) Wetting pattern simulation of surface and drip irrigation systems i- model development. *Misr Journal of Agricultural Engineers* **23**:722-746.

Kumari Reena, Singh RM, Singh DS, Singh SR. and Chandola VK (2012) Wetting front advance under trickle source. *Journal of Environment and Ecology* **30 (1)**: 139-142.

Ma S, Wang T, & Ma SC (2022). Effects of drip irrigation on root activity pattern, root-sourced signal characteristics and yield stability of winter wheat. *Agricultural Water Management 271*, p.107783.

Maulem Y (1976) A new model for predicting the hydraulic conductivity of unsaturated porous media. *Water Resource Research* **12(3)**:513-522.

Philip JR (1971) General theorem on steady infiltration from surface sources with application to point and line source. *Soil Science Society of America Journal* **35**:867-871.

Philip JR (1972) Steady infiltration from buried, surface and perched point, line source in hetrogeneous soils: Analysis *Soil Science Society of America Journal* **36**: 268-2272.

Philip JR and Forrester RI (1975) Steady infiltration from buried, surface and perched point and line sources in hetrogeneous soils: *II Soil Science Society of America, Proceedings.* **39(3)**: 408-414.

Raats PAC (1972) Steady infiltration form sources at arbitrary depth. *Soil Science Society of America Journal* **36**(3): 399-401.

Raats PAC (1977) Laterally confined steady flows of water from sources to sink in unsaturated soil. *Soil Science Society of America Journal* **36**: 294-301.

Richards LA (1931) Capillary conduction of liquids through porous mediums. *Physics* **1**: 318-333.

Schwartzman M and Zur B (1986) Emitter spacing and geometry of wetted soil volume. *Journal of Irrigation and Drainage Engineering* **112(3)**: 242-253.

Singh DK, Rajput TBS, Singh DK, Sikarwar HS, Sahoo RN and T Ahmad (2006) Simulation of soil wetting pattern with drip irrigation from line source. A*gricultural Water Management* **83**: 130-134.

Singh Sita Ram and Verma CL (2010) A viscous resistance model for estimating hydraulic conductivity of soils. *Indian National Science Academy, Proceedings* **76**(1): 41-52.

Subbaiah R (2013) A review of models for predicting soil water dynamics during trickle irrigation. *Journal of Irrigation Science* **31(3)**: 225-258.

Thomas AW, Duke H.R, Zachman DW and Kruise EG (1977) Comparison of calculated and measured capillary potentials from line sources. *Soil Science Society of America Journal* **40**:10-14.

Van Genuchten M Th (1980) A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* **44**: 892-898.

Warrick AW and Lomen DO (1977) Flow from line source above a shallow water table. *Soil Science Society of America Journal* **41(5)**:849-852.

Zachman DW and Adrian WT (1973) A mathematical investigation of steady infiltration from line source. *Soil Science Society of America, Proceeding* **3**7:495-500.

Received: April 28, 2024 ; Accepted: June 21, 2024

Journal of Soil Salinity and Water Quality 16(1), 103-117, 2024

Design and Evaluation of Elevated Field Beds of Fish Pond based Integrated Farming Model under Waterlogged Sodic Conditions in Canal Command

Chhedi Lal Verma[1], YP Singh[1], Atul K Singh[1], SK Jha[1], Sanjay Arora[1], VK Mishra[2] and T Damodaran[3]

[1]ICAR Central Soil Salinity Research Institute- Regional Research Station, Lucknow-226002, Uttar Pradesh, India
[2]ICAR Research Complex for NEH Region, Umiam-793103, Meghalaya, India
[3]ICAR-Central Institute for Subtropical Horticulture, Lucknow-226101, Uttar Pradesh, India
**Corresponding author's Email: mail: lalc_verma@yahoo.com*

Abstract

Land modification based integrated farming system models have been quite successful in reclaiming waterlogged sodic soil. Fish pond or raised and sunken bed based integrated farming systems has potential to combat waterlogging and sodicity problems by keeping water level below critical depths. One of the well managed Fish Pond Bed Integrated Farming System (FPBIFS) model gave an average productivity of rice as 5.0 Mg ha^{-1} against water productivity of 46.25 Rs m^{-3}. Wheat yield and water productivity were obtained as 6.1 Mg ha^{-1} and 66.30 Rs m^{-3}, respectively. Water productivity of coriander, radish and spinach under mixed cropping were 288.76, 244.88 and 93.54 Rs m^{-3}, respectively. The water productivity of average yields of sponge gourd, bottle gourd, pea, carrot, tomato, onion, pumpkin, cow pea and brinjal were observed as 175.78, 96.21, 293.26, 122.83, 198.80, 143.33, 116.21, 148.50 and 208.56 Rs m^{-3}, respectively. The average fish productivity and water productivity were obtained as 3.0 Mg ha^{-1}, and 108.30 Rs m^{-3}, respectively. Equivalent drainage capacity of FPBIFS Models ranged from 1.58 - 2.14 mm day^{-1} with rice-wheat, rice-wheat-moong and vegetable-vegetable farming over the elevated field beds, respectively in waterlogged sodic area.

Key words: Canal command, internal drainage, integrated farming system, waterlogged sodic soil

Introduction

Canal irrigation has resulted to several associated disadvantages besides positive impacts and direct benefits to the society (Moharana *et al*., 2019). Majority of the canals are unlined in India. Overall irrigation efficiency may go as low as 40% in extreme cases in large canal commands under rice-wheat cropping system. Huge amount of water goes as waste from the unlined canals creating waterlogging and salinity problems besides several others environment related problems. Water-logging and salt build up in the root zone is the major problem in canal irrigated area lowering the productivity or making the land unfit for any agricultural production.

It has been estimated that out of 14.06 million ha culturable command area of 42 canal irrigation projects in country, about 1.6 million ha (about 11%) area is suffering from waterlogging. About 6.73 million hectare of land is salt-affected in India (CSSRI, 2024). Lowering of water table condition is pre-requisite for successful sodic land reclamation. Traditional gypsum based sodic land reclamation technology is ineffective under shallow water table conditions due to increased rate of secondary salinisation. Application of repeated dose of gypsum becomes essential to sustain agricultural productivity proving to be uneconomical and environmentally disastrous. Provision of subsurface drainage for lowering water table in waterlogged sodic soil to remove excessive salts through leaching may be uneconomical due to poor water transmission characteristics of the soil. Unavailability of gravity outlet for disposing drainage effluent would further make the subsurface drainage system costlier due to pumping.

Excessive seepage is the prime accused for waterlogging in canal commands. In the seepage prone waterlogged reach of the canal soils pH decreases with soil depth. By bringing good soil from deeper soil profiles (0.60-1.00 m) on soil surface and creating an elevated field bed the soil pH would be made normal and water table will be automatically lowered down enhancing the leaching ability of the soil and reducing the rate of secondary salinisation to the minimum. Fish pond and raised and sunken bed based integrated farming systems is being advocated and tested under high rainfall and waterlogged conditions at various locations for enhancing agricultural productivity (Erickson,1988; Ali, 1995; Shahidul Islam *et al*., 2002; Sahoo *et al*., 2003; Roy Chowdhury *et al*., 2003; Sinhababu and Das, 2004; Alami *et al*., 2009; Kar *et al*., 2010; Ugwumba *et al*., 2010; Rautaray *et al*., 2018). In seepage prone reach of the canal under waterlogged conditions soil having high pH on soil surface and low pH towards deeper profiles could be also brought under cultivation by adopting land modification based integrated farming system approach. A study was conducted on one-hectare Fish Pond Based Integrated Farming System (FPBIFS) at Kashrawan village of Bachhrawan Block of district Raebareli, U.P., India for about 8 years. The size of fish pond was kept as 80 m × 50 m ×1.75 m and largest elevated field bed size was 65 m × 50 m. Elevated field beds and raised beds of either of the Integrated Farming System (IFS) combine effect of subsurface drainage by lowering water table and increased height of elevated field beds or raised beds. Exposed good soil allowed crops to grow and continuous application of irrigation water slowly reclaimed the deeper soil profiles. Too large width of elevated field bed has great risk of salt accumulation and too short width of raised bed results in fast moisture depletion requiring frequent irrigation. Too wide elevated field beds may lose their effectiveness in controlling water table and too short width will be effective but cost of the system will be high. Large scale adoption of FPBIFS or RASBBIFS may require precise calculation of elevated field bed/raised bed width for keeping the efficacy of the system intact and cost at low level.

Materials and Methods

Study Site

More than 1.3 million ha land in the State of Uttar Pradesh (India) was sodic for which the State Government tried hard for reclamation. As a principle, waterlogged area was left un-reclaimed. Nearly 12-15% sodic land in U.P. is suffering with twin problem of waterlogging and sodicity requiring immediate attention of the government for reclamation and management of waterlogged sodic soil for improving the economic conditions of the farmers. The study was undertaken in Sharda Sahayak Canal Command reaches suffering with twin problem of waterlogging and salinity. Representative sites viz village Kashrawan in Raebareli district and Mahraura, Patwakheda and Lalaikheda in Lucknow district were selected for the study.

Initial Fish Pond Integrated Farming Systems

Boundary outline of FPBIFS Model at Kashrawan, Raebareli as shown in Fig. 1. Total area under FPBIFS Model was 10000 m^2 out of which pond area was 4000 m^2 and elevated field bed area was 6000 m^2. Area under field crops, fruit crops, forage crops and vegetable crops were 0.25, 0.15, 0.10 and 0.10 ha, respectively. The depth of the pond was kept as 1.75 m. The size of elevated field bed was large enough having tendency to accumulate salts in the mid of the bed due to slow rate of water table drawdown. Initial soil pH at the site before the construction of the pond were 10.1, 9.7, 9.5, 9.2, 8.9 and 8.8 in 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm depth, respectively. $pH_{1:2}$ after the construction of elevated field bed got reduced to 9.1. The soil $pH_{1:2}$ were observed to be 8.17-8.67, 8.33-9.12, 8.87-9.15, 8.48-9.12, 8.46-8.74 and 8.62-8.92 and corresponding $EC_{1:2}$ were 1.63-4.66, 0.74-1.92, 0.40-.90, 0.31-0.90, 0.22-0.64 and 0.40-0.49 dS m^{-1} at 0-15, 15-30, 30-45, 45-60, 60-90 and 90-120 cm depth, respectively after six years of model construction. Heavy salt accumulation was taking place in the mid-portion of the elevated field bed adversely affecting the crop yields. The width of elevated field bed was 50 m. Organic carbon was low (0.014 to 0.177%) at all locations indicating poor vegetative growth. ESP of the field ranged from 22.48 to 90.20

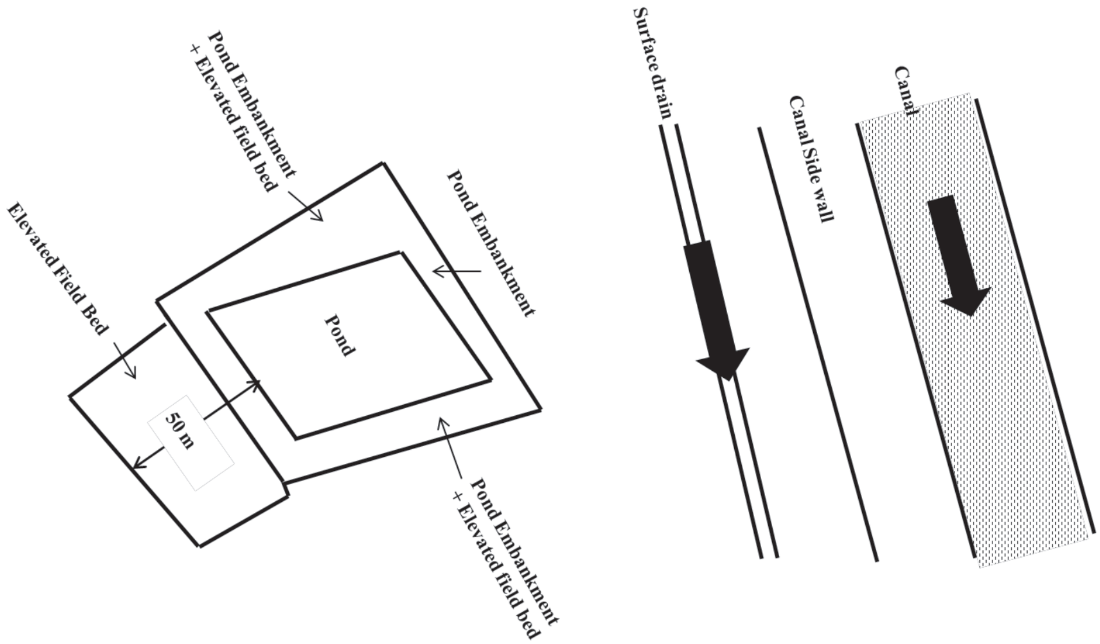


Fig. 1 Boundary outline of first FPBIFS Model at Kashrawan

respectively in a profile depth of 0 to 1.50 m. Area used to be waterlogged during rainy season and no crop was taken for decades. Adjoining area is still lying barren. The model was about 100 m away from the canal. First FPBIFS Model was designed for retaining an average standing water depth of one meter for nearly 10 month and constructed at Kashrawan village in Bachhrawan block of district Raebareli. It is evident that due to continuous seepage from the canal $pH_{1:2}$ and $EC_{1:2}$ are decreasing with increasing soil depths indicating a suitable site for FPBIFS model. Fluctuations of water depths during rainy to summer seasons were kept in mind while deciding the depth of fish pond. Width of elevated field bed was kept as 50 m matching the boundary conditions and convenience to the farmers.

The height of the elevated field bed was kept 1.5 m above ground surface to keep the average water table below 2 m from the surface of elevated field bed to minimize the rate of secondary salinization. The crop was successfully grown over the raised bed for three to four years. B:C ratio of wheat, mustard, onion and garlic were 1.13, 2.43, 4.42 and 15.60 for Rabi 2010 and of rice and sorghum were 1.88 and 2.71 for Kharif 2011. B:C ratio of fish stocking was calculated as 2.63 during first year. Overall B:C ratio for 2010-11 was 4.45 including fish stocking. Soil pH of elevated field beds ranged from 8.17 to 8.67 and EC 1.63 to 4.66 m^{-1}, after five years of pond construction. The model opens a new dimension for reclamation of waterlogged sodic soil. Eucalyptus planted at the boundary of the model grew well changing the local environment. Crop diversity and high return from fish stocking from FPBIFS Model was very well appreciated by the farming community. The size of elevated field bed was large enough having tendency to accumulate salts in the mid of the bed due to slow rate of water table drawdown.

Raised and Sunken Bed Based Integrated Farming System (RASBBIFS) Model

FPBIFS Model is quite expensive and beyond the reach of small and poor farmers. For catering the need of small to marginal farmers RASBBIFS was constructed adjacent to the canal at Kashrawan village in Bachhrawan Block of district Raebareli. Initial soil pH at the site ranged from 9.31 to 10.47 and EC from 0.433 to 1.778 dS m^{-1}. ESP ranged from 30 to 95%. The depth of sunken bed was limited to 0.60 m and width of raised bed at top was 2.0 m. Raised bed the term referred to an elevated field bed with a length of at least 10 or even more times of its width. Water drains out from the sides of the raised bed only. Top width

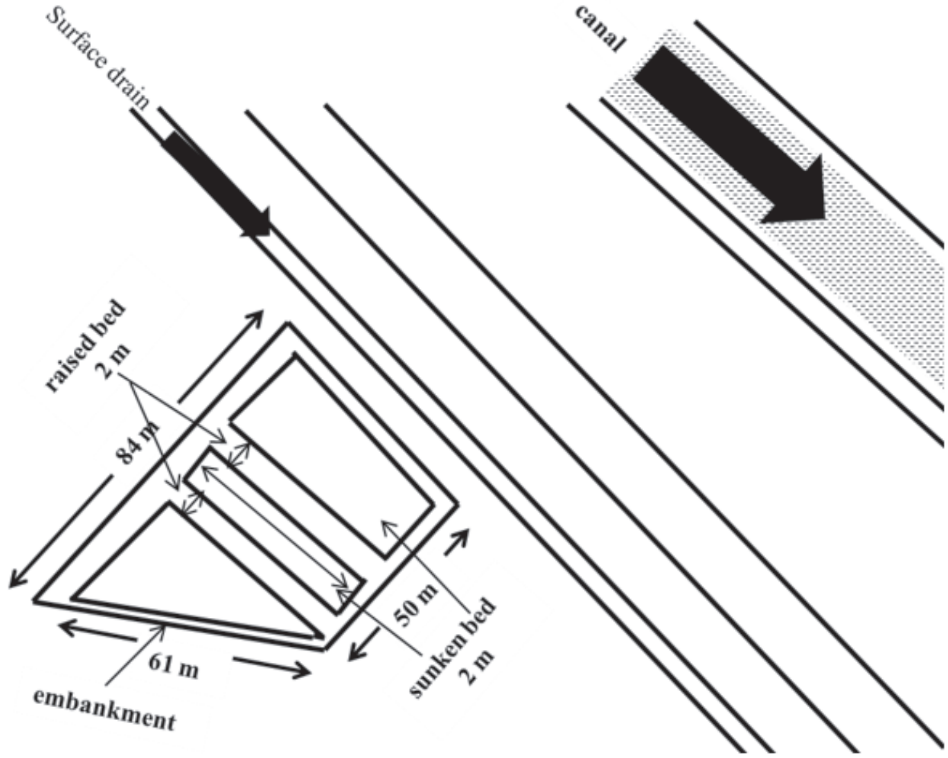


Fig. 2 Boundary outline of RASBBIFS Model at Kashrawan

of raised beds was 2.0 m and 4.0 m on the bottom. Length of raised beds was 60.0 m each. Similarly, width of sunken beds was 7.0 m and length as 60 m. Boundary embankment width was also kept 2.0 m except for the boundary bunds towards south which was only one meter wide on the top. Side slopes of raised and boundary beds is 1:1. Layout plan of experiment as shown in Fig. 2. The model performed quite well. Rice and water chest nut were grown in sunken beds and vegetables over the raised beds. Overall B:C ratio for Kharif 2013 and Rabi 2013-14 were calculated as 2.76 and 1.72. Five years average B:C ratio was worked out as 3.08 without eucalyptus and 6.44 with eucalyptus. This model was success in waterlogged sodic conditions and suitable for resource poor small and marginal farmers. The pH of surface soil reduced to the tune of 8.28 and EC was always < 2.0 dS m^{-1} after five years. No salt build-up appeared till date on the raised bed.

Results and Discussion

Proper depth of sunken bed needs to be worked out based on soil hydraulic parameters viz drainable porosity and saturated hydraulic conductivity. Based on this, Verma *et al*. (2016) developed the first design guidelines for raised and sunken bed based integrated farming system. The same model is extended for design of elevated field bed of FPBIFS Model for long term sustainability.

Design of the System

A design guideline of height of raised bed, depth of sunken bed and width of raised and sunken beds for reclamation and management of waterlogged sodic soils are immensely important hence being elaborated below.

Depth of Sunken Bed (H_s)

A general guideline for deciding depth of sunken bed is that a good quality soil depth should be exposed for providing a favourable soil covers over raised beds for ensuring crop production and exposure of good soil at the bottom of sunken bed or pond. Exposure of good soil would ensure the quality of water for crop or fish raisings. Depth of sunken bed is decided on the basis of its intended use. For deep water rice cultivation, the depth of sunken bed should be kept less than the maximum tolerance limit of the rice varieties. The depth of sunken bed should not exceed 0.60 m for commonly available rice varieties in the region suitable under submerged conditions. Depth of standing water in the sunken bed could be regulated by the provision of water escape from the side. Effective depth of sunken bed is depth of excavation plus the height of raised bed for all practical purposes. Sunken bed intended for the cultivation of water chestnut the depth of sunken bed should be in range of 0.50-1.00 m. For highest input use efficiency of water chestnut the depth of the sunken bed should be kept about 0.50 m. Fertilizers application in deep sunken bed would result in poor input utilization efficiency. Sunken bed intended for fish fingerling raising the depth should be kept in the range of 0.75-1.0 m but for fish stocking water depth requirement ranges from 1.0 to 1.5 m. Seasonal variation of water level in sunken bed with canal seepage should be kept in mind while deciding the depth of sunken bed. Volume of excavated soil from sunken bed should be accommodated in raising the beds. The depth of sunken bed or pond should be kept as deep as it could store on an average one-meter depth of water for fish stocking over a period of 10 months. Water level fluctuations along the canal range from 0 to 1.0 m below ground surface. One-meter water depth is sufficient for stocking the most common species of fishes. Thus, the depth of sunken bed or pond intended for fish stocking should be kept 2.0 m deep. Deep ponds would arrest seepage water rapidly compared to the shallow ponds.

Height Raised Bed/Elevated Bed

Height of raised bed is important and it should be high enough to avoid speedy salt accumulation of soil surface. Too less height of raised bed would keep water table shallow resulting a high rate of secondary salinisation endangering the efficacy and sustainability of the system. Height of raised bed should be such that water level midway of the raised bed should be below critical depth. During a vast survey in Sharda Sahayak Canal Command it was observed that re-sodification of reclaimed sodic land is major problem wherever water table depth is less than 1.5 m. Critical height of the raised bed is the height when resultant salt movement is downward. Water level depth of 1.5 to 2.0 m below ground surface during dry season is considered to be safe from salt accumulation. Thus, height of raised or elevated field beds should be in a range of 1.5 to 2.0 m under waterlogged sodic conditions. The direction of sunken and raised bed should be in the direction of runoff/flood flow to minimize damage during extreme runoff/flood events. For a given width of raised bed water table drop over a unit time increases with the increase in height of raised bed and for given height of raised bed drop in water level is inversely proportional to the width of raised bed.

A model was developed to calculated evaporation losses of water as function of water table depth (E_y) below ground surface as below.

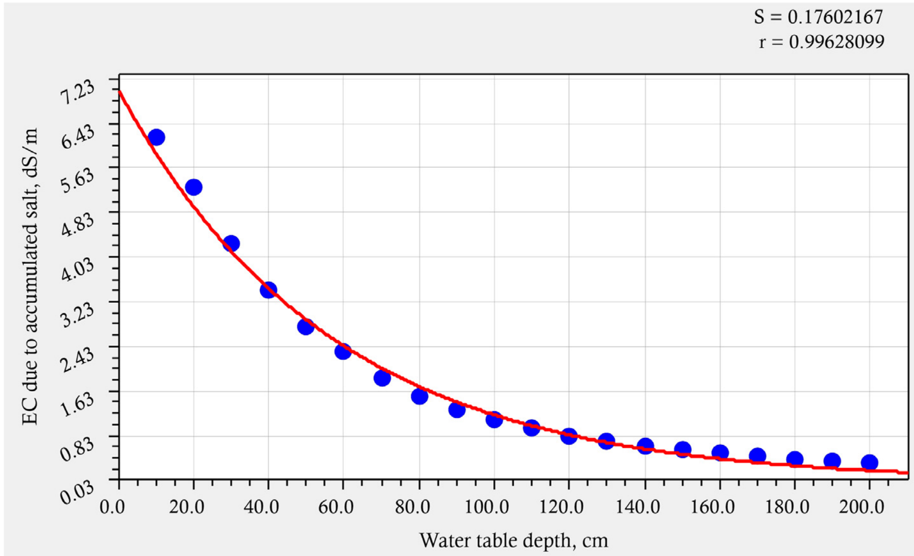
$$E_y = \frac{1}{\left(\frac{1}{E_p}\right) + \alpha\, y^{\beta}} \qquad (1)$$

Where,

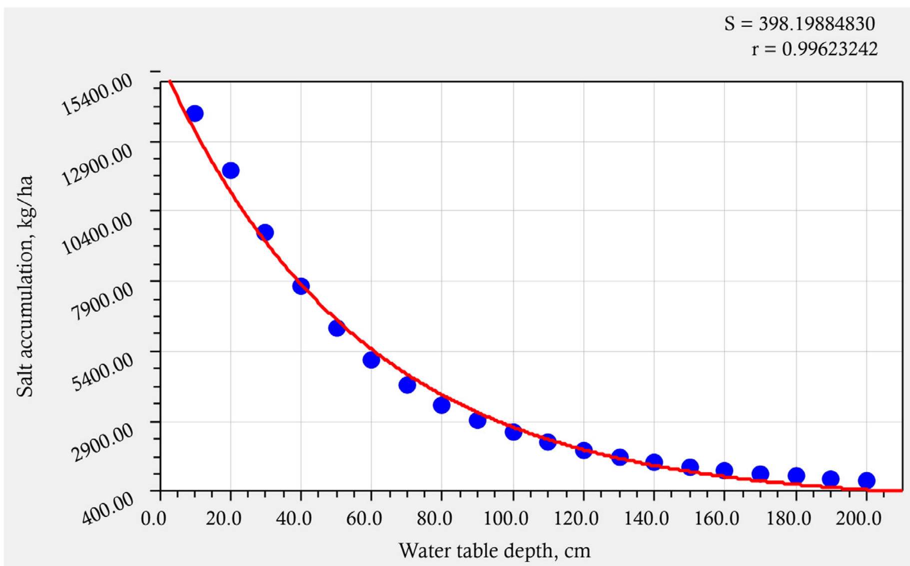
Ep= pan evaporation, cm

α and β are the model constants

The model was tested using the lysimetric data on evaporation of water from soil surface as a function of water level depth below ground surface. The value of α and β were worked out as 0.000055077825 and 1.919572, respectively. The water table depth fluctuates throughout the year. It remains high during rainy and winter seasons and recedes thereafter. Average monthly pan evaporation of the area is 6.240, 5.133, 15.957, 24.098, 22.343, 19.163, 10.772, 10.333, 5.912, 9.700, 9.795 and 9.358 cm for the month of January to December, respectively. Typical water table depths during the corresponding months in the affected reach of the canal were 48.0, 59.5, 61.5, 112.5, 119.5, 101.5, 62.0, 15.0, 22.5, 75.0, 115.5 and 75.0 cm below ground surface. Annual salt accumulation was calculated using the evaporated depth of water from the soil surface for variable water table depths as 4.7 Mg ha^{-1} for which EC of the soil was calculated as 2.092 dS m^{-1}. The model was further used to calculate annual salt accumulation with fixed water table depths ranging from 0 to 200 cm depth (Fig. 3). Salt accumulation was observed to be the maximum with EC of 2.092 dS m^{-1} (14.880 ton/ha) when water table remains at soil surface and



$EC_{wd}=7.0081158\ e^{-0.017639371\ d}$



$SL_{wd}=15759.505\ e^{-0.017682117\ d}$

Fig. 3 Salt accumulation as a function of water table depth

minimum with EC of 0.346 dS m^{-1} (0.780 ton/ha) when water table is 2.0 m deep. For water table depth of 1.5 m the salt accumulation was calculated as 1.29 Mg ha^{-1} against EC of 0.575 dS m^{-1}. If water table remains at 1.5 m below ground surface it may take about 3.6 year to accumulate an annual salt load as that with fluctuating water table. It may take 6.0 year to accumulate similar salt load with 2.0 m deep water table raised bed. Crop raising over the elevated or raised bed would be subjected to improved internal drainage with enhanced salt leaching hence the accumulation of salt in soil profile would be much less. Five years continuous cultivation of designed elevated field beds with intensive vegetables and traditional crop production showed no sign of salt accumulation in the soil profile. Therefore, the height of raised bed is recommended to be 1.5 m to 2.0 m above ground surface.

Raised Bed Width (W)

Once the height raised bed is decided the width of raised bed needs to be calculated with a suitable design formula which combines the effect of height of raised bed and soil parameters to meet the drainage requirements of the crops to be grown over the raised bed. Fig. 4 shows the schematic diagram of raised and sunken bed. In the canal irrigated Indo-Gangetic plains of India salt accumulation is a serious threat for crop production. Excessive wet conditions may prevail or be created after irrigation and adversely affect the crop production due to twin problems of waterlogging and salt accumulations. Alternate drying and wetting of soil is experienced in canal commands. Improving internal drainage of the soil is an immediate solution for both the situations.

Presence of excessive exchangeable sodium in sodic soils disperses the soil drastically resulting to the poor physical soil properties. Increase in exchangeable sodium percentage in the soil makes the soil more dispersed resulting to the breakdown of soil aggregates which lowers the permeability of the soil to air and water. Dispersion also results in the formation of dense, impermeable surface crusts that hinder the emergence of seedlings. The relative hydraulic conductivity (K_{rel}) has following relationship with ESP.

$$\log_e K_{rel} = 1.4072 + 3.3498 \cos(0.03272\, ESP + 0.02283) \quad (2)$$

Excess exchangeable sodium results in high pH of the soil which affects plant growth adversely due to lowering the availability of many essential plant nutrients. The concentration of the calcium and magnesium in the soil solution is reduced as the pH increases due to formation of relatively insoluble calcium and magnesium carbonates by reaction with soluble carbonate of sodium, etc. and results in their deficiency for plant growth. Solubility and availability P, Fe, Mn and Zn, are also affected under high pH conditions. Common toxic elements in sodic soils are sodium, molybdenum and boron and would affect crop growth. During the construction of raised bed the top soil of sunken bed with extremely high pH (9.5 to 10.5) is brought back to the bottom of raised bed having similar high pH. The bottom of the raised bed at original soil surface become thick and remains dispersed to act as impervious layer for all design purpose.

Steady State Approach

Fig. 4 shows a raised bed between two sunken beds created by filling dug out soil from either sides of the sunken beds. Rain or irrigation water would enter the raised bed through soil pores vertically down and discharge horizontally into the sunken beds. A water devoid will be developed in the middle of the raised bed. Half of the water will move horizontally into the sunken on one side and half from the other side. Subsurface water flow, q_x at a distance of x from a unit length of raised bed can be calculated as under.

$$q_x = q\left(\frac{1}{2}W - x\right) \quad (3)$$

Where,

q = steady state subsurface flow into the sunken beds from unit area of the raised beds, $[LT^{-1}]$

q_x = subsurface flow from midpoint of the raised bed to the reference plane located at a horizontal distance of x unit, $[LT^{-1}]$

W = width of raised soil bed, [L]

x = horizontal distance of cross section where subsurface flow is being calculated, [L]

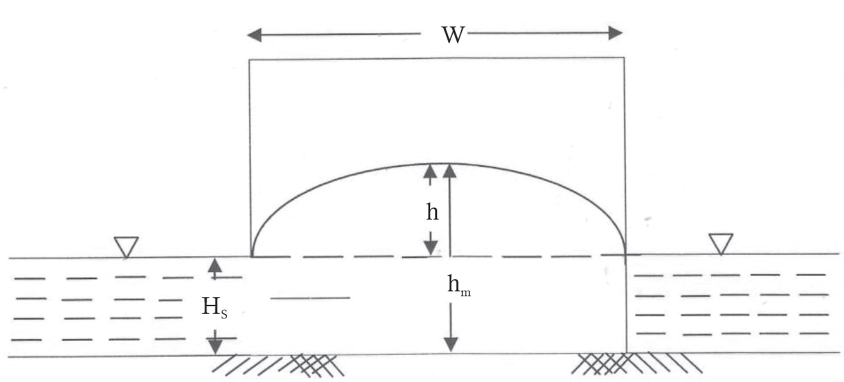


Fig. 4 Schematic diagram of raised and sunken bed

Discharge at any point can be calculated using Darcy's equation. Cross sectional area of flow at a section x distance away from sunken bed is $A=h_x x1=h_x$ as length is considered unity. Therefore, subsurface flow at section x can be written as under.

$$q_x = A.v = h_x\left(K\frac{dh_x}{dx}\right) = \frac{K}{2}\frac{dh_x^2}{dx} \quad (4)$$

Equating Eqn (3) and (4) and integrating under the following boundary conditions, x=0, $h_x=h_s$; x=(1/2)W, $h_x=h_m$ one will get the following equation for raised bed width after ignoring flow above soil interface (Verma *et al*., 2016).

$$W = \sqrt{\frac{4Kh^2}{q}} \quad (5)$$

Where,

q = drainage coefficient of the area (m day^{-1})

K = saturated hydraulic conductivity of the soil (m day^{-1})

h = height of water table midway between the drains (m)

W = width of the raised bed, (m)

Relationship for Transforming Steady State Equation to Transient Condition

Water table profiles between the edges of the elevated field bed are elliptic and keep on changing with time if there is no rainfall or irrigation. Verma *et al*. (2016) derived an expression for transforming steady state equation for calculating width of raised bed to transient conditions making a water balance study of falling water table profiles.

$$q = \left(\frac{\pi}{4}\right).f.\left(\frac{dh}{dt}\right) \quad (6)$$

q =(π/4).f.(dh/dt)

Above equation was used for transforming steady state Eqn. (5) to transient condition by substituting Eqn. (5) into Eqn. (6) as given below.

$$W = \sqrt{\frac{4Kh_o t}{\frac{\pi}{4}f\left(\frac{h_o}{h_t}-1\right)}} \quad (7)$$

Where,

h_o = water table height midway between the raised bed at time t=0, (m)

h_t = water table height midway between the raised bed at time t=t, (m)

f = drainable porosity of the soil (m^3m^{-3})

t = time taken to fall water table from h_o to h_t, (day)

Steady state or transient equations can be used for calculating width of raised bed and length and width of elevated field bed. Raised bed drains only from two sides while elevated field beds drain from all around. For a field situation having saturated hydraulic conductivity as 0.20 m/day, drainage coefficient as 4.00 mm/day, height of bed as 1.50 m with drainage requirement of 0.50 m to soil profile size of elevated field bed was calculate as 20 m × 20 m. Several combinations of the lengths and widths of elevated field bed are possible to clear 0.50 m top soil profile from water. Fig. 5 shows a combination of length and width of elevated field beds of the same system meeting out the drainage criteria of the crop.

For the saturated hydraulic conductivity of the soil (K_s) as 2.20 m day^{-1}, drainable porosity is 15%, the height of raised bed above soil surface is 1.5 m and drainage coefficient of the area of 4 mm day^{-1}. Top 40 cm soil profile needs to be cleared from water table during rainy season within two days. A combination of elevated field bed length and width was calculated as 25 m × 56 m using transient width formula. Water table fluctuations were calculated grid wise to understand the design procedure and combined effect of drainage from either side of the bed. Elliptic water table profile is formed between the opposite sides of the elevated field bed.

Water level profiles were calculated at different points once midway water table reached from surface to 1.12 m below ground surface for above example. Fig 6 and 7 presented the water table profile of the designed plot (56 m × 25 m) when drained from width side and lendth side alone, respectively. Under real field conditions water flows from all around the elevated field. Water table profles when field is drained from all around

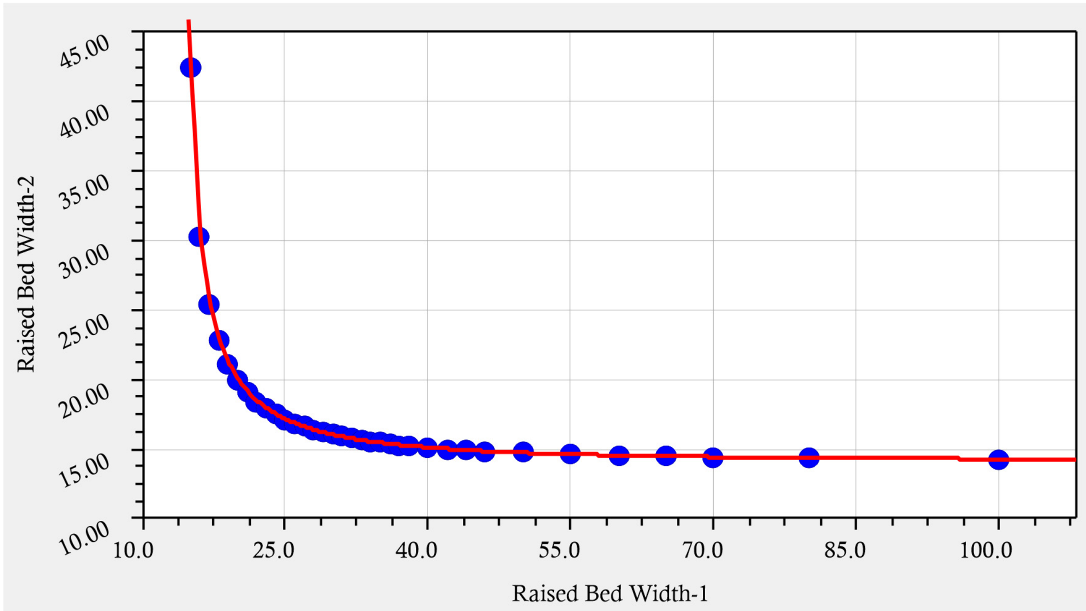


Fig. 5 Combination of length and widths of the elevated field bed

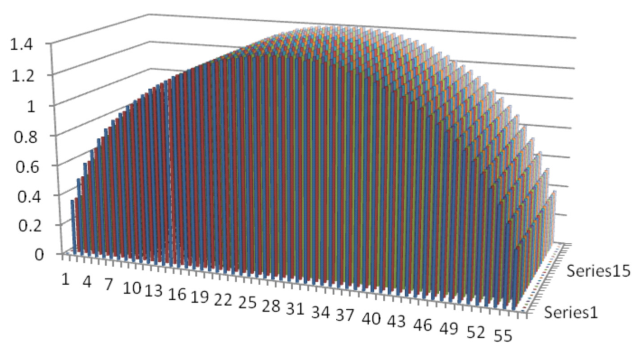


Fig. 6 Water table height within raised bed seen from length side when draining from width sides only

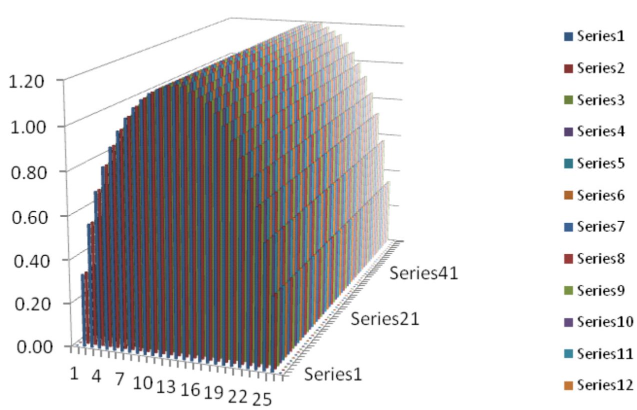


Fig. 7 Water table height within raised bed seen from width side when draining from lenght sides only

as shown in Fig. 8 and 9. A plan of the contour map of the water level in the field can be also prepared as shown in Fig. 10 to 13.

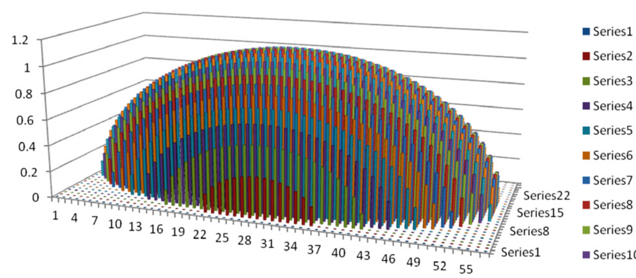


Fig. 8 Water table height within raised bed seen from length side when draining from both sides

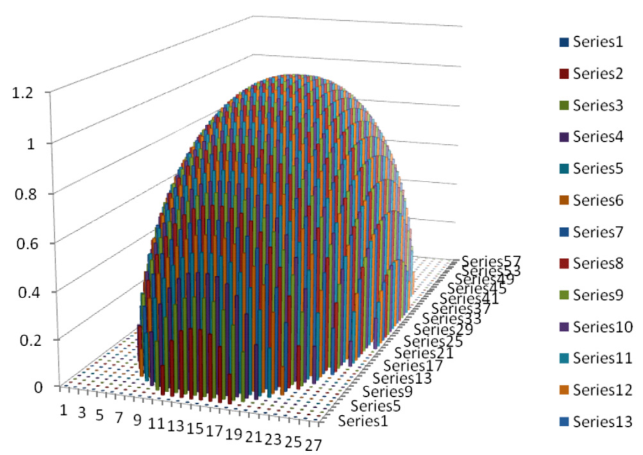


Fig. 9 Water table height within raised bed seen from width side when draining from both sides

Variation of Soil Bulk Density

Variation of average soil bulk density with soil depths of elevated field bed is shown in Fig. 14. Bulk density of the soil surface (0-10 cm) at the

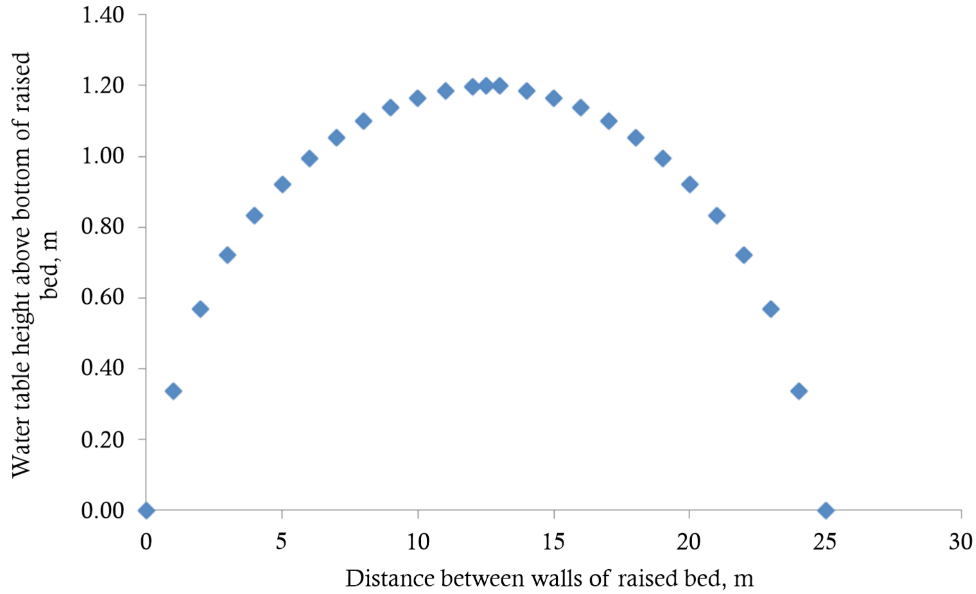


Fig. 10 Elliptic water table height midway between the raised bed across the width

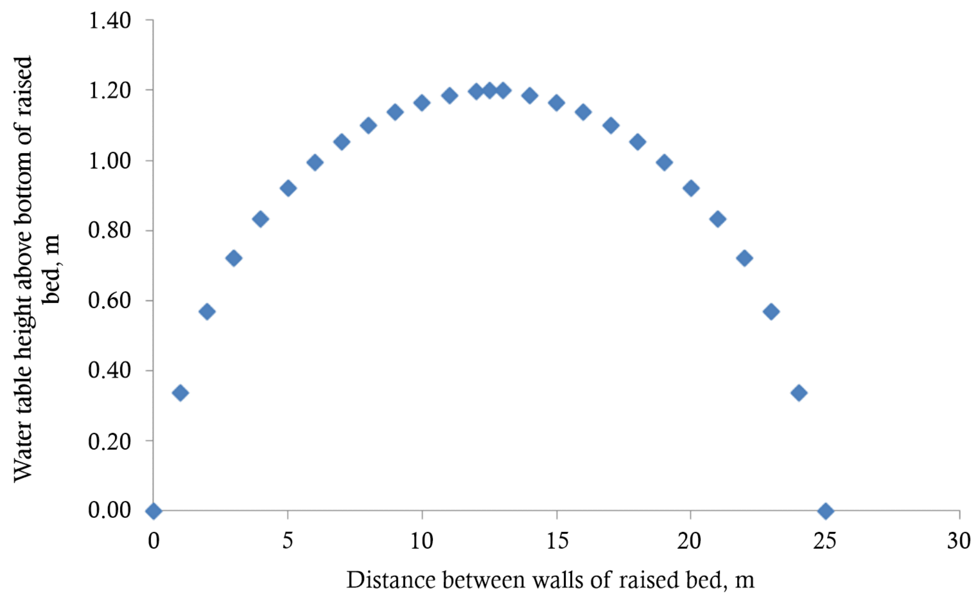


Fig. 11 Elliptic water table height midway between the raised bed across the length

time sampling was observed to be 1.35 g cm^{-3} which is highly variable with tillage operation, pH, irrigation and crop growth. The maximum bulk density was observed at a soil depth of 115-150 cm depth which was 1.63 g cm^{-3}. Sodic soils are highly dispersed in nature causing to increased bulk density and difficult for root to penetrate within soil. Water transmission characteristics are also adversely affected with increase in pH and bulk density. Following relationship explained the variation of bulk density very well with r= 0.99175877 and S=0.01279056.

$$\rho_b = e^{a+\frac{b}{d_s}+c\ln d_s} \qquad (8)$$

where,

ρ_b= bulk density of soil, g cm^{-3}

a, b, c = constants

d_s = soil depth, cm

The constants value of a = 0.31291871, b = -0.60581596 and c =0.033910148 resulted to a r= 0.99175877 and S = 0.01279056.

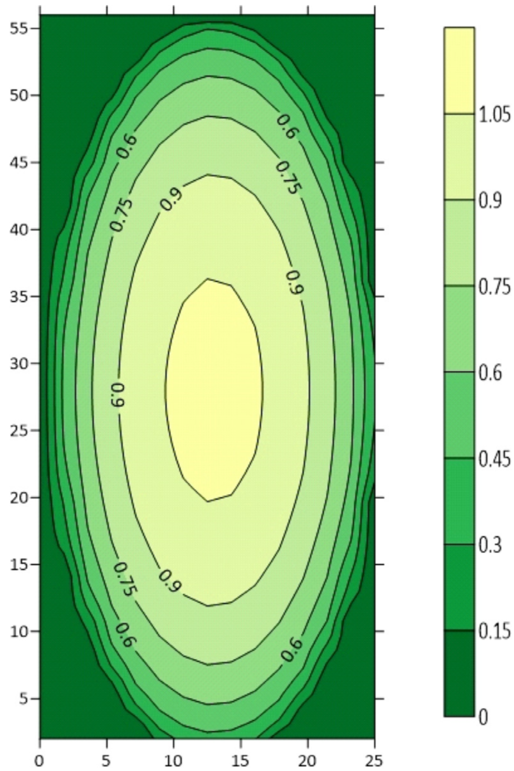


Fig. 12 Plan of water level contour

Case Studies of FPBIFS Models

Case Study 1. Village: Mahraura, Raebareli

Boundary outline of FPBIFS Model at Patwakheda is shown in Fig. 16. Total area under FPBIFS Model was 4430 m^2 out of which pond area was 2100 m^2 and elevated field bed area was 2320 m^2. The depth of the pond was kept as 2.0 m. Designed width of elevated field bed was 15 m. Initial soil $pH_{1:2}$ ranged 9.055 to 10.015 and corresponding $EC_{1:2}$ ranged 1.173 to 2.885 dS m^{-1}, respectively. Organic carbon was low (0.014 to 0.177%) at all locations indicating poor vegetative growth. ESP of the field ranged from 72.638 to 90.680 respectively in a profile depth of 0 to 2.0 m. The range of soil $pH_{1:2}$ was 8.396 to 8.648 while $EC_{1:2}$ ranged and 0.851 to 1.046 dS m^{-1} in the soil profile over a period of four years. The pH of the soil does not change abruptly unless amendment is applied. Intensive cropping with vegetables decreases soil pH much rapidly than the traditional rice wheat cropping. Soil salinity is dynamic process. It changes with time. Rainfall and irrigation dissolved the salts and move it down ward while evaporation keeps on accumulating the salts towards soil surface. The EC of the soil was much below the inhibitive level. Farmer was advised to applied FYM and green manuring for lowering the pH of the soil. Adjoining area is still

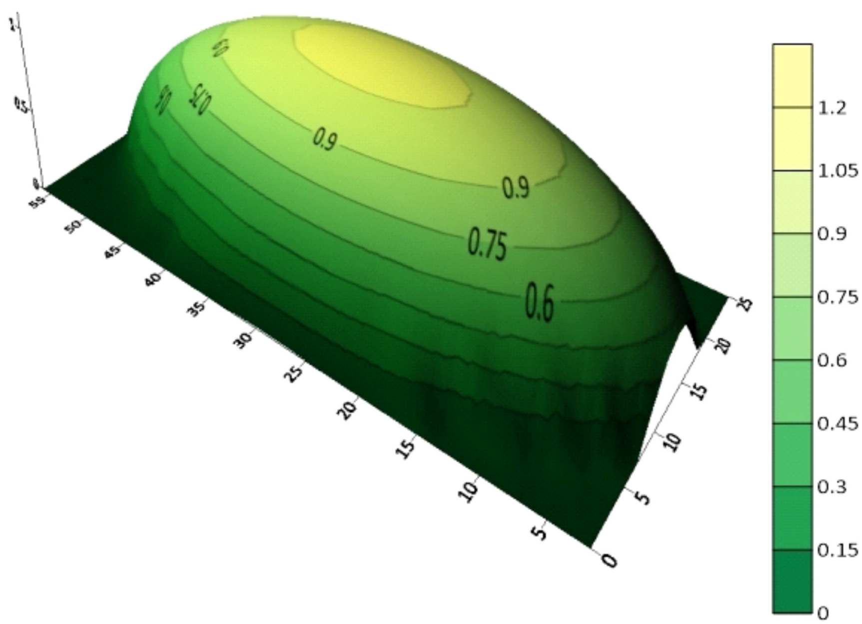


Fig. 13 Side view of the contour lines

Length and Width of Elevated Field Bed

A combination of lengths (W_{-1} or W_{-2} whichever is large) and widths (W_{-1} or W_{-2} whichever is small) of designed elevated field bed to result 0.40 m of drop in midway water table having bed size 56 m × 25 m are shown in Fig. 15.

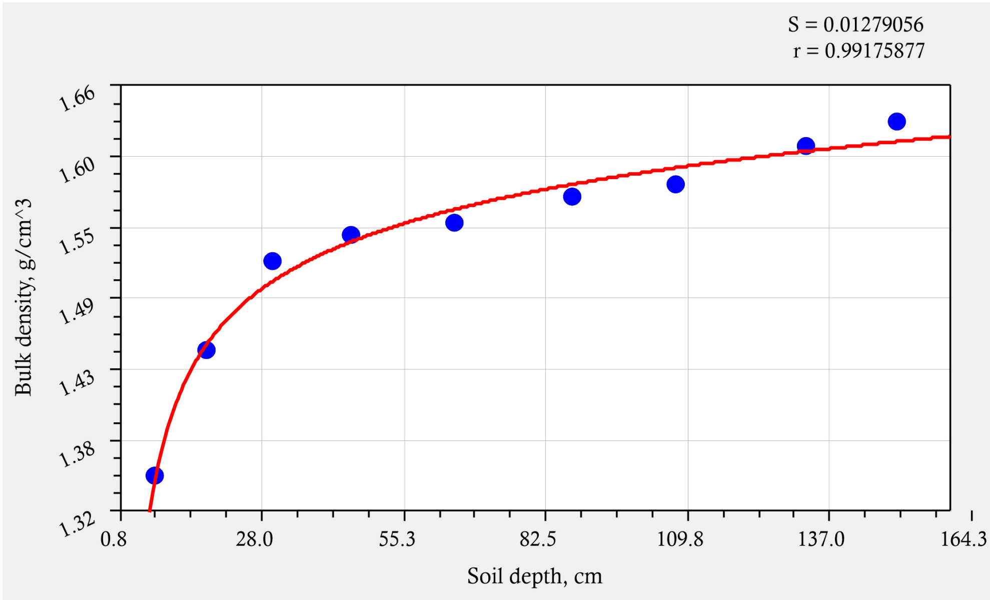


Fig. 14 Variation of bulk density with soil depth

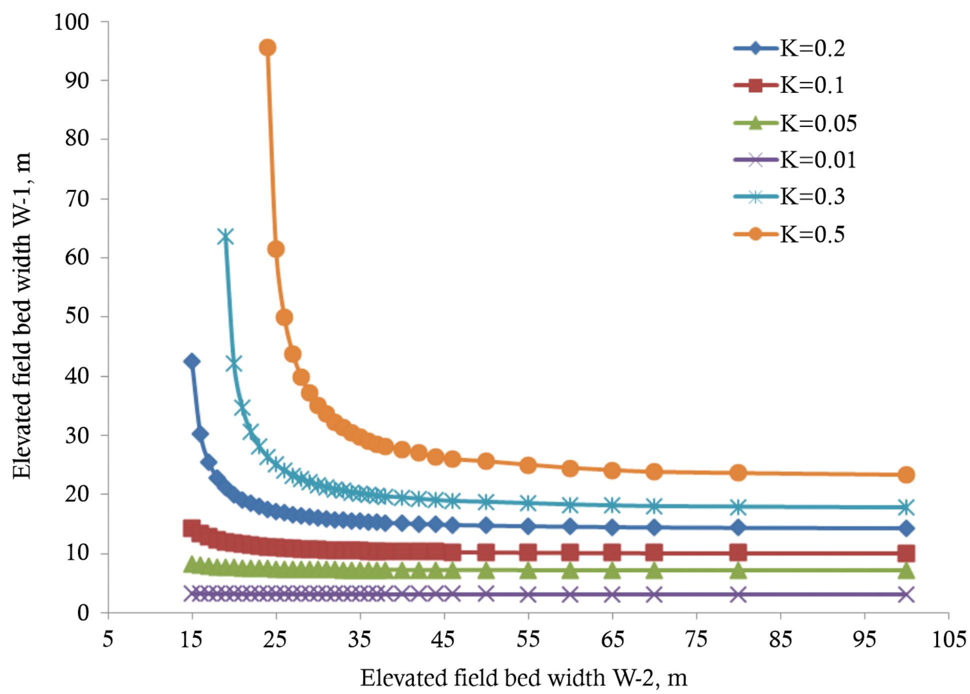


Fig. 15 Combinations of length (W_{-1}) and width (W_{-2}) of designed elevated field beds under different soil conditions

lying barren. The model was immediately adjacent to the canal.

Average productivity of rice, wheat, sponge gourd, bottle gourd, brinjal, radish, spinach, coriander leaf and garlic were obtained as 32.04, 32.07, 200.00, 520.00, 341.67, 330.00, 350.00, 100.00 and 79.34 q ha^{-1} with water use efficiency of 266.97, 263.75, 625.00, 888.98, 1220.24, 638.88, 1250.00 and 408.51 kg ha^{-1}cm^{-1} and corresponding water productivity were 42.71, 57.49, 125.00, 133.33, 195.23, 63.88, 187.50, 187.50 and 548.24 Rs m^{-3}, respectively for newly developed FPBIFS Model of Karuna Shankar at Mahraura village, Raebareli. The average fish productivity of new model was 5.8 Mg ha^{-1} and corresponding water use efficiency and water productivity were 20.11 kg ha^{-1}cm^{-1} and 19.43 Rs m^{-3}, respectively.

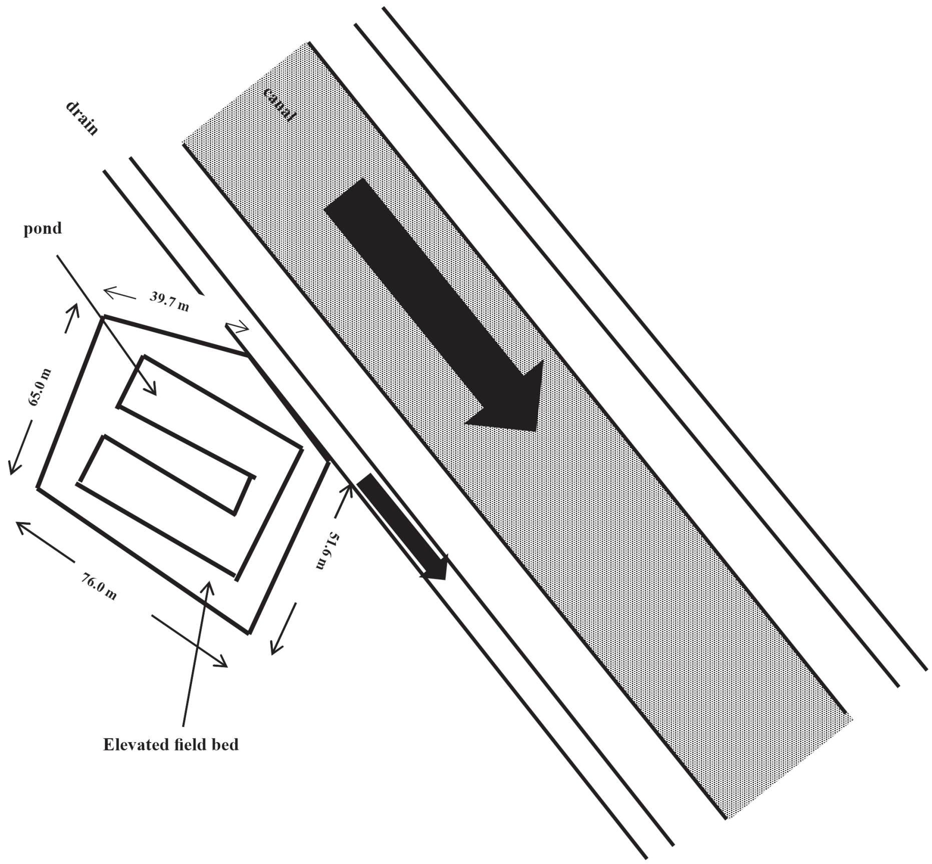


Fig. 16 Boundary outline o RASBBIFS Model at Mahraura

Case Study 2. Village: Patwakheda, Lucknow

The farmer Dinesh is more progressive compared to others working on FPBIFS Models. He prefers to grow vegetables which fetch good market prices and give more labour days for engaging family members from the FPBIFS model (Fig 17). Average productivity of rice he obtained as 5.0 Mg ha^{-1} against water use efficiency of 248.00 kg ha^{-1}cm^{-1} and water productivity of 46.25 Rs m^{-3}, respectively. He used to produce leafy vegetables such as spinach, coriander leaf and radish as a mixed crop. He obtained average yields of coriander, radish and spinach under mixed cropping as 2.9, 6.1 and 2.6 Mg ha^{-1} with corresponding water use efficiency of 952.33, 680.67 and 2944.01 kg ha^{-1}cm^{-1} and water productivity of 288.76, 244.88 and 93.54 Rs m^{-3}, respectively. The average yields of sponge gourd, bottle gourd, pea, carrot, tomato, onion, pumpkin, cow pea and brinjal were reported as 29.2, 23.6, 5.1, 26.8, 50.8, 17.2, 28.2, 19.0 and 62 Mg ha^{-1} with corresponding water use efficiency of 875.18, 962.10, 777.78, 744.44, 1563.65, 955.55, 934.12, 537.44 and 1189.92 kgha^{-1}cm^{-1} and water productivity as 175.78, 96.21, 293.26, 122.83, 198.80, 143.33, 116.21, 148.50 and 208.56 Rs ha^{-1}, respectively. The average fish productivity, water use efficiency and water productivity were obtained as 3.0 Mg ha^{-1}, 29.14 kg ha^{-1}cm^{-1} and 108.30 Rs m^{-3}, respectively. The soil pH and EC got significantly reduced to the normal level increasing fertility of the soil as that of normal soil.

Equivalent Drainage Capacity of IFS Model

The efficacy of PBIFS Model in meeting the internal drainage requirement of the area can be expressed in terms of Equivalent Drainage Capacity (EDC) of IFS Model. The equivalent drainage capacity of the PBIFS Model is the equivalent drainage coefficient which is equivalent to daily water loss depth from the IFS model.

The equivalent drainage capacity of the FPBIFS Model with rice wheat production was calculated as 1.58 mm day^{-1} and with rice+

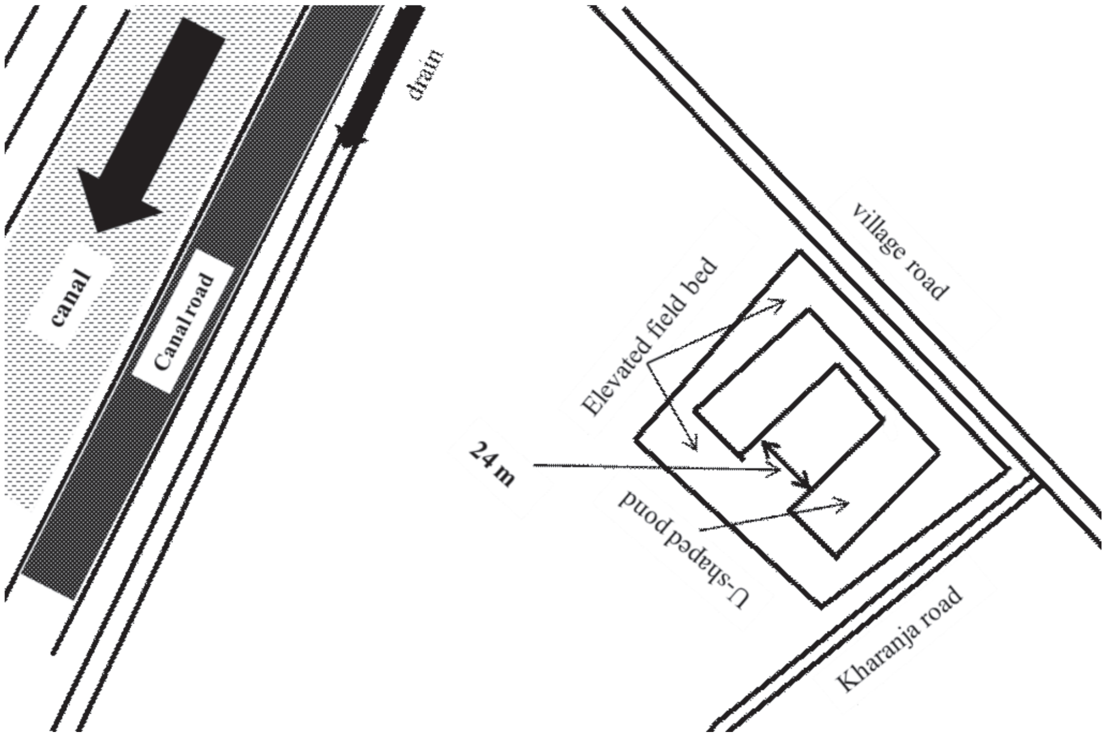


Fig. 17 Boundary outline o FPBIFS Model at Patwakheda

wheat+moong as 3.08 mm day^{-1}. The equivalent drainage capacity of the FPBIFS Model with rice-wheat-moong production system was calculated as 1.69 mm day^{-1} and with vegetable-vegetable was calculated as 2.14 mm day^{-1}. The FPBIFS Model performed hydraulically well meeting out the drainage requirement of the area.

Conclusions

Well-designed FPBIFS Models resulted to higher land and water productivity without showing any sign of salt accumulations over the raised bed. Equivalent Drainage Capacity of FPBIFS Models depended on the farming systems and type of crop grown over the raised beds. EDC of FPBIFS with rice-wheat farming was worked out as 1.58 mm day^{-1}, FPBIFS with rice, wheat and moong farming was calculated as 1.69 mm day^{-1} and FPBIFS with vegetables farming was calculated as 2.14 mm day^{-1}. Crop diversification within two-year period is added advantage of this model. Introduction of the model improves local environment creating a favourable condition for crop production. It is a climate resilient model having potential to incorporate large number of farming systems with a great capacity to increase farm income besides improving nutritional security of the rural mass.

References

Alami MR, Akkas Ali, M, Akhtar HM, Molla MSH, and Islam F (2009) Integrated approach of pond based farming systems for sustainable production and income generation. *Bangladesh Journal of Agricultural Research* **34(4)**: 577-584.

Ali AB (1995) Awareness through uses: paddy-cumfish farming in Malaysia. Paper was presented forthe International Wetlands Symposium held in Yatsu-Higata Ramsar site, Narashino, Chiba, Japan. 28-29 October, 1995.

CSSRI (Central Soil Salinity Research Institute) (2024) Extent and distribution of salt affected soils in India. In: CSSRI. Karnal, India. [Cited June 14, 2024]. https://cssri.res.in/extent-and-distribution-of-salt-affected-soils-in-india/

Erickson CL (1988) Raised field agriculture in the lake Titicaca basin. *Expedition* **30(3)**: 8-16.

Kar G, Kumar A, Sahoo N, Das M and Roychoudhury S (2010) Deep water rice and pond based farming system for enhancing water productivity of seasonal flood prone areas. Research Bulletin of Directorate of Water Management, (Indian Council of Agricultural Research) Bhubaneswar – 751 023.

Moharana PC, Singh RS, Jena RK, Tailor BL and Singh SK (2019) Secondary salinity and waterlogging in the IGNP command area: A threat to agricultural sustainability. *Indian Farming* **69(09)**: 40-43.

Rautaray SK, Mishra A, Mohanty S, Sinha MK, Mishra SN and Ambast SK (2018) Performance of pond based integrated farming systems in different agro-ecosystems: An on-farm survey. *Journal of Indian Society of Coastal Agricultural Research* **36(2)**: 106-114.

Roy Chowdhury S, Sahoo N and Verma HN (2003) Package of practices for water chestnut (singhara) cultivation in shallow waterlogged area. Water Technology Center for Eastern Region, Bhubaneswar (pamphlet).

Sahoo N, Verma HN, Jena SK, Ghosh S, Panda DK, Srivastav RC, Singh R and Tripathi VK (2003) Subsurface water harvesting structures- a new system in micro water resource development in coastal area (pamphlet). Water Technology Centre for Eastern Region, Bhubaneswar.

Shahidul Islam M, Murshid SM Manzur, Moniruzzaman M and Baree Abdul M (2002) Rice cum fish farming in selected Areas of Mymensingh district. *Journal of Biological Sciences* **2(10)**: 715-718.

Sinhababu DP and Das PC (2004) Rice-fish farming system for Rain-fed low land areas (Pamphlet). Central Rice Research Institute, Cuttack.

Ugwumba COA, Okoh RN, Ike PC, Nnabuife ELC and Orji EC (2010) Integrated Farming system and its effect on farm cash income in Awka South agricultural zone of Anambra State, *American-Eurasian Journal of Agricultural & Environmental* Sciences **8(1)**: 01-06,2010.

Verma CL, Singh YP, Damodaran T, Singh AK, Mishra VK and Sharma DK (2016) Developing design guidelines for calculation of width and height of raised and sunken bed system in waterlogged sodic soil. *Journal of Soil Salinity and Water Quality* **8(1)**:59-66.

Received: April 26, 2024; Accepted: June 21, 2024

Journal of Soil Salinity and Water Quality 16(1), 118-125, 2024

Ultrastructural Studies to Evaluate Fish Scales as Indicators of Heavy Metals in *Labeo rohita*

Vibhu Vaid[1]*, SS Hundal[1] and Nisha Vashishat[1]

[1]*Department of Zoology, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
**Corresponding author's E-mail: vibhuvaid30@gmail.com*

Abstract

Environmental pollution by heavy metals has been of nagging concern globally. A preliminary study was undertaken to study structural alterations including lepidontal aberrations on the fish scales of *Labeo rohita* using Scanning Electron Microscopy (SEM). In addition, the atomic percentage of heavy metals on the scales were analysed by Energy Dispersive X-ray microanalysis (EDX). The scales were gathered during two seasons (winter and summer) from Ludhiana's fish markets. Various heavy metals including Aluminium (Al), Chromium (Cr), Zinc (Zn), Nickel (Ni), Copper (Cu), Lead (Pb) and mercury (Hg) were detected on fish scales gathered from local fish markets compared to control groups. In addition, Silicon (Si) was also found on the scales gathered from markets. Heavy metal accumulation in the water source from which fish were gathered might be responsible for deposition of heavy metals on scale's surface. Along with this, lepidontal anomalies on the scale's dorsal surface were examined using EDX. In addition, structural aberrations such as broken, disorganized and eroded circuli, damaged margins of scales, alterations in focus and tubercles were also studied. The intensity of alterations was observed higher in scales of fish larger in size gathered from market compared to fish smaller in size, which might be due to longer duration of heavy metal exposure in the water source. The results clearly suggested that fish scales of *L. rohita* have a potential to be used as indicators of water quality.

Key words: Fish scales, Heavy metals, *Labeo rohita*, SEM-EDX, Water quality indicator

Introduction

Water plays an important role in any nation's development (Vikrma and Sandhu, 2022). India has a range of freshwater assets of 10.55 million hectares (ha) area spread over various geo-climatic areas such as high altitude wetlands (0.12 million ha), cut-off and oxbow lakes meanders (0.10 million ha), riverine systems and streams (5.35 million ha), waterlogged wetlands (0.45 million ha), lakes (0.73 million ha), tanks and reservoirs (3.79 million ha) (Deepak *et al.*, 2022). However, In India, 70% of the riverine water is contaminated with pollutants due to agricultural, chemical and industrial discharge coupled with poor waste disposal and management (Jindal and Sharma, 2011; Lau and Li, 2023). Water pollution induced by heavy metals and related risk to aquatic biota and human health has aroused wide concern globally due to their persistence, toxicity, bioaccumulation, ubiquitous nature and bio-magnification in the food chain (Yang *et al.*, 2023). Heavy metals are naturally occurring element having specific gravity higher than water and they get easily dissolved in water (Ali *et al.*, 2019). Some heavy metals such as iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) are essential for organisms and play role as cofactors in many reactions while others are poisonous with no biological role such as mercury, lead and cadmium (Güngor and Kara, 2017).

Fish serve as suitable bio-indicator of heavy metal contamination as they explore freely among different trophic levels in the water resources (Abdel-Baki *et al.*, 2011). Multiple factors such as seasonal changes, concentration of metals, physico-chemical properties of water, exposure period, metabolic rate and size of fish lead to variations in heavy metal accumulation (Shaikh, 2014). In addition, fish constitute a healthy protein source but the presence of toxic metals in muscles and other tissues could impair human health upon fish consumption. Numerous ecotoxicological studies focus on metal accumulation in various fish tissues such as liver, gills and muscle

(Squadrone *et al.*, 2013). However, fish must be sacrificed in order to sample fish tissues for contamination studies which affect studied species and communities. On the other hand, non-lethal sampling provides an opportunity to gather larger sample size including specimens from endangered and rare species without resulting in death (Baker *et al.*, 2004). Scales provide protection to skin from contamination in the environmental water to which the fish has been exposed due to their external location (Santana *et al.*, 2016). *Labeo rohita* was chosen as model organism due to its sensitivity to heavy metals in water (Jindal and Verma, 2015). Studies have already been conducted on the effect of heavy metals on the structure of fish scales (Brraich and Jangu, 2016; Dwivedi and Sehgal, 2017). However, to our knowledge, effect of different exposure periods and seasons on lepidontal alterations is scarce. Based on the hypothesis, the objective of the current investigation is to study the atomic percentage of heavy metals and surface alterations especially in lepidonts on scales of *L. rohita* of different sizes with respect to seasons.

Materials and Methods

Fish scales of *L. rohita* (Hamilton, 1822) of two sizes i.e. ≤ 40 cm (age <1 year) and >40 cm (age >1 year) were collected from local fish markets of Ludhiana (Punjab) from December 2017 to February 2018 (winter) and April 2018 to June 2018 (summer). 5 scales were gathered from fish in triplicate (n=3) during each month to study ultrastructural alterations. According to fish vendors, fish were captured from Sutlej River and various districts of Punjab, India. Scales of fish gathered from a private fish farm located in the village of Krodian (Tehsil Payal), Ludhiana (long. 76°00 E and lat. 30°70 N) were considered as control. Similarly, 5 scales of control fish were also removed from each fish (n=3) during each month. The farm used all safe fish farming practices. Using forceps, scales were extracted from the second row above the lateral line on the left side of the body of each fish. A fine brush was then used to clean the scales with de-ionized water and gently rubbed between fingers to remove mucous. Ascending ethanol series (30-70%) was utilized to dehydrate scales followed by drying on filter paper. Use of 100% ethanol was discouraged to avoid wilting of scale samples. Double adhesive carbon tape was utilised to mount dehydrated scales on aluminum (Al) stubs. The dorsal surface of mounted scales was kept upwards, sputter coated (to make the scales conductive) using sputter coater and ultrastructural alterations were studied at different magnifications using Scanning Electron Microscopy (SEM, Hitachi S-3400N) facility in Electron Microscope and Nanoscience (EMN) Laboratory, Punjab Agricultural University (PAU), Punjab (India), at accelerating voltage of 15 kV at low probe current (Dwivedi and Sehgal, 2017). The fish scales were compared for ultrastructural alterations such as damaged tubercles, circuli, lepidonts, focus and surface of scale. The atomic percentage (%) of various elements was further determined using Energy Dispersive X-ray microanalysis (EDX, Thermo Noran System SIX, United States of America). The qualitative analysis of heavy metals adsorbed on the surface of scales was performed by placing the scanner attached to SEM on the area of interest followed by extracting peak intensities. To avoid repetition, scales of fish gathered from fish farm and markets during two seasons were abbreviated as follows: Control fish d"40 cm during winter (CSW), control d"40 cm during summer (CSS), control fish >40 cm during winter (CLW), control fish >40 cm during summer (CLS), fish ≤40 cm collected from market during winter (MSW), fish ≤40 cm collected from market during summer (MSS), fish >40 cm collected from market during winter (MLW) and fish >40 cm collected from market during summer (MLS).

Results and Discussion

In the present study, scanning electron micrographs of lateral region of scales of CSW and CLW displayed normal arrangement of circuli, lepidonts and smooth surface at 1.00k SE at 15 kV voltage (low probe current) (Fig. 1a, b). Similarly, scanning electron micrographs of CSS and CLS showed normal arrangement of circuli, lepidonts and smooth surface at 1.00k SE (Fig. 1c, d). In contrast, scanning electron micrographs of scales of MSW, MLW, MSS and MLS displayed damaged lepidonts, broken lepidonts, distorted pattern of circuli, eroded surface, impaired

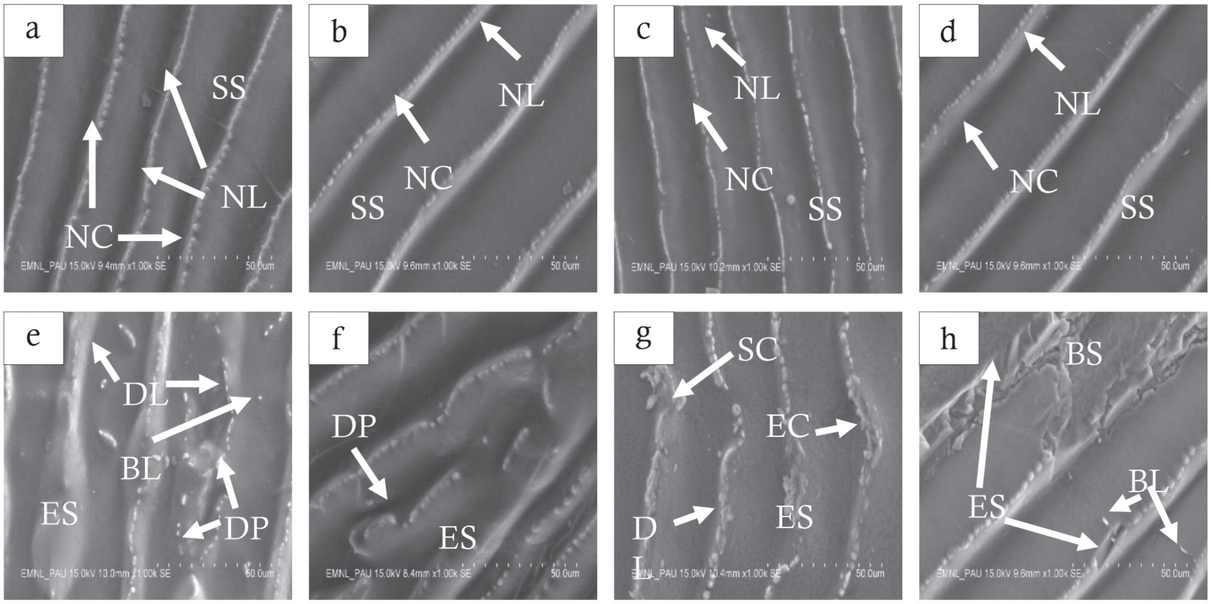


Fig. 1 Scanning electron micrographs of lateral region of scales of **a)** CSW, **b)** CLW, **c)** CSS and **d)** CLS showing NC (normal circuli), NL (normal structure of lepidonts) and SS (smooth surface) at 1.00k SE; Scanning electron micrographs of scales of **e)** MSW, **f)** MLW, **g)** MSS and **h)** MLS showing DL (damaged lepidonts), BL (broken lepidonts), DP (distorted pattern of circuli), ES (eroded surface), SC (sloughed off circuli), DL (damaged lepidonts) and DP (distorted pattern of circuli), EC (eroded circuli), BS (broken surface) and BL (broken lepidonts) at 1.00k SE

lepidonts, sloughed off circuli and distorted circuli pattern, eroded circuli, broken surface and broken lepidonts at 1.00k SE (Fig. 1e, f, g, h). Lepidonts are teeth like structures which help scales to anchor to the fish body and prevent loosening of scales from the skin surface. During winter season, scales of CSW and CLW depicted normal focus in focal area (Fig. 2a, b), normal tubercles (Fig. 3a, b) and smooth surface margin at 100 SE (Fig. 4a, b). Normal focus (Fig. 2c, d), normal tubercles (Fig. 3c, d) and smooth surface margin (Fig. 4c, d) were also observed in scales of CSS and CLS. In contrast, scales of MSW and MLW showed damaged focus (Fig. 2e, f), damaged tubercles (Fig. 3e, f) and torn edges (Fig. 4e, f). Similar patterns were observed in focal region (Fig. 2g, h), posterior region (Fig. 3g, h) and margin of scales (Fig. 4g, h) of MSS and MLS. Ultrastructural alterations in scales gathered from markets might be attributed to larger amount of pollutants in the water source from which fish were collected. The higher severity of damage in summer might be due to elevation in accumulation of heavy metals and metabolic rate of fish with increase in temperature leading to more chances of metal uptake and binding and our observation in this line of Negi and Maurya (2015).

The present study was designed on the basis of the work of Brraich and Jangu (2016). As per the hypothesis of authors, the elemental constitution of fish scales depends upon the water quality. In the current investigation, the atomic percentage of the dorsal surface of scales removed from fish gathered from markets and fish farm of both sizes during two seasons (Winter and summer) is presented in Table 1. The elemental composition of scales of CSW was Magnesium (Mg) (0.73%), Oxygen (O) (61.59%), Phosphorous (P) (14.81%) and Calcium (Ca) (22.87). Atomic percentage of CLW was observed as follows: Ca (19.81%), P (13.89%), O (65.41%) and Mg (0.89%). In contrast, elemental composition of scales of MSW was C (56.66%), Mg (0.28%), O (27.60%), Al (0.06%), Silicon (Si) (0.05), P (5.59%), Nickel (Ni) (0.01%), Ca (9.53%), Cu (0.01%) and Lead (Pb) (0.21%). Similarly, scales of MLW showed atomic percentage of C (38.55%), O (38.73%), Mg (0.48%), P (8.46%), Ca (13.09%), chromium (Cr) (0.06%), Mercury (Hg) (0.15%) and Pb (0.48%). However, O (65.01%), P (14.57%), Mg (0.61%) and Ca (19.81%) were detected on the scales of CSS. Similarly, elemental composition of CLS was as follows: O (62.49%), Ca (22.58%), P (13.96%) and

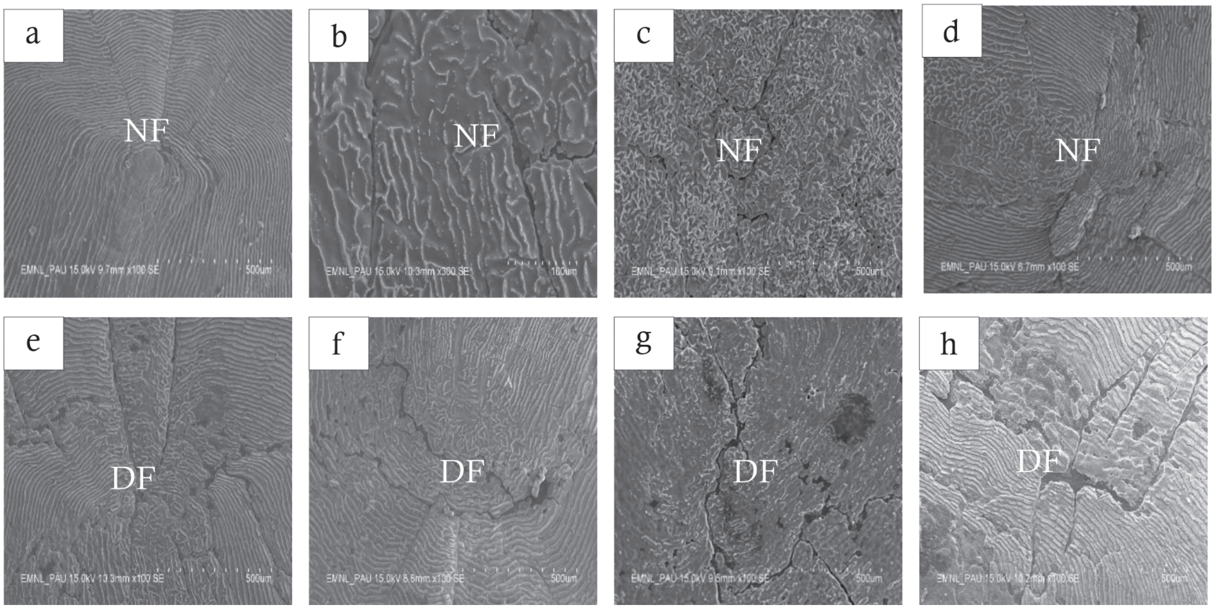


Fig. 2 Scanning electron micrographs of focal region of scales of **a)** CSW **b)** CLW, **c)** CSS and **d)** CLS showing NF (normal focus) at 100 SE; Scanning electron micrographs of scales of **e)** MSW, **f)** MLW, **g)** MSS and **h)** MLS showing DF (damaged focus) at 100 SE

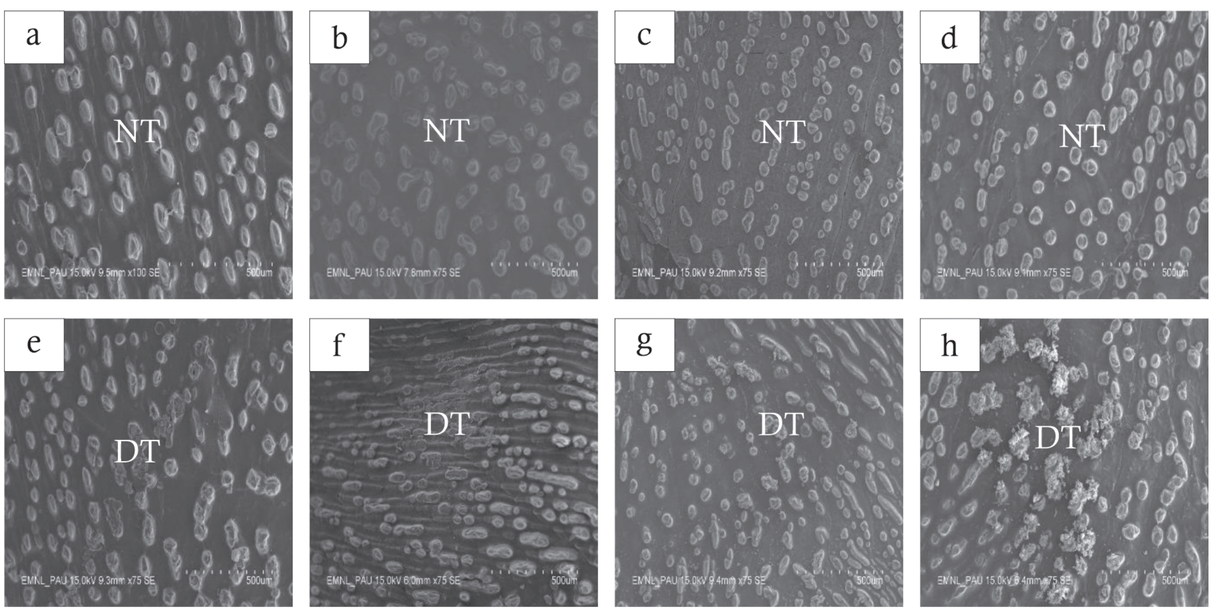


Fig. 3 Scanning electron micrographs of posterior region of scales of **a)** CSW, **b)** CLW, **c)** CSS and **d)** CLS showing NT (normal tubercle) at 100 SE; Scanning electron micrographs of scales of **e)** MSW, **f)** MLW, **g)** MSS and **h)** MLS showing DT (damaged tubercle) at 100 SE

Mg (0.97%). In contrary, scales gathered from MSS indicated the presence of C (58.83%), O (24.58%), Cu (0.09%), Mg (0.33%), Al (0.08%), P (5.63%), Si (0.16%), Ca (10.05%), Ni (0.08%), Zn (0.01%) and Hg (0.16%). Likewise, C (34.26%), P (8.69%), O (42.89%), Mg (0.72%), Al (0.10%), Ca (13.19%), Ni (0.03%), Cr (0.02%) and Zn (0.10%) were observed on the surface of MLS. The atomic percentage of fish scales gathered from market during two seasons clearly indicated the adsorption of heavy metals on their surface, which might be due to heavy metals in the source from where fish were collected. In addition, the atomic percentage of Ca declined in the fish scales gathered from markets compared to control groups. Earlier, accumulation of heavy

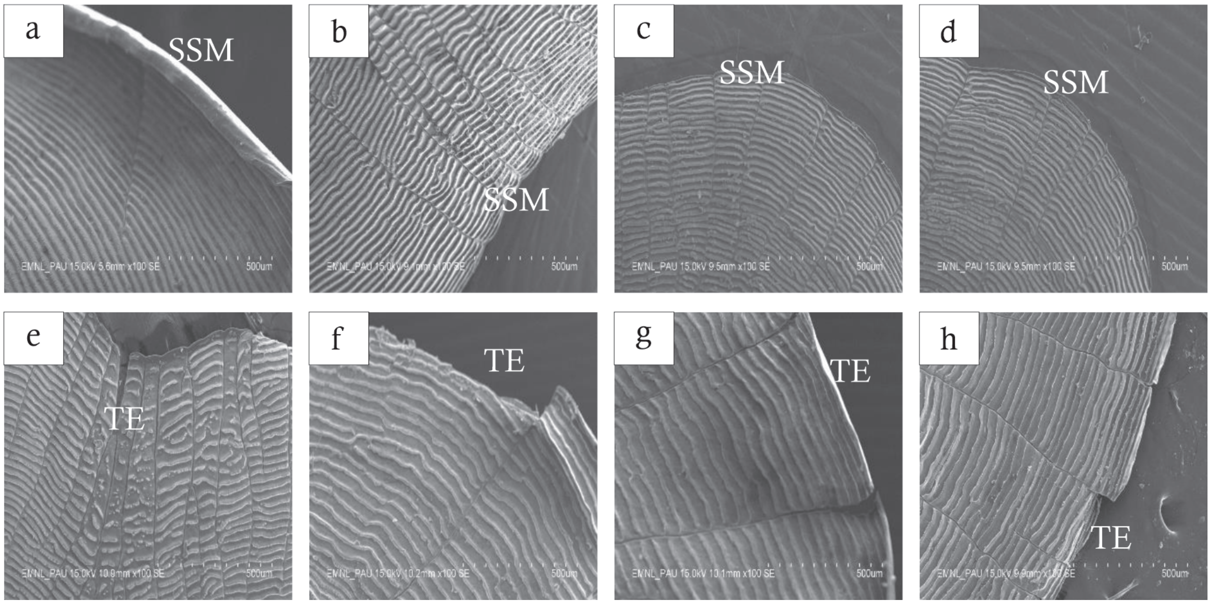


Fig. 4 Scanning electron micrographs of margin of scales of **a)** CSW, **b)** CLW, **c)** CSS and **d)** CLS showing SSM (smooth surface margin) at 100 SE; Scanning electron micrographs of scales of **e)** MSW, **f)** MLW, **g)** MSS and **h)** MLS showing TE (torn edges) at 100 SE

Table 1. Atomic percentage (%) of dorsal surface of fish scales of smaller and larger fish collected from market and fish farm during winter and summer seasons

Seasons	Fish type	Atomic percentage (%) on the dorsal surface of fish scales												
		C	O	Mg	Al	Si	P	Ca	Cr	Ni	Cu	Zn	Hg	Pb
Winter	CSW	-	61.59	0.73	-	-	14.81	22.87	-	-	-	-	-	-
	CLW	-	65.41	0.89	-	-	13.89	19.81	-	-	-	-	-	-
	MSW	56.66	27.60	0.28	0.06	0.05	5.59	9.53	-	0.01	0.01	-	-	0.21
	MLW	38.55	38.73	0.48	-	-	8.46	13.09	0.06	-	-	-	0.15	0.48
Summer	CSS	-	65.01	0.61	-	-	14.57	19.81	-	-	-	-	-	-
	CLS	-	62.49	0.97	-	-	13.96	22.58	-	-	-	-	-	-
	MSS	58.83	24.58	0.33	0.08	0.16	5.63	10.05	-	0.08	0.09	0.01	0.16	-
	MLS	34.26	42.89	0.72	0.10	-	8.69	13.19	0.02	0.03	-	0.10	-	-

metals during two seasons in scales of fish gathered from market were also analysed by inductively coupled argon plasma atomic emission spectrophotometer (ICAP-AES) (Vaid and Hundal, 2019). The results showed duration- and size-dependent heavy metal accumulation in scales. Kaur *et al*. (2018) investigated the accumulation and histological effects of heavy metals on different organs viz. kidney, muscle and liver of *L. rohita* gathered from local market in Ludhiana (India). The results indicated that the elevation in the levels of heavy metals including Cadmium (Cd), Arsenic (As), Zn, Cu, Ni, Cr and Pb in comparison to control. In addition, the values of heavy metals were more than the permissible levels set by WHO/FAO. Furthermore, histological anomalies in studied organs were also recorded. The study concluded accumulation of heavy metals in the fish collected from markets of Ludhiana.

Fish scales are hard calciferous structures having type I collagen fibrils and minerals primarily calcium-deficient hydroxyapatite (HAp) (Gil-duran *et al*., 2016). HAp can be utilized as adsorbent and have an excellent ion exchange capability leading to substitution of Ca with various metal ions (Vila *et al*., 2012). The substitution of Ca with heavy metals present in the water body might be the reason for decrease in the atomic percentage of Ca in market *vis-a-vis* control fish. The current investigation is corroboration with the findings of Pala (2018). The author observed anomalies such as broken lepidonts, displacement of lepidonts and damaged circuli in *Cyprinus carpio* gathered from government sponsored fish farms located in Meghalaya, India, which had various pollution sources. Based on alterations observed, the author suggested that structural aberrations might be due to greater susceptiblity of fish scales to external stressors and their ability to respond to lower levels of contaminants making scales sensitive indicators of water quality. Adsorption of Pb, Fe, Hg, arsenic (As) and Cu on the surface of scales of *Channa punctatus* gathered from river Yamuna, Delhi was testified by Dwivedi and Sehgal (2017) using EDX. The scientists observed higher concentration of Pb and Hg during summer which might be due to stagnant water conditions.

Similarly, effect of Fe and Al on the surface of scales of caged fish, *Oreochromis mossabicus* was studied by Hidayati *et al*. (2014) using SEM. The results showed decline in the number of spherules and ridges whereas the number of pits increased. Khanna *et al*. (2007) also investigated ultrastructural alterations in scales of *Puntius sarana* and *L. rohita* gathered from Ganga using SEM. The results showed ultrastructural aberrations viz. damaged lepidonts, damaged circuli and loss of single and complete row of lepidonts. In addition, seasonal variability in heavy metal accumulation was also conducted by the authors. The results showed higher level of heavy metals such as Fe, Ca and Mg during the monsoon season which might be responsible for lepidontal aberrations. Similarly, Coban *et al*. (2013) also investigated the effect of different concentrations of Cr (7.5, 15, 30 and 60 μg L^{-1}) on scales of *Cyprinus carpio* procured from State Hydraulic Works (Turkey) for the period of 21 days. Alterations were observed in the order: Focal region> anterior region> posterior region. The results revealed that alterations in focus and circuli depend on Cr contration in water. Tandon and Johal (1993) also indicated that Al is responsible for torn edges in the scales of *Tor putitora*.

Kaur and Dua (2015) studied the impact of sublethal concentrations of municipal wastewater (17.7, 26.6 and 35.4%) over a range of time periods- 15, 30 and 60 days on fish scale structure of commercially important fish *L. rohita* procured from Rajasansi, Amritsar. Using SEM, the authors observed time- and concentration-dependent alterations on the scale surface such as lepidontal uprooting, damaged tubercles, radii, circuli and focus. Deposition of heavy metals (Zn, Ni, Cr, Al, Fe, Cd, Cu and Pb) on the scales of fishes (*Catla catla*, *L. calbasu*, *C. carpio*, *L. rohita* and *Cirrhinus mrigala*) gathered from Harike wetland (India) was studied by Brraich and Jangu (2016) using EDX. In addition, structural alterations viz. uprooting of lepidonts, damaged circuli and empty pockets were observed on the scale's surface. The results concluded that atomic percentage of heavy metals acts as indicator of heavy metal accumulation and pollution in Harike wetland. Similarly, the elemental composition of scales of *L. calbasu* gathered from Harike wetland depicted the presence of P (13.43%), Al (0.10%), Zn (0.99%), Mg (0.76%), C (17.18%), Cr (0.32%), Ni (0.04%), Ca (18.4%), Cu (0.14%), O (48.13%), Pb (0.13%) and Si (0.38%) on the scale surface (Jangu and Brraich, 2014).

Conclusions

The study indicated destructive impact of heavy metal pollution on the fish scales especially lepidonts including lepidontal damage and broken lepidonts. In addition, damage in circuli, focus, tubercles and surface margin was also observed. Higher severity of damage in microstructure of scales was observed during summer season than winter season. The intensity of ultrastructural alterations was observed higher in scales of MLS and MLW, which might be due to longer duration of exposure to heavy metal pollution. Different heavy metals including Ni, Cu, Zn, Pb, Al, Cr and Hg were found on the scales gathered from local fish markets when compared to control groups. In addition, Si was also detected on the scales gathered from markets. Higher atomic percentage of metals in scales gathered from market due to higher heavy metal levels in the water source from which fish were collected. Based on above observations, it is suggested that lepidontal alterations and other anomalies on the scales are useful indicators of heavy metal pollution.

However, the scales were gathered from fish markets for the present preliminary study. Therefore, more in situ studies are required to confirm that the deformities are due to heavy metal pollution to eliminate the influence of external parameters. For this, further work can be done to evaluate the effects of individual heavy metals on the surface of scales and at organ level in controlled conditions to know target region of each metal.

Acknowledgement

The authors are thankful to the Head of the Department of Zoology, College of Basic Sciences and Humanities and Electron Microscope and Nanoscience Laboratory, College of Agriculture, Punjab Agricultural University, Ludhiana district, Punjab (India), for providing the necessary facilities to carry out this research work.

References

Abdel-Baki AS, Dkhil MA and Al-Quraishy S (2011) Bioaccumulation of some heavy metals in tilapia fish relevant to their concentration in water and sediment of Wadi Hanifa, Saudia Arabia. *African Journal of Biotechnology* **10**: 2541-2547.

Ali S, Hussain S, Khan R, Mumtaz S, Ashraf N, Andleeb S, Shakir HA, Tahir HM, Khan MKA and Ulhaq M (2019) Renal toxicity of heavy metals (cadmium and mercury) and their amelioration with ascorbic acid in rabbits. *Environmental Science and Pollution Research International* **26**: 3909-3920.

Baker RF, Blanchfield PJ, Paterson MJ, Flett RJ and Wesson L (2004) Evaluation of Nonlethal Methods for the Analysis of Mercury in Fish Tissue. *Transactions of the American Fisheries Society* **133(3)**: 568-576.

Brraich OS and Jangu S (2016) Comparative account of accumulation of heavy metals and structural alterations in scales of five species from Harike wetland, India. *Iranian Journal of Ichthyology* **3(4)**: 275-282.

Coban MZ, Eroglu M, Canpolat O, Calta M and Sen D (2013) Effect of chromium on scale morphology in scaly carp (*Cyprinus carpio* L.). *Journal of Animal and Plant Sciences* **23(5)**: 1455-1459.

Deepak T, Padmavathy P, Rani V, Manimekalai D and Devasena SS (2022) Water quality parameters and nutrient status of selected reservoirs in Tamil Nadu, India. *Indian Journal of Fisheries* **69(4)**: 28-35.

Dwivedi S and Sehgal N (2017) Scale of murrel: A non-invasive approach to monitor heavy metals in freshwater. *Journal of Biological and Medical Sciences* **3(3)**: 15-23.

Gil-Duran S, Arola D and Ossa EA (2016) Effect of chemical composition and microstructure on the mechanical behavior of fish scales from *Megalops Atlanticus*. *Journal of the Mechanical Behavior of Biomedical Materials* **56**: 134-145.

Güngor A and Kara D (2017) Toxicities and risk assessment of heavy metals of the six most consumed fish from the Marmara Sea. *Environmental Science and Pollution Research International* **25(3)**: 2672-2682.

Hidayati D, Sulaiman N, Othman S and Ismail BS (2013) Fish scale deformation analysis using scanning electron microscope: New potential biomarker in aquatic environmental monitoring of aluminum and iron contamination. *AIP Conference Proceedings* **1571**: 563-568.

Jangu S and Brraich OS (2014) Heavy metals accumulation and structural alterations in scales of fish *Labeo calbasu* (Hamilton-Buchanan) from Harika wetland (Ramsar site), India. *International Journal of Scientific Engineering and Research* **5(6)**: 637-641.

Jindal R and Sharma C (2011) Studies on water quality of Sutlej River around Ludhiana with reference to physicochemical parameters. *Environmental Monitoring and Assessment* **174**: 417-425.

Jindal R and Verma S (2015) In vivo genotoxicity and cytotoxicity assessment of cadmium chloride in peripheral erythrocytes of *Labeo rohita* (Hamilton). *Ecotoxicology and Environmental Safety* **118**: 1-10.

Kaur R and Dua A (2015) Scales of freshwater fish *Labeo rohita* as bioindicators of water pollution in Tung Dhab drain, Amritsar, Punjab, India. Guru Nanak Dev university campus, Amritsar, Punjab, India. *Journal of Toxicology and Environmental Health, Part A* **78**: 388-396.

Kaur S, Khera KS and Kondal JK (2018) Heavy metal induced histopathological alterations in liver, muscle and kidney of freshwater cyprinid, *Labeo rohita* (Hamilton). *Journal of Entomology and Zoology Studies* **6(2)**: 2137-2144.

Khanna DR, Sarkar P, Gautam A and Bhutiani R (2007) Fish scales as bio indicator of water quality of river Ganga. *Environmental Monitoring and Assessments* **134**: 153-60.

Lau C and Li XC (2023) Cadmium, chromium, copper, iron, lead, mercury, nickel, and zinc in freshwater fish: Assessing trophic transfer using stable isotope ratios of δ15N and δ13C. *Journal of Environmental Sciences* **128**: 250-257.

Negi RK and Maurya A (2015) Heavy metal concentrations in tissues of major carp and exotic carp from Bhagwanpur Fish Pond, India. *Journal of Fisheries and Aquatic Sciences* **10(6)**: 543-552.

Pala EM (2018) Ultrastructural Deformities in the Scales of *Cyprinus carpio* inhabiting two Government-Sponsored Fish Farms in North-East India Contaminated by Municipal Wastes and Other Pollutants. *Microscopy and Microanalysis* **24(6)**: 729-733.

Santana CA, Lima DMV, Andrade LHC, Suarez YR and Lima SM (2016) Laser-induced fluorescence in fish scales to evaluate the environmental integrity of ecosystems. *Journal of Photochemistry and Photobiology B: Biology* **165**: 80-86.

Shaikh M (2014) Bioaccumulation of Heavy Metals in Tissues of *Labeo rohita* From Nathsagar Dam, Near Aurangabad, Maharashtra. *International Journal of advances in agricultural and environmental engineering* **1(1)**: 54-56.

Squadrone S, Prearo M, Brizio P, Gavinelli S, Pellegrino M, Scanzio T, Guarise S, Benedetto A and Abete MC (2013) Heavy metals distribution in muscle, liver, kidney and gill of European catfish (*Silurus glanis*) from Italian Rivers. *Chemosphere* **90(2)**: 358-365.

Tandon KK and Johal MS (1993) Mineral composition of different regions of the scale of an enlarged fish Tor putitora (Hamilton) using energy-dispersive X-ray microanalysis technique. *Current science* **65**: 572-573.

Vaid V and Hundal SS (2019) Light microscopic studies to evaluate fish scales as non-invasive indicators of heavy metal-contaminated waters. *Environmental Montoring and Assessment* **191**: 638.

Vikrma A and Sandhu HAS (2022) Health Risk Assessment of Gurdaspur, Punjab, India Using Field Experiments and GIS: A Groundwater Perspective. *Journal of the Geological Society of India* **98**: 933-936.

Vila M, Sanchez-Salcedo S and Vallet-Regi M (2012) Hydroxyapatite foams for the immobilization of heavy metals: From waters to the human body. *Inorganica Chimica Acta* **393**: 24-35.

Yang F, Zhang H, Xie S, Wei S, Wei C and Yang X (2023) Concentrations of heavy metals in water, sediments and aquatic organisms from a closed realgar mine. *Environmental science and pollution research international* **30(2)**: 4959-4971.

Received: February 27, 2024; Accepted: June 26, 2024

Journal of Soil Salinity and Water Quality 16(1), 126-140, 2024

Comprehensive Study of Nutrient Status in Guhla Block of Kaithal District, Haryana: Promoting Sustainable Agriculture

Mohit Sharma[1], RS Garhwal[1]*, KK Bhardwaj[2], SK Dubey[3], Anil Kumar[2], Charan Singh[2,4] and Saloni Yadav[2]

[1]*College of Agriculture, CCS HAU, Kaul, Kaithal-136021, Haryana, India*
[2]*Department of Soil Science, CCS HAU, Hisar-125004, Haryana, India*
[3]*ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India*
[4]*Rice Research Station, CCS HAU, Kaul, Kaithal-136021, Haryana, India*
**Corresponding author's E-mail: rsg.rca2011@gmail.com*

Abstract

Understanding the spatial variability in soil fertility is crucial for effective site-specific nutrient management. A soil survey was conducted across 95 villages in the Guhla block of the Kaithal district to create an inventory of soil fertility. Total 190 samples were collected using GPS and analysed for their chemical properties and maps were prepared using GIS. The results revealed that the soils were neutral to alkaline in nature, non-saline, low to high in OC and their soil texture was sandy loam, loam and loamy sand. Bulk density ranged from 1.43-1.59 Mg m^{-3} with a mean value of 1.51 Mg m^{-3}. Most of the soil samples were found to be deficient in N, with only 7 sample were found under medium category, however for available P, 31 samples were low, 140 medium, and 19 high. While for available K, 12 samples were low, 139 medium, and 39 high. Most of the samples were high for available S (92%). The nutrient index for available nitrogen was low. The nutrient indices for organic carbon, P and K were medium, while the nutrient index for S was high. The DTPA extractable Zn, Fe, Cu and Mn content in soil ranged from 0.28-5.98, 0.9-18.40, 0.16-2.98 and 1.10-7 mg kg^{-1}, with mean value of 1.96, 7.66, 1.23 and 3.45 mg kg^{-1}, respectively.

Key words: DTPA, GIS, Nutient Index, Loamy Sand

Introduction

Soil is a vital natural resource, essential for providing food, fodder and fuel for humans and animals for sustainability. Increasing populations of humans and animals increase the demand for food production, which places mounting pressure on our soils. Throughout history, the prosperity and survival of civilizations have been closely tied to the capacity of their local soils to provide essential resources. In order to ensure food security for present and future generations by effectively using soil resources, this presents a huge issue for scientists, planners, administrators, and farmers. The viability of any agricultural system, whether holistic or specialized, depends on the fertility and its overall heath.

Evaluating the fertility status of the soil is essential for making well-informed agriculture decisions. Understanding soil nutrient content helps farmers optimize fertilization, crop selection, and planting methods, improving both crop yields and quality. Soil testing facilitates precise fertilizer recommendations by analysing essential nutrients like nitrogen, phosphorus and potassium, as well as secondary and micronutrients to reducing costs and mitigating environmental impact. Furthermore, these tests can identify nutrient imbalances that might hinder plant growth and yield, allowing for targeted nutrient adjustments to enhance crop productivity. Proper nutrient management, guided by soil fertility assessments, also plays a vital role in minimizing the risk of nutrient runoff into water bodies, thus preventing water pollution and ecological harm. Accurate soil fertility information helps farmers avoid over-fertilization, saving costs and reducing their environmental footprint by applying only necessary nutrients. Regular assessments are integral to sustaining soil health, preventing degradation and ensuring long-term productivity. These assessments provide valuable data for agricultural research and education, benefiting scientists, agronomists and extension services in developing best practices and recommendations for local farming communities.

Kaithal district is located in the north-eastern part of Haryana, covering an area of 2,317 square kilometres. It lies between latitudes 29°31' and 30°12' north and longitudes 76°10' and 76°42' east. It shares its northern border with Patiala district of Punjab and is flanked to the east, west and south by Kurukshetra, Karnal and Jind districts of Haryana. The district is divided into several development blocks, each with its distinct identity. The region is characterized by the presence of several rivers, including the Yamuna, Ghaggar, Markanda, along with seasonal streams originating from the Siwalik range. The landscape is covered with alluvial deposits from both ancient and recent periods, typical of the Indo-Gangetic plain. In irrigated regions, traditional crops *i.e.* maize, gram, moong beans and horticulture have been replaced by rice, wheat and cotton cultivation. The primary crops grown in this region include wheat, rice, sugarcane, cotton and sorghum.

To ensure effective soil management, it is essential to regularly evaluations of soil fertility to monitor alterations in macro and micronutrient levels and to identify the extent of any multi-nutrient deficiencies. In light of this, the current study has been planned with the following main goals in mind: (i) To evaluate the soil fertility status of Guhla block, (ii) To classify the soil according to its fertility characteristics.

Materials and Methods

Study area

The study was carried out at the Guhla block of Kaithal district, located between latitudes 29°31' and 30°12' N, and longitudes 76°10' and 76°42' E. Guhla block has 95 villages and features a tropical steppe climate, which is semiarid and humid. This area experiences hot summers and cold winters, with the monsoon season bringing moist air from the ocean. The district receives an average annual precipitation of 511 mm, which is evenly distributed. The southwest monsoon typically arrives in the last week of June. The district is characterized by two types of soils: sierozem and desert soils. Sierozem soil predominates, while desert soils are found particularly in the northern region. According to the Soil Testing and Research Laboratory in Kaithal, the district's soils range from sandy to sandy loam in texture.

Soil Sampling and Analysis

In the Guhla block of the Kaithal district, 190 soil samples were taken at a depth of 0 to 15 cm for the current study. These samples were collected from 95 villages of Guhla block. The soil samples were randomly collected from farmer's fields using a post hole auger, and the longitude and latitude coordinates of each sampling site were recorded with a handheld GPS device. The locations of all the soil samples collected from the Guhla block is represented in Fig. 1.

The soil samples were air-dried, crushed with a wooden mortar and pestle and passed through 2 mm sieve. Subsequently, the samples were stored in labelled cloth bags in the laboratory for further analysis. Processed soil samples were analysed for nutrient availability by following standard analytical techniques. The pH was measured by taking (soil : water = 1 : 2) 20 g of soil sample into a 100 ml beaker and then adding 40 ml of distilled water into and stirring the suspension intermittently for 30 minutes. The suspension was stirred once again before inserting the electrodes to obtain the pH reading (Jackson, 1973). Then suspension was allowed to stand until clear supernatant liquid is obtained. The clear extract obtained after pH measurement was used for EC measurement (Jackson, 1973).

The soil OC was determined by wet digestion method (Walkley and Black, 1954). The available N in the soil sample was determined by alkaline permanganate method (Subbiah and Asija, 1956). Available P was determined by Olsen *et al.* (1954). Available K in the soil was determined using a flame photometer as described by Jackson (1973). Available S in the soil was determined by using the method provided by Chensin and Yien (1950). The calcium carbonate content of the soil samples

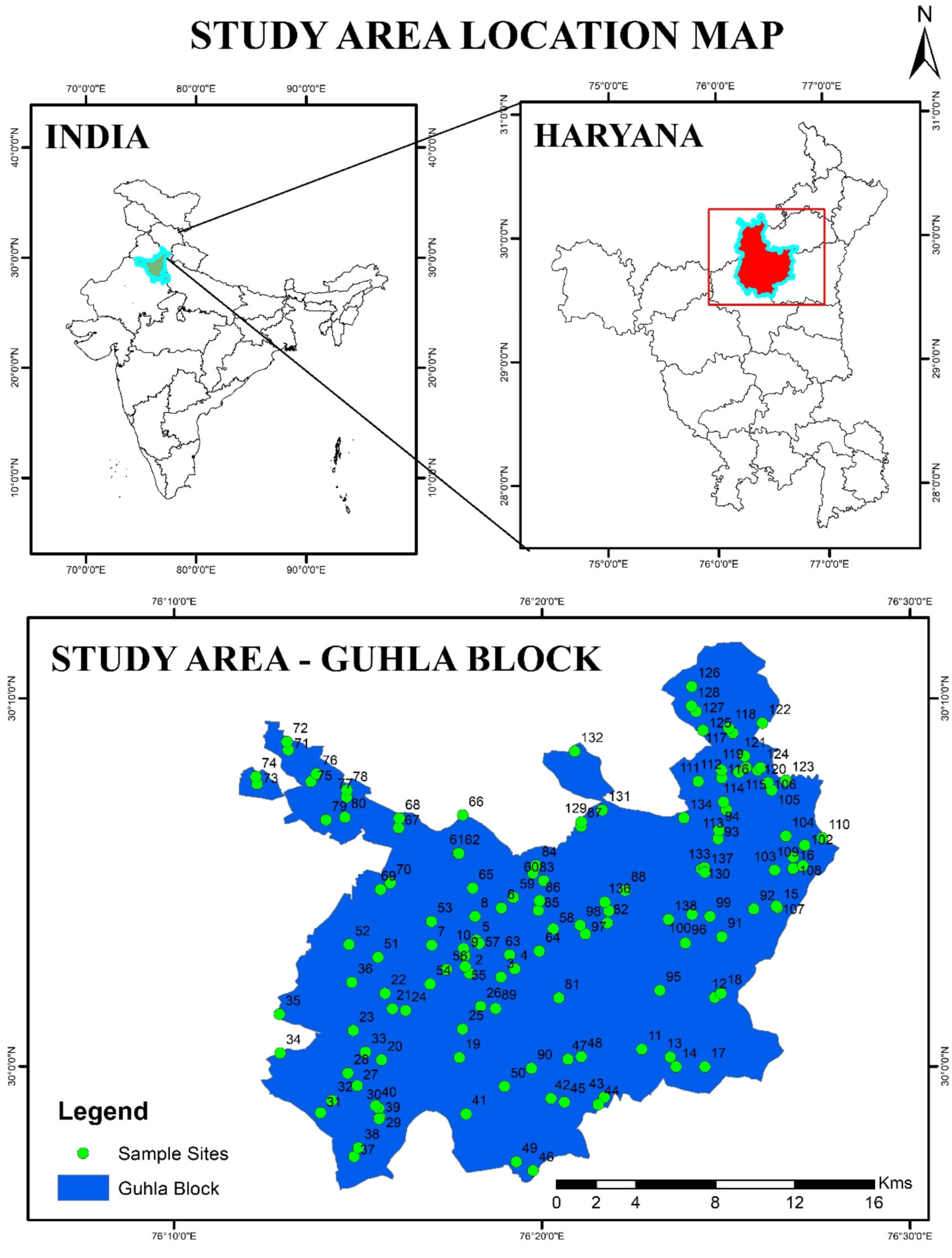


Fig. 1 Location map of Guhla block of Kaithal district

was determined according to Puri (1930). Available Micronutrients in the soil was analysed using DTPA-extractable method (Lindsay and Norvell, 1978). According to the generalized classification adopted for Indian soils, the micronutrient content in soil were categorized as acute, deficient, latent deficient, marginally sufficient, adequate and high (Shukla *et al.*, 2019).

To determine the bulk density in the upper layer, soil cores with a 5 cm inner diameter and 5 cm height were collected. The samples were then oven-dried at 105°C for 24 hours. The bulk density of the soil samples was calculated based on the mass of the soil and the volume of the soil cores.

Table 1. Critical limits of various parameters in the soil (Antil *et al.*, 2001)

Nutrients	Low	Medium	High
Available N (kg ha^{-1})	<250	250-500	>500
Available P (kg ha^{-1})	<10	10-20	>20
Available K (kg ha^{-1})	<125	125-300	>300
Available S (kg ha^{-1})	<20	20-40	>40
Organic carbon (g kg^{-1})	<40	40-75	>75

Soil texture was determined using the International Pipette Method (Piper, 1966).

The Nutrient Index (NI) was calculated using the equation derived by Parker *et al.* (1951):

$$\text{Nutrient Index} = (1 \times N_L + 2 \times N_M + 3 \times N_H) / N \quad \dots (1)$$

where N_L represents the No. of soil samples in the low category, N_M is the No. of soil samples in the medium category, N_N is the No. of soil samples in the high category, and N is the total No. of soil samples. Based on the Nutrient Index value, the soils were classified into three categories: NI values less than 1.67 indicated a low fertility status, values between 1.67 and 2.33 indicated a medium fertility status, and values exceeding 2.33 indicated a high fertility status.

Statistical Analysis

The statistical analysis of the data was performed using the corplot package in R Software. Distribution maps depicting soil micronutrient status were created using ArcGIS 10.3 software. This approach enhanced data visualization and facilitated a clearer understanding of the distribution of micronutrient deficiencies across the Guhla block of Kaithal. The nutrient deficiencies (% of the sampled sites), block boundary were used as different layers of ArcGIS mapping.

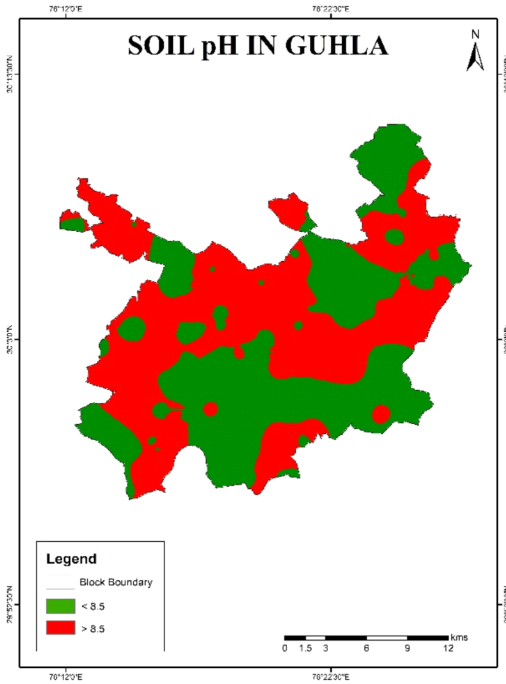
Results and Discussion

Soil pH

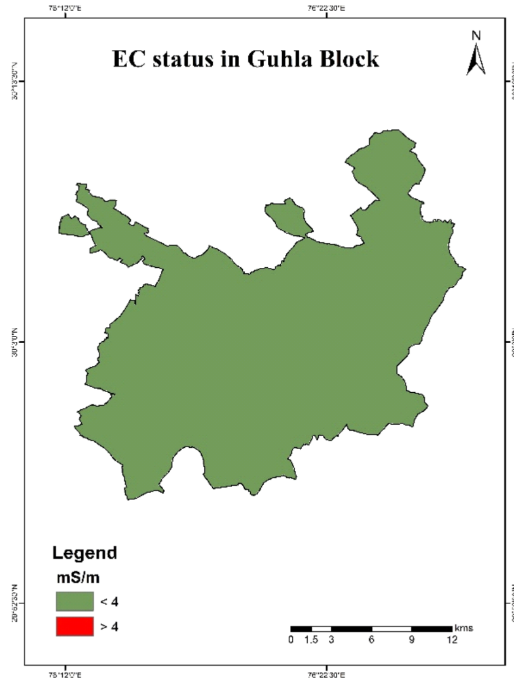
Assessing soil acidity and alkalinity is crucial for optimizing crop yield. The pH value serves as a comprehensive indicator of all acid-base reactions occurring within the soil environment (Mokolobate and Haynes, 2002). The Soil pH varied from 7.29 to 9.30 with an average value of 8.51. Among the 190 soil samples collected, 88 were identified as saline and 102 samples as sodic in nature. The alkaline nature of these soils could be ascribe to the presence of basic parent material or the intereaction between the soil colloids and applied fertilizers, leading to the formation of basic cations on the exchangeable complex of the soil (Gill, 2023). Another probable reason for alkalinity is high base saturation combined with uneven rainfall distribution, resulted in ion accumulation. Similar outcomes were reported by Gora (2013) and Gyawali *et al.* (2016) in the Kaithal district of Haryana. Whereas, Prem *et al.* (2017) reported that soil pH levels in the Ambala district of Haryana varied from 6.8 to 8.2. Pahlavan-Rad *et al.* (2018) reported that the distance from the river was the dominant environmental variable for spatial variability of pH in in flood plain areas. Another probable reason might be the influence of natural and anthropogenic factors on the spatial–temporal variation of soil pH over a short time in a small region (Zhang *et al.,* 2022).

Electrical Conductivity (EC)

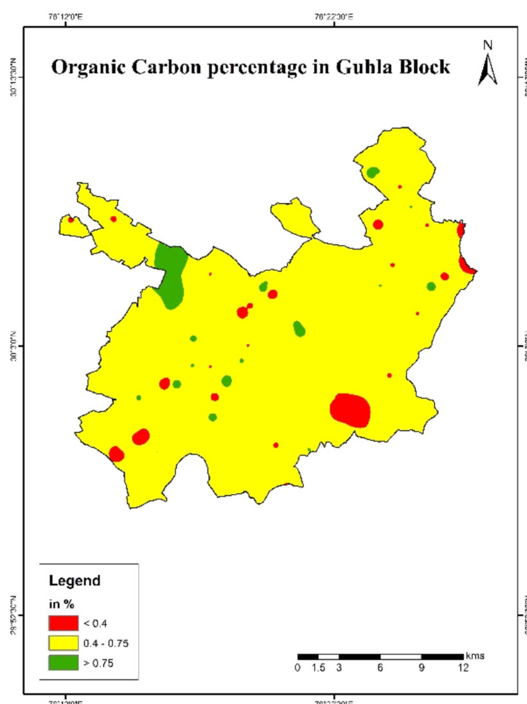
The EC of soil is associated with various soil factors that might impact crop yield. These properties include soil texture, cation exchange capacity (CEC), drainage conditions, salinity, organic matter content and subsurface features (Corwin and Lesch, 2005). The EC of soils varies depending on the amount of moisture held by soil particles (Desavathu *et al.*, 2018). The EC of the soils varied from 0.09 to 0.97 dS m^{-1}, with an average value of 0.33 dS m^{-1}. This implied that all the soil sample of Guhla block were non-saline. The normal EC of the soils may be ascribed to the removal of excess salts by the percolating water due to well drained conditions of soils resulting from intensive cultivation (Prem *et al.*, 2011). Sharma *et al.* (2011) also found low EC due to leaching of base through high water percolation while studying the soils of Western Shiwalik Himalayas in Punjab. Nazif *et al.* (2006) reported similar observations of leaching of base Bhimber of Azad Jammu and Kashmir.



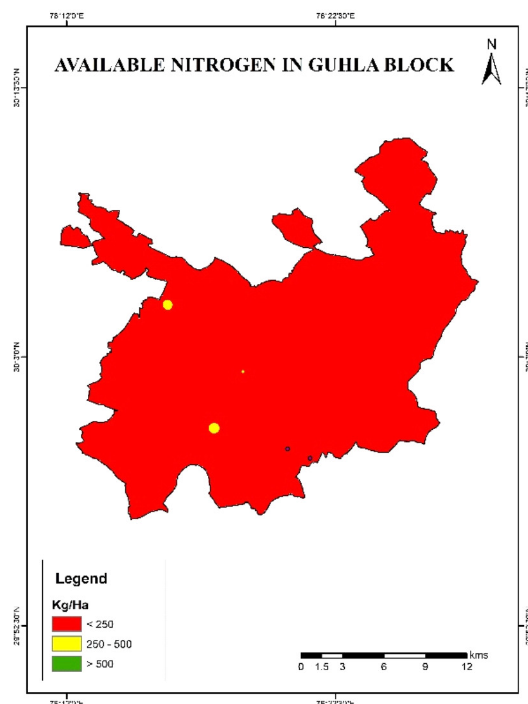
(a)



(b)



(c)

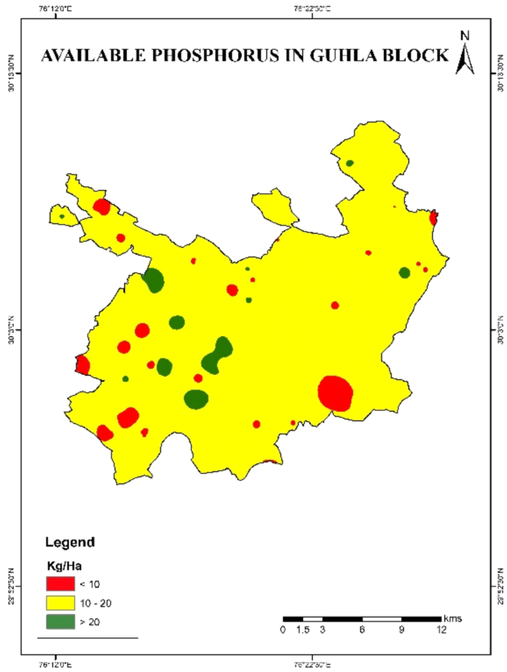


(d)

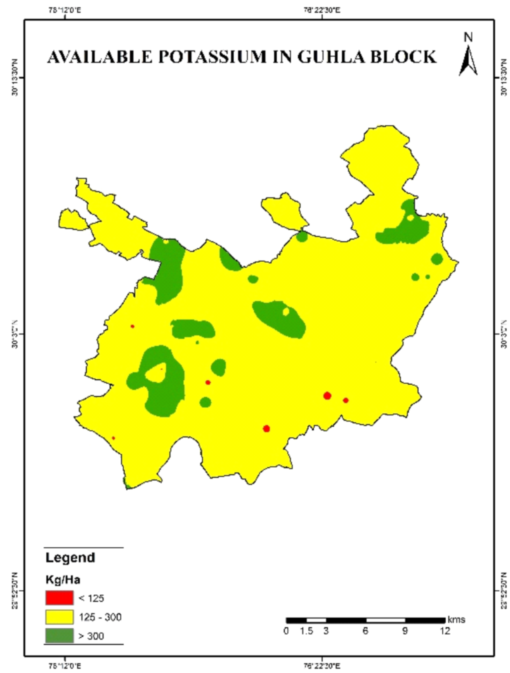
Contd...

Soil Organic Carbon (OC)

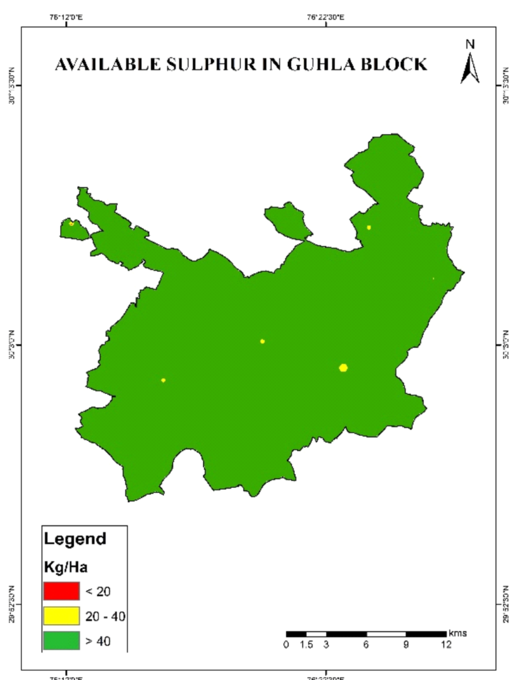
The OC content of soils varied from 0.15-1.21% with an average value of 0.56%. In general out of 190 soil samples, 16 per cent samples fell under low status, 66 per cent samples were medium and 18 per cent of the soil samples were high in OC category. Majority of the samples in Guhla block was found with medium SOC fertility (NI 2.01) level (Table 3). The reason for moderate organic carbon status might be ascribed to the continuous



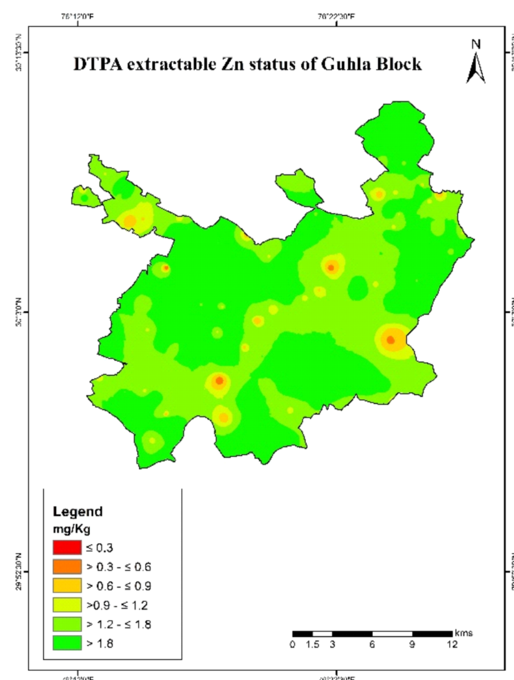
(e)



(f)



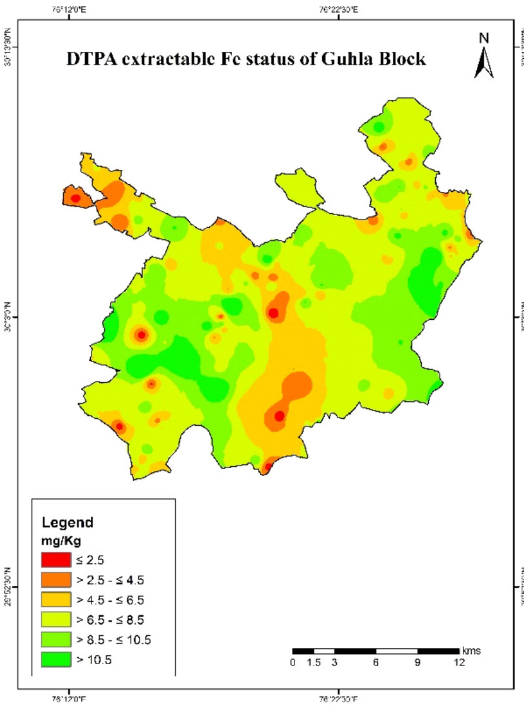
(g)



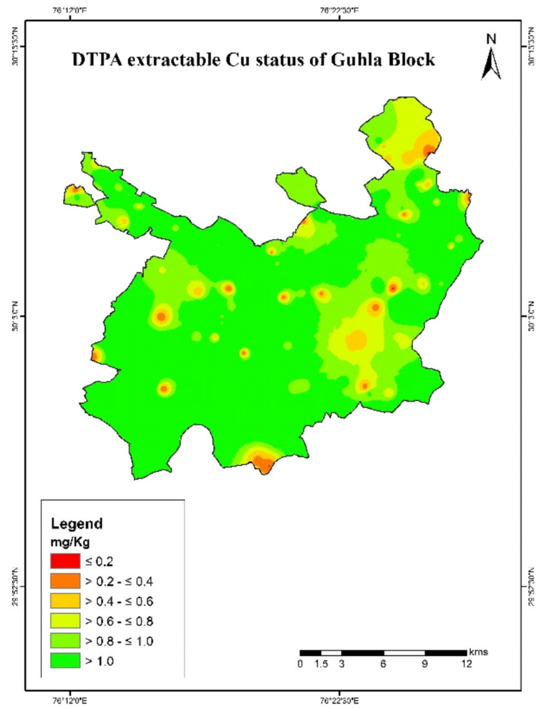
(h)

Contd...

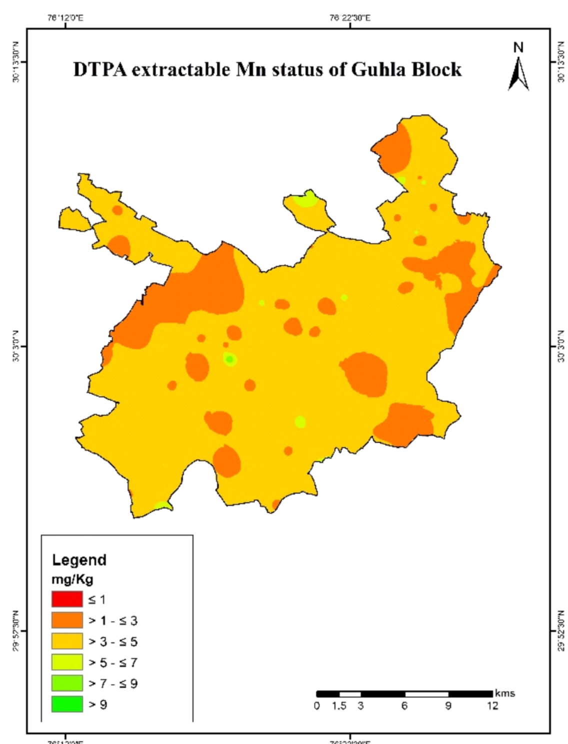
rice-wheat system, which might have contributed more residues in soil. However, 16% samples in Guhla block were found under the low organic carbon category. It might be ascribed due to the rapid decomposition of organic matter in hyperthermic conditions, leading to exceptionally high oxidative environments (Singh *et al.*, 2014). These findings are consistent with those of Gyawali *et al*. (2016) and Gora (2013) in the Kaithal district of Haryana.



(i)



(j)



(k)

Fig. 2 Status and distribution of pH, EC, OC, macro and micro-nutrients in the Guhla block of Kaithal

Calcium Carbonate

In the soils of Guhla block, calcium carbonate was absent. The absence of calcium carbonate showed that non-calcareous sediments have been transported and deposited by water (alluvium) in this region (Kumar, 2019). Also, this might be due to intensive cultivation and tubewell irrigation resulting in leach down of calcium carbonate and their accumulation in the lower horizons (Dinesh *et al.*, 2017). Verma *et al.* (2012) stated that calcium carbonate increased with increase in depth which could be due to illuviation of $CaCO_3$ along with clay and its consequent precipitation due to high pH level (Pal *et al.*, 1999).

Soil Texture

The soil texture of Guhla block varied from sandy loam, loam and loamy sand. The variation in soil texture may be attributed due to the difference in parent material and influences of pedogenesis (Gyawali *et al.*, 2016). These findings are consistent with those of Gyawali *et al.* (2016) and Gora (2013) in the Kaithal district of Haryana.

Bulk Density

The Bulk density content of soils of Guhla block ranged from 1.43 to 1.59 Mg m^{-3} with an average value of 1.51 Mg m^{-3}. The higher bulk density of the soils resulted from the substantial presence of organic matter and clay content. Additionally, the surface soils exhibited a relatively higher bulk density due to their extraction from rice fields that have undergone prolonged flooding for rice cultivation, resulting in the slaking of soil aggregates (Gyawali *et al.*, 2016). These findings are consistent with those of (Singh *et al.,* 2014) and (Motschenbacher *et al.*, 2011).

Available Nitrogen

Nitrogen (N) is essential for plant growth, and its deficiency can lead to significant problems. Plants lacking nitrogen often exhibit a light green coloration, with the older leaves starting to yellow. Some crops may rapidly dry up, resembling symptoms of water shortage (Carter and Knapp, 2001 and Basu, (2011). The available nitrogen content in the soils of the Guhla block varied from 89 to 277 kg ha^{-1}, with an average value of 184 kg ha^{-1}. Out of the 190 soil samples, 183 were observed to be low, and 7 soil samples were moderate in nitrogen content. The available nitrogen content was low (96%) in the major portion of the Guhla block, while only 4% was in the medium category. The majority of the samples were found to have low nitrogen fertility (NI 1.03) levels (Table 3). The low levels of available nitrogen in the soils were attributed to the low efficiency of applied nitrogen, as nitrogen can be lost through various mechanisms *i.e.* NH_3 volatilization, nitrification followed by denitrification, chemical and microbial fixation, leaching and runoff (Prem *et al.*, 2011). Kumar (2019) stated that the higher decomposition rate of organic materials, attributed to the higher temperature in the region, might have contributed to the reduced accessibility of nitrogen in the soil. The results are in line with research conducted in Kaithal district of Haryana by (Gyawali *et al.*, 2016) and (Shabnam, 2021).

Available Phosphorus

Phosphorus (P) is essential for several plant processes, including fruit maturity, early ripening, cell division, growth, and root formation. A constituent of various organic substances such as oils and amino acids, it is essential for the storage and transfer of energy (Desavathu *et al.*, 2018). Plants deficient in phosphorus typically appear dark green in color, with lower leaves turning yellow and drying out over time. This condition ultimately stunts plant growth and reduces leaf size (Tairo and Ndakidemi, 2013). The available P content in the soils of the Guhla block varied from low to high (5 to 35 kg ha^{-1}) with average values of 14.10 kg ha^{-1}. Out of 190 soil samples 16 per cent samples fell under low status, 74 per cent samples were medium and 10 per cent of the soil samples were high in P category. The majority of the samples were found with medium phosphorus fertility (NI 1.93) level (Table 3). This could be due to the external application of phosphatic fertilizers in the field (Habtamu *et al.*, 2014). The findings are consistent with studies observed by Singh *et al.* (2011); Gyawali *et al.* (2016); Prem *et al.* (2017) and Shabnam (2021) in the districts of Haryana.

Table 2. Critical limits of micronutrients in the soil (Shukla *et al.*, 2019)

Micronutrient	Acute	Deficient	Latent deficient	Marginal sufficient	Adequate	High
Zn (mg kg^{-1})	≤0.3	>0.3 - ≤0.6	>0.6 - ≤0.9	>0.9 - ≤1.2	>1.2 - ≤1.8	>1.8
Fe (mg kg^{-1})	≤2.5	>2.5 - ≤4.5	>4.5 - ≤6.5	>6.5 - ≤8.5	>8.5 - ≤10.5	>10.5
Cu (mg kg^{-1})	≤0.2	>0.2 - ≤0.4	>0.4 - ≤0.6	>0.6 - ≤0.8	>0.8 - ≤1.0	>1.0
Mn (mg kg^{-1})	≤1	>1 - ≤3	>3 - ≤5	>5 - ≤7	>7 - ≤9	>9

Table 3. Soil fertility status and Nutrient index of Guhla block (N=190 samples)

Parameters	Range	Mean	Number of samples in the fertility category			NI	Remarks
			Low	Medium	High		(based on NI)
Organic (g kg^{-1})	0.15-1.21	0.56	31	126	33	2.01	Medium
Available N (kg ha^{-1})	89-277	184	183	7	0	1.03	Low
Available P (kg ha^{-1})	5-35	14.10	31	140	19	1.93	Medium
Available K (kg ha^{-1})	110-524	250	12	139	39	2.14	Medium
Available S (mg kg^{-1})	12-298	132	2	6	182	2.94	High
Zn (mg kg^{-1})	0.28-5.98	1.96					
Fe (mg kg^{-1})	0.9-18.4	7.66					
Cu (mg kg^{-1})	0.16-2.98	1.23					
Mn (mg kg^{-1})	1.1-7	3.45					
pH	7.29-9.3	8.51					
EC	0.09-0.97	0.33					
BD (Mg m^{-3})	1.43-1.59	1.51					

Available Potassium

Potassium (K) is a vital nutrient essential for producing high-quality crops. In crops with a potassium deficiency, the leaf margins typically turn brownish and dry up, while the stem tends to remain slender (Nawale and Saraswat, 2013). The available K levels in the soils of the study area varied from 110 to 524 kg ha^{-1}, with a mean value of 250 kg ha^{-1}. Out of the 190 soil samples, 6 per cent samples fell under low status, 73 per cent samples were medium and 21 per cent of the soil samples were high in potassium. This implies that the majority of the samples exhibited medium potassium fertility (NI 2.14) level (refer to Table 3). The significant (moderate or high) potassium content in these soils could be ascribed to the presence of K-rich minerals like feldspar and illite (Sharma *et al.*, 2012). Similar observations were reported by Shabnam (2021) in the Kaithal district of Haryana.

Available Sulphur

The available sulphur (S) content in soils varied from 12 to 298 kg ha^{-1}, with an average value of 132 kg ha^{-1}. Out of the 190 soil samples, 2 per cent samples fell under low status, 6 per cent samples were medium and 182 per cent of the soil samples were high in S. The majority of the samples exhibited high sulphur fertility (NI 2.01) levels (refer to Table 3). This high S status in the soil is likely attributed to the continuous application of sulphur-containing fertilizers, such as $ZnSO_4$, in the rice-wheat cropping pattern (Gyawali *et al.*, 2016). This state is the 3rd largest user of $ZnSO_4$ after Punjab and Andhra Pradesh, with a recorded consumption of 14,651 tonnes (Shukla *et al.*, 2015). The S in the soils is predominantly linked with organic matter (Nor 1981) and in our study soils have moderate to high organic carbon levels. Thus, organic matter releases the mineralizable S in a proportionate amount present in the soil due to the greater plant and microbial activity (Gyawali *et al.*, 2016). Singh *et al.* (2015) observed that the higher the SOC, the higher was the available S content. Similar results were observed by Gora (2013) and Shabnam (2021) in the Kaithal district of Haryana.

DTPA Extractable Zinc, Iron, Copper and Manganese

Zinc

The DTPA Extractable zinc in the soils of Guhla block varied from 0.28 to 5.98 mg kg^{-1}, with a mean value of 1.96 mg kg^{-1}. According to soil test ratings for available zinc content (Table 2), out of total 190 samples, 1% sample fell under acute status, 4% samples were deficient, 8 % samples were latent deficient, 15% samples were marginal sufficient, 24% samples were adequate and 48% samples were high in Zn status. There were sufficiencies (adequate + high) of available Zn in 72% of the sampled sites. Haryana is the third-largest consumer of zinc sulphate in India, with a reported consumption of 14,651 tonnes, following Andhra Pradesh and Punjab. This extensive use of $ZnSO_4$ contributes to the increased zinc sufficiency in the soils (Shukla *et al.*, 2015). These findings align with studies conducted in the Kaithal district of Haryana by Shabnam (2021), which also observed similar levels of available zinc content. Shukla *et al.* (2015) reported that zinc deficiency in Haryana soils (15.3%) is significantly lower than the national average of 40%.

Iron

The soils in Guhla block exhibited available iron content ranged from 0.9 to 18.40 mg kg^{-1}, with a mean value of 7.66 mg kg^{-1}. Based on soil test ratings for available iron (Table 2), out of 190 samples, 10% were acute, 10% deficient, 17% latent deficient, 21% marginal sufficient, 26% adequate,and 16% high in iron. Therefore, 42% of the soils in the study area were sufficient (adequate + high) in available iron. These findings are consistent with previous studies in Kaithal district, Haryana (Shukla *et al.*, 2015). The low iron status may be attributed to higher soil pH and current moisture stress conditions, which convert ferrous (Fe^{2+}) iron into ferric (Fe^{3+}) iron (Shukla *et al.*, 2021).

Copper

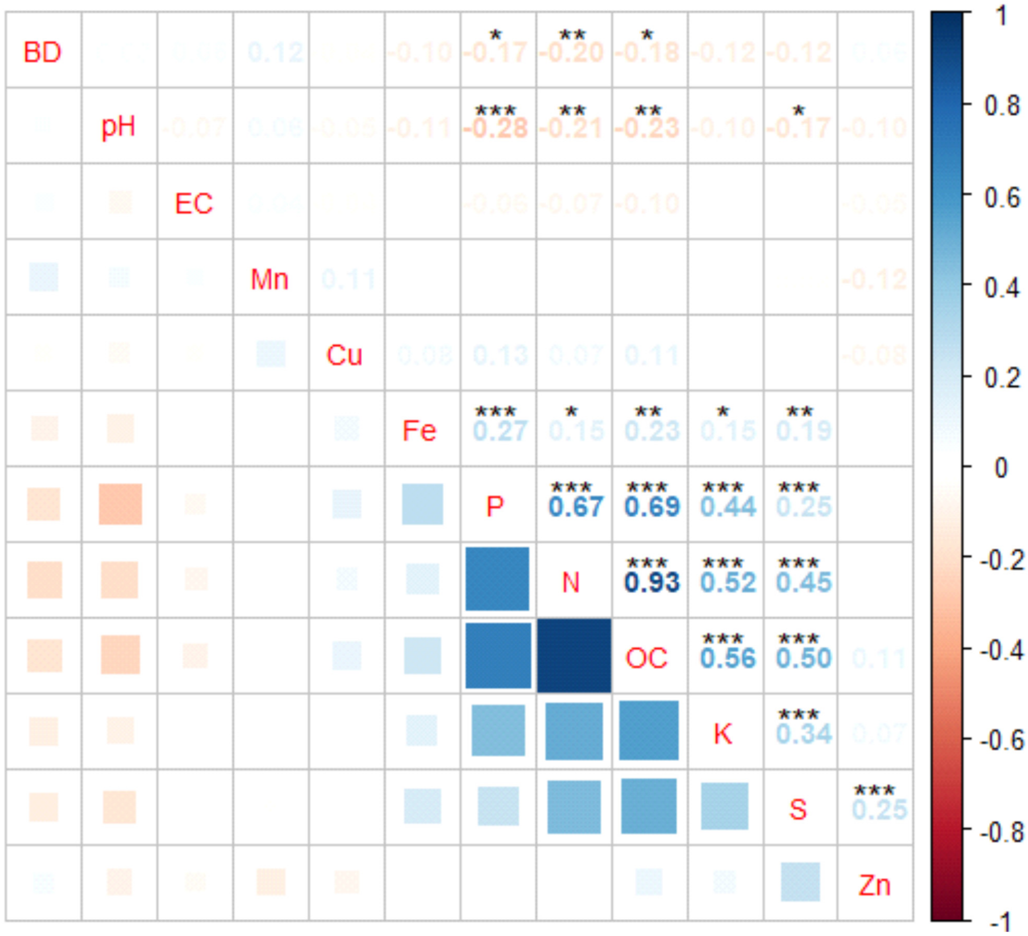
The soils in the Guhla block displayed available copper content ranging from 0.16 to 2.98 mg kg^{-1}, with an average value of 1.23 mg kg^{-1}. Based on soil test ratings for available copper Table 2), out of 190 samples revealed that 3% of the samples were categorized as acute, 9% as deficient, 10% as latent deficient, 7% as marginally sufficient, 18% as adequate, and 53% as high in copper content. This indicates that 71% of the sampled sites had sufficient (adequate + high) levels of available copper, while 12% exhibited deficiency (acute + latent deficient). High organic matter can lead to copper complexion with organic compounds, resulting in copper deficiency in plants. Additionally, high soil pH can contribute to copper deficiency (Shukla *et al.*, 2015). Similar findings for available copper status were reported in Ambala district of Haryana by Prem *et al.* (2017).

Manganese

The soils in the Guhla block exhibited available manganese levels ranging from 1.10 to 7 mg kg^{-1}, with an average value of 3.45 mg kg^{-1}. According to soil test ratings for manganese availability (Table 2), out of 190 samples, 34% were classified as deficient, 58% as latent deficient, and 8% as marginally sufficient in Mn status. The low levels of available Mn in these soils are likely due to their light texture, which undergoes cycles of wetting and drying (Shukla *et al.*, 2015). Moreover, in alkaline soils, Mn availability is reduced because it becomes less accessible at higher pH levels (Sidhu *et al.*, 2009). Similar findings on Mn content were reported in Kaithal district of Haryana (Shabnam, 2021). Shabnam (2021) reported similar observations of available Mn content in Kaithal district of Haryana.

Correlation between Soil Properties and Nutrients

Soil available N was negatively correlated with soil pH (r = -0.21**) (Fig.3). This may result from the soil's increased pH causing a volatilization loss of N (Rajendiran *et al.*, 2020). There was a positive correlation between soil available N and SOC (r = 0.927**), indicating a close relationship between nitrogen and organic matter. Hailu *et al.* (2015) observed that total nitrogen generally followed the trends of soil organic matter, reflecting a significant association between organic matter and total nitrogen, as evidenced by the positive and highly significant correlation. Additionally, nitrogen showed significant and positive



*Significant at 0.05%, **Significant at 0.01%, ***Significant at 0.001% and NS = Non-Significant

Fig. 3 Correlation of soil properties and nutrients of Guhla block

correlations with phosphorus (r = 0.67***), potassium (r = 0.52***) and sulphur (r = 0.45***). These relationships could be attributed to synergistic interactions among these nutrients (Sahoo *et al.*, 2020).

The available P was negatively correlated with soil pH (r = -0.282**). This strong negative correlation may be attributed to the conversion of soluble P into insoluble calcium and magnesium phosphate as soil pH increases, thus reducing its availability (Rajendiran *et al.*, 2020). Available P showed a positive and significant correlation with organic carbon content (r = 0.69***), indicating that higher levels of available phosphorus are associated with higher organic matter (Sharma *et al.*, 2013). Soil available phosphorus is positively correlated with K and S (Fig.3). Similar findings have been observed by (Mishra *et al.,* 2016).

Available K exhibited a positive and significant correlation with organic carbon (r = 0.56**), likely due to the presence of K bearing minerals such as feldspars, illite and mica within the clay and silt fractions (Deka *et al.*, 1995; Reza *et al.*, 2014).

Available S demonstrated a negative correlation with soil pH (r = -0.17*), suggesting that as soil pH increases, the S content decreases. This trend is attributed to the reduced adsorption of sulphate ions in soils, leading to higher losses through leaching (Sahoo *et al.*, 2020). Conversely, there was a strong positive correlation between available S and organic carbon (r = 0.71**), indicating that organic matter acts as a significant reservoir for S (Paul and Mukhopadhyay, 2015).

Correlation studies revealed that there is negative correlation between pH and OC (r = -0.231**). Similar results are also observed by Abad *et al.* (2014) and Dengiz *et al.* (2010).

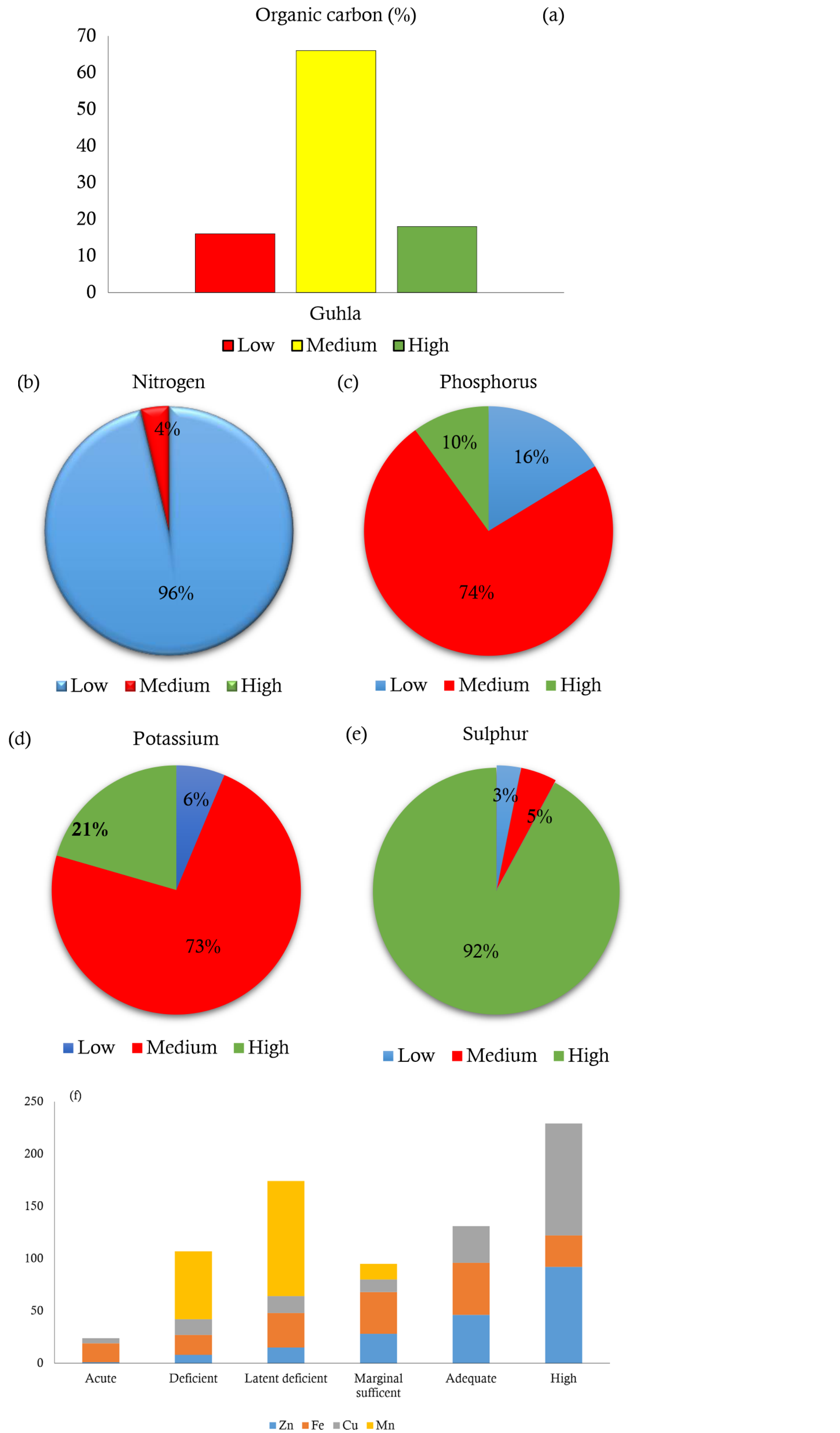


Fig. 4 Frequency distribution of nutrient availability in soils of Guhla block of Kaithal district (per centage of soil samples)

A positive correlation was found between OC and DTPA extractable Fe (r = 0.23**). This was due to organic matter-derived complexing agents enhance the availability of this nutrient in soils (Talukdar *et al.*, 2009). DTPA-extractable Zn, Fe, Cu and Mn did not show significant relationships with soil pH and EC. Similar results are also observed by Pati and Mukhopadhya (2011) and Sahoo *et al*. (2020). The negative correlation of DTPA Zn, Fe and Cu with pH could be due to their precipitation as hydroxides and carbonates, rendering them immobile and less available to plants (Shinde, 2007). The presence of organic matter may contribute to the solubility of Zn, Fe, Cu and Mn by releasing them from the parent material (Sahoo *et al.*, 2020 and Sharma *et al.*, 2003).

Conclusion

The soils of Guhla block were characterized as neutral to alkaline in reaction, non-saline, with low to medium organic carbon content, non-calcareous and varying in texture from sandy loam to loam. Soils were categorized as low in available N content (96% of samples), medium to high in P (74% and 10% of samples, respectively) and K (73 and 21% of samples, respectively) and high in S content (92% of samples). Most soil samples fall into the adequate and high category for Zn (24 and 48% of samples, respectively) and Fe (26 and 16% of samples, respectively). Copper content is high in 53% of the samples), while Mn is categorized as latent deficient in 58% of the samples. Periodic studies of this nature are essential for obtaining precise information on macro and micronutrient deficiencies. Such information is crucial for strategic planning of balanced and site-specific nutrient management. Assessing nutrient deficiencies in agricultural soils globally can support the adoption of a complementary approach, utilizing both organic and inorganic nutrient sources, to achieve nutritional security and improve human and animal health.

Acknowledgement

Under the direction of Professor M. K. Sharma, Head of the Department of Soil Science, and Assistant Professor R. S. Garhwal, who serves as my major advisor, I genuinely express my gratitude, appreciation, and heartfelt thanks to both of you. Throughout my study, I have also been appreciative of the faculty members and my advisory committee for their important advice, support and constructive criticism, as well as their persistent encouragement and valuable recommendations.

References

Abad JRS, Khosravi H and Alamdarlou EH (2014) Assessment of the effects of land use changes on soil physicochemical properties in Jafarabad of Golestan province, Iran. *Bulletin of Environment, Pharmacology and Life Sciences* **3**(3): 296-300.

Antil RS, Kumar V, Narwal RP and Kuhad MS (2001) Nutrients removal and balance in soils of Haryana. Department of Soil Science, CCS Haryana Agricultural University, Hisar, India.

Basu, P. K. (2011). Methods Manual Soil Testing in India: Department of Agriculture and Cooperation Ministry of Agriculture Government of India. New Delhi, 63-67.

Baruah R, Thiyageshwari S, Mani S, Veelu V and Stalin P (2014) Distribution of available iron, manganese, zinc, copper and boron in soils of Cuddalore district of Tamil Nadu. *Journal of the Indian Society of Soil Science* **62**(3): 288-292.

Behera S, Mishra A, Acharya BP, Saren S and Mishra J (2016) Soil fertility status of some villages under East and South Eastern Coastal Plain Agroclimatic Zone of Odisha. *Journal Indian Society Coastal Agriculture Research* **34**: 63-67.

Bhat MA, Grewal MS, Dinesh IS and Grewal KS (2017) Geoinformatics for quantifying salt affected soils in Gohana, Haryana using soil techniques. *International Journal of Current Microbiology and Applied Sciences* **6**(9): 835-58.

Carter GA and Knapp AK (2001) Leaf optical properties in higher plants: linking spectral characteristics to stress and chlorophyll concentration. *Am. J. Bot*. **88**: 677–684.

Chesnin L and Yien CH (1950) Turbidimetric determination of available sulphates. *Proceedings of Soil Science Society of America Journal* **14**: 149-151.

Corwin DL and Lesch SM (2005) Apparent soil electrical conductivity measurements in agriculture. *Comput. Electron. Agric.* **46**: 11-43.

Deka B, Sawhney JS and Mukhopadhyay SS (1995) Clay mineralogy as influenced by landforms in Siwalik Himalayas. *Clay Research* **14**: 16-21.

Dengiz O, Saglam M, Sarioglu FE, Saygin F and Atasoy C (2010) Morphological and physicochemical characteristics and classification of Vertisols developed on Deltaic Plain. *Open Journal Soil Science* **2**: 20-27.

Desavathu RN, Nadipena AR, and Peddada JR (2018) Assessment of soil fertility status in Paderu Mandal, Visakhapatnam district of Andhra Pradesh through Geospatial techniques. *The Egyptian Journal of Remote Sensing and Space Science* **21**(1): 73-81.

Dinesh, Bhat MA and Grewal KS (2017) Characterization and Classification of soils on different Geomorphic Units of North-Eastern Haryana, India. *Agropedology* **27**(02): 103-116.

FAI, (2011) Speciality Fertiliser Statistics FAI, New Delhi. pp 87.

Gill A (2023) *Pedological characterization and classification of soils under different land use in Eastern Agroclimatic Zone of Haryana.* Ph.D Thesis, CCS Haryana Agricultural University, Hisar, India.

Gora V (2013) *Distribution of potassium and sulphur in soils under rice-wheat and cotton-wheat cropping systems of Haryana.* M.Sc Thesis, CCS Haryana Agricultural University, Hisar, India.

Gyawali C, Mohammad B, Daljit D, Dev R and Rishi B (2016) Spatial distribution of physico-chemical properties and macronutrients in rice growing soils of Haryana. *The Ecoscan*, **10**: 365-370.

Habtamu A, Heluf G, Bobe B and Enyew A (2014) Fertility Status of Soils under Different Land uses at wujiraba watershed, North-Western Highlands of Ethiopia. *Agriculture, Forestry and Fisheries* **3**(5): 410-419.

Hailu AH, Kibret K and Gebrekidan H (2015) Characterization and classification of soils of Kabe Sub watershed in South Wollo Zone, North-eastern Ethiopia. *African Journal of Soil Science* **3**(7): 134-146.

Havlin JL, Beatson JD, Tisdale SL and Nelson WL (2005) Soil fertility and fertilizers an introduction to nutrient management, (7th Ed.) *Pearson Education, Inc.*, Pearson Prentice Hall.

Jackson ML (1973) Soil Chemical Analysis. Prentice Hall, New Jersey, USA.

Kumar S (2019) *Characterization, classification and evaluation of soils under Sugarcane Cultivation.* Master Thesis, Soil Science, CCS HAU, Hisar.

Lindsay WL and Norvell WA (1978) Development of DTPA soil test for Zn, Fe, Mn and Cu. *Soil Science Society of American Journal* **42**: 421-428.

Meysner T, Szajdak L and Kus J (2006) Impact of the farming systems on the content of biologically active substances and the forms of nitrogen in the soils. *Agronomy Research* **4**(2): 531-542.

Minakshi, Tur NS, Nayyar VK, Sharma PK and Sood AK (2005) Spatial Distribution of Micronutrient in Soils of Patiala district AGIS Approach.*J. Indian Soc. Soil Sci.* **53**(3): 324-329.

Mishra A, Das D, Saren S and Dey P (2016) GPS and GIS based soil fertility maps of Nayagarh district Odisha. *Annals of plant and soil research* **18**: 23-28.

Mokolobate MS and Haynes RJ (2002) Increases in pH and soluble salts influence the effect that additions of organic residues have on concentrations of exchangeable and soil solution aluminum. *Eur. J. Soil Sci.* **53**(3): 481-489.

Motschenbacher JM, Brye KR and Anders MM (2011) Longterm rice-based cropping system effects on near-surface soil compaction. *Agri. Sci.* **2**(2): 117-124.

Nawale, Anil B, Saraswat and Rajeshwari (2013) Analysis of soil characteristics for crop development in Sangamner tahsil in Ahemadnagar district of Maharashtra. *Appl. Res. Dev. Inst. J.* **9**(6): 29-41.

Nazif W, Perveen S and Saleem I (2006) Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). *Journal of Agricultural and Biological Science* **1**(2): 35-40.

Nor YM (1981) Sulphur mineralization and adsorption in soils. *Plant Soil.* **60**: 451-459.

Olsen SR, Cole CV, Watanabe FS and Dean LA (1954) Estimation of available P in soils by extracting with sodium bicarbonate. *Circular of United States Department of Agriculture* **939**.

Pahlavan-Rad MR. nd Akbarimoghaddam A (2018) Spatial variability of soil texture fractions and pH in a flood plain (case study from eastern Iran). *Catena* **160**: 275-281.

Pal DK, Dasog GS, Vadivelu S, Ahuja RL and Bhattacharya T (1999) Secondary calcium carbonate in soils of arid and semi-arid regions of India. In: *Global Climate Change and Pedogenic Carbonate* (Rattan Lal, John, M Kimble, H Eswaran and BA Stewart, eds.), Lewis Publishers, New York.

Parker FW, Nelson WL, Winters E and Miles JE (1951) The broad interpretation and application of soil test summaries. *Agron J* **43**(3): 103-112.

Pati R and Mukhopadhya D (2011) Distribution of cationic micronutrients in some acid soils West Bengal. *Journal of the Indian Society of Soil Science* **59**: 125–33.

Paul SC and Mukhopadhyay P (2015) Distribution and availability of sulphur in some terai soils under subtropical zone of eastern India. *International Journal of Agriculture, Environment and Biotechnology* **8**(2): 347.

Piper CS (1966) Soil and plant Analysis. Hans Publishers, *Bombay* pp: 50-74.

Prasad SN and Sakal R (1991) Availability of iron in calcareous soils in relation to soil properties. *Journal of the Indian Society of Soil Science* **39**: 658-661

Prem G, Kumar A, Choudhary R, Singh VD, Kumar R and Kumar A (2017) Mapping of available nutrients in soils of Ambala district (Haryana)– A GIS approach. *An Asian Journal of Soil Science* **12**(1): 86-93.

Puri AN (1930) Soil-Their physics and Chemistry. *Reinnlad Publ. Cropn*. NewYork.

Rajendiran S, Dotaniya ML, Coumar MV, Sinha NK, Singh VK, Kundu S and Patra AK (2020) Block level soil fertility status of tribal dominated Jhabua district of Madhya Pradesh, India. *Journal of the Indian Society of Soil Science* **68**(1): 70-77.

Reza SK, Baruah U, Dutta D, Sarkar D and Dutta DP (2014) Distribution of forms of potassium in Lesser Himalayas of Sikkim, India. *Agropedology* **24**(1): 106-110.

Sahoo J, Dinesh BM, Anil AS and Raza M (2020) Nutrient distribution and relationship with soil properties in different watersheds of Haryana. *Indian Journal of Agricultural Sciences* **90**(1): 172-7.

Sarkar D, Baruah U, Gangopadhyay SK, Sahoo AK and Velayutham M (2002) Characteristics and classification of soils of Loktak command area of Manipur for sustainable land use planning. *Journal of the Indian Society of Soil Science* **50**: 196-204.

Shabnam (2021) *Status of macro and micro nutrient in soils of Kaithal and Siwan blocks, district Kaithal.* M.Sc Thesis, CCS Haryana Agricultural University, Hisar, India.

Sharma BD, Mukhopadhyay SS and Jassal HS (2011) Morphological, chemical and mineralogical characterization of developing soils and their management in western Shiwalik Himalayas. *Archives of Agronomy and Soil Science* **57**(6): 609-630.

Sharma BD, Sidhu GS, Sarkar D and Kukal SS (2012) Soil organic carbon, phosphorous, and potassium status in rice–wheat soils of different agro-climatic zones in Indo-Gangetic Plains of India. *Communications in Soil Science and Plant Analysis* **43**(10): 1449-1467.

Sharma RP, Megh Singh and Sharma JP (2003) Correlation studies on micronutrients vis-à-vis soil properties in some soils of Nagpur district in semi-arid region of Rajasthan. *Journal of the Indian Society of Soil Science* **51**: 522-7.

Sharma RP, Singh RS, and Sharma SS (2013) Vertical distribution of plant nutrients in alluvial soils of Aravalli range and optimization of land use. *International Journal of Pharmaceutical and Chemical Sciences* **2**(3): 1377–89.

Sharma VK, Dwivedi SK, Tripathi D and Ahmed Z (2006) Status of Available Major and Micronutrients in the Soils of Different Blocks of Leh District of Cold Arid region of Ladakh in relation to Soil Characteristics. *J. Indian Soc. Soil Sci*. **54**(2): 248-250.

Shinde YR (2007) 'Physico-chemical properties and nutrient availability of soils of Udgir and Deoni tehsils of Latur district'. M Sc (Agri.) thesis, MPKV, Parbhani.

Shukla AK, Malik RS, Tiwari PK, Prakash C, Behera SK, Yadav H and Narwal RP (2015) Status of micronutrient deficiencies in soils of Haryana. *Indian Journal of Fertilisers* **11**(5): 16-27.

Shukla AK, and Behera SK (2019) All India coordinated research project on micro-and secondary nutrients and pollutant elements in soils and plants: Research achievements and future thrusts. *Indian Journal of Fertilisers* **15**(5): 522-543.

Shukla AK, Behera SK., Prakash C, Patra AK, Rao CS, Chaudhari SK and Green A (2021) Assessing multi-micronutrients deficiency in agricultural soils of India. *Sustainability* **13**(16): 9136.

Sidhu GS and Sharma BD (2009) DTPA-extractable micronutrients status in soil under rice-wheat system and their relationship with soil properties in different agro-climatic zones of Indo-Gangetic Plains of India. *Communi. Soil Sci. Plant Anal*. **41**: 29-51.

Singh A, Phogat VK, Dahiya R, and Batra SD (2014) Impact of long-term zero till wheat on soil physical properties and wheat productivity under rice–wheat cropping system. *Soil and Tillage Research* **140**: 98-105.

Singh M, Grewal KS, Panwar BS and Narwal RP (2011) GPS and GIS based fertility maps of major nutrients in soils of Haryana. Research Bulletin, Department of Soil Science, CCS Haryana Agricultural University.

Subbiah BV and Asija GL (1956) A rapid procedure for the determination of available nitrogen in soils. *Current Scienc* **25**: 259-260.

Tairo, Eutropia V, Ndakidemi and Patrick A (2013) Possible benefits of rhizobial inoculation and phosphorus supplementation on nutrition, growth and economic sustainability in grain legumes. *Am. J. Res. Commun*. **1**(12): 532–556.

Talukdar MC, Basumatary A and Dutta SK (2009) Some of DTPA- extractable cationic micronutrients in soils under rice and sugarcane ecosystems of Golaghat district in Assam. *Journal of the Indian Society of Soil Science* **57**: 313–6.

Thangasamy A, Naidu MVS, Ramavatharam N and Reddy CR (2015) Characterisation, classification and evaluation of soil resources in Sivagiri Micro-watershed of Chittoor district in Andhra Pradesh for Sustainable Land Use Planning. *Journal of the Indian Society of Soil Science* **53**(1): 11-21.

Verma TP, Singh SP, Ramgopal, RP Dhankar, Rao RVS and Lal T (2012) Characterization and evaluation of soils of Trans Yamuna area in Etawah district, Uttar Pradesh for sustainable land use. *Agropedology* **22**(1): 26-34.

Vijayakumar R, Arokiaraj A and Prasath PMD (2011) Micronutrients and their relationship with soil properties of natural disaster-prone coastal soils. *Research Journal of Chemical Science* **1**: 8-12.

Walkley A and Black IA (1934) An examination of dagjareff methods for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37**: 29- 37.

Zhang X, Xiang DQ, Yang C, Wu W and Liu HB (2022) The spatial variability of temporal changes in soil pH affected by topography and fertilization. *Catena* **218**, 106586.

Received: February 15, 2024; Accepted: June 29, 2024

Journal of Soil Salinity and Water Quality 16(1), 141-142, 2024

Proceedings of the 7th National Salinity Conference *"Rejuvenating Salt Affected Ecologies for Land Degradation Neutrality under Changing Climate"* held during 14-16 February, 2024

Key Recommendations

1. Digital Soil Mapping (DSM) with spectroscopic technique has huge opportunities for periodic update of SAS mapping and prediction of SAS parameters using spectral library. This new methodology integrated with advanced approaches like artificial intelligence, hyper spectral remote sensing and big data algorithms will provide real-time monitoring as updation of SAS for enabling the stakeholders for developing effective interventions to halt land degradation.
2. Arresting soil sodification to meet targets of land degradation neutrality needs refinement and upscaling of the alternative amendments materials and associated management approaches
3. The BIS based groundwater quality map of India could be the effective basis for planners, policy makers and other stake holders for devising site specific strategies integrating reclamation and deficit irrigation management approaches with high value crops for livelihood security in challenged ecologies.
4. Enhancing crop productivity by various breeding approaches focusing on developing best crop model for sustainable crop productivity in changing climate scenario.
5. The changing expectation of the stakeholder can be met through developing alternate land use system using high value crops. There is need for policy framework for promotion and upscaling of the novel land management approaches in vulnerable agroecologies .
6. Establishment of flexible dynamic long-term experiments under salt affected ecologies to study the ecological benefits and to generate evidences on soil health, yield, system performance and changes in energy-water-environment nexus.
7. Integration of science and technology with the involvement of stakeholders is needed to scale-up sustainable management practices. The water sustainability index suggests that Rajasthan, followed by Punjab, Haryana, Gujarat, and Uttarakhand must be given top priority for scaling up water management practices.

Other Salient Points Needs Attentions

- Alternate land use system with holistic approach may be are of the sustainable solutions for coastal-ecology in Sundarban Delta. There is need for policy framework to promote the Land Modification Models in coastal delta region.
- Sub-surface drainage technology followed by layering of Resource Conservation Technologies and tolerant crop varieties can help in providing resilience to stress hazard and in reducing payback period of SSD cost.
- Impact assessment of NRM technologies must be done using robust analytical tools to convince policy makers.

- The drainage system should be designed in such a way that the farmers may have options from initial years to operate it as a conventional drainage system or as a controlled/variable drainage system in saline Vertisols of TBP Command, Karnataka, India.
- The scope of low cost drip irrigation should be explored for its wider adoption in managing the problem of salinity and poor quality water for irrigation.
- Use of multi-media platform for farm advisory and active role of farmwomen need to be utilised for rapid dissemination of salinity management technologies.
- Affirmative Govt. policies on drainage and land reclamation at state and central levels need to be facilitated to accelerate the pace of reclamation of waterlogged saline soils in the country
- Participatory drainage project approach for increasing participation of private sector, FPOs, farmers and Govt state implementing department is also needed to harness efficacy of private sector for large scale reclamation.
- Efficacy of nano-urea needs to relooked and improved in view of farmers' reservation

Application Form for Life/Annual/Associate/Institutional Membership*

Indian Society of Soil Salinity and Water Quality

(Registered under Societies Act. XXI of 1860)

(Registration No. ROS-088, Dated : 6-8-2008)

Registered Office: Central Soil Salinity Research Institute; Zarifa Farm, Karnal-132001, Haryana, India

1. Name of the Applicant ____________________
   (In Block Letters) (Surname) (First name) (Middle name)
2. Designation or Position: ____________________
3. Name & Address of the Organisation: ____________________
4. Mailing Address : ____________________

Telephone No. (Prefix ISD/STD code) Office : __________ Residence : __________

Fax: __________ Mobile : __________ Email: __________

5. Permanent Address : ____________________
6. Date of Birth : __________ Nationality: __________
7. Academic Qualifications: ____________________
8. Field of Specialization: ____________________

I/We hereby apply for Life/Annual/Associate/Institutional Membership of the Indian Society of Soil Salinity and Water Quality. The details of the Demand Draft are as follows:

Demand Draft No. __________ Drawn on Bank __________

Dated __________ Amount Rs. __________

I/We testify that the above statements are correct and agree that if admitted. I/we shall be governed by the Rules and Regulations of the Indian Society of Soil Salinity and Water Quality as long as I am /we are member(s). I/we further agree to promote the objectives of the society as far as shall be within my/our power and that, if my/our membership is discontinued, I/we shall return any means of new membership identification I/we may have received from the society and remit upon resignation any unpaid fees or dues owing to the society. I/we further undertake to abide by either professional conduct rule or code that the Society may frame from time to time. **(Strike through which are not applicable)**

Date __________ Signature of the Applicant

Category of Membership*	Subscription Rate		Admission fee (only one time)	
	Inland (₹)	Foreign($)	Inland(₹)	Foreign ($)
Life Member	4,000	250	50	-
Annual Member	450	50	50	-
Student Member (for one year)	250	25	50	-
Institutional Members (Lump sum for 30 years)	25,000	-	-	-
Institutional Members (Annual)	3,500	-	-	

DD/Cheques (Crossed) are payable to "Indian Society of Soil Salinity and Water Quality" Karnal. Please add Rs. 100/- for outstation cheques.

Please mail the completed form along with remittance bank draft/local cheque to: **Dr. Gajender Yadav, General Secretary, Indian Society of Soil Salinity and Water Quality, Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal-132001, Haryana, India**
Tel: +91-184-2209380, 2209310 (O); Fax: +91-184-2290480; E-mail: salinitysocietykarnal@gmail.com; gajender.icar@gmail.com

For Office use only

Proposed by :

Seconded by: Admitted on General Secretary