Journal of Soil Salinity and Water Quality

Volume: 15 No. 1 2023 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 subscription, submission of articles, editorial enquiry and advertisements, please contact: isswq2008@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

ISSN 0976-0806

Journal of Soil Salinity and Water Quality

Volume 15 2023 Number 1

CONTENTS

Journal of Soil Salinity and Water Quality 15(1), 1-14, 2023

Advances in Reclamation and Management of Sodic Waters for Irrigation#

OP Choudhary* and MS Mavi

Department of Soil Science, PAU, Ludhiana-141004, Punjab, India
**Corresponding author E-mail: opc_2k@yahoo.com*

Abstract

Sustainable management of water resources is an international priority to meet the demands of future populations for food and fiber. However, increasing demands for freshwater use for municipal and industrial processes coupled with increasing world food needs leaves very less fresh water available for agriculture. Thus, agriculture will either need to reduce acreage under irrigation, which is undesirable since it will reduce food supply, or irrigate with alternative water sources such as saline/sodic ground waters. This is possible but sustained use of poor-quality water requires consideration of their impacts on both crop production and soil health. In different states of India, 32-84% ground waters surveyed are saline and/or sodic. Injudicious use of sodic waters poses grave risks of causing irrigation-induced sodification that is insidious and impacts soil health in terms of deteriorating soil physical, chemical and biological parameters. The development of salinity and sodicity problems not only reduces crop productivity but also limits the choice of crops. It is, therefore, imperative that plans are carefully drawn and executed to sustain crop production, reduce soil sodification and minimize deterioration of soil conditions over the long-term. In this context, it has been observed in many instances that water previously considered unsuitable for irrigation can be used with site-specific and careful management. In Punjab, about 42% ground waters are brackish and about 70% of these are sodic waters having high sodium absorption ration (SAR) as well as residual sodium carbonate (RSC), posing a serious threat to sustainable crop production, especially in the south-western region of the state. To prevent the degradation of the state's land and water resources, emerging technological interventions for optimally using sodic-waters for supplementing irrigated agriculture are of paramount importance. In this context, the long-term research work carried over more than three decades has developed many technologies for judicious use of sodic-waters for sustaining crop productivity and maintaining soil health in these challenging environments. Remedial technologies have been developed at the, root-zone, crop and cropping systems, and field scale. These include conjunctive uses based on available water qualities, chemical amelioration of sodic- soils and irrigation waters, mobilising native calcite through organic amendments, growing tolerant crop cultivars, fertiliser use, and irrigation management technologies. Although the emphasis is placed on managing sodic waters in the Indian context, the developed practices are expected to be helpful to promote irrigation with sodic waters, thereby partly alleviating the forecasted scarcities in water for agriculture in many other arid and semi-arid regions in the world confronting similar challenges.

Key words: Sodic water, Irrigation water quality, Management of sodic environment, Soil health, Crop productivity

Introduction

Sustainability of water resources is a critical issue for fulfilling the rising water demands of various competitive sectors including agriculture, which is the largest water user and consumes over 70% of the abstracted freshwater globally (Singh, 2015). The issue has become more challenging in the light of dwindling resource base due to urbanization, contamination, and climate change impacts. There is a growing realization especially for countries in the arid and semi-arid climatic zones that these countries are approaching full utilization of their surface water resources. Therefore, sustainable development of water resources requires that we respect the hydrological

The paper was presented as Lead Paper in 6th National Conference on "Salinity Management for Land Degradation Neutrality and Livelihood Security under Changing Climate" held at Tiruchirappalli, Tamil Nadu in joint collaboration of the Indian Society of Soil Salinity & Water Quality; ICAR-Soil Salinity Research Institute, Karnal: Tamil Nadu Agricultural University; and Indian Council of Agricultural Research during 11-13th October, 2022.

cycle by using the marginal but renewable water resources judiciously to supplement meagre surface water resources and avoid water scarcity through their long-term use.

The Indian National Water Policy in 2012 had clearly enunciated that to meet the required food grain production of 2050, the efficiency of surface water use has to increase to 60% (now 30-40%) and of ground water to 75%. In addition, the poor quality sodic (containing high carbonates of Na) and/or saline ground waters constitute a major portion (32-84%) of the total irrigation potential of ground waters in different states of the country. In Punjab, majority (69%) of the 42% poor quality ground waters are sodic in nature posing serious threat to sustainable crop production especially in the south-western region of the state (Sharma *et al.,* 2010). In this context, the long-term research work conducted at PAU, Ludhiana and ICAR-CSSRI, Karnal focused on managing and developing strategies for safe and judicious use of sodic waters in agriculture for sustaining crop productivity and maintaining soil health in these challenging environments (Choudhary *et al.*, 2004; Choudhary *et al.*, 2011b; Choudhary and Mavi, 2019; Minhas *et al.*, 2021) and these sodic waters can rather become a valuable resource for irrigation.

Chemical Composition of Sodic Irrigation Water

Sodic waters contain high concentration of dissolved carbonates and bicarbonates (CO_3^{2-}+ HCO_3^-) of sodium (Na^+) greater than chlorides and sulphates; and high proportion of Na^+ with respect to Ca^{2+} + Mg^{2+} (United States Salinity Laboratory, 1954). The soluble Na percentage is generally > 75 and the ratio of divalent cations to total cations is < 25 for sodic waters. Residual alkalinity, defined as $[HCO^-_3 + CO_3^{2-}] – [Ca^{2+} + Mg^{2+}]$, determines the potential of irrigation water to create alkalinity hazard in the soil. This has been expressed as residual sodium carbonate (RSC) by Eaton (1950) and is being used as an index of water-suitability for irrigation of crops in the soil testing laboratories of India. In general, sodic waters having high RSC test low in electrical conductivity (EC) but some waters termed as saline-sodic test high in RSC, sodium absorption ration (SAR) and EC. Other parameters for knowing the potential of irrigation waters to create alkalinity/ sodicity hazards are: Sodium Adsorption Ratio [SAR = (Na)/√(Ca + Mg)/2], concentrations expressed in $mmol_c\ L^{-1}$ and new adjusted SAR denoted as (adj. RNa). It is defined as $Na/\sqrt{[(Ca_x + Mg)/2}$, where Ca_x represents the Ca in applied water modified due to salinity (ionic strength) and HCO_3^-/Ca^{2+} ratio (Ayers and Westcot, 1985).

Rengasamy and Marchuck (2011) gave the concept of 'CROSS' (Cation ratio of soil structural stability) where flocculation values for K relative to Na was 0.56 and that Mg relative to Ca was 0.60 and is expressed as $CROSS = C_{Na} + 0.56C_K/[(C_{Ca} + 0.60C_{Mg})/2]^{0.5}$. However, the use of CROSS in place of SAR is advisable for waters having saline waters having EC < 4 dS m^{-1} and Mg concentration > Ca concentration.

Strategies Managing Sodic Waters for Sustainable Crop Productivity

If the challenges of sustaining global food supplies are met, it is essential that the sodic ground waters are used appropriately to sustain crop production. There are two options to manage and sustain crop productivity in a salt-affected environment:

i) Modifying the environment to suit the plant and,

ii) Modifying the plant to suit the environment.

Both these approaches have been used, either individually or in combination. Practical options for the safe use of poor-quality waters for sustainable crop production should focus on improving the physical and chemical properties of soils receiving sodic waters and controlling the buildup of sodicity in the soil. Such an approach will not only add an additional water source in arid and semi-arid areas, but also can minimize the problem of rising water tables in shallow water table canal command areas.

Management strategies to sustain productivity using sodic waters include crop selection, irrigation management strategies, chemical/

organic amend-ments, and fertility management. No single management practice is able to control sodicity of irrigated soils in itself but rather a combination of practices is required. Nevertheless, each manage-ment option is described separately for better understanding in the following sections.

Laser Leveling of the Land and Rain Water Harvesting

Suitable land leveling and provision of 30-40 cm high strong bunds for capturing and retaining rainwater are the essential prerequisites for managing the land irrigated with sodic water. Laser levelling is very important in sodic-water irrigated soil for uniform water application, reducing any micro-relief and micro-depression which ensures uniform leaching of salts and sodium. The surface soil should be protected against the beating action of raindrops, which can be achieved through ploughing the field in between rains. This practice, besides increasing the intake of rainwater helps in controlling the unproductive losses of water through weeds and evaporation. These practices also promote uniform salt leaching and self-reclamation through the rain-induced dissolution of soil calcium carbonate.

Selection of Suitable Crops and Varieties

The guiding principle is to select suitable crops and varieties capable of producing high yields and economic returns under varying levels of soil Na saturation for achieving sustainable high agricultural productivity under sodic irrigation system. This is because crops differ in tolerance to soil salinity and sodicity/alkalinity (Mass and Hoffman, 1977; Ayers and Westcot, 1985), which may form the basis of selection of crops for growing on soils irrigated with varying levels of sodicity in water. Most of the crops, however, show varying levels of sensitivity to increasing levels of sodicity in the soil at different growth stages (germination, early seedling development, and reproductive and grain formation).

Rice and wheat are the crops most commonly recommended for growing in salt-affected soils during the reclamation process as both these crops can tolerate higher levels of salinity and sodicity. However, rice is not recommended to be grown with saline and sodic waters as rice and other high-water requiring crops need large number of irrigations (24-28) that can appreciably increase the salt load and Na build-up in the soils and hasten the degradation of the soils through sodification. So, under poor-quality water irrigation, low water requiring crops that are tolerant or semi-tolerant to the salts should be raised wherever possible. Furthermore, the crop grown in the previous season greatly influences the productivity of the crop in the subsequent season. In a monsoonal climate, crops that favour higher retention and *in situ* conservation of rainwater, which is salt-free, result in less sodicity development in the soil profile at the end of the season, providing a better environment for the next crop (Tyagi, 2003). Among three important cropping sequences (rice–wheat, cotton–wheat and sorghum–wheat) under sodic water irrigation, the productivity of the rice–wheat system was higher than the other two systems. In more arid areas, where fresh water during the *rabi* season is scarce, similar trends were observed with mustard, which replaces wheat because of its high salt tolerance and requirement of only one or two post-sowing irrigations compared with four or five irrigations in case of wheat (Tyagi, 2003). However, long-term experiments show a greater reduction in productivity of sodic irrigated wheat grown after high irrigation requiring rice crop as compared with the wheat grown after low irrigation requiring millet and cotton crops (Bajwa and Josan, 1989 a,b).

Adequate information needs to be generated about tolerance and production-efficiency of different crops (varying in rooting-behaviour) in soils undergoing sodification due to long-term sodic water irrigation. Choudhary *et al.* (1996 a,b) reported that tolerant wheat and barley genotypes had penetrative root system and higher spike density than the sensitive ones. Varieties of crops having high yield potential should be preferred over those having lower yield potential. A typical example is that of high yielding wheat cultivar

PBW-343 that should be preferred over other wheat cultivars (PBW 550 and PBW 502) to obtain acceptable yield levels without any loss in grain quality in soils irrigated with sodic waters with RSC > 5 me L^{-1} (Choudhary *et al*., 2007, 2012a). Further, wheat cultivar PBW 658 performed better under high RSC and EC water irrigation than HD 2967 and PBW 621 (Pawittar *et al*., 2018). Sodicity tolerance of crop plants also depends upon the ability of plant-roots to exclude Na and absorb nutritionally adequate amounts of Ca (otherwise deficient (below 2 meL^{-1}) under sodic environment). Crops having higher tolerance to soil Na saturation have also been reported to maintain relatively higher Ca/Na and lower Na/K ratios in shoots by restricting Na absorption (Choudhary *et al*., 1996b; Singh *et al*. 2018).

Growth and yield of three cotton cultivars were adversely affected by long-term irrigation with sodic waters having RSC of 5, 10 and 15 me L^{-1} (Choudhary *et al.,* 2001). Compared with canal water irrigation, relative seed-cotton yield under ESP build-up of 56.2 was 69% in F-846, 49% in LD-327 and only 29% in F-505. Cultivar F-846 produced larger bolls than the other two cultivars under irrigation with higher RSC waters. The harmful effects of high RSC water on fibre quality (2.5% span length and bundle strength) were also not observed in the tolerant cultivar F-846. Among Bt cotton hybrids, RCH 134 was observed to perform better than MRC 6301 and MRC 6304 (Choudhary *et al.,* 2012b) because of its early vigour during emergence and seedling stage.

Concerted efforts over the past four decades have resulted in the development of promising salt-tolerant varieties in rice, wheat and mustard. However, there is a growing realization that the development of multiple stress-tolerant crop genotypes must be prioritized by integrating molecular and genomics tools with conventional breeding approaches (Sharma and Singh, 2015). In spite of that, only a few have become popular among the farmers. Major reasons behind limited adoption of such lines by the farmers are low level of salt tolerance relative to the locally adapted landraces and poor grain quality (Singh *et al.,* 2010). Choudhary *et al.* (2010) found that highly salt tolerant tomato cultivar, *Edkawi* performed poorly compared with the performance of locally developed cultivar, *Punjab Chuhara* under sodic-water irrigation both under drip and furrow irrigation. The recent trends in the development of salt-tolerant rice cultivars include greater emphasis on quantitative trait loci (QTL) mapping and marker-assisted breeding for introgression of markers tightly linked to the submergence tolerance gene (SUB1) and QTL for sodicity tolerance at the seedling stage (qSAL-TOL) in the background of high-yielding cultivars (Singh *et al.,* 2010).

Use of Amendments to Alleviate Impacts of Sodic Irrigation Water

Chemical amendments

The adverse effects of alkali water irrigation on physico-chemical properties of soils can be mitigated by the application of chemical amendments that provide soluble calcium to knock out exchangeable sodium adsorbed on clay surfaces. There are two main types of amendments: those that add calcium directly to the soil and those that dissolve calcium from calcium carbonate ($CaCO_3$) already present in the soil. Calcium containing amendments include gypsum (hydrated calcium sulfate) and calcium chloride. Gypsum is moderately soluble in water and it is the most commonly used amendment. Acid-forming, or acidic amendments include sulphuric acid, elemental sulphur and pyrite. Sulphuric acid reacts immediately with the native calcium carbonate in the soil to release soluble calcium for exchange with sodium. However, elemental sulphur and pyrite must be oxidized by soil bacteria and react with water to form sulfuric acid to reclaim sodic soil environment. But it may take several months (Choudhary, 2017).

The need for gypsum application for ameliorating the sodic irrigation effects is of recurring nature in contrast to reclamation of a native sodic or alkali soil. Application of gypsum has earlier been recommended when RSC of irrigation water exceeded 2.5 me L^{-1}. However,

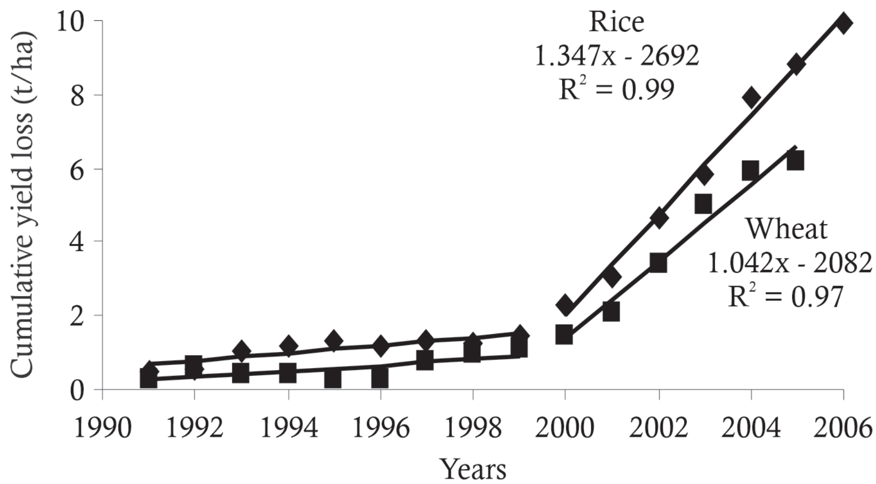

Fig. 1 Cumulative yield loss in response to sodic water irrigation compared to good quality canal water over the years
Source: Choudhary *et al.* (2011a)

later researches have shown that factors such as the level of the deterioration of the soil, cropping intensity, water requirement and sodicity tolerance of crop/s and economic condition of the farmers will ultimately will dictate the amount of gypsum required. Sustainable yields of crops in rice-wheat system, irrigated with alkali water (RSC > 4 me L^{-1}) are possible with occasional application of gypsum and FYM. Gypsum to supply 2.5 and 5.0 me L^{-1} to sodic irrigation water for wheat and rice, respectively, was found to be sufficient for maintenance of higher yields (Bajwa and Josan, 1989a). Gypsum applied with each irrigation or on cumulative basis were observed to be equally effective for wheat crop but in case of rice (requiring large number of irrigations), gypsum applied with each irrigation particularly under high RSC water irrigation showed an edge over its cumulative application. In a long-term experiment (10 years) on sugarcane, Choudhary *et al.* (2004) observed that the beneficial effect of gypsum was pronounced in increasing cane and sugar yield under sodic (30%) compared with saline-sodic water irrigation (13%). In spite of the well-established benefits of gypsum for alkali soils, unassured availability and deterioration in quality of gypsum due to several impurities is forcing researchers to look for some alternative methods for reclaiming the sodic and sodic water irrigated soils.

Organic amendments

It is generally accepted that additions of organic materials ameliorate sodic soil conditions through mobilization of Ca^{2+} from native $CaCO_3$ present in the soil. Choudhary *et al.* (2011a) observed that continual irrigation with sodic water (SW) resulted in the gradual increase in soil pH and ESP in a calcareous soil. Significant harmful effects of SW irrigation were observed after 7-9 years in grain yields of rice and wheat crops irrigated with RSC 12.5 me L^{-1} relative to canal water irrigated crops. Nevertheless, the adverse effects were not pronounced in the initial years when these crops were irrigated with sodic water having RSC 10 me L^{-1} (Fig. 1). It was conclusively found that with mobilization of Ca^{2+} from $CaCO_3$ during decomposition of organic materials such as FYM, green manuring (GM, *Sesbania aculeata*), the need of gypsum required for controlling the harmful effects of sodic water irrigation can be eliminated in rice-wheat cropping system in calcareous soils. In sugarcane crop, FYM was found to be more effective under saline-sodic (38 %) than under SW irrigation (23%) (Choudhary *et al.,* 2004). Complimentary effects of gypsum and FYM in improving sugar yield were observed under sodic irrigation (12.3 t ha^{-1}) but in saline-sodic irrigation, sugar yield under FYM (10.8 t ha^{-1}) was at par with gypsum plus FYM treatment.

Biochar, a carbon-rich, porous product is formed due to thermo-chemical conversion of biomass at temperature around 350-700 °C under low oxygen conditions. Its application to low fertility degraded soils have attracted interest (Amonette and Joseph, 2009; Akhtar *et al.*, 2015; Sun *et al.*, 2018). In general, biochar has been shown to improve soil physicochemical properties and thus may provide a favourable habitat and nourishment to both plants and soil microbes in degraded soils (Al-Wabel *et al.*, 2013, Saifullah *et al.*, 2018; Mavi *et al.*, 2020). Enhanced soil available nutrients through cation exchange, adsorption of toxic compounds, reduced osmotic effects in root zone by improving water availability and improved soil pH status, all could be an explanation for the positive impacts of biochar application on soil flora and fauna (Chaganti *et al.*, 2015, Saifullah *et al.*, 2018; Mavi *et al.*, 2023b). With this background, long-term field experiments conducted by PAU Soil Salinity Team suggest that biochar (derived from rice straw) holds promising potential as a soil amendment in ameliorating soil functions and promoting plant productivity under saline water irrigated conditions (Chahal *et al.*, 2018; Singh *et al.*, 2019). Experiment in soil irrigated with saline water but amended with rice straw biochar under cotton-wheat system showed significant improvement in aboveground biomass (both in cotton and wheat), possibly due to its beneficial effects on soil properties such as soil EC, organic carbon, microbial population, water and nutrient availability, bulk density, soil aggregation, and proliferation of roots (Singh *et al.*, 2021, 2022). Further, the work also showed that the successive application of rice straw biochar for 5 years doubled the total soil organic C concentration and stocks in plots irrigated by saline water under a cotton-wheat cropping system (Mavi *et al.*, 2023a). However, our future work will focus on life-cycle analysis of biochar as soil amendment which would help in understanding the various aspects associated with the overall process of biochar production and benefits in terms of energy utilization, yield improvement and carbon sequestration under sodic environments with different cropping systems.

New Interventions to Ameliorate Sodic Irrigation Effects

Industrial gypsums: Mined gypsum is the most commonly used chemical amendment for sodic soil and water reclamation because of its abundant availability and low cost. Of late, supply and quality of gypsum available to the farmers is not assured/deteriorated and therefore, the supplied gypsum is not showing the same level of effectiveness at several places. Under such scenario, using yellow calcium sulphate available from the iron and steel industry could be an alternative source of calcium for agricultural production for the sodic environment. Thus, the Soil Salinity Team at PAU Ludhiana is working to explore the potential of using yellow gypsum as an indigenous source of calcium in ameliorating sodified soils. Similar, to mined gypsum, yellow gypsum also positively influenced seed cotton and canola yield and reduced pH in soils irrigated with water of high RSC.

In addition, an emerging amendment for reclamation of sodic soils is Flue gas desulfurization gypsum (FGDG) which is a bye-product of scrubbing sulphur from combustion gases in coal-fired power generation plants. FGDG (chemically calcium sulfate dihydrate, $CaSO4_2.H_2O$) has become widely available as a byproduct of forced-oxidation wet scrubbers that are used to reduce sulfur emissions (SOX) from coal-fired power plants using a spray of limestone slurry. FGDG is widely used in building materials (such as wallboard, plaster coatings, and concrete). It has the potential to reclaim sodic soils as an alternative to mined gypsum. Applications of FGDG in cultivated soil improve physicochemical properties, decline nutrients loss, supplement nutrients for soil and improve crop yield; thereby increasing the overall productivity. Recognizing the role of FGDG in the reclamation of sodic soil as an alternative to mine gypsum, CSSRI and NTPC have jointly initiated a collaborative project to study the efficiency of FGDG in the reclamation of sodic soils and monitoring of the heavy metal(s) uptake, crop growth and quality of soil and leachates in FGDG amended soils.

An experiment on reclamation of sodic soils with the application of FGD gypsum showed that the soil pHs declined by 8-11 percent after one year of application of FGDG/mined gypsum in sodic soil at 0-15 cm depth under experimental conditions at ICAR-CSSRI. Similarly, a significant change in pHs was observed at 15-30 cm depth. The decrease in soil sodicity and neutralization of soil alkalinity over the period has improved paddy growth and yield. The paddy grain increased by 30-50% with FGDG/gypsum application compared with unamended control. The wheat grain yield increased by 50-80 with the application of FGDG/gypsum in sodic soil (Basak *et al.*, 2022). The application of FGDG for reclamation of the sodic soils of different regions of the country viz., Haryana, Uttar Pradesh, and Punjab have been executed from kharif season (2021) through participation experiments. Conjunctive use of gypsum with bio-augmented material or municipal city waste compost (Rai *et al*. 2020: Sundha *et al*. 2018, 2020) has also been advocated for reclaiming soil sodicity. However, further experimentation is continued to validate these results with a range of sodicity build-up in the soil and confirm the role of these alternatives on heavy metal build-up, if any, under long-term scenario.

Microorganisms have a great potential to reduce the stress caused by sodic environment. in continued quest to search for alternate sources which not only have capacity to ameliorate sodic-irrigation effects but also are relatively beneficial for soil health. The research efforts have been initiated at PAU, Ludhiana in collaboration with ICAR-CSSRI Regional Centre, Lucknow to evaluate the performance and potential of microbial bio-formulations in improving crop yield and soil functionality under sodic environment. Preliminary results suggest that halophytic microbial bio-formulations can help to reduce the quantity of gypsum required to ameliorate harmful sodic irrigation effects in cotton.

Additionally, after successfully utilizing biochar produced from rice-residue for ameliorating soil salinity and carbon sequestration, work has been initiated at PAU Ludhiana for studying the role of biochar (Bhullar *et al.*, 2019) and sewage sludge as an alternative organic source for ameliorating the soil irrigated with high RSC water.

Fertility Management

Excess salts in the soil solution, high pH and excessive exchangeable Na, and adverse soil physical properties due to long- term use of sodic waterers and sodification influence availability of native and applied fertilizer nutrients (*e.g.* phosphorus) and their losses (aggravation of N losses through NH_3 volatilization). Ammonia volatilization is a major N loss mechanism and it increases with increase in EC, RSC and SAR of irrigation waters. To decrease losses of N and increase N use efficiency, splitting of fertilizer N so as to match crop demands at different growth stages, deep incorporation, slow release N-fertilizers and application of urease inhibitors have been found to be useful. Generally, application of higher dose (25-50%) of N for sodified soils than that for normal soils constitutes one strategy to overcome the adverse effects of salinity. Nevertheless, for improving N use efficiency, a better strategy seems to be to substitute a part of inorganic fertilizer requirements through organic materials. Following the application of N through inorganic fertilizer sources, a large pool of NH_4^+ liable to be lost through volatilization is bound by applied organic matter such as FYM or SPM (Sugarcane press mud) in sodic water irrigates soil, temporarily binding the ammoniacal N and subsequently release N to crops during its growing season (Yaduvanshi and Swarup, 2005). Bajwa and Singh (1992) observed that under flooded alkaline soil conditions, urea, ammonium sulphate and ammonium chloride placed in reduced zone produced similar rice yields whereas nitrate containing fertilizers were appreciably inferior. In case of wheat, effectiveness of fertilizers containing both NH_4^+-N and NO_3^--N was similar. Using sodic water for irrigation leads to lower fertilizer use efficiencies, increased fertilizer loss and decrease in the efficiency of rhizobium nodulation. Moreover, the overall fertiliser use is also low and highly imbalanced, i.e. skewed towards nitrogen only. So, the issues related to appropriate timing and placement of fertilizers, adjustment of the timings of leaching treatment as well choice of slow nutrient release fertilizers require further research (Minhas *et al.*, 2022). Further, various site-specific nutrient management (SSNM) tools such as Nutrient Expert, Green Seeker, LCC (leaf colour chart), remote sensing coupled with ICTs etc. should be evaluated for enhancing nutrient use efficiency (NUE) in differential levels of alkalinity developed in soils due to sodic-water irrigations.

Long term irrigation with sodic water also decreases the availability of micronutrients such as Zn and Fe resulting in deficiency of these nutrients when soils are generally calcareous. Besides being poor in available Zn, the use efficiency and recovery of applied Zn is further adversely affected due to 85-90% fixation of applied Zn (Chauhan *et al.*, 1999). Rice crop, though tolerant to soil sodicity, is sensitive to Zn deficiency which may appear 15 to 21 days after transplanting in the form of brown spots on fully matured leaves causing stunted growth and ultimately severe yield reductions. Therefore, application of Zn is an important requirement along with gypsum for optimum crop yields in sodic/sodic-water soils. In a sodic soil amended with 10 to 15 t ha^{-1} of gypsum and 10 to 20 kg $ZnSO_4$ ha^{-1} was enough to meet Zn requirement of crops (Singh and Bajwa, 1987).

Irrigation Management

Conjunctive use

Combined use of canal and sodic waters is a good option for reducing sodicity hazards of irrigation water on soil health and crop productivity. This is particularly true in situations where canal water supplies are either un-assured or inadequate and farmers often pump sodic groundwater for supplemental irrigation.

For efficient use, good quality waters can be used to grow sensitive crops and sodic waters for tolerant crops. In some situations, poor and good quality waters are available either simultaneously or at intervals. The appropriate options include (i) different quality waters can be blended in the supply network making tailor-made water available for each crop and all soil conditions and, (ii) alternating the use of good and poor-quality water (Bajwa and Josan, 1989b; Choudhary *et al.,* 2006; Choudhary, 2017), and (iii) switching these water sources according to critical stage of crop growth during the growing season. Rhoades *et al.* (1992) advocated the adoption of seasonal cyclic use, called 'dual rotation' strategy where non-saline non-sodic water is used for salt/sensitive crops/ initial stages of tolerant crops to leach out the accumulated salts from irrigation with salty waters to previously grown tolerant crops. Sharma and Minhas (2005) reported that this strategy may work better in arid climate with very low rainfall but it is of natural occurrence in the monsoonal climate. Blending is a promising practice in areas where freshwater supplies can be made available on demand. Mixing of sodic and canal water is done in such a proportion so that final SAR/RSC is maintained below threshold limit of the crop to be grown.

The proportion of blending two different water supplies (canal and sodic water) depends on the crops to be grown, extent of sodicity of water and freshwater supplies and economically acceptable yield reductions. Allocation of the two kinds of waters separately, if available on demand, can be done to different fields, seasons or crop growth stages so that salinity/ sodicity stresses are minimized during sensitive growth stages in the crop. Cyclic use of multi-quality waters can be made inter- or intra-seasonal (Minhas *et al.*, 2007b). Shelhevet (1994) have opined that cyclic use is more common and offers several advantages over blending. Moreover, mixing of two types of waters also requires the creation of additional facilities. Better quality water can be used for pre-sowing and early stages of crop growth and then switching to sodic water later on when the already established crop is able to tolerate relatively higher sodicity levels. Minhas *et al.* (2007b) observed that sustainability yield index of rice and wheat when sodic and good quality waters were used either by blending or by their alternate inter- or intra seasonal use, ranged from 0.52-0.75 and 0.79-0.95, respectively. Marginal improvements in the yield index over blending indicate a higher sustainability with the cyclic uses.

Bajwa and Josan (1989b) reported reduced crop yields of rice-wheat rotation due to increased pH and ESP and reduced infiltration rate (14%) in a sandy loam soil when put under sodic water (ECw 1.35 dS m^{-1}, RSC 10.1 meq L^{-1}, adj. SAR 26.7) for 6 years. However, when sodic irrigation was applied alternatively with canal irrigation, it resulted in increased yields of both the crops that were maintained at par with canal water except when there were two irrigations with sodic water (CW-2SW) in the cyclic option. In fact, in rice-wheat cropping system, farmers having some access to canal water supplies can sustain crop yields compared with situations where farmers do not have canal waters supplies at all (Minhas *et al.*, 1996). In alternative use, buildup of salt and ESP in the soil should be periodically monitored for better results. For crops sensitive at germination stage, cyclic option involving SW should address problem of seedling emergence due to crusting by ensuring pre-sowing irrigation with good quality canal water. Bajwa and Josan, (1989b), Choudhary *et al*. (2006) and Choudhary and Ghuman (2008) reported that alternating irrigations with canal water (CW) and sodic water (SW) maintained low soil ESP, and helped in sustaining good yields of rice and wheat, sunflower and cotton.

Yearly or seasonal conjunctive use strategy for canal and alkali (RSC 15) waters was evaluated for six years (2003-09) in potato-sunflower–green manure crop rotation (AICRP-SSW, 2010-17). The modes where higher number of canal water (CW) irrigations were applied, gave higher yields compared to the modes with higher number of alkali water (AW) irrigations in both the crops. Averaged over 6 years, the relative yield (RY) of potato was 67, 54, 78 and 61% under year-wise cyclic mode (1yCW : 2yAW, 1yAW : 2yCW, 2yCW : 1yAW and 1yAW : 2yCW) treatments, respectively. Similarly, the relative yield of sunflower was 60, 55, 73 and 56 for respective cyclic modes. In a seasonal cyclic strategy of irrigating potato with alkali water and sunflower with canal water (AWp : CWs), low relative yields (48% for potato and 60% for sunflower) were recorded. The *Sesbania* green manure crop was grown with monsoon rainwater but responded to sodicity buildup associated with previous crops. Higher proportions of SW used in cyclic option can also lower the quality of the harvested product. Reduction in potato grade and weight loss during storage and, smaller seeds and lower oil content in the case of sunflower was observed (Chauhan *et al.*, 2007). In onion, the proportion of 'A' grade bulbs was higher in 1TW : 1AW cyclic mode; at par with good quality water (TW) irrigation (Chauhan and Kaledhonkar, 2018). The proportion of lower grade bulbs (C grade) and weight loss during storage were higher under AW irrigation and the treatments with higher number of AW irrigations in a cyclic mode. Chauhan and Kaledhonkar (2018) also reported higher water use efficiency (WUE) of about 560 kg ha-cm^{-1} in 1TW : 1AW and TW treatments than mixing treatment of 2TW and 1AW (540 kg ha-cm^{-1}) and AW treatment (240 kg ha-cm^{-1}).

It became evident that in cyclic strategy, pre-sowing/first irrigation should be given with canal water. However, this may not happen in many canal commands where canal water supplies progressively decrease from the head reach to the tail reach (Tyagi, 2003) and even may not be available at the time of sowing of a crop. Choudhary and Ghuman (2008) observed greater decline in seed-cotton yield (16.5% $year^{-1}$) than that in wheat yield (5.9% $year^{-1}$). Compared with the SW treatment, yield of cotton and wheat were higher (93-98%) when the irrigation cycle started with CW and involved one SW (2CW:SW, CW:SW). The yields of cotton and wheat also remained higher in an irrigation cycle starting with SW but followed by 2CW irrigation (SW:2CW). But with cycles (SW:CW, 2SW:CW) involving one CW, the decline in seed-cotton yield was relatively greater (18-23%) than in the wheat yield (10%) after six years. Long-term sustainability of

Table 1. Effect of different irrigation cyclic modes on crop yields (t ha^{-1}) under cotton-wheat rotation in different time periods

Irrigation treatments/ Cyclic modes	Wheat				Cotton			
	1996-97 to 2001-02		2002-03 to 07-08		1997 to 2002		2003 to 2008	
	Mean	SYI#	Mean	SYI	Mean	SYI	Mean	SYI
CW@	5.20f*	0.79	5.21d	0.85	1.32d	0.54	2.02d	0.55
SW	4.43a	0.65	4.07a	0.61	0.95a	0.41	1.31a	0.35
2CW:SW$	5.10ef	0.77	5.01d	0.83	1.26cd	0.53	1.93cd	0.57
CW:SW	4.95cd	0.75	4.88cd	0.81	1.21bcd	0.51	1.85bcd	0.55
CW:2SW	4.70b	0.72	4.61bc	0.73	1.15bcd	0.49	1.64abcd	0.51
SW:2CW	4.82bcd	0.73	4.88cd	0.81	1.22cd	0.56	1.82bc	0.55
SW:CW	4.70b	0.71	4.63bc	0.73	1.08abc	0.47	1.59abc	0.45
2SW:CW	4.75bc	0.73	4.31ab	0.66	1.02ab	0.42	1.52ab	0.44

@CW – Canal water; SW- Sodic water; $ Cyclic use of 2CW and one SW irrigation
*Means sharing the same letter(s) in a column do not differ significantly at p<0.05 according to DMRT; # SYI – Sustainable yield index,
Source: Choudhary (2017)

2CW:SW, CW:SW and SW:2CW was established during the next 6 years (7-12 years) when optimum wheat and cotton yields (90-96% RY) were achieved (Choudhary, 2017). This trend was also confirmed by sustainable yield index values (Table 1).

The SYI indicating the minimum guaranteed yield as referenced to the maximum observed yield (Y_{max}). It ranged from 0.55-0.57 for cotton and 0.81-0.83 for wheat in 2CW:SW, CW:SW and SW:2CW treatments after 12 years, respectively. The SYI values for these treatments were higher for both crops relative to CW:2SW, SW:CW and 2SW:CW treatments. Lower SYI values for cotton might have resulted due to large variability in seed-cotton than wheat yields in different years. It suggests that although pre-sowing irrigation to cotton should be given always with good quality CW for ensuring better germination of cotton, sustainable seed-cotton yield can also be obtained even with occasional pre-sowing irrigation with SW followed by 2CW irrigations (SW:2CW). It is due to lower buildup of ESP (ESP < 10 in surface 0.3 m soil) in this treatment (similar to that observed in 2CW : SW) that controlled the precipitation of Ca^{2+} as $CaCO_3$. This treatment simulates the situations where availability of CW is not assured at the time of sowing. The proposed strategy offers the additional advantage of integrated water resources management by using low quality water for soil amelioration while saving better-quality water for producing high-value crops.

Irrigation interval

A general recommendation under sodic soil conditions is to apply light and frequent irrigations for overcoming the effects of poor hydraulic properties of soils. Under arid conditions, higher transpiration rates from wetter soils due to frequent saline irrigations may lead to increased soil solution salt concentration (1.5 to 2.0 folds) adjacent to growing roots, thus disapproving the case for a higher irrigation frequency.

In a long-term study, Bajwa *et al.* (1993) reported that crop responses to short irrigation intervals involving sodic and saline-sodic waters depended upon the season in which the crop was grown and its relative salt and Na tolerance. Frequent irrigation schedules during the summer season moderated the soil temperature and thus, increased crop yield over the long irrigation intervals.

Irrigation method

The distribution of water and salts vary with the method of irrigation. The surface irrigation methods such as border strips check basins and furrows are the oldest and are most commonly practiced in India. However, these irrigation methods generally result in excessive irrigation and non-uniformity in water applications.

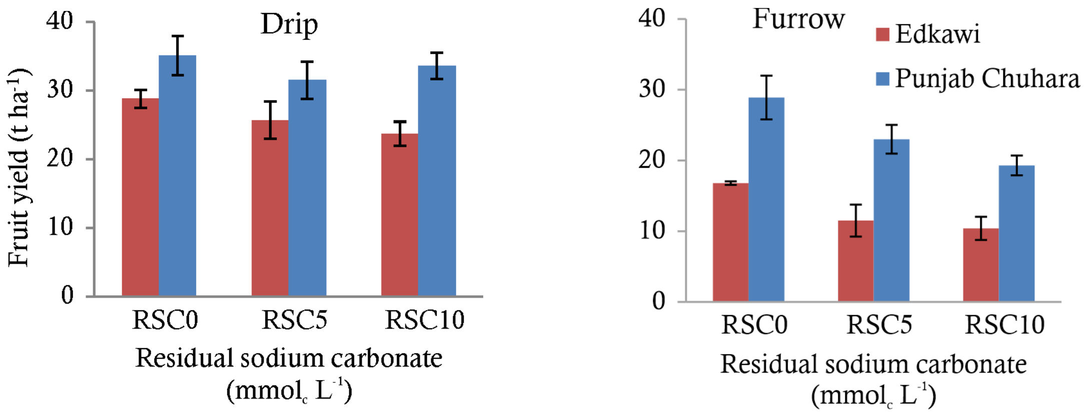

Fig. 2 Tomato fruit yields (t ha^{-1}) as influenced by RSC of irrigation water under drip and furrow irrigation (after three years in 2003-04)
Source: Choudhary *et al.* (2010)

Consequently, on-farm irrigation efficiency is low (50-60%). Drip irrigation has revolutionized the production of some high-value crops. Due to the formation of the wetting front by the movement of water due to regular and frequent water supply in drip irrigation, salts are pushed away towards the periphery of the front. Thus, drip irrigation has the potential to enhance the threshold limits of crop salt and Na tolerance by modifying the pattern of salt distribution.

While irrigating tomato crop with sodic waters high in bicarbonates, Choudhary *et al.* (2010) observed that effects on soil physical and chemical properties can be more severe in furrow than in drip-irrigation. On the other hand, better soil moisture conditions and lesser deterioration in soil properties when irrigated with medium and high RSC water under drip irrigation can lead to higher tomato yields than under furrow irrigation (Fig. 2).

Leaching requirement

The first requisite for crop production in saline soils is to lower salinity to acceptable limits, which is accomplished through the process of leaching. The extent of leaching required during reclamation depends upon initial salinity, salt tolerance of crops to be grown, and depth of the water table. One recommendation is the application of excessive water to meet the leaching requirement (LR) and maintain a desirable salt and water balance in the soil having adequate drainage. The concept of LR for achieving salt balance holds good for situations with very low rainfall. But it is of natural occurrence in monsoonal type climate where rains are concentrated in 2-3 months. In general, LR increases with the salinity of the water supply and the salt sensitivity of the crop. However, 30-50% higher salinity build up even in light-textured soil was observed when 50% extra saline water was applied to meet the leaching requirement and so was true when applying 50% extra sodic water under rice-wheat and maize-wheat systems (Minhas and Bajwa, 2001; Choudhary *et al.*, 2011b). The general strategy to use the monsoon rainwater to take care of LR and to maintain low salt build-up in the root zone soil seems to be more helpful.

Conclusions and Future Research Needs

Recent trends suggest that the use of sodic waters for irrigation for crop production will increase in the future. But indiscriminate and unmindful use of these sodic waters can, directly and indirectly, affect the soil's physical, chemical, and biological properties and reduce crop growth, yield, and quality. Therefore, adopting site-specific management options is crucial for controlling the build-up of salts in soils ensuring their safe use for the sustainability of crop production. Selection of crops, cropping patterns, and crop varieties that produce satisfactory yields under Na-rich environments are important. Conjunctive use options of available water qualities, appropriate irrigation methods, and leaching strategies are crucial and critical to reduce Na and salt build-up in soil and maintain crop yields. The optimal use of chemical amendments and fertilizers including time and mode of their application and their combined and judicious use along with organic materials will ensure efficient utilization of these inputs to ameliorate the soil and water sodicity.

We believe that the time has come to consider these sodic ground waters as useful resources rather than an environmental burden. Adopting specific systems of management while using these sodic waters should therefore give us an opportunity to shift from subsistence farming to progressive farming. Using alternate sources of gypsum having high purity and assured quality, biochar derived from different biomass and, microbial-mediated calcite dissolution to reduce soil and water sodicity looks promising and should further be explored.

References

Amonette J and Joseph S (2009) Characteristics of biochar: Micro-chemical properties. In: Lehmann J and Joseph S (eds) *Biochar for Environmental Management: Science and Technology*, Earthscan, London, pp 35-52.

Akhtar SS, Andersen MN and Liu F (2015) Residual effects of biochar on improving growth, physiology and yield of wheat under salt stress. *Agriculture Water Management* **158**: 61–68.

Al-Wabel MI, Al-Omran A, El-Naggar AH, Nadeem M and Usman AR (2013) Pyrolysis temperature induced changes in characteristics and chemical composition of biochar produced from conocarpus wastes. *Bioresource Technology* **131**: 374–379.

Ayers RS and Westcot DW (1985) Water quality for agriculture. *Irrigation Drainage Paper 29*, FAO, Rome, Italy, Rev. 1, p 174.

Bajwa MS and Josan AS (1989a) Effect of gypsum and sodic irrigation water on soil and crop yields under rice-wheat rotation. *Agricultural Water Management* **16**: 53-61.

Bajwa MS and Josan AS (1989b) Effect of alternating sodic and non-sodic irrigations on the build-up of sodium in the soil and on the crop yields in northern India. *Experimental Agriculture* **25**: 199-205.

Bajwa MS and Singh B (1992) Fertilizer nitrogen management for rice and wheat crops grown in alkali soils. *Fertilizer News* **37**: 47-59.

Bajwa MS, Josan AS and Choudhary OP (1993) Effect of frequency of sodic and saline-sodic irrigations and gypsum on the build-up of sodium in soil and crop yields. *Irrigation Science* **14**: 21-26.

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. Front. Environmental Science* **10**: 935785. doi: 10.3389/fenvs.2022.935785.

Bhullar RS, Mavi MS and Choudhary OP (2019) Adverse impact of sodicity on soil functions can be alleviated through addition of rice straw biochar. *Communications in Soil Science and Plant Analysis* **50**, 19: 2369-2383.

Chahal SS, Choudhary OP and Mavi MS (2017) Organic amendments decomposability influences microbial activity in saline soils. *Archives of Agronomy and Soil* Science **63**: 1-14.

Chahal SS, Choudhary OP and Mavi MS (2018) Microbial activity is constrained by the quality of carbon and nitrogen under long-term saline water irrigation. *Communications in Soil Science and Plant Analysis* **49**, 11: 1266-1280.

Chaganti VN and Crohn DM (2015) Evaluating the relative contribution of physiochemical and biological factors in ameliorating a saline-sodic soil amended with composts and biochar and leached with reclaimed water. *Geoderma* **259**: 45–55.

Chauhan RPS, Singh BB, Singh RK and Singh VP (1999) Strategic nutrient management for sustained rice production in sodic soil. *Fertilizer News* **44**: 13-26.

Choudhary OP and Bajwa MS (2021) *Sodic irrigation waters and their management.* In: Minhas PS *et al* (eds) *Managing Salt-affected Soils in India*. ICAR Publication, New Delhi, India. *pp 485-513*

Choudhary OP, Josan AS, Bajwa MS and Kapur ML (2004) Effect of sustained sodic and saline-sodic irrigations and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. *Field Crops Research* **87**: 103-116.

Choudhary OP (2017) Long term impact of cyclic use of sodic and canal waters for irrigation on soil properties and crop yields in cotton-wheat rotation in a semi-arid climate. *Agricultural Research* **6**: 267-272.

Choudhary OP and Ghuman BS (2008) Cyclic use of sodic and non-sodic canal waters for irrigation in cotton-wheat cropping system in a semi-arid region. *Journal of Sustainable Agriculture* **32**: 269-286.

Choudhary OP, Brar JS, Saroa GS and Sekhon KS (2012a) Wheat response to increasing levels of residual alkalinity in irrigation water in a semi-arid region. *Journal of Crop Improvement* **26**: 802-815.

Choudhary OP, Brar JS, Sekhon KS and Shankar A (2012b) Response of Bt cotton hybrids to irrigation with sodic waters with high residual alkalinity in semi-arid region. *In: Proc National Seminar on Development in Soil Science – 2012*, 77th Annual Conv. Indian Society of Soil Science, Ludhiana. pp 223.

Choudhary OP, Ghuman BS and Saroa GS (2007) Response of 'PBW 343' wheat (*Triticum aestivum*) to increasing levels of residual alkalinity in irrigation water in semi-arid regions. *Indian Journal of Agricultural Science* **77**: 150-153.

Choudhary OP, Ghuman BS, Dhaliwal MS and Chawla N (2010) Yield and quality of two tomato (*Solanum lycopersicum* L.) cultivars as influenced by drip and furrow irrigation using waters having high residual sodium carbonate. *Irrigation Science* **28**: 513-523.

Choudhary OP, Ghuman BS, Singh B, Buresh RJ, and Thuy N (2011a) Effects of long-term use of sodic water irrigation, amendments and crop residues on soil properties and crop yields in rice-wheat cropping system in a calcareous soil. *Field Crops Research* **121**: 363-372.

Choudhary OP, Ghuman BS, Josan AS and Bajwa MS (2006) Effect of alternating irrigation with sodic and non-sodic waters on soil properties and sunflower yield. *Agricultural Water Management* **85**: 151-156.

Choudhary OP, Grattan SR and Minahs PS (2011b) Sustainable crop production using saline and sodic waters. In: Lichtfouse E (ed) *Alternate Farming Systems, Biotechnology, Drought Stress and Ecological Fertilisation. Sustainable Agriculture Reviews* **6**: 293-318. Springer Dordrecht, New York.

Choudhary OP, Josan AS and Bajwa MS (1996a) Rooting and yield relationships in different barley cultivars grown under increasingly soil sodicity stress conditions. *Crop Improvement* **23**: 1-11.

Choudhary OP, Josan AS and Bajwa MS (1996b) Tolerance of wheat and triticale to sodicity. *Crop Improvement* **23**: 238-246.

Choudhary OP, Josan AS and Bajwa MS (2001) Yield and fibre quality of cotton cultivars as affected by sustained sodic irrigations in semi-arid conditions. *Agricultural Water Management* **49**: 1-9.

Eaton FM (1950) Significance of carbonates in irrigation waters. *Soil Science* **69**: 123-133.

Mavi MS, Singh G, Choudhary OP, Singh A, Vashisht BB, Sekhon KS, Pathania N and Singh BP (2023a) Successive addition of rice straw biochar enhances carbon accumulation in soil irrigated with saline or non-saline water. *Environmental Research* **217**: 114733.

Mavi MS, Singh G, Choudhary OP and Dey D (2023b) Moderation of nitrogen availability through the application of pyrolyzed and unpyrolyzed organic materials in saline water irrigated soil. *Environment Monitoring & Assessment* **195**: 467.

Mavi MS, Bhullar RS and Choudhary OP (2020) Differential ability of pyrolysed biomass derived from diverse feedstocks in alleviating salinity stress. *Biomass Conversion and Bio-refinery* **12**: 5229–5240.

Minhas PS, Dubey SK and Sharma DR (2007) Comparative effects of blending, intra/ inter-seasonal cyclic uses of alkali and good quality waters on soil properties and yields of paddy and wheat. *Agricultural Water Management* **87**: 83–90.

Minhas PS, Sharma DR and Sharma DK (1996) Perspective of sodic water management for paddy wheat cropping system. *Journal of Indian Water Resources Society* **2**: 57- 61.

Minhas PS and Bajwa MS (2001) Use and management of poor-quality waters for the rice-wheat based production system. In: Kataki PK (ed) *The Rice-Wheat Cropping System of South Asia: Efficient Production Management*. Food Products Press, an imprint of The Haworth Press, Inc. pp 273-306.

Minhas PS, Qadir M and Yadav RK (2021) Groundwater irrigation induced soil sodification and response options. *Agricultural Water Management* **215**: 74-85.

Rai AK, Basak N and Sundha P (2020) Alternate reclamation sources of sodic soils. In: Minhas PS et al (eds) *Managing Salt-Affected Soils for Sustainable Agriculture*. ICAR Publication, New Delhi. pp 332–345.

Rengasamy P and Marchuk A (2011) Cation ratio of soil structural stability (CROSS). *Arid Soil Research & Rehabilitation* **49**: 280-285.

Sharma DK and Singh A (2015) Salinity research in India-Achievements, challenges and future prospects. *Water and Energy International* **58**: 35-45.

Sharma PK, Sood A, Setia RK, Singh N, Meenakshi and Verma VK (2010) Groundwater quality for irrigation in Punjab. *Punjab Remote Sensing Center, Ludhiana*. pp 63.

Singh A (2015) Land and water management planning for increasing farm income in irrigated dry areas. *Land Use Policy* **42**: 244–250.

Singh B and Bajwa MS (1987) Ammonia volatilization from salt-affected soils fertilized with urea under submerged conditions. *Journal of the Indian Society of Soil Science* **35**: 358-364.

Singh G, Bundela DS, Sethi M, Lal K and Kamra SK (2010) Remote sensing and geo- graphic information system for appraisal of salt-affected soils in India. *Journal of Environmental Quality* **39**: 5–15.

Singh G, Mavi MS, Choudhary OP, Kaur M and Singh BP (2022) Interaction of pyrolysed and un-pyrolysed organic materials enhances carbon accumulation in soil irrigated with water of variable EC. *Soil & Tillage Research* **215**: 105193.

Singh G, Mavi MS, Choudhary OP, Gupta N and Singh Y (2021) Rice straw biochar application to soil irrigated with saline water in a cotton-wheat system improves crop performance and soil functionality in north-west India. *Journal of Environmental Management* **295**: 113277.

Singh R, Mavi MS and Choudhary OP (2019) Saline soils can be ameliorated by adding biochar generated from rice-residue waste. *Clean Soil, Air, Water* **47**(2): 1700656

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.

Sun J, Yang R, Li W, Pan Y, Zheng M and Zhang Z (2018) Effect of biochar amendment on water infiltration in a coastal saline soil. *Journal of Soils Sediments* **18**: 3271–3279.

Sundha P, Basak N, Rai AK, Yadav RK and Sharma DK (2018) Utilization of municipal solid waste compost in reclamation of saline-sodic soil irrigated with poor quality water. *Journal of the Indian Society of Soil Science* **66**: 28–39.

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

Tyagi NK (2003) Managing saline and alkali water for higher productivity. In: Kijne JW et al (eds) *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CABI Publishing, Wallingford, U.K, pp 69-88.

United States Salinity Laboratory Staff (1954) Diagnosis and Improvement of Saline and Alkali Soils, *United States Department of Agriculture*. *Handbook 60*. pp 160.

Yaduvanshi NPS and Swarup A (2005) Effect of continuous use of sodic irrigation water with and without gypsum, farm yard manure, pressmud and fertilizer on soil properties and yields of rice and w-heat in a long-term experiment. *Nutrient Cycling in Agroecosystems* **73**: 111-118.

Received: April 26, 2023: Accepted: June 16, 2023

Journal of Soil Salinity and Water Quality 15(1), 15-24, 2023

Soil Salinity and Variable Moisture Regimes Impacts on Growth Attributes of *Eucalyptus* in North-western Punjab, India

Baljit Singh[1], GPS Dhillon[1], Avtar-Singh[2]* and Pritpal Singh[3]

[1]*Department of Forestry and Natural Resources, Punjab Agricultural University (PAU), Ludhiana, Punjab, India*
[2]*PAU Regional Research Station, Bathinda, Punjab, India*
[3]*PAU-Farm Advisory Service Centre (FASC), Bathinda, Punjab, India*
**Corresponding author E-mail: avtar-bti@pau.edu*

Abstract

The reclamation of saline waterlogged soils via afforestation depends exclusively on plantation of tolerant tree species with fast growth habits and greater biomass production together with the ability to withstand ambient soil salinity. Soil salinity and water logging significantly influence the growth performance of *Eucalyptus* species which has large potential as cost-effective and eco-friendly measure for the reclamation of salt affected and waterlogged landscapes. We therefore, studied the response of *Eucalyptus* (clone PE-11) under aerobic (60% water filled pore space; WFPS) and water logged (120% WFPS) moisture regimes established at four levels of soil salinity ($EC_{1:2}$=0-12 dS m^{-1}). There was a significant salinity × moisture regimes interaction effect on *Eucalyptus* growth attributes. These results revealed a significant (p<0.05) decrease in plant height (~33.6-65.2%) and collar diameter (~56.9-73.1%) with increased $EC_{1:2}$. There was a linear significant relationship between soil salinity and tree height (R^2=0.812*-0.996**; p<0.05) for trees planted at 60 and 120% WFPS. Soil salinity ($EC_{1:2}$=4 dS m^{-1}) significantly decreased the stem biomass by 72.9 g $tree^{-1}$ (by ~42.1%) than the non-saline soil. Leaves biomass was significantly decreased by ~63.3 g $tree^{-1}$ at 120% WFPS as compared to 60% WFPS. Soil salinity significantly decreased the leaves biomass by ~32.2, 59.9 and 66.9%, respectively at $EC_{1:2}$ of 4, 8 and 12 dS m^{-1} over non-saline soil. Averaged across the soil salinity levels, root biomass was significantly higher by ~6.3-times at 60% WFPS than the 120% WFPS. The decreased plant growth attributes were responsible for reduced dry wood biomass of *Eucalyptus*. These results revealed that tree growth decreased significantly with increased $EC_{1:2}$, regardless of the moisture regime. Similarly, regardless of the salinity level, *Eucalyptus* growth was significantly decreased at increased moisture regime.

Key words: Biomass, Soil salinity, Moisture regimes, Waterlogging, Soluble salts, Net primary production, Eucalyptus

Introduction

Soil salinity-affected landscapes occupy nearly 1 billion ha area globally, which comprised ~7-10% of total land surface (Szabolcs, 1994; Wicke *et al.,* 2011). Soil salinity has largely affected crop production on nearly 20% of the total cultivated (~33% of total irrigated croplands) across the globe (Fagodiya *et al*., 2022). The accumulation of soluble salts has been most wide-spread in arid and semi-arid regions, where evaporation exceeds rainfall, which is inadequate to leach out the soluble salts from the root zone (Larchar, 1995; Singh *et al.*, 2023). Latest reports highlighted that every year ~10% additional croplands are getting salinized, and by 2050 around 50% of the arable land would be salt-affected (Kumar and Sharma, 2020). The irrational irrigation water management practices, lack of suitable drainage systems, and the use of poor- quality irrigation water are the major reasons for waterlogging and salinity problems in South Asia especially in India, Pakistan and Bangladesh (Hossain, 2010).

Farm forestry has emerged as most productive land-use for already waterlogged and saline landscapes (Tomar *et al.,* 2003). The reclamation of saline waterlogged soils via afforestation and/ or agroforestry consisted of plantation of tolerant tree species with fast growth habits and greater biomass production together with the ability to withstand ambient soil salinity has large potential as cost-effective and eco-friendly land reclamation measure (Dagar and Minhas, 2016). Amongst the different forestry species, *Eucalyptus* is characterised by high transpiration rate and straight growing architecture, and has been the most economically viable alternative for the management of waterlogged saline soils (Jeet-Ram *et al.,* 2007).

Eucalyptus is a native of Australia where more than 600 species exist, which are now been widely grown across the globe (Rassaeifar *et al.,* 2013). It is considered suitable for saline or sodic soils, waterlogged area especially for draining excess water as well as for preventing erosion induced land degradation (Dagar *et al.,* 2016; Singh *et al.*, 2019; Kaur and Monga, 2021; Avtar-Singh *et al.,* 2022). *Eucalyptus* grows under a wide range of climatic and soil conditions from warm to hot, sub-humid to humid and from fertile to degraded soils. However, a large difference in growth attributes leads to differential change in plant productivity due to considerable reduction in plant growth due to high concentration of soluble salts (Ali *et al.,* 1987; Singh *et al.,* 1991). The growth and development of plants under waterlogging are mainly hindered by reduced levels of oxygen in the soil around the root zone (Christianson *et al.,* 2010). The shallow water depth accomplice side-by-side with accumulation of salts in soil profile, and is activated by high evaporative demands in dry land areas (Singh, 2013). Salinity build-up in dry land regions may occur due to changes in water balance in the catchment area by remobilization of salts stored underground (Sharma *et al.,* 2020; Singh *et al.,* 2023).

The waterlogging and soil salinity are major problems associated with land degradation in irrigated agriculture and are adversely affecting a portion of utilized irrigation potential of major and medium irrigation projects in India. Such landscapes have threatened the food, fibre and fuel security of these countries and warrant immediate attention for inexpensive and environmentally acceptable solutions for reclaiming and managing these soils (Qadir and Oster, 2004; Singh *et al.,* 2019; Kumar *et al.,* 2021a, b). The saline soils contain high concentrations of soluble salts in the combinations of chlorides (Cl) and sulphates (SO_4) of calcium (Ca), magnesium (Mg) and sodium (Na) which form as white encrustations on the soil surface particularly in dry lands (Stirzaker *et al.,* 2002). *Eucalyptus* clones have been reported to behave differentially in response to alteration in ground water table and accumulation of soluble salts in the surface soils layer (Avtar-Singh *et al.,* 2022; Madiwalar *et al.,* 2023).

The screening of *Eucalyptus* clones is important for wide-scale implementation of any land development project (Madiwalar *et al.,* 2023). Therefore, the present study was conducted to investigate the response of *Eucalyptus* clone at different combinations of moisture regimes and soil salinity levels. We hypothesized that *Eucalyptus* plants established under less soluble salts environment and at optimum moisture regimes would have increased growth and net primary production in different above-and below-ground biomass components. Till date there is no information available in the literature on growth of *Eucalyptus* clone (PE-11) in response to changed moisture regime and level of soil salinity (Avtar-Singh *et al.,* 2022). We therefore, compared different combinations of moisture regimes viz. aerobic; 60% water filled pore space (WFPS) and waterlogged; 120% WFPS) and four levels of soil salinity (viz. $EC_{1:2}$= 0, 4, 8 and 12 dS m^{-1}) in drums on growth attributes of *Eucalyptus* for identifying the optimum moisture regime and salinity levels at which it could outperform and could be promoted for large scale development of degraded landscapes. The present study would help framing policies for land restoration of saline and waterlogged landscapes, and would help enhance C sequestration both in soils as well as in plant biomass for increased C sustainability of forest ecosystems.

Material and Methods

Brief description of experimental site

The present study was conducted at research farm of Punjab Agricultural University (P.A.U.), Ludhiana, (latitude 30.9°N and longitude 75.8°E), in north-western Punjab (India). The experimental area is characterized as hot humid, semi-arid, sub-tropical with monsoonal climate. Average annual rainfall in the study area is ~700 mm, of which nearly 80% is received during monsoon season extending from July to September and the rest about 20% during the winter season. The maximum temperature above 38.0°C is common during summer and frequent frosty spells are experienced during winters. The average annual rainfall is ~759 mm; ~80.0% of it is received through south-west *monsoon* during June to September. The experiment was conducted in the year 2018-19 on a sandy loam soil (72.4, 17.1 and 10.5%, sand, silt and clay, respectively; *Typic Ustorthents*) (USDA, 1930). At the start of the experiment, the field soil (0-15 cm) tested 7.34 in $pH_{1:2}$ and 0.31 dS m^{-1} in electrical conductivity ($EC_{1:2}$) (Jackson, 1973). Soil organic C concentration determined using wet digestion method (Walkley and Black, 1934) for the surface (0-15 cm) soil depths was 3.91 g kg^{-1}.

Experiment description and design

The experiment was conducted to study the effect of different levels of salinity and moisture regimes on growth of *Eucalyptus* (clone PE-11). The experiment was conducted in plastic drums of volume = 0.229 m^3 (100 cm high × 54 cm diameter). Soil samples were collected in bulk, ground and packed by adding 350 kg $drum^{-1}$. Four salinity levels (viz. $EC_{1:2}$= 0, 4, 8 and 12 dS m^{-1}) were created in the soil by addition of sodium chloride (NaCl) in the drums. Soil salinity levels of 4, 8 and 12 dS m^{-1} were created by dissolving 280, 560 and 840 g NaCl $(100\ L)^{-1}$ water. The aerobic moisture regime was simulated by maintaining water content at 60% water filled pore space (WFPS) in all treatments of salinity for first three months and two water levels viz. aerobic (60% WFPS) and water logged (120% WFPS) were maintained (Singh *et al.*, 2010). Water filled pore space refers to the ratio of volumetric soil water content to total soil porosity, and water determined from its bulk density (D_B) and moisture content, while considering particle density of soil as constant. (2.6 g cm^{-3}) (Singh and Singh, 2007; Singh *et al.*, 2010). For the determination of D_B, soil cores (inner diameter=7.2 cm) were collected. The soil was oven dried at 105°C for 24 h, and dry soil weight was recorded (Blake and Hartge, 1986). The D_B (Mg m^{-3}) was calculated as a ratio of weight of soil and volume of soil sample.

The *Eucalyptus* saplings (90 days old) were planted, and fertilizer-N, P and K were applied in the month of July every year at 12g N (as urea, 46% N), 25g P_2O_5 (as diammonium phosphate, DAP, 18%N and 46% P_2O_5) and 6g K_2O (muriate of potash, MOP, 60% K_2O) per tree (Avtar-Singh *et al.,* 2022). Therefore, a total of 24 drums (2 moisture regimes × 4 salinity levels × 3 replications) were used for conducting the experiment.

Measurement of growth attributes

Collar diameter and plant height were measured periodically (i.e. at 3, 5 and 10 months after planting) in respective treatment. Plant height was measured using measuring tape and expressed as 'cm'. The collar diameter was measured with vernier clipper and also expressed as 'cm'. Different components of net primary production were recorded at 10 months after planting. The total tree biomass from each treatment was removed from the drum and weighed. The tree biomass was partitioned as above-ground (viz. stems and leaves) and below-ground (viz. root). After partitioning, three sub-sample from each treatment and component were dried in an over at 60±5°C till constant weight, and expressed on dry weight basis (Madiwalar *et al.*, 2023).

Statistical analysis

The data on tree growth parameters, above-and below-ground biomass and C were statistically analysed using analysis of variance (ANOVA) technique in complete randomized block design (RBD) in factorial combinations (Cochran and Cox, 1966) using SPSS for Windows 16.0 (SPSS Inc., Chicago, U.S.A.). Least Significant Difference (LSD) test values were tested at $p<0.05$ level of probability.

Results and Discussion

Tree height and collar diameter of *Eucalyptus*

The tree growth attributes were significantly influenced by moisture regime and salinity levels (Table 1). Statistically, there were non-significant ($p<0.05$) differences in plant height amongst the 60 and 120% WFPS moisture regime after 3 months of planting. The plant height (regardless of the salinity level) was decreased by ~34.8 and 48.2%, respectively after 5 and 10 months of their

Table 1. Plant height and collar diameter of *Eucalyptus* at different levels of soil salinity (viz. electrical conductivity; $EC_{1:2}$) and moisture regimes (e.g. in aerobic; 60% water filled pore space (WFPS), and submerged; 120% WFPS) at different times after planting in north-western Punjab, India.

Soil salinity	Moisture regime		Mean	Moisture regime		Mean	Moisture regime		Mean
($EC_{1:2}$; dS m^{-1})	60% WFPS	120%WFPS		60% WFPS	120%WFPS		60% WFPS	120%WFPS	
	3 months after planting			5 months after planting			10 months after planting		
				Plant height (cm)					
0	111.7 (7.0)[†]	114.5 (12.7)	113.1	160.7 (14.0)	123.2 (9.7)	141.9	211.2 (12.4)	134.5 (11.3)	172.8
4	100.8 (12.4)	99.3 (9.0)	100.1	123.8 (12.8)	105.8 (8.1)	114.8	179.2 (8.6)	120.8 (7.6)	149.9
8	85.8 (5.2)	87.2 (7.9)	86.5	110.3 (8.0)	92.4 (6.5)	101.4	155.8 (13.8)	101.2 (12.0)	128.5
12	75.7 (5.0)	74.4 (4.1)	75.1	98.8 (12.5)	—	49.4	142.3 (11.9)	—	71.2
Mean	93.5	93.9		123.4	80.4		172.1	89.1	
LSD (p<0.05):	Salinity = 8.17, Moisture regime = NS, Salinity × moisture regime = NS			Salinity = 11.4, Moisture regime = 8.0, Salinity × moisture regime = 16.1			Salinity = 11.3, Moisture regime = 8.6, Salinity × moisture regime = 16.5		
				Collar diameter (cm)					
0	0.73 (0.11)	0.70 (0.08)	0.72	1.33 (0.07)	0.83 (0.09)	1.08	2.13 (0.12)	1.07 (0.08)	1.60
4	0.55 (0.09)	0.56 (0.13)	0.56	1.05 (0.10)	0.71 (0.13)	0.88	1.70 (0.07)	0.92 (0.07)	1.31
8	0.42 (0.07)	0.44 (0.03)	0.43	0.78 (0.09)	0.52 (0.04)	0.65	1.58 (0.09)	0.61 (0.03)	1.09
12	0.32 (0.06)	0.29 (0.07)	0.31	0.57 (0.06)	—	0.29	1.37 (0.11)	—	0.69
Mean	0.51	0.49		0.93	0.52		1.69	0.65	
LSD (p<0.05)	Salinity = 0.08, Moisture regime = NS, Salinity × moisture regime = NS			Salinity = 0.09, Moisture regime = 0.06, Salinity × moisture regime = 0.13			Salinity = 0.09, Moisture regime = 0.06, Salinity × moisture regime = 0.13		

[†]Values in the parenthesis indicate standard error from mean ($S.E._M$)

establishment. The *Eucalyptus* plants are known to have higher transpiration rate of ~0.5-6.0 mm day^{-1} (Zahid *et al.,* 2010), and therefore have higher water consumption of ~5324 L water $year^{-1}$ depending upon tree species (Chaturvedi *et al.,* 1988). Although, *Eucalyptus* trees are considered to have higher evaporative capacity, governed by higher aerodynamics conductance, which makes them most suitable for bio-drainage purpose (Kidanu *et al.*, 2005), yet the results of present study showed significant decrease in tree growth of clone PE-11 at prolonged water logging simulated by 120%WFPS. Tree height decreased significantly with increased $EC_{1:2}$ of soils, regardless of the growth stage (Figure 1). There was a linear relationship (R^2=0.812* to 0.996**; $p<0.05$) between soil salinity and tree height for trees planted at 60 and 120% WFPS. The relationships (Eq. 1-6) could therefore, best be described by a linear significant function (Table 2). However, it was important to observe a similar growth pattern of *Eucalyptus* trees at different moisture regimes, regardless of the soil salinity. The relationship between the tree height at 60 and 120% moisture regimes (Figure 2) could best be described by a linear function (Eq. 1).

Plant height (cm) at 120% WFPS=0.3688 (plant height; cm) at 60% WFPS) + 56.83, R^2=0.776*; $p<0.05$ (1)

Soil salinity significantly ($p<0.05$) influenced *Eucalyptus* tree growth characteristics at different growth stages (Table 1). Data pooled for $EC_{1:2}$ levels showed a decrease in tree height by ~34.8% at 5 months and by ~48.2% at 10 months after

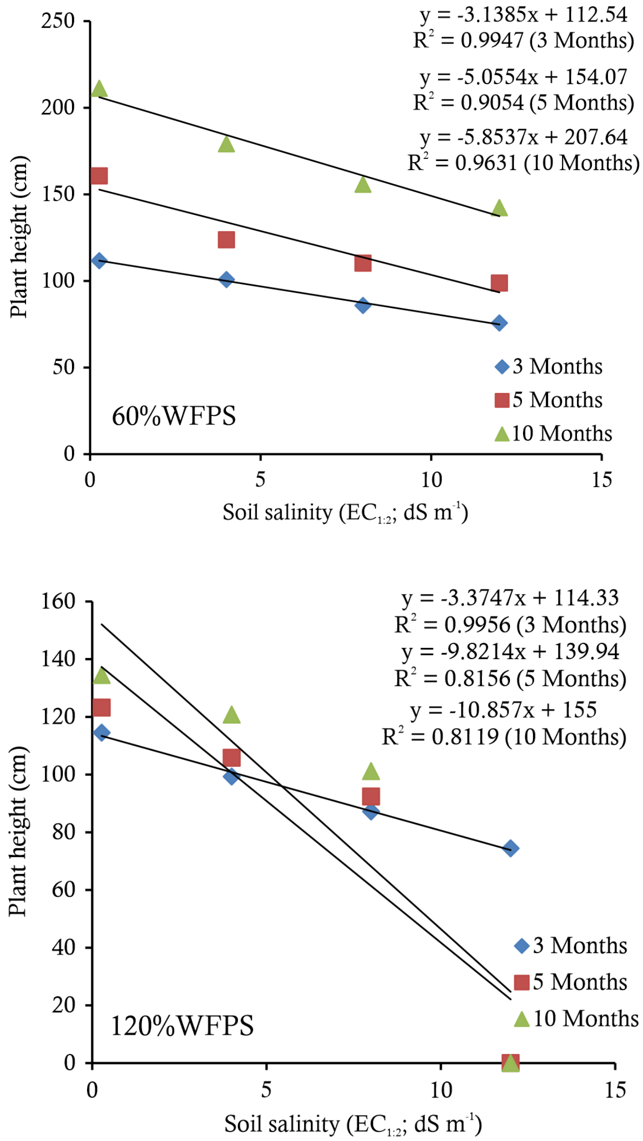

Fig. 1 Relationship between soil salinity and plant height of *Eucalyptus* at different moisture regimes viz. aerobic; 60% water filled pore space (WFPS) and submerged; 120% WFPS at different times after planting in north-western Punjab, India

Table 2. Linear function relationship between tree height and soil salinity levels at different moisture regimes (e.g. in aerobic; 60% water filled pore space (WFPS), and submerged; 120% WFPS) in north-western Punjab, India

Equation No.	Equation (X=soil salinity level, $EC_{1:2}$; dS m^{-1} and Y=Tree height, cm)	Coefficient of determination (R^2)†
Aerobic soils (60% WFPS)		
Eq. 1	y = -3.1385x + 112.54 (3 Months)	R^2 = 0.995**; $p<0.01$
Eq. 2	y = -5.0554x + 154.07 (5 Months)	R^2 = 0.905*; $p<0.05$
Eq. 3	y = -5.8537x + 207.64 (10 Months)	R^2 = 0.963**; $p<0.01$
Water logged soils (120% WFPS)		
Eq. 1	y = -3.3747x + 114.33 (3 Months)	R^2 = 0.996**; $p<0.01$
Eq. 2	y = -9.8214x + 139.94 (5 Months)	R^2 = 0.816*; $p<0.05$
Eq. 3	y = -10.857x + 155.0 (10 Months)	R^2 = 0.812*; $p<0.05$

†Regression relationships significant at $p<0.05$ were marked by *, and at $p<0.01$ were marked by **

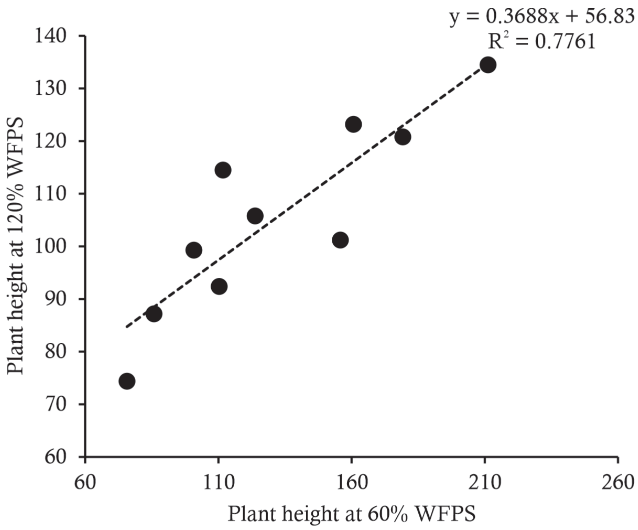

Fig. 2 Relationship between plant height of *Eucalyptus* at different growth stages in north-western Punjab, India. Data pooled for moisture regimes and soil salinity level, excluding data for treatments where plants were died

planting. It was important to observe that trees died at high salinity ($EC_{1:2}$=12.0 dS m^{-1}) level when planted at 120% WFPS. At $EC_{1:2}$=12.0 dS m^{-1}, tree height (regardless of the moisture regime) was decreased significantly by ~33.6, 65.2 and 58.8%, respectively at 3, 5 and 10 months after planting. *Eucalyptus* provides one of the most feasible options for cultivation where the soil and water are moderately saline, especially if the soil has a dense structure with a shallow groundwater table (Marcar and Benyon, 2003; Dagar and Minhas, 2016; Dagar *et al.,* 2016).

It was observed that salinity and moisture level interaction was non-significant for plant height after 3 months of their planting, but was significant thereafter (Table 1). These results therefore, showed that *Eucalyptus* clone PE-11 plants could with stand high moisture level during the initial growth phase, but with increased EC there was a significant decrease in plant height. It has been reported that water logging increases the unfavourable effects of soil salinity due to anoxia interferences with the mechanisms that allow many plants to tolerate salt accumulation (Crawford, 1982; Avtar-Singh *et al.,* 2022). It could be ascribed to the fact that *Eucalyptus* plants are habitually planted in marginal lands for land rehabilitation and reclamation, as they are able to use groundwater of moderate to high salinity (Marcar and Benyon, 2003). Similar to these results, Dunn *et al.* (1994) reported that *Eucalyptus* clones tested under five soil salinity classes ($EC_{1:2}$ ranged between 0.75 and >1.75 dS m^{-1}) revealed large (~15-88%) variation in tree survival and ~2-66% of the variation in plant height production. Gafni and Zohar (2007) reported large variation on impact of hydrological and salinity on 11 selected *Eucalyptus* species on bio-drainage potential and ability to withstand against waterlogging and salt accumulation in Israel.

After 3 months of plantation, there was a non-significant difference in collar diameter of *Eucalyptus* established under two contrasting moisture regimes (Table 1). However, at 5 and 10 months after planting, collar diameter was decreased by ~44.1 and 61.5%, respectively for clones planted at 120% WFPS than at 60% WFPS. With increase in salinity level collar diameter of clones was significantly decreased, regardless of the moisture regimes. The interaction effect of salinity x moisture regime on collar diameter at 5 and 10 months after planting was statistically non-significant. A similar growth pattern of plant height and collar diameter could be ascribed to tree response to soil salinity level and the moisture regimes.

Biomass yield of different components

These results revealed that *Eucalyptus'* stem biomass varied between 96.5 to 283.5 g $tree^{-1}$ at 60% WFPS and between 5.3 to 62.9 g $tree^{-1}$ at 120% WFPS (Table 3). Regardless of soil salinity level, stem biomass significantly decreased by ~5.4-times at 120% WFPS as compared to 60% WFPS moisture regime. Soil salinity of $EC_{1:2}$=4 dS m^{-1} significantly decreased the stem biomass by ~72.9 g $tree^{-1}$ (by ~42.1%) than the non-saline soil. These results revealed that with further increase in salinity level, the stem biomass decreased significantly. The decreased stem biomass with increased salinity could be ascribed to decreased plant height owing to reduced collar diameter, which resulted in decreased net primary production as above-ground biomass. The results of the present study corroborate earlier research findings of Madiwalar *et al.* (2023) who reported linear decrease in net primary production in

Table 3. Components of net primary production viz. stem biomass, leaves biomass, root biomass and total biomass of *Eucalyptus* at different levels of soil salinity (viz. electrical conductivity; $EC_{1:2}$) and moisture regimes (e.g. in aerobic; 60% water filled pore space; WFPS and submerged; 120% WFPS) at 10 months after planting in north-western Punjab, India

Soil salinity	Moisture regime		Mean	Moisture regime		Mean
($EC_{1:2}$; dS m^{-1})	60% WFPS	120%WFPS		60% WFPS	120%WFPS	
	Stem biomass (g $plant^{-1}$)			Leaves biomass (g $plant^{-1}$)		
0	283.5 (17.9)[†]	62.9 (7.0)	173.2	133.2 (14.1)	47.0 (4.5)	90.1
4	159.2 (14.9)	41.3 (5.5)	100.3	81.9 (6.0)	40.2 (5.0)	61.1
8	108.7 (10.8)	10.1 (2.0)	59.4	69.1 (5.2)	3.0 (1.7)	36.1
12	96.5 (10.8)	5.3 (1.6)	50.9	59.6 (5.1)	—	29.8
Mean	162.0	29.9		85.9	22.6	
LSD (p<0.05):	Salinity=14.7, Moisture regime= 10.4 Salinity × moisture regime=20.8			Salinity=11.4, Moisture regime=8.0, Salinity × moisture regime=16.1		
	Root biomass (g $plant^{-1}$)			Total biomass (g $plant^{-1}$)		
0	251.8 (15.1)	47.2 (4.9)	149.5	668.5 (21.0)	157.1 (10.7)	412.8
4	120.0 (13.0)	29.0 (6.1)	74.5	361.1 (34.3)	110.6 (8.1)	235.8
8	85.6 (14.8)	4.3 (0.7)	44.9	263.4 (14.0)	17.4 (5.0)	140.4
12	66.0 (10.8)	2.3 (0.6)	34.2	222.1 (16.6)	7.6 (2.4)	114.8
Mean	130.8	20.7		378.8	73.2	
LSD (p<0.05):	Salinity=11.1, Moisture regime= 7.8, Salinity × moisture regime=15.7			Salinity=16.4, Moisture regime=11.6, Salinity × moisture regime=23.1		

[†]Values in the parenthesis indicate standard error from mean ($S.E._M$)

Eucalyptus trees' above-and below-ground biomass due to decreased growth attributes. Our results revealed that leaves biomass significantly decreased by ~63.3 g $tree^{-1}$ at 120% WFPS as compared to 60% WFPS. The reduced leaves biomass under increased moisture availability could be ascribed to the development of saturated moisture regimes, which causes decreased O_2 concentration known as a state of hypoxia in soils (Ahmed *et al.*, 2013). The growth and development of plants under waterlogged environments is significantly influenced by the decreased O_2 levels in soil rhizosphere (Christianson *et al.*, 2010). The tree species stereotypically experience a wide range of resource limitations which eventually impacts its productivity, through their interactive influence on rate of photosynthesis and growth (Vellini *et al.,* 2008).

Soil salinity significantly decreased the leaves biomass by ~32.2, 59.9 and 66.9%, respectively at $EC_{1:2}$ of 4, 8 and 12 dS m^{-1} over non-saline soil. Similar to the stem and leaves biomass, soil salinity and water logging significantly influence the root biomass of *Eucalyptus*. Averaged across the soil salinity levels, root biomass was significantly higher by ~6.3-times at 60% WFPS than the 120% WFPS. Root biomass was significantly higher for non-saline soil by ~4.4-times than at high salinity ($EC_{1:2}$=12 dS m^{-1}). The total dry wood biomass showed large variation between 222.1 and 668.5 g $tree^{-1}$ at 60% WFPS and between 7.6 and 157.1 g $tree^{-1}$ at 120% WFPS. These results showed that water logging (120% WFPS) significantly decreased the total dry wood biomass by ~4.6-times than at 60% WFPS moisture regime. The decreased growth of *Eucalyptus* species has been reported due to high concentration of soluble salts which increase the osmotic pressure and decrease the osmotic potential of soil solution which means that the soil water is held with extra energy produced by the presence of salts (Ali *et al.,* 1987; Singh *et al.,* 1991). It is obvious that the plants with lesser number of branches, girth and height may have the less dry wood weight, which is very clear from the results of present studies and has been reported earlier as well (Ibrahim *et al.*, 1991; Ashraf *et al.,* 1998). *Eucalyptus* plant grown under high salinity may have less dry weight because there was stunted growth, reduction in cell division, ion toxicity and reduction in plant turgor

(Ashraf *et al.,* 1998; Ashraf and Khan, 1993). These results corroborate earlier research findings of Avtar-Singh *et al.* (2022) who reported differential response of five different *Eucalyptus* clones under increased salinity level. The relationship developed for 12 species within the genera *Eucalyptus*, *Casuarina, Melaleuca* and *Tipuana* tested under five soil salinity classes viz. EC= 0.75-1.0, 1.0-1.25, 1.25-1.5, 1.5-1.75 and >1.75 dS m^{-1} revealed ~15-88% of the variation in tree survival and ~2-66% of the variation in plant height production (Dunn *et al.,* 1994).

Soil salinity effect on relative proportion of different NPP components

Figure 3 illustrates the effect of soil salinity (regardless of moisture regimes) on proportion of different components of *Eucalyptus's* plant. As a proportion of total dry wood biomass, stem biomass comprised ~42.0-44.3%; and was significantly higher at $EC_{1:2}$=12 dS m^{-1}, while the lowest for non-saline soil. It was significantly highest at higher soil salinity ($EC_{1:2}$=12 dS m^{-1}), while the other salinity levels did not differ significantly. The leaves biomass comprised between 21.8 and 26.0% of total dry wood biomass of *Eucalyptus*. The proportion of leaves biomass as a proportion of total biomass was

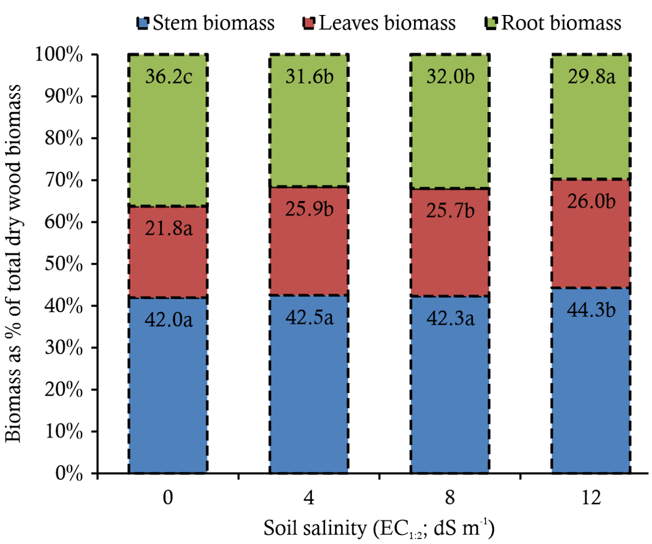

Fig. 3 Relative proportion of different components of net primary production of *Eucalyptus* at different soil salinity levels in north-western Punjab, India. Data pooled for plant growth stages and moisture regimes, excluding data for treatments where plants were died. Mean values followed by different letters ate significantly different at p<0.05 by Least Significant Difference (LSD) test

significantly lower for non-saline soil, while the other soil salinity levels were at par. It was important to observe that root biomass was the second major components of *Eucalyptus* dry wood biomass production in soils having variable soluble salt concentration and moisture regime. As a proportion of total dry wood biomass, the root biomass (29.8-36.2%); was significantly higher for non-saline soil, the lowest for highest at higher salinity ($EC_{1:2}$=12 dS m^{-1}), while the other salinity levels in-between. These results corroborate earlier research that growth of *Eucalyptus* trees was accompanied by a reduction in soil salinity; relationship between tree DBH and salinity was significant, however, correlation with salinity was more pronounced for diameter than for height (Barton and Montagu, 2006). A significant difference in plant growth traits could be explained by the differences in adaptation of plants to varying salinity levels within the sites (Olukoye *et al.,* 2003).

Conclusions

These results showed a significant decrease in *Eucalyptus* growth characteristics viz. plant height and collar diameter with increase in soil salinity level. The effect of increased salinity was more pronounced at higher moisture regime (120% WFPS). Soil salinity and water logging significantly decreased the net primary production in different tree components viz. stem, leaves and root biomass of *Eucalyptus*. These results revealed that the total dry wood biomass showed large variation between 222.1 and 668.5 g $tree^{-1}$ at 60% WFPS and between 7.6 and 157.1 g $tree^{-1}$ at 120% WFPS, and was decreased by ~4.6-times under 120% WFPS moisture regime. These results highlight decreased potential of carbon sequestration in trees' above-and below-ground biomass of PE-11 planted under nearly-saturated (120% WFPS) environments having salinity hazards. Therefore, the cultivation of PE-11 clones should be encouraged in areas of low soil salinity having no problem of waterlogging.

References

Ahmed FM, Rafii MY, Ismail MR, Juraimi AS, Rahim HA, Asfaliza R and Latif MA (2013) Waterlogging tolerance of crops: breeding, mechanism of tolerance, molecular approaches, and future prospects. *Bio Med Res Intl*, 1-10.

Ali S, Chaudary MA and Aslam F (1987) Growth of L*eucaena* at different salinity levels. *Leucaena Res. Rep*. 8: 53. Barani Agri. College, Rawalpindi, Pakistan.

Ashraf MY and Khan AH (1993) Effect of NaCl on growth and nitrogen status of sorghum *In:* Naqvi SSM, Ansari RU, Flower JJ and AzmiAR (eds.),*Proc. of International Symp.on Current Developments in Salinity and Drought Tolerance of Plants.* Plant Physiology Division AEARC Tandojam 70060, Pakistan, pp: 84–88.

Ashraf MY, Ali Y and Qureshi TM (1998) Effect of salinity on photosynthetic efficiency and yield of rice genotype. *Pakistan Journal of Biological Sciences* **1**: 72-75.

Avtar-Singh, Singh P, Dhillon GPS, Sharma S, Singh B and Gill RIS (2022) Differential impact 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* https://doi.org/10.1007/s11104-022-05700-1

Barton CVM and Montagu KD (2006) Effect of spacing and water availability on root: shoot ratio in *Eucalyptus camaldulensis. Forest Ecology and Management* **221**: 52–62.

Blake GR and Hartge KH (1986) Bulk density. In: Klute, A. (Eds.), Methods of Soil Analysis (Part-I). Agron No. 9. Am Soc Agron, Madison, USA.

Chaturvedi AN, Sharma SC and Srivastava R (1988) Water consumption and biomass production of some forest tree species. *The International Tree Crops Journal* **5**: 71–76.

Christianson JA, Llewellyn DJ, Dennis ES and Wilson IW (2010) Comparisons of early transcriptome responses to low-oxygen environments in three dicotyledonous plant species. *Plant Signal Behaviour* **5**: 1006–1009.

Cochran WG and Cox GM (1966) *Experiment Designs*. New York: Wiley.

Crawford RMM (1982) Physiological responses to flooding. *In:* Ziegler H (ed*) Water Relations and Carbon Assimilation.* Springer-Verlag, Berlin, pp: 453–478.

Dagar JC, Lal K, Mukesh-Kumar, Jeet-Ram, Chaudhari SK, Yadav RK, Singh G, Sharif Ahamad and Kaur Amarinder (2016). Impact of eucalyptus geometry on biomass production, water table drawdown, carbon sequestration and inter-crop yield on waterlogged saline soils of North-West India. *Agriculture, Ecosystem & Environment* 233: 33-42.

Dagar JC and Minhas PS (2016) Agroforestry to rehabilitate the indian coastal saline areas. In: Dagar JC and Minhas PS (eds.), *Agroforestry for the Management of Waterlogged Saline Soils and Poor-quality Waters*. Advances in Agroforestry 13, DOI 10.1007/978-81-322-2659-8_8

Dunn GM, Tayloff DW, Nesteff MR and Beetson B (1994) Performance of twelve selected Australian tree species on a saline site in southeast Queensland. *Forest Ecology and Management* **70**: 255-264.

Fagodiya RK, Malyan SK, Singh D, Kumar A, Yadav RK, Sharma PC and Pathak H (2022) Greenhouse gas emissions from salt-affected soils: mechanistic understanding of interplay factors and reclamation approaches. *Sustainability* **14**(19):11876. https://doi.org/10.3390/su141911876

Gafni A and Zohar Y (2007) Hydrological and salinity impacts of a bio-drainage strategy application in the Yizreel Valley, Israel. *Hydrological Processes* **21**: 2164–2173.

Hossain MA (2010) Global warming induced sea level rise on soil, land and crop production loss in Bangladesh. In: 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, pp: 77-80, 1-6 August, 2010, Published on DVD, https://www.iuss.org/19th%20WCSS/Symposium/pdf/0419.pdf

Ibrahim KM, Collins JC and Collin HA (1991) Effect of salinity on growth and ionic composition of *Coleus blumet* and *Salvia splendens. Journal of Horticultural Science* **66**: 215–222.

Jackson ML (1973) *Soil Chemical Analysis – Advanced Course*. A manual of methods useful for instruction and research in soil chemistry, physical chemistry, soil fertility and soil genesis. 2nd edition Madison U.S.

Jeet-Ram, Garg VK, Toky OP, Minhas PS, Tomar OS, Dagar JC and Kamra SK (2007) Biodrainage potential of *Eucalyptus tereticornis* for reclamation of shallow water table areas in north-west India. *Agrofor Syst* **69**: 147–165.

Kaur M and Monga G (2021) Eucalyptus trees plantation: A review on suitability and their beneficial role. *International Journal of Bio-resource and Stress Management* **12**(1): 016-025. HTTPS://DOI. ORG/10.23910/1.2020.2174.

Kidanu S, Mamo T and Stroosnijder L (2005) Biomass production of Eucalyptus boundary plantations and their effect on crop productivity on Ethiopian highland Vertisols. *Agroforestry Systems* **63**: 281–290. https://doi.org/10.1007/s10457-005-5169-z

Kumar P and Sharma PK (2020) Soil salinity and food security in India. *Front Sustain Food Syst* **4**:533781. doi: 10.3389/fsufs.2020.533781

Kumar S, Kumar D, Sekhon KS, Singh P, Phogat M and Choudhary OP (2021a) Soil application of boron impacts its solubility, yield and fibre quality of cotton in calcareous soil of north-western India. *Journal of Environmental Biology* **42**: 1534-1543.

Kumar S, Kumar D, Sekhon KS, Singh P, Phogat M, Kakralia S and Choudhary OP (2021b) Effect of soil applied boron on depth-wise distribution of root biomass of cotton grown in a calcareous soil of north-western India. *Journal of Soil Salinity and Water Quality* **13**(1):79-85.

Larchar W (1995) *Physiological Plant Ecology*. Springer-Verlag, Berlin. pp. 396–409.

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 the Indian National Science Academy*. https://doi.org/10.1007/s43538-022-00141-x

Marcar NE and Benyon R (2003) Careful tree selection limits salinity spread. *Farming Ahead* **109**: 53–55.

Olukoye GA, Wamicha WN and Kinyamario JI (2003) Assessment of the performance of exotic and indigenous tree and shrub species for rehabilitating saline soils of Northern Kenya. *African Journal of Ecology* **41**: 164–170. doi:10.1046/j.1365-2028.2003.00430.x.

Qadir M and Oster JDV (2004) Crop and irrigation management strategies for saline sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment* **323**(1–3): 1–19.

Rassaeifar M, Hosseini N, Haji HA, Zandi P, Moradi AA, Rassaeifar M, Hosseini N, Hasani N, Zandi P and Aghdam A (2013) Allelopathic effect of *Eucalyptus globulus*' essential oil on seed germination and seedling establishment of *Amaranthus blitoides* and *Cyndon dactylon*. *Trakia Journal of Sciences* **1**: 73–81.

Sharma S, Singh P and Sodhi GPS (2020) Soil organic carbon and biological indicators of uncultivated vis-à-vis intensively cultivated soils under rice–wheat and cotton–wheat cropping systems in South-western Punjab. *Carbon Management* **11**(6):681-695. https://doi.org/10.1080/17583004.2020.1840891

Singh A (2013) Groundwater modelling for the assessment of water management alternatives. *Journal of Hydrology* **481**: 220–229.

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 K, Yadav JSP and Singh V (1991) Tolerance of trees to soil salinity. *Journal of the Indian Society Soil Science* **39**: 549–556.

Singh P and Singh H (2007) Release pattern of sulphur from sulphitation pressmud amended sub-tropical recent floodplain soils. *Journal of Research (Punjab Agricultural University)* **44**(1): 28-34.

Singh P, Sharma S, Nisar S and Choudhary OP (2023) Structural stability and organic matter stabilization in soils: Differential impacts of soil salinity and sodicity. *Journal of Soil Science and Plant Nutrition*. https://doi.org/10.1007/s42729-023-01136-3

Singh P, Singh H and Bahl GS (2010) Phosphorus supplying capacity of pressmud-amended recent floodplain soils under different moisture regimes. *Journal of the Indian Society of Soil Science* **58**: 168-181.

Stirzaker R, Vertessy R and Sarre A (2002) Trees, water and salt–an Australian guide to using trees for healthy catchments and productive farms. Joint Venture Agroforestry Program; Rural Industries Research and Development Corporation, pp: 144.

Szabolcs I (1994) Soils and salinization. *In* Handbook of plant and crop stresses. *Edited by* M. Pessarakli. Marcel Dekker, New York.

Tomar MD, James DE, Isenhart TM (2003) Optimizing the placement of Riparian practices in a watershed using the terrain analysis. *J Soil Water Conserv* **58**: 198–206.

USDA (1930) A pipette method of mechanical analysis of soils based on improved dispersion procedure. Technical Bulletin No. 170, United States Department of Agriculture, Washington, DC. pp:1-23.

Vellini ALTT, Paula NF, Alves PLCA, Pavani LC, Bonine CAV, Scarpinati EA and Paula RC (2008) Growth and physiological traits of eucalypt clones under different water regimes. *Revista Árvore* **32**: 651-663.

Walkley A. and Black CA: An examination of the Digtjareff method for determination of soil organic matter and a proposed modification of chromic acid titration method. *Soil Science* **37**: 29-38.

Wicke B, Smeets E, Domburg V, Vashev B, Gaiser T and Turkenburg W (2011) The global technical and economic potential of bioenergy from salt-affected soils. *Energy Environ Science* **4**: 2669–2681. doi: 10.1039/C1EE0 1029H

Zahid DM, Shah FR and Majeed A (2010) Planting *Eucalyptus camaldulensis* in arid environment-is it useful species under water deficit system? *Pakistan Journal of Botany* **42**: 1733–1744.

Received: December 31, 2022: Accepted: February 14, 2023

Journal of Soil Salinity and Water Quality 15(1), 25-37, 2023

Optimization of Subsurface Drain Spacing and Depth for Sugarcane under Waterlogged Vertisols of Canal/Lift Irrigated Areas of Maharashtra, India

SD Rathod

Agricultural Research Station, Kasbe Digraj, Sangli-416 305, Maharashtra, India
**E-mail: sdrathod2004@gmail.com*

Abstract

The problems of waterlogging, salinity and sodicity of Vertisols declined the productivity of different crops especially sugarcane in recent decades of Maharashtra. Subsurface drainage is required to combat the twin problems of irrigation induced soil salinity and waterlogging. The field experiments for increasing sugarcane productivity in waterlogged Vertisols through subsurface drainage system were conducted at Agricultural Research Station, Kasbe Digraj, Sangli, Maharashtra (India) during 2012-13 to 2017-18. Four drain spacings (10, 20, 30 and 40 m) as main factor and three drain depths (0.75, 1.0 and 1.25 m) as sub-factor in split plot design were included for achieving objectives. The results revealed that 40 m drain spacing recorded significantly highest pooled mean height of sugarcane, milleable cane height, No. of internodes, No. of milleable canes per clump, cane yield followed by 30, 20 and 10 m. Whereas, the significantly highest pooled mean height of milleable cane, weight of single milleable cane, cane yield, CCS (%) and sugar yield were observed under 1.25 m drain depth followed by 1.0 and 0.75 m. The economic analysis revealed that 40 m drain spacing and 1.25 m depth recorded significantly highest pooled mean of B:C ratio, gross and net monetary returns. The interaction effect was non-significant. Thus, the drain spacing of 40 m and 1.25 m depth are recommended for optimum drainage, less NO_3-N losses, economically optimal growth, yield and quality dynamics of sugarcane under waterlogged Vertisols of canal/lift irrigated areas of Maharashtra, India.

Key words: Drain depth, Drain spacing, Subsurface drainage system, Sugarcane, Waterlogged Vertisols

Introduction

Irrigated agriculture in India as well as in the world is under stress due to twin problems of waterlogging and soil salinity (Valipour, 2014; Ambast *et al.,* 2007). In India, out of 6.74 Mha salt affected soils, almost half of the area (3.1 Mha) is suffering from irrigation induced salinity in different canal commands (Kamra and Sharma, 2016: Fagodiya *et al.,* 2022). More than 1.1 Mha areas under black cotton soils (Vertisols and associated soils) in different states of India are facing waterlogging and salinity problems. Vertisols cover an area of 26 Mha in India, and are predominant in the states of Madhya Pradesh (10.7 Mha), Maharashtra (5.6 Mha), Karnataka (2.8 Mha), Andhra Pradesh (2.2 Mha), and Gujarat (1.8 Mha) (Bhattacharyya *et al.,* 2013). These soils are generally deep to very deep and heavy texture with clay content varying from 40-70%. Because of their inherent physio-chemical and hydrological characteristics such as narrow workable moisture range, deep and wide cracks; poor internal drainage, low hydraulic conductivity, less infiltration rates and drainable porosity poses serious problems even at low salinity level. In black cotton soils (Vertisols and associated soils), Sugarcane is a major cash crop cultivated in Maharashtra. Further, around 70% of the total water available through irrigation system for farming in Maharashtra state is used for only sugarcane crop having around only 5 to 6% of the total cultivable land of the state and creating waterlogging, salinity and sodicity problems (CACP, 2012). The problems of waterlogging, salinity and sodicity declined the productivity of different crops and fertility of Vertisols in recent decades of Maharashtra. The best example is that of sugarcane as the productivity of sugarcane reduced from 150 Mg ha^{-1} in 1970's during the initial stages of introduction of irrigation to 50-

60 Mg ha^{-1} in 2000's after waterlogging and salinity of soil (Rathod *et al.*, 2011). In all such cases, Vertisols, where productivity is either low or the lands have become unproductive; drainage improvement through subsurface drainage system (SSDS) along with application of suitable amendments is required (Mukhopadhyay *et al.*, 2023). The need of drainage provisions in irrigation projects has been well acknowledged by the researchers worldwide and now a days it is considered as an integral part of large irrigation schemes. However, the effectiveness of SSDS depends upon the optimal combination of drain spacing (DS) and drain depths (DD).

Farmers of Sangli and Kolhapur districts in Maharashtra are using SSDS with drain spacing of 10-20 m for saline, saline-sodic, sodic and waterlogged soils. But this increased the initial adoption cost of SSDS, drained excess water and created moisture deficit conditions during summer season under the canal/lift irrigation systems with high irrigation interval of 25-30 days due to rotational supply of water. Sometimes, farmers are using ball valves at the outlet of SSDS for control of excess drainage of water as well as nutrients. Karegoudar *et al*. (2019), Nash *et al.* (2014) and Singh *et al.* (2000) reported NO_3-N losses under closely spaced drains. Randall (2004) studied the SSDS characteristics during 15-year period on a Webster clay loam soil in Minnesota and reported that the DS less than 27.4 m had observed more than 50% nitrate losses. Carter and Camp (1994) reported that there was no statistically significant cane sugar yield advantage to subsurface drains spaced closer than 42 m in clay loam soil of Louisiana. Boonstra *et al*. (2002) also reported that the sugarcane yield recorded in control, 30, 45 and 60 m drain spaced treatments with 0.9 m drain depth were 80, 115, 105 and 84 Mg ha^{-1}, respectively at Ukai-Kakrapar Command (Gujarat), India. It is found from above reviews that SSDS increased the productivity of sugarcane under waterlogged and saline soils. However, the results reported by Karegoudar *et al*. (2019), Singh *et al.* (2000), Nash *et al.* (2014) and Randall (2004) about nutrient losses through closely spaced drains; and drain spacings suggested by Camp and Carter (1994), Boonstra *et al*. (2002) and Raju *et al.* (2016) are in contraction whether to choose closely spaced or widely spaced drains for better sugarcane productivity under waterlogged-saline soils. Further, these results are creating misunderstanding among farmers as well as scientists regarding drain spacing. This emphasized the need for further verification of these results for the benefit of the farming community of Maharashtra, India.

Materials and Methods

Experimental details

The experimental soil was clayey in texture with average clay content of 59.73%. The field capacity, permanent wilting point and bulk density of soil were 39.24%, 18.90% and 1.30 gm cc^{-1}, respectively. The pHs and electrical conductivity of soil (ECe) were 7.65 to 7.93 and 0.49 to 1.15 d*S* m^{-1} respectively. The water table depth was within 0.30 m in rainy season and 0.6 to 1.54 m in winter and summer season. The average saturated hydraulic conductivity of soil was 0.096 m/day. The quality of irrigation was C_1S_1 (low salinity and sodium hazards) in *Kharif* and C_2S_1 (medium salinity and low sodicity hazards) in both *rabi* and summer season.

The field experiment for evaluating the effect of subsurface drain spacing and depth of drain for sugarcane under waterlogged Vertisols of Maharashtra was carried out during 2012-13 to 2017-18 with two Adsali plant canes (16-18 months crop duration) and one ratoon (12 months crop duration) at Agricultural Research Station, Kasbe Digraj, Sangli district (M.S.), India. Experiment was carried out in split plot design with four DSs as a main factor and three DDs as sub-factor. The four DSs of 10, 20, 30 and 40 m and three DDs of 0.75, 1.00 and 1.25 m were taken under split plot design and replicated three times. This formed the twelve combinations of DS and DD.

SSDS with different combinations of DS and DD

Treatments		Description
$L_{10}D_{1.25}$	:	DS 10 m and DD 1.25 m
$L_{10}D_{1.0}$	:	DS 10 m and DD 1.0 m
$L_{10}D_{0.75}$	:	DS 10 m and DD 0.75 m
$L_{20}D_{1.25}$	:	DS 20 m and DD 1.25 m

$L_{20}D_{1.0}$	:	DS 20 m and DD 1.0 m
$L_{20}D_{0.75}$	:	DS 20 m and DD 0.75 m
$L_{30}D_{1.25}$	:	DS 30 m and DD 1.25 m
$L_{30}D_{1.0}$	:	DS 30 m and DD 1.0 m
$L_{30}D_{0.75}$	:	DS 30 m and DD 0.75 m
$L_{40}D_{1.25}$	:	DS 40 m and DD 1.25 m
$L_{40}D_{1.0}$	:	DS 40 m and DD 1.0 m
$L_{40}D_{0.75}$	:	DS 40 m and DD 0.75 m

The experimental size of 216 m × 54 m was surveyed with Dumpy level at 18 m × 18 m grid for preparation of the contour map and layout of SSDS. The parallel SSDS (gridiron) was installed as per layout of 12 treatment combinations of DSs and DDs by using 80 mm diameter perforated corrugated Poly Vinyl Chloride (PVC) drainage pipes with geo-textile synthetic filter as lateral drains and non-perforated corrugated PVC pipe of 80 mm diameter as a collector drain. These lateral drains were connected to the collector drain at a slope of 0.2%. The collector drain was laid on a uniform grade of 0.2%. The concrete inspection chambers having 0.9 m diameter and 2.5 m height with ladder and top cover were installed for collection of drain discharge periodically from each treatment combination. The two *Adsali* canes (Variety: CoM-86032) planted at a spacing of 1.37 m × 0.3 m spacing during August, 2012 to December, 2013 and August, 2016 to December, 2017 and one ratoon were taken during January, 2014 to February, 2015. The agronomic practices, irrigation applications, fertilizer applications and plant protection practices were common to all treatments. The following physical, chemical and hydrological properties of soil; growth, yield, quality and economic parameters of sugarcane under different combinations of DS and DD were recorded during the investigation.

Determination of physical properties of waterlogged vertisols

The bulk density with core sampler method (Dastane, 1967), particle density of soil by Pycnometer method (Blake, 1965) and total porosity of soil calculated by using particle density and bulk density of soil (Brady and Weil, 1996) at initial and after harvest of sugarcane i.e., 18 months after drainage at 0-30, 30-60, 60-90 and 90-120 cm soil depth. Further, bulk density, particle density and total porosity of soil were averaged for 0-120 cm soil profile and used for studying the percent improvements observed due to SSDS with 12 different combinations of DSs and DDs.

Determination of chemical properties of waterlogged vertisols

The chemical properties of soil *viz.*, pHs by Potentiometric (Jackson, 1973) and electrical

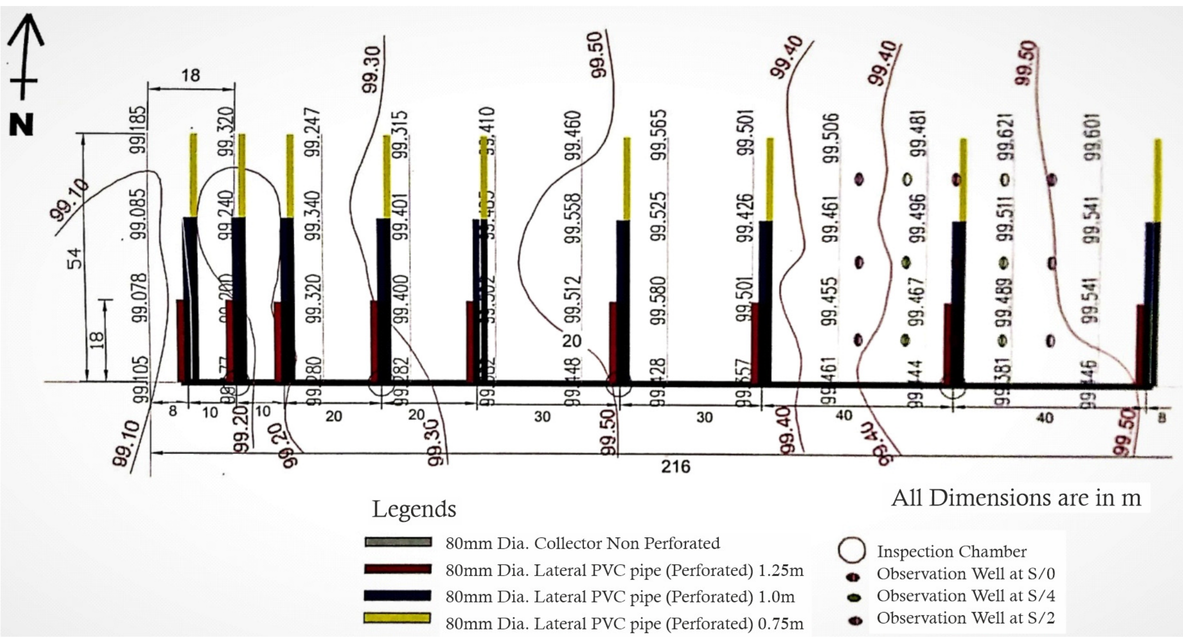

Fig. 1 Contour plan and layout of SSDS with different combinations of DS and DD

conductivity (ECe) of soil with Conductometric (Jackson, 1973) at different soil depths (0-30 cm, 30-60 cm 60-90 cm and 90-120 cm) were determined at initial and after harvest of sugarcane (18 months after drainage). The pHs and ECe of soil were averaged for 0-120 cm soil profile and used for calculating the percent improvements under SSDS with 12 different combinations of DSs and DDs.

Determination of hydrological properties of waterlogged vertisols

The methods used to determine the hydrological properties of soil such as drainage coefficient, mid-span water table (MWT) height, the saturated hydraulic conductivity and drainable porosity of soil are given below,

Drainage coefficient

The drainage coefficient, q (mm day^{-1}) was computed by using equation 1.

$$q = \frac{Q}{A} \times 1000 \qquad \ldots(1)$$

Where,

Q = average drain outflow for the certain drain out period, m^3 day^{-1}

A = area drained, m^2

Field measurement of water table depths and drain discharges

Five piezometers were installed to record the water table depth across the subsurface drain for each combination of depth and spacing. One piezometer was installed on lateral drain and remaining at a distance of half and quarter of drain spacing at both sides of lateral drain by using a 120 mm outside diameter auger to a depth of 1.7 m from the soil surface for periodically measurement of WTDs after rainfall or irrigation. An 80 mm internal diameter PVC pipe with perforations was then lowered in each piezometer to a depth of 1.7 m, while ensuring that a 30 cm length was above the ground level to prevent runoff water from flowing in. End caps were fitted to both ends of the pipe to prevent the intrusion of materials into the piezometers. Coarse sand was backfilled throughout the whole perforated section of pipe. This was to prevent clogging of the perforations by clay and silt particles. WTDs at each piezometer were measured by gradually lowering the locally made measuring meter with float in the piezometers until metered hollow pipe floats on water. On the other hand, drainage outflows (Q) in m^3 day^{-1} were manually measured at drainage outlet points, using a bucket and a stop watch.

Saturated hydraulic conductivity of soil

It was necessary to the study the heterogeneity of soil for determination of saturated hydraulic conductivity of soil (K_{sat}) in m day^{-1}. Accordingly, layer wise soil heterogeneity were studied by digging hole with 24 cm outer diameter post hole auger up to 370 cm depth and found heterogeneity at 0-30 cm, 30-130 cm, 130-250 cm, 250-300 cm and 300-370 cm. It was, therefore, in-situ K_{sat} values at four various places in the field at 0-130 cm, 130-250 cm, 250-300 cm and 300-370 cm soil depth were determined by Hooghoudt's single auger hole method. The K_{sat} values of particular water transmitting layer (depth of drains + Hooghoudt's equivalent depth, de) contributed flow to drains for particular DS and DD combinations were calculated before and after harvest of sugarcane as a weighted K_{sat} of different soil layers. The 'de' was calculated by Moody's empirical equation for each DS and DD combination as d/L > 0.3.

$$\frac{L}{de} = 8\{\ln(L/R) - 1.15\}/\pi \qquad \ldots(2)$$

Where,

L= drain spacing, m

r = radius of drain pipe, m

Drainable porosity of soil

The drainable porosity of soil (f) is not usually a constant, but besides other things, it is a function of water table depth (WTD) or in other words soil depth (Taylor, 1960). The time of drawdown and shape of the WT depends on the particular way in which f is related to WTD. Thus, it is convenient and often necessary in drawdown studies to express f as a function of WTD. In this study, f corresponding to different WTDs was determined from WT drawdown and drain discharge measurements at the experimental site. It was calculated from the drain outflow measurements and its corresponding MWT heights above drain level by using equation 3.

$$f = \frac{Q \times T}{A\,(ho - ht)} \qquad \ldots(3)$$

Where,

Q = average drain outflow for the drainage period during which the WT dropped from ho to ht, m^3 hr^{-1}

t = total drain out time, hr

A = area drained, m^2

ho = MWT height above the drain level at t = 0, m

ht = MWT height above the drain level at t= t, m

Growth parameters of sugarcane

Height of sugarcane: The height of sugarcane was recorded from ground level to the end of the last fully opened leaf from randomly selected nine sugarcanes (3 sugarcanes on above lateral area, 3 on the L/2 area i.e., DS/2 and 3 on L/4 area *i.e.*, DS/4 at harvest {510 days after planting (DAP)}. The average height of these nine sugarcanes was recorded as height of sugarcane in cm.

Milleable cane height: The milleable cane height was recorded from ground level to the base of the last fully opened leaf (last node) from randomly selected nine milleable canes (3 milleable canes on lateral area, 3 on L/2 area and 3 on L/4 area at harvest (510 DAP). The average height of these nine milleable canes was recorded as milleable cane height in cm.

***Number of internodes per milleable cane*:** Number of internodes present on milleable cane was recorded from base of cane stalk to fully opened leaf base. The average number of internodes of nine randomly selected milleable canes was recorded at harvest of sugarcane.

***Average intermodal length*:** The milleable cane height measured at harvest was divided by the number of internodes of each cane and recorded as average intermodal length, expressed in cm.

Yield and quality dynamics of sugarcane

***Number of milleable canes per clump*:** The number of milleable canes per clump was recorded at harvest. The number of milleable canes was counted randomly of nine eye buds (3 clumps on lateral area, 3 clumps on L/2 and 3 clumps on L/4 area. The average number of milleable canes from nine clumps was recorded as number of milleable canes per clump.

***Cane diameter/ girth of milleable cane*:** The diameter of cane (cm) was recorded at harvest. This was recorded from exactly central internodal portion of top, middle and bottom internodes using Vernier Caliper and expressed in centimeter. The values of top, middle and bottom portion of nine canes were selected and averaged.

Milleable cane weight: The weights of nine randomly selected milleable canes were recorded at harvest and the average of those was worked out and expressed as single cane weight in Kg.

***Cane yield*:** All milleable canes in the net plot were cut close to the ground level. The green tops and trash were removed and cane yield per net plot was recorded. The net plot for different treatment was different because of the drainage effect of different combinations of subsurface DS and DD on sugarcane growth. The sugarcane yield was calculated by converting the yield of net areas to one hectare and expressed in Mg ha^{-1}.

***Commercial cane sugar percentage* (CCS %):** It is the amount of white commercial sugar obtained from cane juice after removing total soluble solids. It was calculated by using the following formula.

$$\text{CCS (\%)} = [\text{Sucrose (\%)} - \text{Brix (\%)} - \text{Sucrose (\%)} \times 0.40] \times 0.73 \qquad \ldots(4)$$

Sugar yield or commercial cane sugar (CCS)

Sugar yield (Mg ha^{-1}) was calculated by using the following formula as suggested by Sastry and Venkatachari (1960),

$$\text{Sugar yield (Mg ha}^{-1}) = \frac{\text{CCS (\%)} \times \text{Sugarcane yield (Mg ha}^{-1})}{100}$$

Where, CCS = Commercial cane sugar (%)

Economic feasibility of SSDS with different DS and DD

Following economic parameters were worked out to find the suitable combination of DS and DD.

Initial adoption cost of SSDS with different combinations of DS and DD: The initial costs on adoption of SSDS were worked out for each treatment and their replications. The initial cost of SSDS includes purchase cost of different materials, labour and consultancy charges required for preparation of contour and layout of SSDS; excavation and installation of SSDS. The maintenance of SSDS was required from one year after installation of SSDS.

Cost of sugarcane production: The total cost of sugarcane production was calculated by adding the yearly cost of SSDS in cost of cultivation of sugarcane. Maintenance cost on SSDS was also added from second year after installation of SSDS while calculating the cost of sugarcane production.

Gross monetary returns: The gross monetary returns per hectare were worked out by considering the yield of main produce and by produce from different treatments with prevailing market price of sugarcane and by produce.

N*et monetary returns:* The net monetary returns per hectare were calculated by deducting the cost of sugarcane production per ha from gross monetary returns per hectare.

Benefit: Cost ratio: The benefit: cost ratio (B:C ratio) was worked out by dividing the cost of sugarcane production to the gross monetary returns in each treatment under study.

Statistical analysis

The split plot design with four main factors and three sub-factors with three replications were used for statistical analysis of growth, yield and quality dynamics of sugarcane (Panse and Sukhatme, 1967).

Results and Discussion

Growth, yield and quality dynamics of sugarcane under SSDS with different combinations of DS and DD

It is observed from Table 1 to 3 that the significant differences in pooled mean of height of sugarcane, milleable cane height, No. of internodes, weight of single milleable cane, No. of milleable canes

Table 1. Effect of SSDS with different DSs and DDs on growth dynamics of sugarcane under waterlogged Vertisols

Treatments	Height of sugarcane (cm)				Height milleable cane (cm)				No. of internodes				Length of internodes (cm)			
	2013-14	2014-15	2017-18	Pooled Mean	2013-14	2014-15	2017-18	Pooled Mean	2013-14	2014-15	2017-18	Pooled Mean	2013-14	2014-15	2017-18	Pooled Mean
DS																
L_1 (10 m)	423.81	337.12	446.17	402.37	243.39	155.60	256.50	218.50	25.61	17.08	22.22	21.64	9.63	9.15	11.60	10.13
L_2 (20 m)	443.36	349.07	468.00	420.14	273.92	175.18	280.56	243.22	27.17	18.18	23.33	22.89	10.19	9.63	12.11	10.64
L_3 (30 m)	461.44	357.45	479.72	432.87	295.44	188.78	306.44	263.56	28.50	19.12	25.06	24.22	10.43	9.88	12.30	10.87a
L_4 (40 m)	480.39	368.16	491.33	446.63	313.11	200.88	339.11	284.37	29.19	19.61	27.39	25.40	10.75	10.25	12.46	11.15a
SE±	2.74	3.11	4.54	3.50	4.17	2.01	4.20	4.03	0.31	0.22	0.46	0.35	0.13	0.13	0.24	0.15
CD at 5%	9.48	10.74	15.70	10.21	14.42	7.10	14.54	11.75	1.08	0.76	1.59	1.03	0.45	0.45	NS	0.45
DD																
D_1 (0.75 m)	442.00	346.64	465.17	417.94	266.08	170.73	281.21	186.24	26.65	17.81	23.50	22.65	10.11	9.57	12.02	10.99
D_2 (1.0 m)	452.13	352.43	470.04	424.87a	280.48	179.20	295.25	195.58	27.56	18.46	24.50	23.51a	10.20	9.69	12.12	11.09
D_3 (1.25 m)	462.63	359.78	478.71	433.71a	297.83	190.40	310.50	207.55	28.65	19.22	25.50	24.46a	10.44	9.92	12.20	11.25
SE±	2.77	2.83	3.42	3.37	4.77	1.42	4.76	2.62	0.38	0.27	0.48	0.42	0.17	0.17	0.19	0.25
CD at 5%	8.29	8.48	10.26	9.56	14.31	4.26	14.27	5.28	1.13	0.80	1.43	1.21	NS	NS	NS	NS
Interaction																
DS × DD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 2. Effect of SSDS with different DSs and DDs on yield dynamics of sugarcane under waterlogged Vertisols

Treatments	Weight of single milleable cane (kg cane^{-1})				No. of milleable canes /clump				Girth of cane (cm)			
	2013-14	2014-15	2017-18	Pooled mean	2013-14	2014-15	2017-18	Weighted mean	2013-14	2014-15	2017-18	Pooled mean
DS												
L_1 (10 m)	1.68	1.12	1.99	1.60	11.28	8.31	12.67	10.86	9.64	9.28	9.12	9.35
L_2 (20 m)	1.83	1.22	2.07	1.71	11.78	8.86	13.00	11.36	9.62	9.27	9.48	9.46
L_3 (30 m)	1.98 a	1.32 a	2.24 a	1.85 a	12.03	9.50	13.06	11.66	9.50	9.17	9.45	9.37
L_4 (40 m)	2.13 a	1.42 a	2.31 a	1.95 a	13.19	10.53	14.33	12.81	9.47	9.15	9.69	9.44
SE±	0.06	0.04	0.065	0.05	0.09	0.19	0.29	0.14	0.16	0.13	0.13	0.13
LSD (p=0.05)	0.19	0.13	0.22	0.14	0.32	0.65	1.00	0.29	NS	NS	NS	NS
DD												
D_1 (0.75 m)	1.79	1.19	1.92	1.43	11.65	8.94	12.54	10.22	9.57	9.22	9.34	9.38
D_2 (1.0 m)	1.91 a	1.27 a	2.13	1.54	12.15	9.38	13.21	10.70 a	9.55	9.21	9.38	9.38
D_3 (1.25 m)	2.03 a	1.35 a	2.41	1.65	12.42	9.58	14.04	10.95 a	9.57	9.22	9.58	9.46
SE±	0.05	0.03	0.08	0.05	0.16	0.14	0.50	0.20	0.12	0.10	0.09	0.12
LSD (p=0.05)	0.15	0.10	0.23	0.10	0.47	0.41	NS	0.41	NS	NS	NS	NS
Interaction												
DS×DD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS= not significant

Table 3. Effect of SSDS with different DSs and DDs on CCS (%), cane and sugar yield under waterlogged Vertisols

Treatments	CCS (%)				Cane yield (Mg ha^{-1})				Sugar yield (Mg ha^{-1})			
	2013-14	2014-15	2017-18	Pooled Mean	2013-14	2014-15	2017-18	Weighted Mean	2013-14	2014-15	2017-18	Pooled Mean
DS												
L_1 (10 m)	13.96	13.09	13.95	13.67	122.92	73.82	141.68	87.03	17.17	9.67	20.14	15.66
L_2 (20 m)	14.10 a	13.23 a	14.00	13.78	153.25	91.25	168.90	107.64	21.62	12.08	24.64	19.45
L_3 (30 m)	14.17 a	13.30 a	14.22 a	13.90 a	179.69	107.30	200.85 a	126.54	25.47	14.28	29.83	23.19 a
L_4 (40 m)	14.28 a	13.41 a	14.28 a	13.99 a	201.48	118.49	214.04 a	140.12	28.80	15.91	29.65	24.79 a
SE±	0.06	0.06	0.05	0.05	4.59	2.48	11.28	3.72	0.62	0.32	0.82	0.68
LSD (p=0.05)	0.21	0.20	0.17	0.15	15.87	8.60	39.03	7.92	2.14	1.09	2.85	1.97
DD												
D_1 (0.75 m)	13.98	13.11	14.01	13.70	147.66	87.04	153.41	102.18	20.66	11.42	21.47	13.86
D_2 (1.0 m)	14.07	13.20	14.10	13.79	163.43	96.65	179.52	113.56	23.03	12.78	25.92	15.63
D_3 (1.25 m)	14.33	13.46	14.23	14.01	181.91	109.46	211.35	128.20	26.10	14.75	30.80	18.01
SE±	0.04	0.04	0.03	0.05	3.80	2.01	9.66	3.50	0.53	0.27	0.85	0.46
LSD (p=0.05)	0.13	0.13	0.09	0.13	11.38	6.04	28.97	7.06	1.60	0.80	2.56	0.93
Interaction												
DS × DD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

per clump, CCS (%), cane yield and sugar yield were observed under DS (main factor) and DD (sub-factor). However, the interaction effect of drain spacing and depth on growth, yield and quality dynamics of sugarcane was non-significant. The DS of 40 m recorded significantly maximum pooled mean height of sugarcane (446.63 cm), milleable cane height (284.37 cm), No. of internodes (25.40), No. of milleable cane per clump (12.81 Nos.), cane yield (140.12 Mg ha^{-1}) followed by DS of 30 m, 20 m and 10 m (Table 1 to 3). Whereas, 30 m DS was performed at par with 40 m drain spaced treatment for length of internodes, weight of single milleable cane, CCS (%) and sugar yield. The girth of internodes was non-significant under DSs. This might be due to less NO_3-N losses through slow drainage under higher spaced drains. The drainage coefficient observed under treatment combination of 10 m DS with 1.25 m DD and 40 m DS with DD of 1.25 m were 6.93 mm day^{-1} and 2.18 mm day^{-1} respectively (Table 6). Sugarcane growth was adversely affected due to excess losses of nitrogen in the form of NO_3-N through excess drainage under closely spaced drains. Excess drainage of around 50% of Nitrogen and 17% of irrigation water were recorded from paddy fields in Saline clay loam soils of Tungabhadra Project (TBP) Command Area of Karnataka, India (Karegoudar, *et al*. 2019). Nash *et al.* (2014) reported annual NO_3-N loss through tile drainage water with SSDS ranged from 28.3 to 90.1 kg N ha^{-1}. Nangia *et al*. (2009) also observed that a tile DD of 1.5 m and increasing the tile DS from 27 to 40 m reduced NO_3-N losses by 50% (while reducing crop yield by 7%) Randall (2004) reported that the SSDS characteristics during 15-year period on a Webster clay loam soil in Minnesota showed that more than 50% of the annual nitrate loss occurred in 10% and 18% of the days drainage occurred when tile DS was 15.2 and 27.4 m, respectively. This was extremely important that the DS less than 27.4 m had observed more than 50% nitrate losses (Randall, 2004). Further, nitrogen requirement of *Adsali* sugarcane crop (16-18 months crop period) was very high i.e., 400 kg ha^{-1} for present experimental soil site. Hence, the sugarcane pooled yield trend observed under different DS were 40 m DS (140.12 Mg ha^{-1}) > 30 m DS (126.54 Mg ha^{-1}) > 20 m DS (107.64 Mg ha^{-1}) > 10 m DS (87.03 Mg ha^{-1}). These results are very useful for farming community. Because they always misunderstood that closer spaced drain gives more yield. Further, they don't know about the losses of nitrogenous fertilizers. The second reason might be due to less water stress on sugarcane growth by slow drainage in higher spaced drains under high irrigation interval period (generally 25-30 days) adopted by the co-operative lift irrigation schemes. Generally, irrigation interval for furrow irrigation was 10-12 days in summer, 18-20 in winter and 14-15 days in rainy season in Maharashtra. But due to rotational supply system of lift/canal irrigated sector of Maharashtra, farmers can get irrigation water generally after every 25-30 days. Under this situation, if SSDS was installed; it removes 4 to 10% of irrigated water just within 2 to 3 days. Hence crop may face the deficit water stress during later stages or 5-10 days before irrigation. The third reason may be the spatial variability in salinity of the experimental soil (0.4 to 1.15 dS m^{-1}). However, the critical salinity tolerance limit of sugarcane was 1.71 dS m^{-1} (FAO, 1985). The fourth reason might be that sugarcane appears to be exceptionally resistant to waterlogging, with standing periods of up to 14 days of shallow standing water or saturated soil in a Florida study (Glaz and Morris 2010; Glaz et al. 2004). Hence, slow drainage by higher spaced drains may not adversely affect the sugarcane yield. But as per FAO guidelines on crop yield response to water, the yield response factor (Ky) of sugarcane is greater than one (>1.2) indicating more sensitivity towards water deficit with proportional larger yield reductions when water use is reduced because of stress (Doorenbos and Kassam, 1979). Hence, DS of 10 m recorded significantly lowest pooled yield of sugarcane (87.03 Mg ha^{-1}). Camp and Carter (1994) reported that there was no statistically significant sugarcane yield advantage to subsurface drains spaced closer than 42 m; the DS recommended for draining Jeanerette silty clay loam soil in Louisiana was 42 m. Tiwari and Goel (2017) also reported that the DS should be within 20-50 m for fine textured soils in semi-arid regions.

Further, the significantly highest pooled mean height of milleable cane (207.55 cm), weight of single milleable cane (1.65 kg), cane yield (128.20 Mg ha^{-1}), CCS (14.23%) and sugar yield (18.01 Mg ha^{-1}) were observed under DD of 1.25 m followed by 1.0 m and 0.75 m DD (Table 1 to 3). Further, the DD of 1.0 m was performed at par with 1.25 m DD for height of sugarcane, No. of internodes per cane and No. of milleable canes per clump. The length and girth of internodes were non-significant under different DD. These might be due to different rate of WT drop under different DD (Table 6). The percent improvement in physico-chemical and hydrological properties of soil were more under deep drains for a given spacing, and provided faster and better congenial condition at greater soil depth for deep rooted crops like sugarcane (Table 6). The opposite condition was observed for shallow drained treatments. Hence, shallow depth recorded significantly lowest growth, yield and quality parameters of sugarcane as compared to deep drains (Table 1 to 3). Tiwari and Goel (2017) reported that the DD of SSD should be more than 1.2 m for optimum crop growth and to avoid breakages of pipes by heavy loaded vehicles may be sugarcane tractors and other vehicles. The DD of 0.9 to 1.2 m below ground surface were increasingly used in humid and semi-arid climates (Abu-zeid, 1992). In India, Ritzema *et al.* (2008) and Srinivasulu *et al.* (2005) noted that under gravity flow conditions, DD can be reduced to 0.9 to 1.0 m. Sarwar and Feddes (2000) also reported that deeper drains performed technically better in relation to crop growth and soil desalinization.

Economic feasibility of SSDS with different combinations of DS and DD for cultivation of sugarcane under waterlogged vertisols

As presented in Table 4, the economic analysis of SSDS with varying DS and DD revealed that the DS of 40 m recorded significantly highest pooled mean of gross monetary returns (Rs 379571.20 ha^{-1}), net monetary returns (Rs. 237707.20 ha^{-1}) and B: C ratio (2.55) followed by DS of 30 m, 20 m and 10 m. The higher spaced drain recorded superior economics as compared to closely spaced drains. This was due to the fact that closely spaced drains required more initial investment on SSDS as compared to widely spaced drains for a given drain depth (Table 5). Further, the yield of sugarcane also recorded higher under widely spaced drains of 40 m as compared to closely spaced drains of 10 m for a given drain depth (Table 3). In case of drain depth, 1.25 m recorded significantly highest pooled mean of gross monetary returns (Rs. 347299.70 ha^{-1}), net monetary returns (Rs. 203851 ha^{-1}) and B:C ratio (2.33) followed by DD of 1.0 and 0.75 m as the deeper drains provided faster and better physico-chemical and hydrological properties of soil at greater soil depth for deep rooted crops like sugarcane and thereby the higher yield (Table 3, 4 and 6). The interaction effect of DS and DD was non-significant. The results of B: C ratio is corroborated with the findings of Raju *et al*. (2017) who observed up to 134% increase in B:C ratio

Table 4. Economic feasibility of SSDS with different DSs and DDs for sugarcane under waterlogged Vertisols

Treatments	Gross monetary returns (Rs ha^{-1})				Net monetary returns (Rs ha^{-1})				B:C ratio			
	2013-14	2014-15	2017-18	Weighted mean	2013-14	2014-15	2017-18	Weighted mean	2013-14	2014-15	2017-18	Pooled mean
DS												
L_1 (10 m)	332980.79	199989.87	384455.56	235780.10	92794.54	82722.97	136529.39	86875.21	1.39	1.70	1.55	1.55
L_2 (20 m)	415158.92	247197.07	457544.93	291579.70	178982.05	135178.03	214946.80	147654.50	1.76	2.21	1.89	1.95
L_3 (30 m)	486778.80	290678.96	544100.70	342780.40	251358.62	179955.85	302813.63	200033.60	2.07	2.62	2.25	2.31
L_4 (40 m)	545814.38	320982.89	579849.35	379571.20	311213.92	211159.50	339478.40	237707.20	2.33	2.92	2.41	2.55
SE±	12425.08	6735.84	30558.04	10069.28	12425.08	6735.84	30558.04	10069.28	0.05	0.06	0.13	0.08
LSD (p=0.05)	42996.46	23309.07	105744.74	21461.67	42996.46	23309.07	105744.74	21461.67	0.18	0.21	0.44	0.23
DD												
D_1 (0.75 m)	400021.89	235781.41	415601.64	276595.40	163749.74	123647.09	172886.32	133787.60	1.70	2.11	1.71	1.87
D_2 (1.0 m)	442734.54	261834.76	486320.87	307655.50	206131.04	149369.08	243267.58	164516.10	1.88	2.34	2.01	2.08
D_3 (1.25 m)	492793.24	296520.43	572540.40	347299.70	255881.07	183746.10	329172.27	203851.50	2.08	2.64	2.36	2.33
SE±	10284.40	5458.65	26181.04	9483.67	10284.40	5458.65	26181.04	9483.67	0.04	0.05	0.11	0.06
LSD (p=0.05)	30832.63	16365.02	78490.74	19138.81	30832.63	16365.02	78490.74	19138.81	0.13	0.15	0.32	0.13
Interaction												
DS × DD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Cost of sugarcane production and initial investment on adoption of SSDS with different DSs and DDs

Sr. No.	Items	$L_{10}D_{0.75}$	$L_{10}D_{1.0}$	$L_{10}D_{1.25}$	$L_{20}D_{0.75}$	$L_{20}D_{1.0}$	$L_{20}D_{1.25}$	$L_{30}D_{0.75}$	$L_{30}D_{1.0}$	$L_{30}D_{1.25}$	$L_{40}D_{0.75}$	$L_{40}D_{1.0}$	$L_{40}D_{1.25}$
1	Initial investment on SSDS (Rs ha^{-1})	219238	233268	247297	126175	133789	139135	107700	114116	120531	88547	93623	98699
2	Yearly cost of SSDS considering 25 years life of SSDS (Rs ha^{-1} $year^{-1}$)	8769.52	9330.70	9891.88	5047.00	5351.56	5565.40	4308.01	4564.63	4821.25	3541.87	3744.91	3947.95
3	Cost of sugarcane cultivation (Rs ha^{-1}) 2013-14	230856	230856	230856	230856	230856	230856	230856	230856	230856	230856	230856	230856
4	Cost of ratoon (Rs ha^{-1}) 2014-15	105000	105000	105000	105000	105000	105000	105000	105000	105000	105000	105000	105000
5	Cost of sugarcane cultivation (Rs ha^{-1}) 2017-18	235587	235587	235587	235587	235587	235587	235587	235587	235587	235587	235587	235587
6	Cost of maintenance of SSDS needed from 2014-15 and onwards (Rs ha^{-1} $year^{-1}$)	2936.20	2936.20	2936.20	1697.72	1697.72	1697.72	1158.48	1158.48	1158.48	1078.48	1078.48	1078.48
7	Cost of sugarcane production 2013-14 (Rs ha^{-1}) = Sr.No.2+3	239625.52	240186.7	240747.88	235903	236207.56	236421.4	235164.01	235420.63	235677.25	234397.87	234600.91	234803.95
8	Cost of sugarcane production 2014-15 (Rs ha^{-1}) = Sr.No.2+4+6	116705.72	117266.9	117828.08	111744.72	112049.28	112263.12	110466.49	110723.11	110979.73	109620.35	109823.39	110026.43
9	Cost of sugarcane production 2017-18 (Rs ha^{-1})= Sr.No.2+5+6	247292.72	247853.9	248415.08	242331.72	242636.28	242850.12	241053.49	241310.11	241566.73	240207.35	240410.39	240613.43

Table 6. Drainage coefficient, drainable porosity, bulk density, soil desalination and water table under SSDS with different combinations of DS and DD

Sr. No.	Treatments	Average drainage coefficient ($mm.d^{-1}$)	Drainable porosity (%)	Improvement in bulk density of soil after drainage (%)	Improvement in soil porosity after drainage (%)	Desalination of soil after drainage (%)	Depth of average water table (m), 10 days after heavy rainfall of 147 mm
1.	$L_{10}D_{1.25}$	6.93	10.58	20.76	13.74	55.53	0.693
2.	$L_{10}D_{1.0}$	4.07	10.14	20.00	13.56	57.92	0.549
3.	$L_{10}D_{0.75}$	1.49	3.87	18.60	12.30	59.44	0.355
4.	$L_{20}D_{1.25}$	4.05	6.96	17.82	11.80	36.73	0.472
5.	$L_{20}D_{1.0}$	2.78	5.07	17.13	11.37	46.30	0.332
6.	$L_{20}D_{0.75}$	1.04	2.50	15.97	11.18	49.38	0.216
7.	$L_{30}D_{1.25}$	2.86	5.48	16.51	10.90	31.47	0.335
8.	$L_{30}D_{1.0}$	2.00	4.96	15.51	10.49	33.86	0.235
9.	$L_{30}D_{0.75}$	0.80	1.99	13.81	8.51	41.43	0.178
10.	$L_{40}D_{1.25}$	2.18	4.91	16.36	10.88	25.26	0.125
11.	$L_{40}D_{1.0}$	1.90	4.43	14.89	9.99	27.84	0.072
12.	$L_{40}D_{0.75}$	0.72	1.65	12.58	8.40	39.18	0.042

for sugarcane crop. Raju *et al.* (2015) and, Chinnappa and Nagaraj (2007) also recorded similar results.

Finally, DS of 40 m and DD of 1.25 m were found economically optimal among other DSs and DDs for sugarcane under waterlogged Vertisols of Maharashtra. Carter and Camp (1994) also suggested 42 m for sugarcane for silty clay loam soil. Talukolaee *et al.* (2016) also recommended 30 m DS and DD of 0.9 m instead of 15 m DS and DD of 0.65 m for optimum properties of soil and higher canola yield in Iran. Tiwari and Goel (2017) also reported that the DS should be within 30-50 m for fine textured soils, DD > 1.2 m and drainage coefficient of 2 mm day^{-1} for semi-arid regions. In this investigation the highest sugarcane yield was obtained under DS of 40 m, DD of 1.25 m and drainage coefficient of 2.18 mm day^{-1} which was nearer to recommended drainage coefficients of 2 mm day^{-1} for semi-arid regions. Hence, the previous research works supported the present research outputs as well.

Conclusions

The narrow workable soil moisture range and very low hydraulic conductivity have always been considered as hurdles in getting potentially higher crop outcomes from highly fertile Vertisols. The heavy waterlogging condition in these soils during rainy season sometimes makes it impossible to carry out farm operations and hence causes land to leave fallow. Further, the irrigated *Vertisols* are highly prone to soil degradation if proper irrigation water management and drainage infrastructure are not in place. In Maharashtra, the canal and lift irrigation schemes are supplying continuous water supply but creating twin problems of waterlogging and salinity. The optimum drainage is the only possible solution to minimize these soil constraints. The present study evaluated subsurface drainage system with four drain spacings of 10, 20, 30 and 40 m and three drain depths of 0.75, 1.00 and 1.25 m for finding out the optimal combination of drain spacing and drain depth for optimum growth of sugarcane under waterlogged Vertisols of Sangli, Maharashtra. To conclude, the losses of NO_3-N with excess drainage of irrigation water through subsurface drainage system with closely spaced drains reported by Karegoudar, *et al*. (2019), Nash *et al.* (2014), Nangia *et al*. (2009), Randall (2004), and Singh *et al.* (2000) have been played a decisive role. Hence, in this study, the subsurface drainage system with 40 m drain spacing and 1.25 m drain depth has been recommended for optimum drainage, less NO_3-N losses and, economically higher cane/sugar yield under lift/canal irrigated Vertisols of Sangli district in Maharashtra, India.

Acknowledgements

Authors are thankful to the Rashtriya Krishi Vikas Yojana (RKVY) Division, Govt. of India, New Delhi; Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, for sanctioning the project and availing fund through Department of Agriculture, Maharashtra, and Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar.

References

Abu-Zeid M (1992) 5th Annual workshop-Subsurface Drainage on Problematic Irrigated Soils: Sustainability and Cost Effectiveness Feb. 8-15, Lahore, Pakistan.

Ambast SK, Gupta SK and Singh G (2007) *Agricultural Land Drainage: Reclamation of Waterlogged Saline Lands.* Central Soil Salinity Research Institute, Karnal, India, pp 231.

Bhattacharyya T, Pal DK, Mandal C, Chandran P, Ray SK, Sarkar DVK, Srivastava A, Sidhu GS, Singh RS, Sahoo AK, Dutta D, Nair KM, Srivastava R, Tiwary P, Nagar AP and Nimkhedkar SS (2013) Soils of India: Historical perspective, classification and recent advances. *Current Science* **104 (10)**: 1308-1323.

Blake GR (1965) Particle density. In: *Methods of Soil Analysis,* part I, Agronomy, number 9. C.A. Black, edited by American Society of Agronomy, Madison, Wisc. pp.371-373.

Boonstra J, Ritzema HP, Wolters W, Oosterbaan RJ, Res L, Lieshout van AM, CSSRI, NGRAU, UASD, RAU, GAU... (2002) *Research on the Control of Waterlogging and Salinization in Irrigated Agricultural Lands-Recommendations on Waterlogging and Salinity Control Based on Pilot Area Drainage Research*.. CSSRI, Karnal and Alterra-ILRI, Wageningen, pp 100. (http://library.wur.nl/WebQuery/ wurpubs/348820) (accessed on 20 Feb 2020).

Brady NC and Weil RR (1996) *The Nature and Properties of Soils* (11th edition). Prentice Hall, New York.

CACP (2012) *Price Policy for Sugarcane- the Sugar Season 2013-14.* http://cacp.dacnet.nic.in/RPP/Sugarcane-2013-14.pdf.46-47.

Carter CE and Camp CR (1994) Drain spacing effect on water table control and cane sugar yields. *Americal Society of Agricultural Engineers,* **37(5)**: 1509-1513.

Chinnappa B and Nagaraj N (2007) An economic analysis of public interventions for amelioration of irrigation-induced soil degradation. *Agricultural Economics Research Review* **20**: 375-384.

Dastane NG (1967) A Practical Manual for Water Use Research. Navabharat Prakashan, Poona, India, p.5.

Doorenbos J and Kassam AH (1979) Yield response to water. FAO Irrigation and Drainage Paper No. 33, Rome, Italy.

FAO (1985) Guidelines on crop salt tolerance data. FAO Irrigation and Drainage Paper No. 29. Rome, Italy.

Fagodiya RK, Malyan SK, Singh D, Kumar A, Yadav RK, Sharma PC and Pathak H (2022) Greenhouse gas emissions from salt-affected soils: mechanistic understanding of interplay factors and reclamation approaches. *Sustainability* 14(19):11876. https://doi.org/10.3390/su141911876

Glaz B and Morris DR (2010) Sugarcane response to water table depth and periodic flood. *Agronomy Journal* **102**: 372-380.

Glaz B, Morris DR and Daroub S H (2004) Periodic flooding and water table effects on two sugarcane genotypes. *Agronomy Journal* **96**: 832-838.

Jackson ML (1973) *Soil Chemical Analysis*. II Edn. Prentice Hall of India Pvt. Ltd., New Delhi, 113-124.

Kamra SK and Sharma DK (2016) Critical evaluation of performance and organizational framework of subsurface drainage projects in Haryana and Maharashtra. *Water and Energy International* **59(1)**: 64-72.

Karegoudar AV, Vishwanath J, Anand SR, Rajkumar RH, Ambast SK and Kaledhonkar MJ (2019) Feasibility of Controlled Drainage in Saline Vertisols of TBP Command Area of Karnataka, India. *Irrigation and Drainage* **68**: 969–978.

Mukhopadhyay R, Fagodiya RK, Narjary B, Barman A, Prajapat K, Kumar S, Bundela DS and Sharma PC (2023). Restoring soil quality and carbon sequestration potential of waterlogged saline land using subsurface drainage technology to achieve land degradation neutrality in India. *Science of The Total Environment* 163959. https://doi.org/10.1016/j.scitotenv.2023.163959

Nangia V, Gowda PH, Mulla DJ and Sands GRZ (2009) Modeling impacts of tile drain spacing and depth on nitrate-nitrogen losses. *Vadose Zone Journal* **9**: 61-72.

Nash P, Nelson K and Motavalli P (2014) Reducing nitrogen loss in subsurface tile drainage water with managed drainage and polymer-coated urea in a river bottom soil. *Journal of Water Resource and Protection* **6**: 988-997.

Panse VC and Sukhatme PV (1967) *Statistical Methods for Agric. Workers*. II. Enlarged Edn. ICAR, New Delhi.

Raju R, Thimmappa K, Pathan AL and Siddayya (2016) Impact of saline soil reclamation on enhancing farm productivity and farmers' income in Karnataka: An economic analysis. *International Journal of Tropical Agriculture* **34(2)**: 303-310.

Raju R, Thimmappa K, Pathan AL and Siddayya (2017) Saline soil reclamation through subsurface drainage in

Karnataka - An economic impact analysis. *Farm Science* **30**: 74-78.

Raju R, Tripathi RS, Thimmappa K, Parveen Kumar, Satyendra Kumar (2015) Impact of waterlogged saline soil reclamation on land productivity and farm income: An economic study from Haryana. *Agricultural Economics Research Review* **28**: 177-182. DOI: 10.5958/0974-0279.2015.00032.4.

Randall GW (2004) Subsurface drain flow characteristics during a 15 year period in Minnesota. In. Proc. 8th Intl. Drainage Symp. Drainage VIII. 21-24 March, 2004. Sacramento, CA. ASAE.

Rathod SD, Gorantiwar SD, Dahiwalkar SD, Kamble BM, Patil SB and Kathmale DK (2011) Performance and economic feasibility of mole drainage in irrigated Vertisols. *Journal of Soil Salinity and Water Quality* **3(1)**: 37-40.

Ritzema HP, Satyanarayana TV, Raman S and Boonstra J (2008) Subsurface drainage to combat waterlogging and salinity in irrigated lands in India: Lessons learned in farmers' fields. *Agricultural Water Management* **95(3)**: 179-189.

Sarwar A and Feddes RA (2000) Evaluating Drainage Design Parameters for the Fourth Drainage Project, Pakistan by using SWAP Model: Part II- Modeling Results. *Irrigation and Drainage Systems* **14 (4)**: 281-299.

Sastry SK and Venkatachari A (1960) Nutrient requirements of sugarcane at Rudrur, Andhra Pradesh. Proc. 4th All India Conf. Sugarcane Researchers and Dev. Workers, pp 146.

Singh M (2000) Modelling of salinization and nitrogen losses under subsurface drainage system. Unpublished Ph. D. thesis, Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi.

Srinavasulu K, Sujani Rao C, Lakshmi GV, Satyanarayana TV and Boonstra J (2005) Model studies on salt and water balances at Konanki pilot area. Andhra Pradesh, India. *Irrigation and Drainage Systems* **18**: 1-17.

Talukolaee JM, Ritzema H, Darzi-Naftchalli A and Shahnazari A (2016) Subsurface drainage to enable the cultivation of winter crops in consolidated paddy fields in Northern Iran. *Sustainability* **8(249)**: 1-19.

Taylor GS (1960) Drainable porosity evaluation from outflow measurements and its use in drawdown equations. *Soil Science* **90**: 38-345.

Tiwari P and Goel A (2017) An overview of impact of subsurface drainage project studies on salinity management in developing countries. *Applied Water Science* **7**: 569-580, DOI 10.1007/s13201-015-0329-4.

Valipour M (2014) Drainage, waterlogging, and salinity. *Archives of Agronomy and Soil Science* **60**: 1625-1640.

Received: December 29, 2022: Accepted: April 30, 2023

Journal of Soil Salinity and Water Quality 15(1), 38-45, 2023

Characterization and Mapping of Groundwater Quality of Sonipat District in Haryana, India

Ram Prakash[1]*, Dinesh[1], Sanjay Kumar[2], Ankush[1] and Charan Singh[1]

[1]*Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*
[2]*Department of Soil and Water Engineering, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*
**Corresponding author E-mail: ramsansanwal@gmail.com*

Abstract

A survey of groundwater quality for irrigation of different crops was conducted at different villages of Sonipat district, Haryana during 2020-2021. A total 765 water samples were collected and analyzed for various haydrochemical parameters pH, EC, (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (CO_3^{2-} , HCO_3^-, Cl^- and SO_4^{2-}) by using standard procedures. Irrigation indices such as SAR, RSC, were calculated for these samples. The pH, EC, SAR and RSC in groundwater ranged from 6.50 to 11.50, 0.24-22.32 (dS m^{-1}), 0.22 to 45.28 ($(mmol^{-1})^{1/2}$ and 0.00-14.40 (me l^{-1}), respectively. The trend among the average ionic concentration of cations and anions were $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and anions were $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$. According to AICRP,1989 in Sonipat district 31.37, 19.48, 4.44, 18.56, 6.54,3.66 and 15.95 per cent samples were found in good, marginally saline, saline, high SAR saline, marginally alkali, alkali and highly alkali categories, respectively. Spatial variability maps of EC, SAR and RSC of irrigated ground water were also prepared in the Sonipat district.

Key words: Groundwater, Saline, Alkali, SAR, RSC, Cations and Anions

Introduction

Optimum economic development of water resources in an area requires an integrated approach that coordinates the use of both surface and groundwater resources. After evaluation of total water resources and preparation of alternative management plans, decisions can then be made by the bodies that are going to utilize the water resources of the area in future. Judicious management and monitoring of soil and water are essential for sustainable agriculture. Over drafting of ground water and its quality deterioration are the major threats to crop production in arid and semiarid regions (Pradhan *et al.*, 2011). Water has played an important role in the development and growth of human civilization. In modern times, water has critical importance in the economic growth of all contemporary societies (Yadagiri *et al.*, 2015). The contamination with various chemical and biological sources and exploitation of ground water sources created pressure on groundwater resources (Ramprakash *et al.,* 2018; Singh *et al.*, 2017). However, it is important for not only the availability of groundwater, but also its sufficient quality for use in irrigation purposes. For groundwater extraction water, wells are drilled and it is presumed that overexploitation of water will continue indefinitely with time. Typically, the development of water supplies from groundwater begins with a few pumping wells scattered all over the area. With the passage of time, more wells are drilled and the rate of extraction increase, as a result the aquifer discharge increases over recharging capability. Continued water extraction without a management plan could eventually deplete the groundwater resource. By regulating inflow and outflow from the basin, an underground reservoir can be made to function beneficially and indefinitely just as a surface water reservoir. Forecasts of future water demand indicate that improper management or neglect of significant groundwater resources cannot be tolerated if adequate, reliable water supplies are to be maintained (Jadhao, 2013).

The quantity and quality of groundwater are equally important for every society's socioeconomic growth (Omran *et al.,* 2014).

Irrigation water quality is primarily determined by the type of water and the concentrations of dissolved solids and salts (Arya *et al.,* 2021). The general and fundamental criteria to determine the quality of irrigation water depend on the total content of soluble salt (salinity hazards), relative proportion of sodium, calcium, and magnesium, sodium absorption ratio, residual sodium carbonate (RSC) (sodium hazards), and quantity of toxic elements. The salts in irrigation water originate from the dissolution or weathering of the rocks, dissolution of lime, gypsum, and other dissolved minerals. Soil processes also affect the water quality concerning agricultural activities such as accelerated soil erosion, runoff, compaction, macropore flow, leaching, etc. Because each groundwater system has a varied chemical composition, the suitability of water at a certain location is determined by groundwater geochemistry. Any change depends on various factors, including rock-water intrusion, mineral dissolution, soil-water intrusion, and anthropogenic activity (Chaudhary *et al.,* 2018). One of the most important elements influencing groundwater quality is the geological location. In hot arid regions where rainfall is scarce, groundwater use increases the groundwater salinity and limits the selection of crops for cultivation. It is therefore, vital to determine the irrigation water quality. By keeping the above facts, an investigation was carried out to access groundwater quality of Sonipat District, Haryana, used for irrigation purposes by accessing different water quality parameters. There has been very little information on the groundwater quality for irrigation in the Sonipat district region, and variations in water quality parameters have been recorded. Therefore, an investigation of the nature, properties, and quality of irrigation is needed for proper irrigation to determine the potential of secondary salinization/sodification in this location. To get a comprehensive picture of the groundwater quality for irrigation purposes of a region/block, a significant number of samples from throughout the area has been evaluated. In light of the above, 765 water samples were collected from the Sonipat region for this research, and water quality status was assessed.

Material and Methods

Study area

Sonipat district has a sub-tropical continental monsoon climate. The district lies in the central part of the state and having temperature regimes of hot semi-arid regions. The soil of this district are sandy to clay loam textured. It is predominantly an agricultural district. About 70 percent of people are engaged in different agricultural pursuits. It is situated in the heart of green revolution belt of the state. Wheat, rice, sugarcane, barley, maize and mustard are the main crops of the district. The total geographical area is 0.21 M ha, out of which 0.17 M ha area is cultivable. Net sown area is nearly 80.27 percent of the total area. The area sown more than once is 1, 47,000 hectares bringing the total cropped area (gross sown area) to 3, 16,000 hectares. The district has a high irrigation intensity of 187 percent. The net irrigated area by canals is 91,000 hectares and net irrigated area by tube wells is 78,000 hectares. Sonipat district is a part of the Indo-Gangetic plain. It has almost a plain topography with general slope from north to south. A natural depression exists in north and northwest of Gohana. The maximum elevation of the plain is 235 meters above mean sea level. As per the physiographic regions, the study area can be divided into three regions namely: active floodplain, abandoned floodplain of recent past and upland plain. The study area has not much geological diversity. Sonipat district is dominated by Quaternary to Recent age deposits of Indo-Gengatic plains. It is almost covered by alluvial deposits of clay, loam, silt and sand brought down by Yamuna River during quaternary to recent age. To find out the quality of underground water in Sonipat district a survey experiment was conducted and a total 765 water samples were collected from running tube wells and their locations were recorded from different villages of eight blocks viz., Rai (67), Ganaur (62), Murthal (45), Gohana (103),Kathura (135), Kharkhoda (53), Mundlana (215) and Sonipat (85) of Sonipat district, Haryanaduring 2021-2022to evaluate the quality of groundwater for irrigation for different crops and the location map is prepared (Fig. 1).The samples were collected in thoroughly

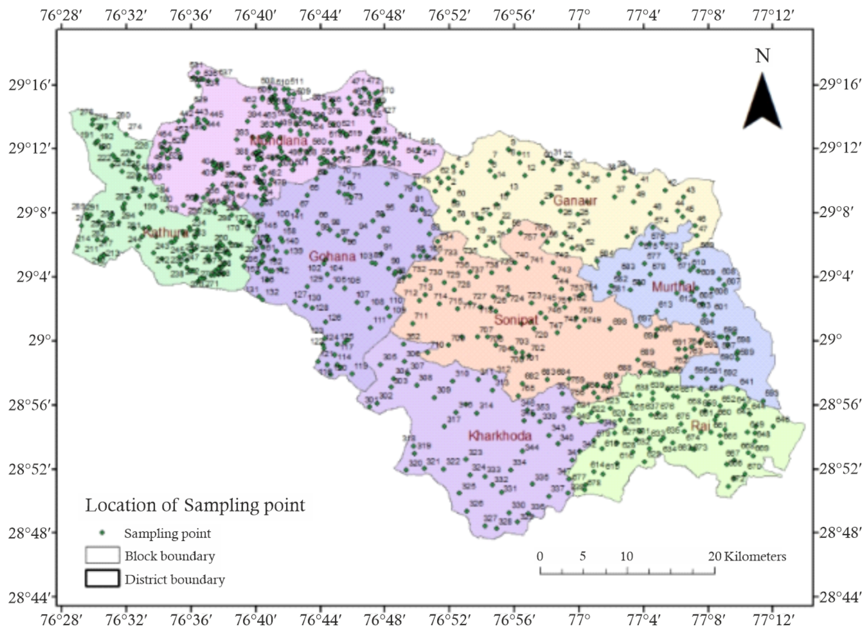

Fig. 1 Location map of sampling points in Sonipat district

cleaned, properly labeled and carefully corked plastic bottles. Before collection of water in a particular bottle, the bottle is rinsed thoroughly with the respective samples of groundwater and immediately after collection samples were transferred laboratory for chemical analysis. The chemical analysis was accomplished at CCS Haryana Agricultural University, Hisar, India as per the standard methods relevant to analysis of groundwater. Electrical Conductivity (EC) was measured by conductivity meter and pH by digital pH meter. Sodium (Na^+) and potassium were measured by flame photometer. Calcium and magnesium were determined with standard EDTA solution titrimetrically. Carbonate and bicarbonate were estimated by titration with H_2SO_4, Chloride by titrating against standard silver nitrate ($AgNO_3$) solution. The colorimetric analysis of sulphate was done by spectrophotometer. Measurements were done in triplicate to ensure reliability and good quality control. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) are calculated as:

a) Sodium adsorption ratio (SAR) {Richards, 1954}:

$$\text{SAR}\,(\text{mmol}\,\text{l}^{-1})^{1/2} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

b) Residual sodium carbonate (RSC) (Eaton, 1950):

$$\text{RSC}\,(\text{me}\,\text{l}^{-1}) = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP, 1989) on Management of Salt affected Soils and Use of Saline Water in Agriculture.

Results and Discussion

In the Sonipat district, electrical conductivity (EC) ranged from 0.24 to 22.32 dS m^{-1} with a mean of 2.90 dS m^{-1} (Table 1). It was observed that in Sonipat district, 381 samples had EC 0-2 dS m^{-1} 215 samples had EC ranges from 2-4 dS m^{-1}, 90 samples had EC ranges from 4-6 dS m^{-1} 44 samples had EC ranges from 6-8 dS m^{-1}, 15 samples had EC ranges from 8-10 dS m^{-1}, 9 samples had EC ranges from 10-12 dS m^{-1} and 10 samples had EC ranges from >12 dS m^{-1} (Table 2). To study the spatial distribution of EC in the whole district, a spatial variable map was prepared by using ArcGIS through the interpolation of the available data at 765 sampling points (Fig.2). The variation of EC in Sonipat district is grouped into7 classes with a class interval of 2 dS m^{-1}. The most dominating range of EC is 0-2 dS m^{-1} which occupied maximum area in the district and

Table 1. Range and mean of different water quality parameters for Sonipat district

Sr. No.	Quality parameter	Range	Mean
1	pH	6.50-11.50	8.04
2	EC (dS m^{-1})	0.24-22.32	2.90
3	RSC (me l^{-1})	0.00-14.40	1.32
4	SAR (mmol $l^{-1})^{1/2}$	0.22-45.68	9.14
5	Ca^{2+} (me l^{-1})	0.10-39.40	2.68
6	Mg^{2+} (me l^{-1})	0.20-44.75	6.58
7	Na^{+} (me l^{-1})	0.37-192.87	19.45
8	K^{+} (me l^{-1})	0.06-2.79	0.39
9	CO_3^{2-} (me l^{-1})	0.00-0.80	0.84
10	HCO_3^{-} (me l^{-1})	0.00-120.00	4.71
11	Cl^{-} (me l^{-1})	0.50-133.60	13.75
12	SO_4^{2-} (me l^{-1})	0.00-86.76	9.18

covering all the blocks of the district. The next dominating range was 2-4 dS m^{-1} which is covering a large portion. EC ranging from 10-12 and >12 dS m^{-1} is observed in small sport in the district. Sharma et *al.* (2021) reported similar results in the Madanapalle block of Chittor District, A.P.The pH ranged from 6.50 to 11.50 with a mean of 8.04 (Table 1).The sodium adsorption ratio (SAR) were found to be ranged between from 0.22 to 45.68 (mmol $l^{-1})^{1/2}$ with a mean value of 9.14 (mmol $l^{-1})^{1/2}$. Spatial variability of SAR of groundwater used for irrigation in Sonipat district presented in (Fig.3). The residual sodium carbonate (RSC) was found to be ranged between from 0.00 to 14.40 mel^{-1} with a mean value of 1.32 mel^{-1}. Spatial variability of RSC of groundwater used for

Table 2. Average chemical composition of groundwater samples of Sonipat district in different EC classes

EC classes (dS m^{-1})	No. of samples	Na^{+}	Ca^{2+}	Mg^{2+}	K^{+}	CO_3^{-2} (mel^{-1})	HCO_3^{-}	Cl^{-}	SO_4^{-2}	RSC	SAR (mmol $l^{-1})^{1/2}$
0-2	381	8.23	0.92	2.38	0.21	0.10	2.44	3.83	2.61	0.00	5.56
2-4	215	18.54	2.33	6.68	0.39	0.89	5.27	11.65	9.60	0.68	9.81
4-6	90	32.52	4.02	11.32	0.60	1.76	7.19	24.46	18.26	4.17	13.44
6-8	44	45.46	6.53	16.78	0.85	2.51	8.42	42.38	22.06	5.19	16.71
8-10	15	61.34	11.02	20.80	1.02	3.24	9.88	56.47	30.03	6.36	20.20
10-12	9	76.07	14.95	26.89	1.32	3.84	11.38	67.22	35.48	7.33	22.40
>12	10	116.77	24.43	32.89	1.80	5.56	25.89	98.27	56.71	9.46	29.46

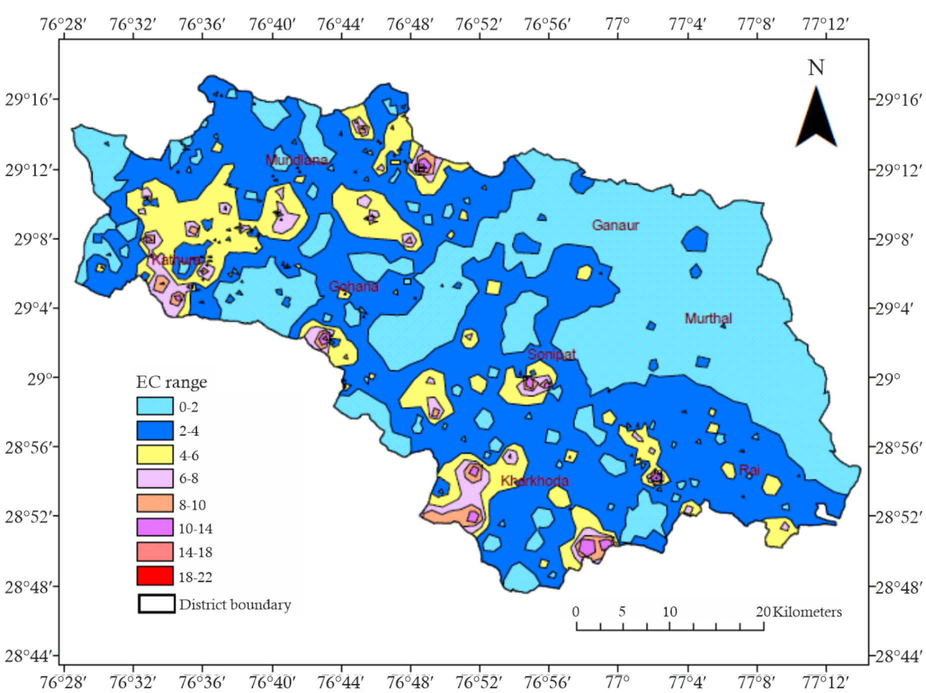

Fig. 2 Spatial variable map for EC of groundwater in Sonipat district

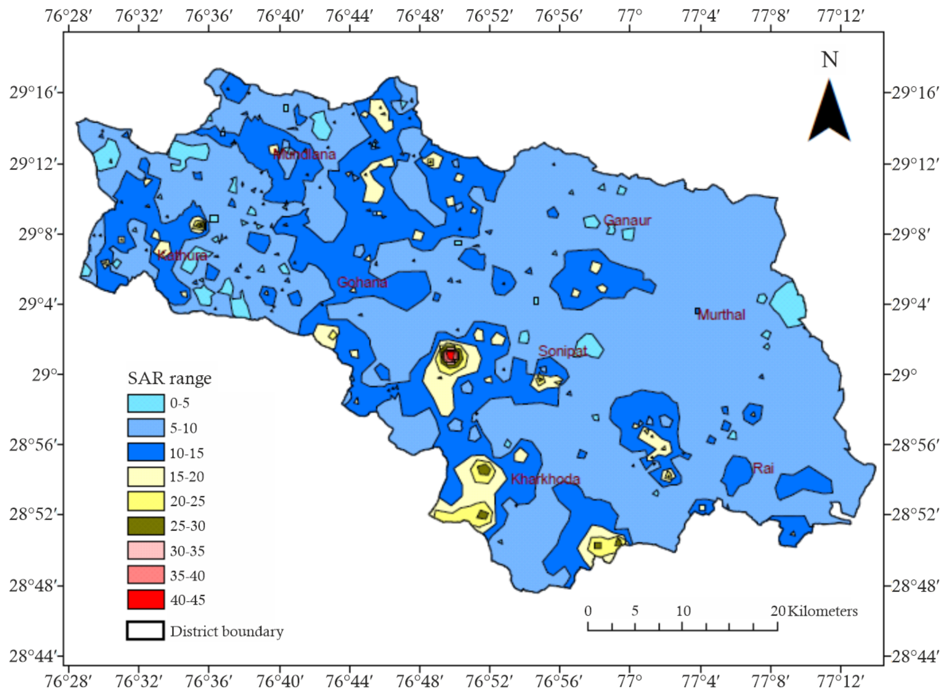

Fig. 3 Spatial variable map of SAR of groundwater in Sonipat district

irrigation in Sonipat district presented in (Fig.4). In case of anions, chloride was the dominant anion with maximum the concentration of chlorides in groundwater samples varied from 0.50 to 133.60 me l^{-1} with the mean value of 13.75 me l^{-1} (Table 1). The mean values for CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} were found to be 0.84, 4.71, 13.75 and 9.18 mel^{-1}, respectively (Table 1). The mean of cation according to the different EC classes in Sonipat district, average Na^+ was the highest and its value increased with the increase in EC ,the lowest mean value (8.23 me l^{-1}) was found in the

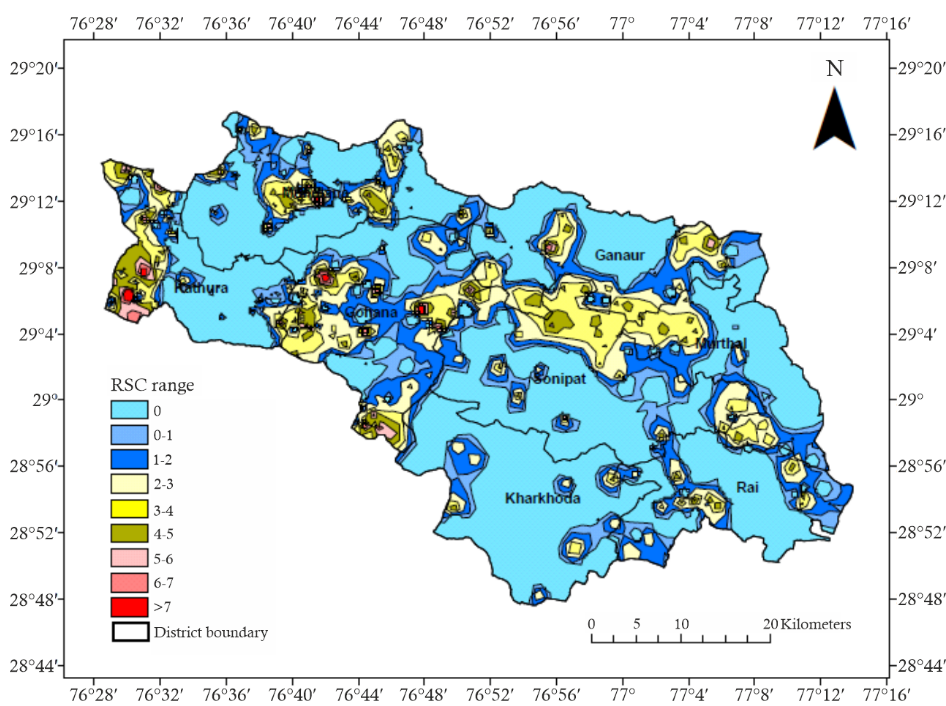

Fig. 4 Spatial variable map of RSC of groundwater in Sonipat district

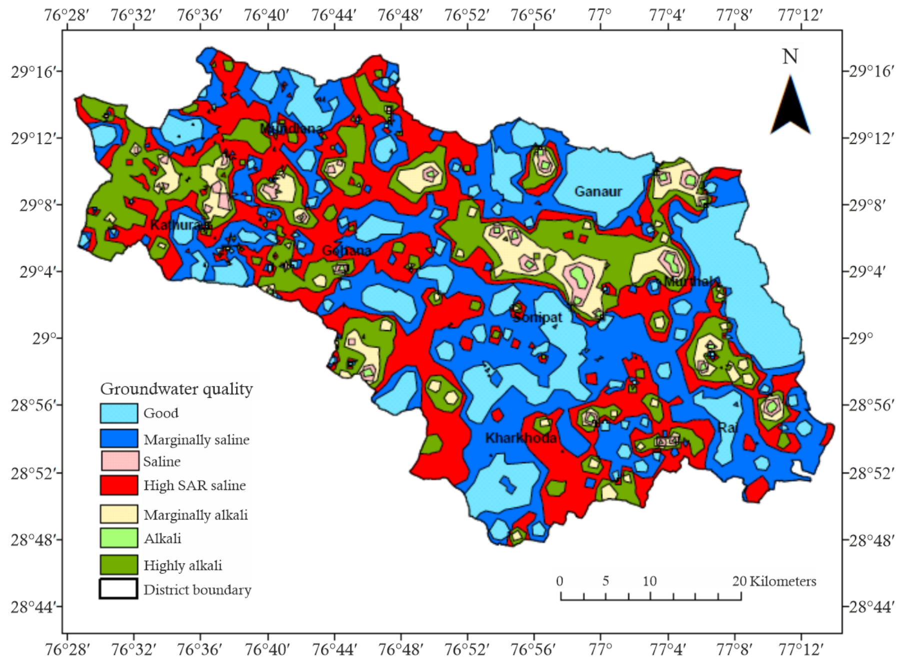

Fig. 5 Spatial variable map of groundwater quality in Sonipat district

class 0-2, the highest mean value (116.77 me l^{-1}) was laid in calss of >12 EC dS m^{-1} (Table 2). Among cations, Na^+ was highest and also varied widely from 0.37 to 192.87 me l^{-1} (Table 1), followed by magnesium (0.20–44.75 mel^{-1}) and calcium (0.10–39.40 mel^{-1}). Average values for Na^+, Mg^{2+}, Ca^{2+} and K^+ were 19.45, 6.58, 2.68 and 0.39 mel^{-1}, respectively (Table 1). The main source of sodium in natural water is feldspar erosion, evaporation, and clay (Cheremisinoff, 1997). Sodium salts have a very high solubility and remain in solution. Typical concentrations of sodium in natural waters are between 5-50 mg l^{-1}. The mean cationic composition was observed in order of$Na^+ > Mg^{2+} > Ca^{2+} > K^+$ likewise the anionic composition was observed in order of $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$. Prakash *et al*. (2021) reported the same order of abundance of cations and anions in Sonipat block of Sonipat district was in order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ likewise the anionic composition was observed in order of $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$. Same observation was observed by Pradhan *et al*. (2011) in Gohana block of Sonipat district.Earlier observations by Shahid *et al*. (2008) reported similar trend of enhancement of Na^+ and Cl^- in ground water in arid and semiarid areas.

According to AICRP, 1989 classification, it was found that overall in Sonipat district, 31.37, 19.48, 4.44, 18.56, 6.54, 3.66 and 15.95 per cent samples were found in good, marginally saline, saline, high SAR saline, marginally alkali, alkali and highly alkali categories, respectively (Table 3). Groundwater quality map for Sonipat district according to AICRP criteria was prepared to study its spatial variability in the district (Fig. 5). In the district, 31.37 percent samples are under good category but spatial variable map of block indicates less area under good quality. This is due to higher concentration of tubewells in that area and accordingly more samples were collected from that area. Good category groundwater is 22.39% in Rai, 48.39% in Ganaur block 62.22% in Murthal block, 27.18% in Gohana, 28.15% in Kathura, 32.08% in Kharkhoda25.11% in Mundlana block and 35.29% in Sonipat block of the district and highly scattered in other blocks whereas, maximum good quality (62.22%) was found in Murthal block of Sonipat district (Table 3). Area of the district having EC < 2 can come under good quality category but among these area where SAR < 10 and RSC e" 2.5 will come under marginally alkali and alkali. Most of the area where EC is more than 4 dS/m went under high SAR saline in comparison to saline condition, whereas, in both condition EC is more than 4 dS/ m. With this fact area under high SAR saline is increased and area under saline condition is reduced. There is a little problem of alkalinity in

Table 3. Ground water quality distribution (%) in different blocks of Sonipat district

Water quality	Rai	Ganaur	Murthal	Gohana	Kathura	Kharkhoda	Mundlana	Sonipat	District
Good	22.39	48.39	62.22	27.18	28.15	32.08	25.11	35.29	31.37
Marginally saline	32.84	17.74	8.89	9.70	15.56	22.64	25.58	15.29	19.48
Saline	0.00	0.00	0.00	6.80	10.37	0.00	6.51	0.00	4.44
High SAR saline	20.89	6.45	0.00	18.45	19.25	30.19	24.29	12.94	18.56
Marginally alkali	10.45	6.45	17.78	10.68	1.48	9.43	0.00	15.29	6.54
Alkali	5.97	11.29	4.44	6.80	0.00	1.89	0.00	8.25	3.66
Highly alkali	7.46	9.68	6.67	20.39	25.19	3.77	18.60	12.94	15.95
Total samples	67	62	45	103	135	53	215	85	765

groundwater of the district because marginally alkali and alkali categories were observed very scattered with small polygons.

Conclusions

The dominance of major ions were in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and were $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$ for cations and anions, respectively. Therefore, the chemical composition of the groundwater was characterized by the Na–Cl water type. It was observed that in Sonipat district average Na^+ (116.77 mel^{-1}) and Cl^- (98.27 mel^{-1}) was the highest and its value increased with the increase in EC of ground water, It was found that maximum good quality 62.22 percent samples were found in Murthal block among all the blocks of Sonipat district. Therefore, the groundwater should be blended with canal water before irrigation which implies that regular monitoring of groundwater is imperative to avoid major environmental threat. The spatial distribution maps generated for various physico-chemical parameters using GIS techniques could be valuable for policy makers for initiating groundwater quality monitoring in the area.

Acknowledgements

The authors are thankful to Indian Council of Agricultural Research (ICAR), New Delhi under Grant of AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, at ICAR-Central Soil Salinity Research Institute, Karnal for technical help.

References

Arya S, Subramani T, Vennila G and Karunanidhi D (2021) Health risks associated with fluoride intake from rural drinking water supply and inverse mass balance modeling to decipher hydrogeochemical processes in Vattamalaikarai River basin, South India. *Environmental Geochemistry and Health* **43(2)**: 705-16.

Chaudhary V (2018) Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. *Applied Water Science* **8(8)**: 218-235.

Cheremisinoff NP (1997) Principles of geology. In: Cheremisinoff NP (ed) *Groundwater Remediation and Treatment Technologies,* William Andrew Publishing, pp. 1-37, https://doi.org/10.1016/B978-081551411-4.50003-X.

Eaton FM (1950) Significance of carbonate in irrigation waters. *Soil Science* **69(2)**: 123-133.

Jadhao, RB (2013) Ground water resource assessment: a case study on Murthal Block of Sonipat district. *Journal of Applied Chemistry* **3(5)**: 16-23.

Omran ESE, Ghallab A, Selmy S, and Gad AA (2014) Evaluation and mapping water wells suitability for irrigation using GIS in Darb El-Arbaein, South Western Desert, Egypt. *International Journal of Water Resources and Arid Environments* **3(1)**: 63-76.

Pradhan S, Chadrasekharan H, Jain N and Yadav BR (2011) Characterization of groundwater quality for Irrigation in 'Gohana' block of Sonepat District, Haryana. *Journal of Agricultural Physics* **11**: 63-70.

Prakash Ram, Dinesh and Kumar Sanjayt (2021)Survey and Mapping of Groundwater Quality of Sonipat Block in Sonipat District of Haryana, India. *Journal of Soil Salinity and Water Quality* **13(2)**: 221-227.

Ramprakash, Rajpaul, Kumar, Sanjay, Satyavan and Sharma, SK (2018) Mapping of groundwater quality for irrigation in Fatehabad district of Haryana,India. *Journal of Soil Salinity and Water Quality* **10(2)**: 186-191.

Richards LA (1954) Diagnosis*and Improvement of Saline and Alkali Soils.* USDA Hand Book, No.60.

Shahid M, Singh AP, Bhandari DK and Ahmad I (2008) Groundwater quality appraisal and categorization in Julana Block of Jind District, Haryana. *Journal of the Indian Society of Soil Science* **56(1)**: 123-125.

Sharma Sonal, Singh YV, Anuj Saraswat Anju, Prajapat Vinod and Kashiwar SR (2021) Groundwater Quality Assessment of Different Villages of Sanganer Block in Jaipur District of Rajasthan. *Journal of Soil Salinity and Water Quality* **13(2)**: 248-254.

Singh VK, Ramprakash, Rajpaul, Kumar, Sanjay, Singh, Kuldeep and Satyavan (2017) Evaluation of groundwater quality for irrigation in Gulha block of Kaithal district in Haryana. *Journal of Soil Salinity and Water Quality* **9(2)**: 241-248.

Yadagiri K, Sundaraiah R and Sateesh P (2015) Assessing groundwater quality and its suitability for irrigation purpose in Kothur area, Mahabubnagar district, Telangana State, India. *Indian Journal of Applied Research* **5(1)**: 222-225.

Received: February 9, 2023: Accepted: June 23, 2023

Journal of Soil Salinity and Water Quality 15(1), 46-51, 2023

GIS Mapping of Groundwater Quality for Irrigation in Hisar District of Haryana, India

Ram Prakash[1]*, Dinesh[1], Sanjay Kumar[2] and Kamaldeep[3]

[1]*Department of Soil Science, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*
[2]*Department of Soil and Water Engineering, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*
[3]*College of Agriculture, CCS Haryana Agricultural University, Hisar-125004, Haryana, India*
**Corresponding author E-mail: ramsansanwal@gmail.com*

Abstract

A survey of groundwater quality for irrigation was conducted in different villages of Hisar district, Haryana during 2021-2022 and 380 water samples were collected and analyzed for various hydro-chemical parameters viz. pH, EC, (Ca^{2+}, Mg^{2+} , Na^{+} and K^{+}) and anions (CO_3^{2-} , HCO_3^-, Cl^- and SO_4^{2-}) by using standard procedures. Irrigation indices such as SAR, RSC, were calculated for these samples. The pH, EC, SAR and RSC in groundwater ranged from 6.35 to 9.48, 0.20-14.90 (dS m^{-1}), 2.10-32.87(mmol $l^{-1})^{1/2}$ and 0.00-6.30 (mel^{-1}), respectively. The trend among the average ionic concentration of cations and anions were $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and anions were $Cl^- > SO_4^{2-} > HCO_3^- > CO_3^{2-}$. According to AICRP,1989 in Hisar district 26.3, 20.5, 5.5, 39.2, 1.1,1.1 and 6.3 per cent samples were found in good, marginally saline, saline, high SAR saline, marginally alkali, alkali and highly alkali categories, respectively. Spatial variability maps of EC, SAR and RSC of ground water used for irrigation in the district were also prepared.

Key words: Saline water, Alkali water, SAR, RSC, Special variability maps, Cations and Anions

Introduction

Underground water is important natural resource on earth used for drinking and irrigation purposes. In present day agriculture, most of the irrigation needs are met through the underground water. Although there is a plentiful supply of water, it cannot be replenished. One of the major qualities of water is that it can dissolve all the natural compounds, but this advantage makes it more vulnerable to local pollutants. These pollutants adversely affect the groundwater quality (Yadav *et al*., 2009). India accounts for 2.2% of the global land and 4% of the world's water resources and 16% of the world's population. Presently groundwater is the most important source of irrigation in India, thus deserving considerable attention for use in a sustainable way quantitatively and qualitatively (Toumi *et al*., 2015). The total groundwater potential in India is estimated as 43.1 M ha-m and the utilizable groundwater for irrigation is assessed as 32.47 M ha-m. It is likely to increase to 35 M ha-m by 2025 (Minhas, 2000). In Haryana, during the year 1966-67, about 1.3 million ha out of the total cultivated area of 3.6 million ha was irrigated (22% from groundwater and 78% from surface water). By the year 2010-11, the irrigation facilities with groundwater were developed for about 2.9 million ha area, the share is more than 57 % of the net irrigated area. This shows that groundwater utilization has increased considerably over the years. The average groundwater table in the districts of the state of Haryana has decreased as a result of this indiscriminate exploitation. As per the research, the present trend of declining groundwater depth could reduce India's total food grain production by around 25% or more by 2050.Water quality is a key concern due to rising demand these days. Quality aspects decide whether groundwater is suitable for specific use or not (Prakash *et al*., 2021). The physical, chemical, and biological characteristics of the water, that are used to assess its quality, are altered by agricultural, industrial, and human use. Its quality is likely to change from source to source and day by day. Any change in the natural quality may disturb the equilibrium system and would make it unfit for designated uses. Irrigation water quality is primarily determined by the type of water and the concentrations of dissolved solids and salts (Arya *et al.,* 2021). The general and fundamental criteria to determine the quality of irrigation water depend on the total content of soluble salt (salinity hazards), relative proportion of sodium, calcium, and magnesium, sodium absorption ratio (sodium hazards), residual sodium carbonate (RSC), and number of toxic elements. The salts in irrigation water originate from the dissolution or weathering of the rocks, dissolution of lime, gypsum, and other dissolved minerals. The availability of water either through surface or groundwater resources is becoming critical every day. In Haryana state, 37% of water is of good quality, 8% normal and 55% is of poor quality. Out of this poor-quality water, 11% is saline, 18% is alkali, and 26% is saline-alkali (Manchanda, 1976). For the sustainable development of society, groundwater is indispensable. Hence survey and characterization of groundwater quality in every region of the country is a prerequisite for its better supervision and utilization (Rao, 2018). By keeping the above facts, an investigation was carried for groundwater quality of Hisar district, Haryana, used for irrigation purposes by assessing different water quality parameters. There has been very little information on the groundwater quality for irrigation in the Hisar district region, and variations in water quality parameters have been recorded. Therefore, an investigation of the nature, properties, and quality of irrigation is needed to determine the potential of secondary salinization/ sodification in this location. To get a comprehensive picture of the groundwater quality for irrigation purposes of a region/block, a significant number of samples from throughout the area must be evaluated. In light of the above, 380 water samples were collected from the Hisar region for this research, and water quality status was assessed.

Material and Methods

Study area

Hisar district geomorphology is divided into two major categories: fluvial origin landforms and aeolian origin landforms. Fluvial landforms found in this district include older deep alluvial plains, palaeo-channels, and palaeo-channels, while eolian landforms include dune complexes, eolian plain deep, interdunal flats, and sand dunes. Hisar district is divided into nine blocks, namely, Agroha, Adampur, Barwala, Hansi-I, Hansi-II, Hisar-I, Hisar-II, Narnaund and Ukalana, Hisar town is the headquarter of the district. The Hisar district has a tropical monsoonal climate and is classified as arid. Summer maximum day temperatures range from 40 to 46 °C, while winter temperature ranges from 1.5 to 4 °C. The main characteristics of the climate in the district are its dryness, temperature extremes, and scarcity of rainfall. Winds are strong and frequent from May to July. The Hisar district receives approximately 450 mm of rain per year on average. During the South West Monsoon season, which lasts from June to September, approximately 75 to 80% of the annual rainfall is received. In general, rainfall in the district increases from southwest to northeast. The district is located in the Ghaggar basin of the Indo-Gangitic plains. Out of the total irrigated area of the district 76.83% area is irrigated by canal and rest 23.17% is irrigated by ground water. There are sand dunes in canal command area, over which rain fed crops are grown. The district's soils are classified into three types: arid brown solonized (in the north eastern parts of Narnaund and Uklana Mandi blocks), sierozem (in the major parts of Barwala, Hansi-I, Hansi-II, Hisar-I & Agroha blocks, and parts of Uklana, Narnaund, Adampur, and Hisar-II blocks), and desert soils (in southern western parts covering part of Adampur and Hisar-II blocks). Sandy loam soils cover 81% of the total district area, *i.e.,* 327000 ha, and are useful for macro and minor irrigation in this area. The district area is irrigated by shallow tube wells and Bhakra Canal network system. Hisar district, Haryana during 2021-2022 to evaluate the quality of groundwater for irrigation for different crops and the location map is prepared (Fig. 1). The samples were collected in thoroughly cleaned, properly labeled and carefully corked plastic bottles. Before collection of water in a particular bottle, the bottle is rinsed with the respective samples of groundwater and immediately after collection

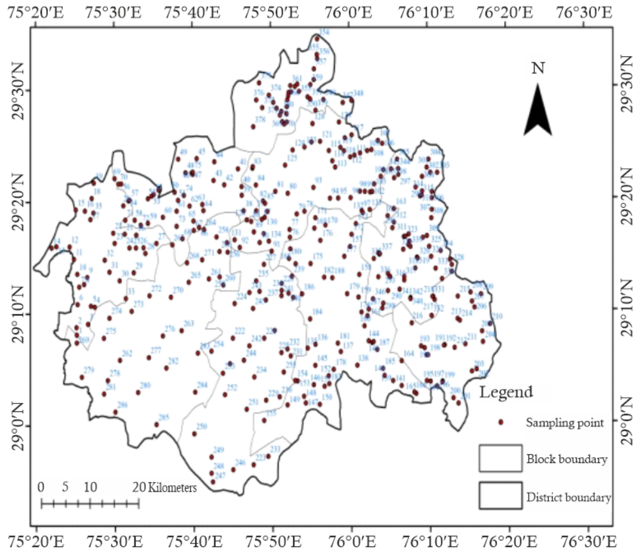

Fig. 1 Location map of sampling points in Hisar district

Table 1. Range and mean of different water quality parameters for Hisar district

Sr. No.	Quality parameter	Range	Mean
1	pH	6.35-9.48	7.73
2	EC (dS m^{-1})	0.20-14.90	4.30
3	RSC (me l^{-1})	0.00-6.30	0.44
4	SAR (mmol $l^{-1})^{1/2}$	2.10-32.87	11.81
5	Ca^{2+} (me l^{-1})	0.08-12.50	2.87
6	Mg^{2+} (me l^{-1})	0.21-32.00	8.52
7	Na^{+} (me l^{-1})	1.50-108.20	29.57
8	K^{+} (me l^{-1})	0.02-17.36	0.74
9	CO_3^{2-} (me l^{-1})	0.00-2.90	0.45
10	HCO_3^{-} (me l^{-1})	0.10-12.50	4.36
11	Cl^{-} (me l^{-1})	1.60-132.00	25.27
12	SO_4^{2-} (me l^{-1})	0.03-60.80	11.16

samples were transferred laboratory for chemical analysis. The chemical analysis was accomplished at CCS Haryana Agricultural University, Hisar as per the standard methods relevant to analysis of groundwater. Electrical Conductivity (EC) was measured by conductivity meter and pH by digital pH meter. Sodium (Na^+) and potassium were measured by flame photometer. Calcium and magnesium were determined with standard EDTA solution titrimetrically. Carbonate and bicarbonate were estimated by titration with H_2SO_4, Chloride by titrating against standard silver nitrate ($AgNO_3$) solution. The calorimetric analysis of sulphate was done by spectro-photometer. Measurements were done in triplicate to ensure reliability and good quality control. Sodium Adsorption Ratio (SAR) and Residual Sodium Carbonate (RSC) were calculated as:

a) Sodium adsorption ratio (SAR) {Richards, 1954}:

$$\mathrm{SAR\,(mmol\,l^{-1})^{1/2}} = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

b) Residual sodium carbonate (RSC) (Eaton, 1950):

$$\mathrm{RSC\,(me\,l^{-1})} = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$$

Water samples were classified into different categories as per the classification of All India Coordinated Research Project (AICRP, 1989) on Management of Salt Affected Soils and Use of Saline Water in Agriculture.

Results and Discussion

In the Hisar district, electrical conductivity (EC) of water ranged from 0.20 to 14.90 dS m^{-1} with a mean of 4.30 dS m^{-1} (Table 1). It was observed that in Hisar district, 111 samples had EC range of 0-2 dS m^{-1}, 101 samples had EC ranges from 2-4 dS m^{-1}, 63 samples had EC ranges from 4-6 dS m^{-1}, 65 samples had EC ranges from 6-8 dS m^{-1}, 17 samples had EC ranges from 8-10 dS m^{-1} and 23 samples had EC ranges from >10 dS m^{-1} (Table 2). To study the spatial distribution of EC in the whole district, a spatial variable map was prepared by using ArcGIS through the interpolation of the available data at 380 sampling points (Fig. 2). The variation of EC in Hisar district is grouped in to 6 classes with a class interval of 2 dS m^{-1}. The most dominating range of EC is 0-2 dS m^{-1} which occupied maximum area in the district and covering all the blocks of the district. The next dominating range was 2-4 dS m^{-1}, which is covering a large portion. EC ranging from 8-10 and >10 dS m^{-1} is observed in small part of the district. The pH ranged from 6.35 to 9.48 with a mean of 7.73 (Table 1). The sodium adsorption ratios (SAR) were found to be between 2.10 to 32.87 (mmol $l^{-1})^{1/2}$ with a mean value of 11.81 (mmol $l^{-1})^{1/2}$. Spatial variability of SAR of groundwater used for irrigation in Hisar district presented in (Fig.4). The residual sodium

Table 2. Average chemical composition of groundwater samples of Hisar district in different EC classes

EC classes (dS m^{-1})	No. of samples	Na^+	Ca^{2+}	Mg^{2+}	K^+	CO_3^{-2} (mel^{-1})	HCO_3^-	Cl^-	SO_4^{-2}	RSC	SAR (mmol l^{-1})$^{1/2}$
0-2	111	7.36	0.75	2.25	0.27	0.09	2.03	5.45	2.45	5.39	10.64
2-4	101	20.05	2.12	6.37	0.83	0.59	4.63	16.12	7.94	2.34	10.34
4-6	63	33.19	3.94	11.74	0.61	0.27	5.47	29.60	13.48	0.34	12.47
6-8	65	47.97	4.58	13.77	0.74	0.83	5.94	40.79	18.75	0.39	16.45
8-10	17	62.03	5.31	15.59	1.73	0.78	6.39	47.97	29.10	0.30	19.44
>10	23	92.17	7.82	22.18	2.15	0.42	6.67	89.54	26.53	0.43	24.35

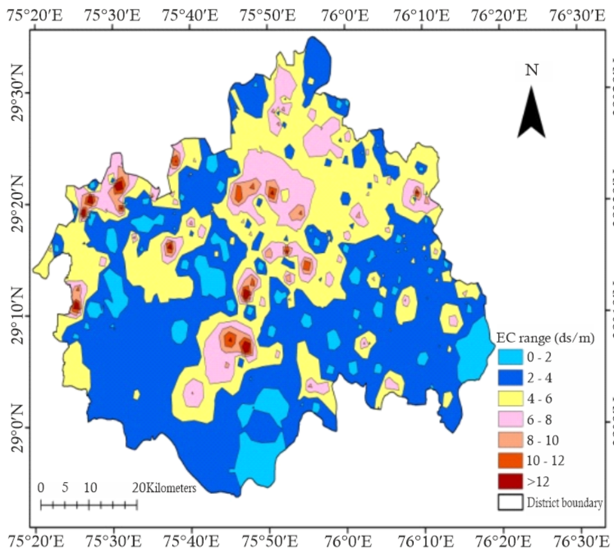

Fig. 2 Spatial map for EC of groundwater in Hisar district

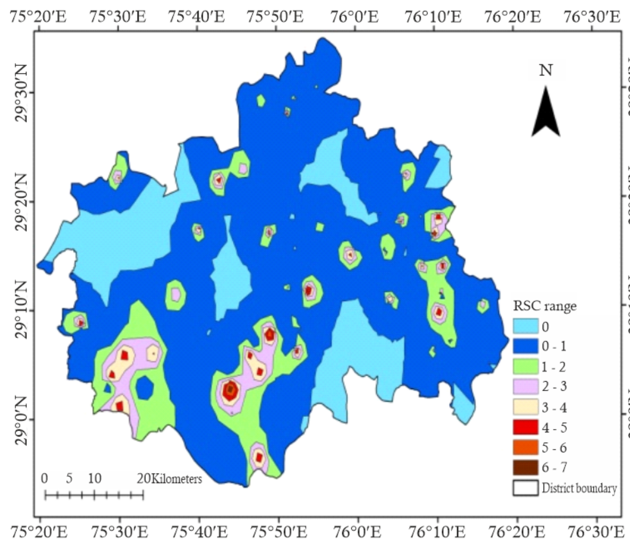

Fig. 3 Spatial map of RSC of groundwater in Hisar district

carbonate (RSC) was found to be ranged between from 0.00 to 6.30 mel^{-1} with a mean value of 0.40 mel^{-1}. Spatial variability of RSC of groundwater used for irrigation in Hisar district presented in (Fig. 3). In case of anions, chloride was the dominant anion with maximum the concentration of chlorides in groundwater samples varied from 1.60 to 132.00 me l^{-1} with the mean value of 25.27 me l^{-1}. The concentration of bicarbonates in groundwater samples varied from 0.10 to 12.50 mel^{-1} with a mean value of 4.36 me l^{-1}. The mean values for CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} were found to be 0.45, 4.36, 25.27 and 11.16 mel^{-1}, respectively (Table 1). Table 2 illustrate the mean of anions according to the EC classes in district, the Cl^- was the highest and its value increased with the increase in EC. Dhaka *et al*. (2022) surveyed of ground water of Pali district Rajasthan and he collected fifty-five water samples and reported that chloride was observed as dominant anion in underground irrigation waters of both Marwar

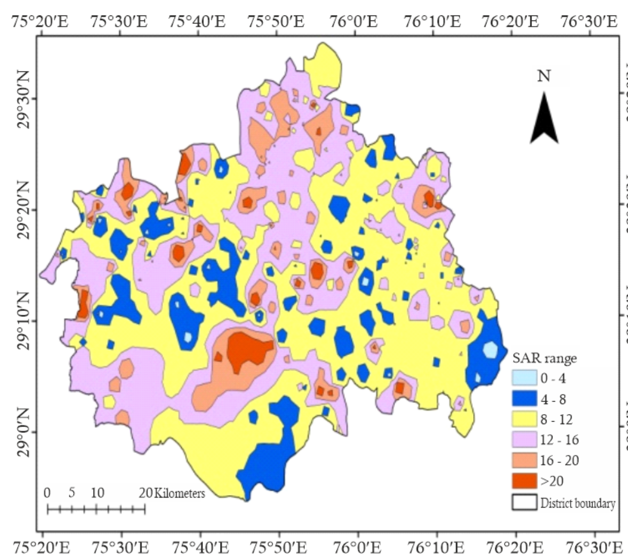

Fig. 4 Spatial map of SAR of groundwater in Hisar district

Junction and Rani tehsil. The concentration of sodium in groundwater samples varied from 1.50 to 108.20 mel^{-1} with an average value of 29.57 mel^{-1} (Table 1), followed by magnesium (0.21 to 32.00

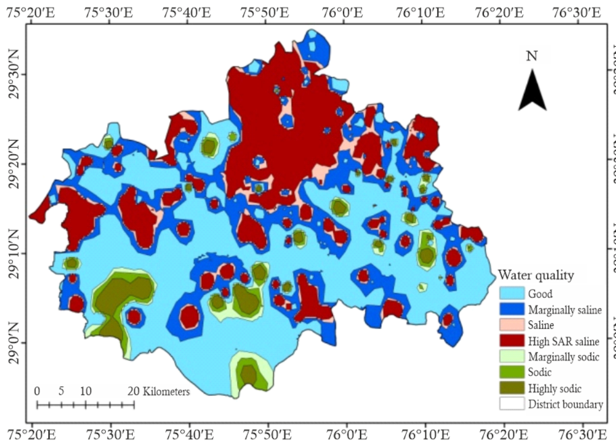

Fig. 5 Spatial map of groundwater quality in Hisar district

mel^{-1}) and calcium (0.08 to 12.50 me l^{-1}). Mean values for Na^+, Mg^{2+}, Ca^{2+} and K^+ were 29.57, 8.52, 2.87 and 0.74 me l^{-1}respectively. Table 2 illustrate the mean of cation according to the different EC classes in Hisar district, Na^+ was the highest and its value increased with the increase in EC. Its lowest mean value (7.36 me l^{-1}) was found in the class 0-2, the highest mean value (92.17 me l^{-1}) was laid in the EC class of >10 dS m^{-1}. The mean cationic composition was observed in order of Na^+> Mg^{2+} > Ca^{2+} > K^+ likewise the anionic composition was observed in order of Cl^- > SO_4^{2-} >HCO_3^-> CO_3^{2-}. Prakash *et al.* (2021) reported the same order of abundance of cations and anions in sonipat block of Sonipat district was in order of Na^+> Mg^{2+} > Ca^{2+} > K^+ likewise the anionic composition was observed in order of Cl^- > SO_4^{2-} >HCO_3^-> CO_3^{2-}. Dhaka *et al.* (2022) characterization and quality assessment of ground waters of Marwar Junction and Rani Tehsils of Pali, Rajasthan reported that sodium was dominant cation followed by magnesium, calcium and potassium. The results of the present investigation were in accordance with the findings of Bali (2015). Bangar *et al.* (2022) studied groundwater quality assessment, characterization and mapping for Madhya Pradesh, India for Irrigation purpose and observed that most of the ground water samples under good water class had dominance of Ca followed by Na and then Mg. In case of anions, Cl was dominant ion followed by HCO_3 and CO_3. Further spatial maps were prepared for EC, pH, SAR and RSC of groundwater using GIS software (GIS software ArcMap 9.3.1).

According to AICRP classification, it was found that in Hisar district, 26.3, 20.5, 5.5, 39.2, 1.1, 1.1 and 6.3 per cent samples were found in good, marginally saline, saline, high SAR saline, marginally alkali, alkali and highly alkali categories, respectively (Fig. 6). Groundwater quality map for Hisar district according to AICRP criteria was prepared to study its spatial variability in the district (Fig. 5).

In the district, 26.3 percent samples are under good category but spatial variable map of block level indicates less area under good quality. This is due to higher concentration of tube wells in that area and accordingly more samples were collected from that area. Area of the district having EC < 2 can come under good quality category but among

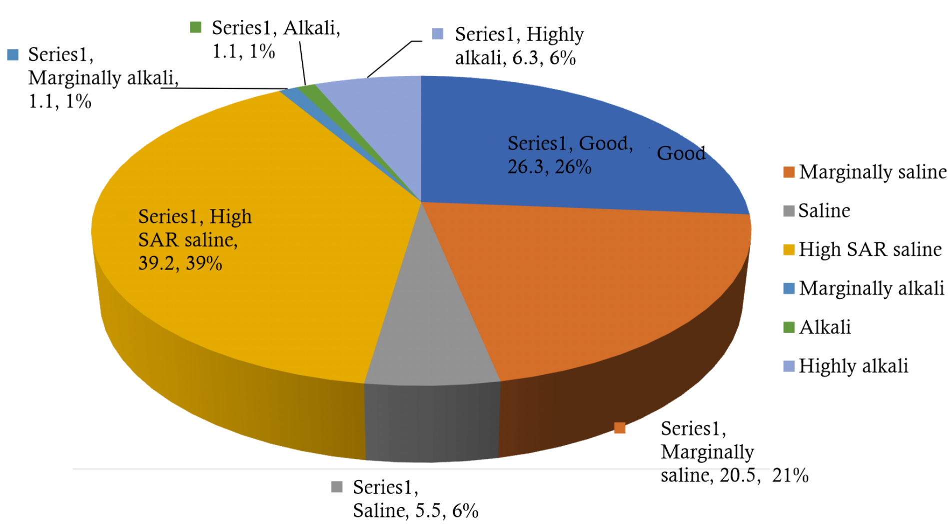

Fig. 6 Status of groundwater quality (percent) in Hisar district

these areas where SAR < 10 and RSC ≥ 2.5 will come under marginally alkali and alkali. Most of the area where EC is more than 4 dS m^{-1} went under high SAR saline in comparison to saline condition, whereas, in both condition EC is more than 4 dS m^{-1}. With this fact area under high SAR saline is increased and area under saline condition is reduced. There is a little problem of alkalinity in groundwater of the district because marginally alkali and alkali categories were observed very scattered with small areas.

Conclusions

This study provides reliable data about water quality occurring in Hisar district for farmers, researcher and planner. The dominance of major ions was in the order of $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+}$ and anions were $Cl^{-} > SO_4^{2-} > HCO_3^{-} > CO_3^{2-}$ for cations and anions, respectively. Therefore, the chemical composition of the groundwater was characterized by the Na–Cl water type. The spatial distribution maps generated for various physico-chemical parameters using GIS techniques could be valuable for policy makers for initiating groundwater quality monitoring in the area.

Acknowledgements

The authors are thankful to Indian Council of Agricultural Research (ICAR), New Delhi for Grant under AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, at ICAR-Central Soil Salinity Research Institute, Karnal and technical support.

References

Arya VS, Singh S, Rao GS and Hooda RS (2011) Sub-soil water studies using remote sensing and geographical information system. *International Journal of Scientific and Technology* **6**: 71-76.

Bali B, Kumawat BL, Singh A and Chopra R (2015) Evaluation of ground water in Sriganganagar district of Rajasthan. *The Ecoscan* **9(1&2)**: 133-136.

Bangar KS, Kumawat Narendra, Kaledhonkar MJ, Parmar BB and Tagore GS (2022) Groundwater quality assessment, characterization and mapping for Madhya Pradesh, India for Irrigation Purpose. *Journal of Soil Salinity and Water Quality* **14(1)**: 33-52.

Dhaka Suman, Singh Ranjeet, Chanwla Chintu, Serawat Asha and Sharma RK (2022) Characterization and quality assessment of ground waters of Marwar Junction and Rani Tehsils of Pali, Rajasthan. *Journal of Soil Salinity and Water Quality* **14(1)**: 28-32.

Eaton FM (1950) Significance of carbonate in irrigation waters. *Soil Science* **69**(2): 123-133.

Manchanda HR (1976) *Quality of Ground Water in Haryana,* CCSHAU, Hisar. pp. 160.

Minhas PS (2000) An inventory of India's water resources. Training Course on "Use of saline water for irrigation" from 26 June to 16 July, 2000. CSSRI, Karnal. 2000. 1-14.

Prakash R and Dinesh Kumar S (2021) Survey and mapping of groundwater quality of Sonipat Block in Sonipat district of Haryana, India. *Journal of Soil Salinity and Water Quality* **13**(2): 221-227.

Rao DK, Panchaksharjah S, Pati BN, Narayana A and Raiker DLS (2018) Chemical composition of irrigation waters from selected parts of Bijapur district, Karnataka. *Mysore Journal of Agricultural Science* **16**: 426-432.

Richards LA (1954) *Diagnosis and Improvement of Saline and Alkali Soils.* USDA Hand Book, No.60.

Toumi N, Hussein BHM, Rafrafi S and Neama E (2015) Groundwater quality and hydrochemical properties of Al-Ula Region, Saudi Arabia. *Environmental Monitoring and Assessment* **187**: 1-16.

Yadav AK, Khan P, Saxena U (2009) Geochemical observation of fluoride in ground water of Tonk (Rajasthan). *Rasayan Journal of Chemistry* **2(4)**: 994-1000.

Received: April 12, 2022; Accepted: June 23, 2023

Journal of Soil Salinity and Water Quality 15(1), 52-60, 2023

A New Model to Measure in Situ Saturated Hydraulic Conductivity Using Auger Hole with Flat Bottom

Gyan Singh[1], Chhedi Lal Verma[2] and DM Denis[3]

[1]Ph.D.Research Scholar (S&WCE), Vaugh Institute of Agricultural Engineering & Technology, Sam HigginBottom University of Agriculture, Technology & Sciences, Prayagraj-211007, Uttar Pradesh, India
[2]Senior Scientist & Ex. Professor, ICAR-Central Soil Salinity Research Institute, Regional Research Station, P.O. Alambagh, Lucknow-226005, Uttar Pradesh, India
[3]Head of Department (Irrigation & Drainage Engineering), Vaugh Institute of Agricultural Engineering & Technology, Sam HigginBottom University of Agriculture, Technology & sciences, Prayagraj-211007, Uttar Pradesh, India
**Corresponding author E-mail: lalc_verma@yahoo.com*

Abstract

The value of saturated hydraulic conductivity (K_s) are essentially required for the design of subsurface drainage and design of elevated field beds for reclamation and management of waterlogged saline as well as sodic soils. Hooghoudt (1936) model for K_s was modified in the present study to improve the estimate. A model for K_s measurement was also developed and compared with existing model. Ernst (1950) model is widely used for field application. The newly proposed model calculated the value of K_s as 0.248 m day^{-1}. Hooghoudt, modified Hooghoudt and Ernst model gave the values of K_s as 0.436, 0.455 and 0.255 m/day. The K_s value obtained by newly developed model was closest to the value obtained by the Ernst model with deviation of 0.8% only. The new model is quite simple to understand with best accuracy hence recommended for field application.

Key words: Auger hole method, Elevated field bed, Saturated hydraulic conductivity, Subsurface drainage, Waterlogged saline soil

Introduction

India is suffering with salt accumulation in soil over an area of 9.5 Mha. out of which 3.0 Mha is sodic. Indo - Gangetic plains is having sizable area of 1.31 Mha under sodic condition (Singh *et al.*, 2016). Sizable area of sodic soil located in large canal command is suffering with twin problems of waterlogging and sodicity. Subsurface natural drainage of the area is insufficient to handle the seepage loss from the large canals at different reaches of the canals. Waterlogged saline soil mostly lying in arid and semi-arid area and are easily reclaimed by improving internal drainage through subsurface drainage. Design and proper functioning of subsurface drainage in waterlogged saline soil as well as elevated field bed of integrated farming system in waterlogged sodic area is dependent on saturated hydraulic conductivity (K_s) of the soil which is a basic input parameter to the drain spacing or raised bed width calculation equations. The K_s is space and time-dependant hence one must adequately assess a representative value. Estimation of a representative value of K_s conductivity is time consuming and expensive, hence one has to optimize for the available budget and desired accuracy. K_s of soil can be obtained by correlation methods or with hydraulic methods which maybe either laboratory or in-situ methods (Woesten, 1990). Correlation methods are quick and based on predetermined relationships of soil properties (Woesten and van Genuehten, 1988). Aronovici (1947) correlated silt and clay content with hydraulic properties of soil. Singh and Verma (2010a and b) derived viscous resistance model and drag resistance model for estimation of K_s from particle size distribution data. These model have their own limitations and merits for field applicability. Smedma and Rycroft (1983) generalized tables with K_s values for various soil textures. These methods are subjected to random errors. Hydraulic methods based on flow conditions in the soil making use of Darcy's law and the boundary conditions of the flow.

Researchers also proposed field dripper methods for in-situ measurement of unsaturated hydraulic functions (Warrick, 1985; Shani *et al*., 1987; Ojha *et al*., 2020).The K_s value is also calculated from the equation using the values of hydraulic head and discharge recorded in fields or laboratories. Gallage *et al*. (2013) developed a new permeameter for the measurement of unsaturated hydraulic conductivity of the soil using directly measured suction. Jacka *et al*. (2014) compared K_s values obtained from Guelph permeameter, laboratory permeameter and single ring infiltrometer for mountain podzols. All the test provided similar mean values. Laboratory methods are laborious than correlation methods but quick and cheap also eliminate uncertainties involved in relating soil properties to K_s values. Laboratory methods also have limitations as that of correlation methods in terms of variability and representativeness. In situ hydraulic methods may be either small scale or large scale. The small scale methods are quick covering many locations and avoiding complexities with least expense. Variability is minimized in case of the in-situ methods due to coverage of large soil volume. Infiltro meter and inverse auger hole methods employ similar hypothesis for measuring in-situ K_s of soil in absence of water table. Infiltrometer method measures vertical saturated hydraulic conductivity of surface soil while inverse auger hole method measures horizontal K_s of subsoil (Hoorn, 1979). The auger hole method for measurement of in-situ K_s of the soil in presence of water table for design of subsurface drainage systems is a quick, simple and reliable (Hooghoudt, 1936; Kirkham, 1945, 1955; Bavel and Kirkham, 1948; Ernst, 1950; Johnson *et al*., 1952). Hooghoudt (1936) developed first auger hole model for in-situ K_s measurement which is quite simple. Ernst (1950) reported by van Beers (1970) and Bouwer and Jackson (1974) developed another model of in-situ K_s using auger hole data. Method is used for field applications too. Accurate estimation of K_s is needed for the design of sub-surface drainage systems (Barua and Alam, 2013). Barua and Alam (2013) analyzed the flow of auger hole numerically when it is penetrating to impervious layer and when it is suspended above an impervious layer and developed similar expression of K_s as that by Ernst (1950). These models are complex and still there is a need for simpler model for in-situ K_s estimation. Inverse auger hole method by Hoorn (1978) is used for K_s estimation in absence of water table. The present study is devoted to develop a new model of K_s estimation using auger hole data.

Materials and Methods

Hooghoudt (1936) auger hole Model

A definition sketch of auger hole method for in-situ K_s measurement are shown in Fig. 1. Hooghoudt (1936) developed following equation for K_s.

$$K_s = \frac{2.3\,r\,S}{(2D+r)}\tan\alpha_H \tag{1}$$

$$\tan\alpha_H = \frac{\log_{10} H_o - \log_{10} H_t}{t} \tag{2}$$

where,

H_o = water table depth in the hole below static water level after bailing out water

H_t = water table depth in the hole below static water level after time t of bailing out water

D = Water level depth before bailing

S = rD/0.19

r = radius of the hole

t = time

Modification of Hooghout (1938) auger hole model

Hooghoudt Eqn. (1) can be modified by replacing the expression for S = rD/0.19 with an expression of S=1/C. C is the geometry or shape factor of Ernst (1950). The Eqn. (1) with this modification becomes.

$$K_s = \frac{2.3\,r}{C(2D+r)}\tan\alpha_H \tag{3}$$

Ernst (1950) developed following equation for K_s.

$$K_s = C\,\frac{\Delta h}{\Delta t} \tag{4}$$

C= geometry or shape factor f(h, D, r, d) defined by following expressions

When, depth of impervious layer d > 0.5 D

$$C = \frac{4000\frac{r}{h'}}{\left(20+\frac{D}{r}\right)\left(2-\frac{h'}{D}\right)} \quad (5)$$

When, depth of impervious layer d =0

$$C = \frac{3600\frac{r}{h'}}{\left(10+\frac{D}{r}\right)\left(2-\frac{h'}{D}\right)} \quad (6)$$

If all the values are written in cm and time in sec the K_s value would be in m/d.

New Model Development

Hypothesis: Rate of rise of water level within the auger hole ($\frac{dh}{dt}$) after bailing out water below static water level is directly proportional to effective saturated area of the auger hole (A_s) causing flow within the hole (Fig. 1). Mathematically it can be expressed as below.

$$\frac{dh}{dt} \propto A_{sT} \quad (7)$$

Further, the rate of rise of water level within the hole ($\frac{dh}{dt}$) is inversely proportional to the specific empty volume of the hole (V_{es})

$$\frac{dh}{dt} \propto \frac{1}{V_{es}} \quad (8)$$

Rate of rise of water level within auger hole is also directly proportional to geometry or shape factor C. It can be written as below.

$$\frac{dh}{dt} \propto C \quad (9)$$

Combining Equation (6), (7) and (8) one will get the following hypothesis expression.

$$\frac{dh}{dt} \propto \frac{CA_{sT}}{V_{es}} \quad (10)$$

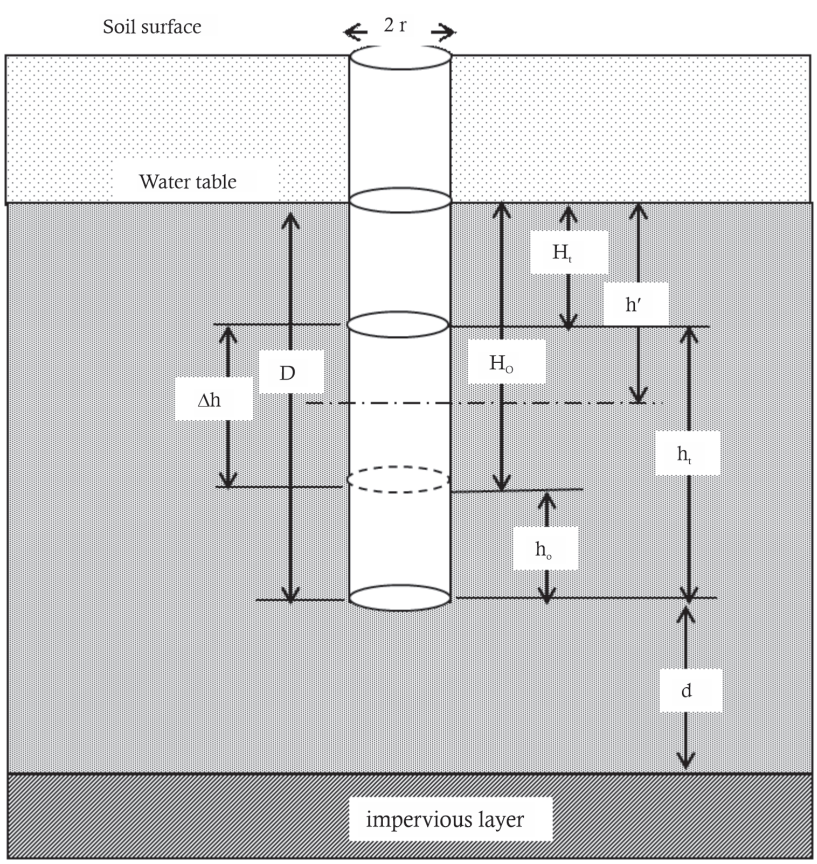

Fig. 1 Definition sketch of auger hole

Introducing a proportionality constant of water flow towards the flow, K_s known as saturated hydraulic conductivity of the soil, if the hydraulic gradient is unity (i=1) as that of Infiltration rate from Infiltrometer [$v=K_s\, i$ $v= K_s$]. Therefore, Eqn. (4) becomes

$$\frac{dh}{dt} = K_s \frac{CA_{sT}}{V_{es}} \quad (11)$$

a) When depth of impervious layer is below the bottom of the hole (s>0)

Eqn (10) can be solved for flat bottom geometry. Saturated bottom area of the hole through which water entering the hole can be written as below.

$$A_{sT} = \pi r^2 \quad (12)$$

Saturated circumferential area through which water entering the hole can be written as below.

$$A_{sT} = 2\pi r\,(D-h) \quad (13)$$

Thus Total saturated area through which flow is taking place can be written as below

$$A_{sT} = \pi r^2 + 2\pi r (D-h) \quad (14)$$

$$A_{sT} = 2\pi r \left\{ (D-h) + \frac{r}{2} \right\} \quad (15)$$

Specific volume of hole is defined as the volume of hole per unit depth of saturated hole i.e. $\left(\frac{V_{sh}}{D}\right)$. Since the saturated volume of the soil removed from hole i.e. the volume of the hole up to static water level within the soil is $\pi r^2 D$ when the depth of the saturated portion of the hole is D, hence the specific empty saturated volume of the hole becomes.

$$V_{es} = \frac{\pi r^2 D}{D} = \pi r^2 \quad (16)$$

Substituting Eqn (14) and (15) into Eqn (9) one will arrive at,

$$\frac{dh}{dt} = CK_s \left[\frac{2\pi r \left\{ (D-h) + \frac{r}{2} \right\}}{\pi r^2} \right] \quad (17)$$

$$\frac{dh}{dt} = CK_s \left\{ \frac{2\pi r (D-h) + \pi r^2}{\pi r^2} \right\} \quad (18)$$

$$\frac{dh}{dt} = CK_s \left\{ \frac{2}{r}(D-h) + 1 \right\} \quad (19)$$

$$\frac{dh}{dt} = CK_s \left\{ \frac{2D}{r} - \frac{2h}{r} + 1 \right\} \quad (20)$$

$$\frac{dh}{dt} = CK_s \left\{ \left(1 + \frac{2D}{r}\right) - \frac{2h}{r} \right\} \quad (21)$$

$$\frac{dh}{dt} = CK_s \left\{ \left(\frac{2D+r}{r}\right) - \frac{2h}{r} \right\} \quad (22)$$

Separating variable and integral the above equation under the limit of

$$t = o,\ h = h_o \text{ and } t = t,\ h = h_t \quad (23)$$

$$\int_{h_o}^{h_t} \frac{dh}{\frac{2D+r}{r} - \frac{2}{r} h} = CK_s \int_o^t dt \quad (24)$$

If $\alpha = \frac{2D+r}{r}$ and $\beta = \frac{2}{r}$ the above Equation can be also written as below.

$$\int_{h_o}^{h_t} \frac{dh}{\alpha - \beta h} = CK_s \int_o^t dt \quad (25)$$

General solution of the indefinite integral of the above form can be written as below.

$$\int \frac{dx}{ax + b} = \frac{1}{a} \ln(ax+b) \quad (26)$$

Where a=β and b =α

Therefore the integration of equation (23) be can

$$-\frac{1}{\beta} \ln(\alpha - \beta h) \Big]_{h_o}^{h_t} = \frac{K_s}{C} t \Big]_o^t \quad (27)$$

Substituting the volume of $\alpha = \frac{2D+r}{r}$ and $\beta = \frac{2}{r}$

$$CK_s\, t \Big]_o^t = \frac{r}{2} \ln \left\{ \left(\frac{2D+r}{r}\right) - \frac{2h}{r} \right\} \Big]_{h_t}^{h_o} \quad (28)$$

$$CK_s t = \frac{r}{2} \ln\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_o}{r}\right\} - \ln\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_t}{r}\right\} \tag{29}$$

$$K_s = \frac{r}{2C}\frac{\ln\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_o}{r}\right\} - \ln\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_t}{r}\right\}}{t} \tag{30}$$

$$K_s = 1.15\frac{r}{C}\frac{\log_{10}\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_o}{r}\right\} - \log_{10}\left\{\left(\frac{2D+r}{r}\right) - \frac{2h_t}{r}\right\}}{t} \tag{31}$$

Which can be further simplified as below.

$$K_s = 1.15\frac{r}{C}\frac{\log_{10}\left\{\left(D+\frac{r}{2}\right) - h_o\right\} - \log_{10}\left\{\left(D+\frac{r}{2}\right) - h_t\right\}}{t} \tag{32}$$

$$K_s = 1.15\frac{r}{C}\tan\alpha_p \tag{33}$$

Where,

$$\tan\alpha_p = \frac{\log_{10}\left\{\left(D+\frac{r}{2}\right) - h_o\right\} - \log_{10}\left\{\left(D+\frac{r}{2}\right) - h_t\right\}}{t} \tag{34}$$

Eqn. (32) can be finally written as below.

$$K_s = \frac{K_{s-index-p}}{C} \tag{35}$$

Where,

$$K_{s-index-p} = 1.15 r \tan\alpha_p \tag{36}$$

(b) When depth of impervious layer is at the bottom of the hole (d=0)

When bottom of the auger hole is penetrating the impervious layer, the flow from the bottom reduces to zero. Thus total saturated area through which flow is taking place can be written from Eqn. (13) as below

$$A_{sT} = 0 + 2\pi r(D-h) = 2\pi r(D-h) \tag{37}$$

Since the specific volume of hole is πr^2 Eqn. 16 reduces to,

$$-\frac{dh}{dt} = CK_s\left[\frac{2\pi r\{(D-h)\}}{\pi r^2}\right] \tag{38}$$

$$-\frac{dh}{dt} = CK_s\left\{\frac{2(D-h)}{r}\right\} \tag{39}$$

Separating variables and integrating the above equation under the limit of Eqn. (39)

$$CK_s\int_o^t dt = -\frac{r}{2}\int_{h_o}^{h_t}\frac{dh}{D-h} \tag{40}$$

General solution of the indefinite integral of the above form can be written as below.

$$\int\frac{dx}{a-x} = -\ln(a-bx) \tag{41}$$

Therefore the integration of equation (39) would be

$$CK_s t\Big]_o^t = -\ln(D-h)\Big]_{h_o}^{h_t} \tag{42}$$

$$K_s = \frac{r}{2C}\frac{\ln(D-h_o) - \ln D - h_t}{t} \tag{43}$$

Changing the natural log to the base of 10 as below.

$$K_s = 1.15\frac{r}{C}\frac{\log_{10}(D-h_o) - \log_{10}(D-h_t)}{t} \tag{44}$$

Which can be further simplified as below.

$$K_s = 1.15\frac{r}{C}\tan\alpha_{pp} \tag{45}$$

Where,

$$\tan\alpha_{pp} = \frac{\log_{10}(D-h_o) - \log_{10}(D-h_t)}{t} \tag{46}$$

Eqn. (44) can be finally written as below.

$$K_s = \frac{K_{s-index-pp}}{C} \tag{47}$$

Where,

$$K_{s-index-pp} = 1.15 r \tan\alpha_{pp} \tag{48}$$

Application of the Model

Three auger holes of 10 cm diameter and 150 cm deep were constructed near Mahraura village along the Sharda Sahayak Canal in district Raebareli. After the preparation of the holes they were left for 24 hours for attaining their static water level. Impervious layer in the region lies below 3 m of ground surface. Average static water level was observed as 50 cm below the ground surface. The water was bailed out upto 120.5 cm depth and rate of rise was measured. Average rise of water table is shown in Fig. 2. Water depth before the bailing out of water was 100 cm. Water depth below ground surface was changed to water level height above the bottom of the hole. ($D+r/2-h_o$) and ($D+r/2-h_t$) and their respective $\log_{10}$ values were calculated. $\log_{10}(D+r/2-h_o) - \log_{10}(D+r/2-h_t)$ were plotted against elapsed time t and slope of the line (tan α) was worked out. Eqn. (26) was employed to calculate K_s value of the soil. K_s value was also calculated be Hooghoudt (1936) model, Ernst (1950), infiltrometer and constant head permeameter method for the purpose of comparison.

Results and Discussion

Water level fluctuations

The water level within the hole rose from 120.5 cm to 83.2 cm below the ground surface over a time span of 900 second. Saturated depth of auger hole or the depth of water filled in the hole before bailing out of water was measured as 100 cm. The variation of water level within the hole against time is shown in Fig. 2. The variation in water level height above bottom of the hole (h_t) in cm against time (t) in minute was well explained by the following function.

$$h_t = 43.05342\left(1.71808 - e^{-0.11201357\,t}\right) \qquad (49)$$

Calculation of K_s value

1. Proposed method

The water in the auger hole which was initially 50 cm deep below the soil surface came down to a level of 70.5 cm (H_o=120.5 cm bgl) below the static water level which rose to the level of 33.2 cm (H_t=83.2 cm bgl) below static water level over a time of 900 s. Thus the rise in water table in time Δt=900 s was recorded as Δh= 37.3 cm and rate of rise was calculated as $\Delta h/\Delta t$=0.04144. The height of water level above the bottom of hole immediately after the bailing was h_o=29.5 cm and after 900 s it was h_t= 66.8 cm. The value of h^1 was calculated as 51.85 cm. The value of 20+D/r was calculated as 40 and $2-h^1/D$ as 1.4815 and their product as 59.26. The value of 4000 (r/h^1) was calculated as 385.7281. The value of C was calculated by taking ratio of 4000 (r/h^1) and ($20+D/r$)($2-h^1/D$) as 6.5091.Calculation of $K_{s\text{-index}}$ is presented in Table 1. Plotted values of $\log_{10}(D+r/2-h_o) - \log_{10}(D+r/2-h_t)$ against time is shown in Fig. 3. The variation was linear ($\log_{10}(D+r/2-h_o) - \log_{10}(D+r/2-h_t)$= 0.030622478 + 0.019463673 t) and slope of the line was worked out 0.019463673. The $K_{s\text{-index}}$ was calculated as 1.612 m/day and K_s value was calculated as 0.248 m/day.

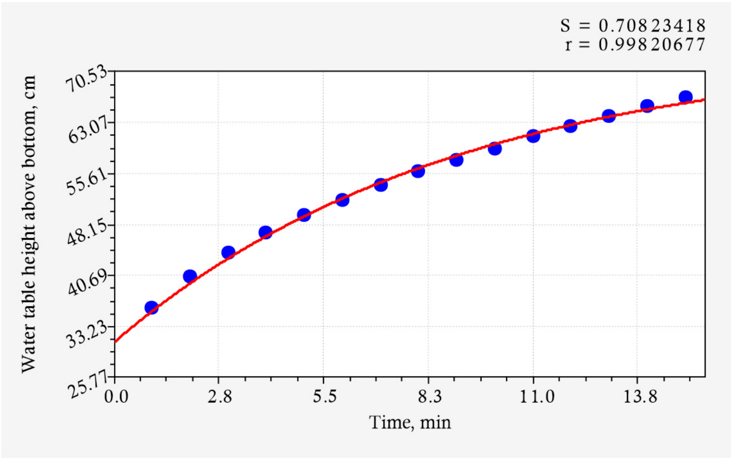

Fig. 2 Variations of water level within the hole after the bail out

Table 1. Calculation of tan α and K_s using proposed auger hole method

Time min	Depth to water level bgl D_T cm	Saturated depth, D cm	r cm	Water level height above bottom h_t= 150-D_T cm	D+r/2 cm	D+ (r/2)-h_o cm	D+(r/2)-h_t cm	log_{10} [(D+(r/2)) -h_o]	log_{10} [(D+(r/2)) -h_t)	log_{10} [(D+(r/2)) -h_o]-log_{10} [(D+(r/2)) -h_t]
0	120.5	100	5	29.5	102.5	73	73	1.863323	1.863323	0
1	114	100	5	36.0	102.5	73	66.5	1.863323	1.822822	0.040501
2	109.5	100	5	40.5	102.5	73	62	1.863323	1.792392	0.070931
3	106	100	5	44.0	102.5	73	58.5	1.863323	1.767156	0.096167
4	103	100	5	47.0	102.5	73	55.5	1.863323	1.744293	0.11903
5	100.5	100	5	49.5	102.5	73	53	1.863323	1.724276	0.139047
6	98.2	100	5	51.8	102.5	73	50.7	1.863323	1.705008	0.158315
7	96	100	5	54.0	102.5	73	48.5	1.863323	1.685742	0.177581
8	94.1	100	5	55.9	102.5	73	46.6	1.863323	1.668386	0.194937
9	92.4	100	5	57.6	102.5	73	44.9	1.863323	1.652246	0.211077
10	90.7	100	5	59.3	102.5	73	43.2	1.863323	1.635484	0.227839
11	89	100	5	61.0	102.5	73	41.5	1.863323	1.618048	0.245275
12	87.5	100	5	62.5	102.5	73	40	1.863323	1.60206	0.261263
13	86	100	5	64.0	102.5	73	38.5	1.863323	1.585461	0.277862
14	84.5	100	5	65.5	102.5	73	37	1.863323	1.568202	0.295121
15	83.2	100	5	66.8	102.5	73	35.7	1.863323	1.552668	0.310655

C= 6.5091, tan α = 0.019463673, $K_{s\text{-index}}$ = 1.15 r tan α, $K_{s\text{-index}}$=1.612 m/day, K_s=$K_{s\text{-index}}$/C=1.612/6.5091=0.248 m/d

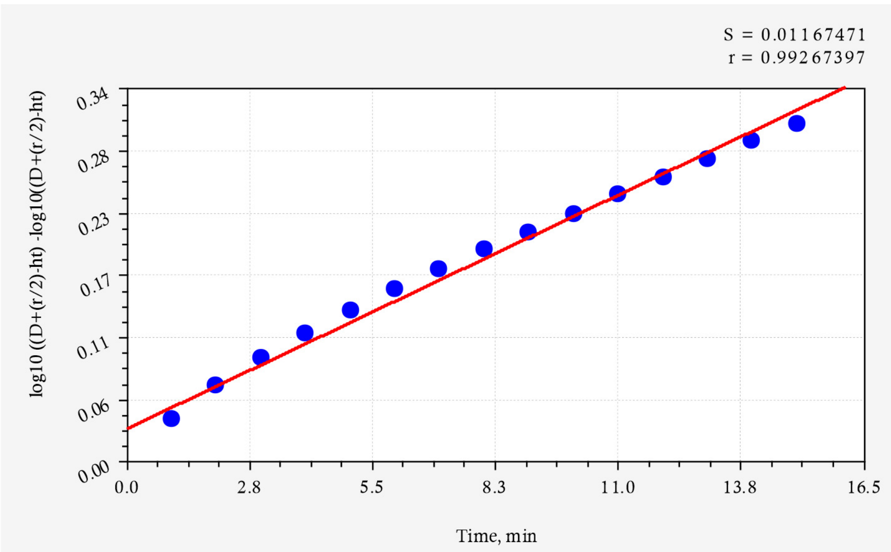

Fig. 3 Variations of log_{10} (D+r/2-h_o) – log_{10} (D+r/2-h_t) against time

2. Hooghoudt (1936) method

The plotted line between $\log_{10} H_o - \log_{10} H_t$ against time t is shown in Fig. 4. The variation is linear and slope was measured as 0.020512578 and variations was explained by the following linear equation.

$$\frac{\log_{10} H_o - \log_{10} H_t}{t} = \frac{2.3\,r\,S}{K_s\,(2D+r)} \qquad (50)$$

Eqn. (50) after plotting the data was obtained as below.

$$\log_{10} H_o - \log_{10} H_t = 0.03108224 + 0.020512578\,t \quad (51)$$

The K_s value was calculated as 0.436 m/day for S=rD/0.19= 0.263158 and tan α= 0.020512578 using following equation.

$$K_s = \frac{2.3\ r\ S}{(2D+r)} \tan\alpha \qquad (52$$

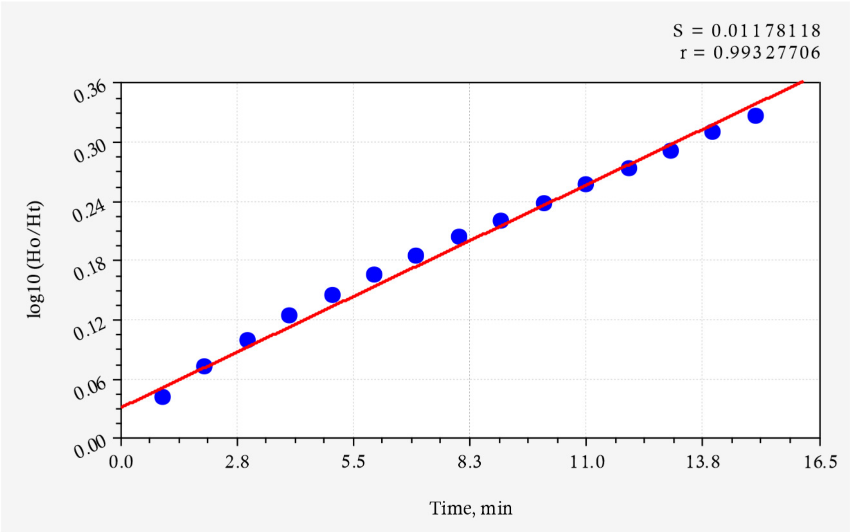

Fig. 4 Variation of $\log_{10} H_o - \log_{10} H_t$ with time

3. Modified Hooghoudt (1936) method

The Hooghoudt (1936) model was modified by replacing S=rd/0.19 with S=1/C. The value of C is the same as that of Ernst (1950) geometry factor. The value of K_s was obtained as 0.455 m/day.

4. Ernst (1950) method

The water in the auger hole which was initially 50 cm deep below the soil surface came down to a level of 70.5 cm (H_o=120.5 cm bgl) below the static water level which rose to the level of 33.2 cm (H_t=83.2 cm bgl) below static water level over a time of 900 s. Thus the rise in water table in time Δt=900 s was recorded as Δh= 37.3 cm and rate of rise was calculated as Δh/Δt=0.04144. The height of water level above the bottom of hole immediately after the bailing was h_o=29.5 cm and after 900 s it was h_t= 66.8 cm. The value of h^1 was calculated as 51.85 cm. The value of 20+D/r was calculated as 40 and 2-h^1/D as 1.4815 and their product as 59.26. The value of 4000 (r/h^1) was calculated as 385.7281. The value of C was calculated by taking ratio of 4000 (r/h^1) and (20+D/r)(2-h^1/D) as 6.5091. Finally the K_s value was calculated as 0.27 m/day.

Considering the K_s value obtained from Ernst (1950) model as a reference value the per cent deviations of the K_s values obtained as 74.40, 2.00 and -0.80% by Hooghoudt (1936), Modified Hooghoudt (1936) and Proposed Model, respectively. The proposed model gave identical value of K_s with minimum percent deviation. Modified Hooghoudt (1936) model gave the second best value of K_s. Except for the Hooghoudt (1936) model all three models gave K_s values extremely close to each other hence recommended for field application.

Conclusions

In-situ measurement of K_s value provides more accurate value for the design of subsurface drainage and the width of elevated field beds of fish pond based integrated farming system models under waterlogged sodic or saline conditions. Auger hole method of Hooghoudt (1936) was used initially for in-situ K_s estimation which uses empirical relationship of S=rD/0.19 based on sand tank model studies. Ernst (1950) model gives accurate value of K_s and recommended for the field application. Barua and Alam (2013) obtained another solution analyzing the flow of auger hole numerically giving identical values of K_s as that by Ernst (1950). The proposed correction in Hooghoudt model yielded good result. A newly developed model which is simple to understand flow process gave extremely close value of K_s as that of Ernst model. The new model is recommended for field application due to its simplicity and accuracy.

References

Aronovici VS (1947) The mechanical analysis as anindex of subsoil permeability. *Soil Science Society of American Proc.* **11**: 137-141.

Barua G and Alam A (2013) An analytical solution for predicting transient seepage into ditch drains from a ponded field. *Adv Water Resourc* **52**: 78-92.

Bavel van, CHM and Kirkham D (1948) Fieldmeasurement of soil permeability using auger holes. *Proc Soil Sc Soc Am* **13**: 90-96.

Bouwer H and Jackson RD (1974) Determining soil properties. In: J. van Schilfgaarde (ed.) *Drainage for Agriculture, Agronomy*. Am. Soc. of Agronomy, Madison, pp.**17**: 611-672, USA.

Ernst LF (1950) A new formula for the calculation of the permeability factor with the auger hole method. T.N.O. Groningen 1950. Translated from the Dutch by H. Bouwer, Cornell Uni, Ithaca. N Y, 1955.

Gallage Chaminda, Kodikara Jayantha and Uchimura Taro (2013) Laboratory measurement of hydraulic conductivity functions of two unsaturated sandy soils during drying and wetting processes. *Soil and Foundations* **53(3)**: 417-430.

Gautam Barua and Wazir Alam (2013) Hydraulics of an auger hole in an unconfined aquifer of finite horizontal and vertical extents. *Journal of Earth Science India* **6(III)**: 90-125.

Hooghoudt SB (1936) Brijdragen tot de kennis van enige natuurkundige groothenden van den grond. *Verslagen Landbouwkundig Onderzoek* **42(13)B**: 449-541.

Hoorn JWV (1979) Determination of hydraulic conductivity with inversed auger hole and infiltration method. *Proc. Int. Drain. Workshop, Rubi.* 25, ILRI, Wageningen, The Netherlands.

Jacka Luskas, Pavlasek Jirka, Kuraz Vaclav and Pech Pavel (2014) A comparison of three measuring methods for estimating the saturated hydraulic conductivity in the shallow subsurface layer of mountain podzols. *Geoderma* **219-220**: 82-88.

Johnson HP, Frevert RK, and Evans DD(1952) Simplified procedure for the measurement and computation of soil permeability below the watertable. *Agri Engg* **33**: 283-286.

Kirkham D (1945) Proposed method for held measurement of permeability of soil below the water table. *Proc Soil Soc Am* **11**: 93-99.

Kirkham D (1955) Measurement of the hydraulic conductivity of soil. In: Proc. Symp. on Permeability of soils. *Am Soil for Testing Materials Spec Tech Publ* No 163.

Ojha RP, Verma CL, Denis DM and Arora Sanjay (2020) Line-source field dripper for the measurement of in situ unsaturated hydraulic conductivity function. *Current Science* **118 (12)**: DOI: 10.13140/RG.2.2.32396.13441.

Singh AK, Arora S, Singh YP, Verma CL, Bhardwaj AK, and Sharma N (2016) Irrigation water management strategies for wheat under sodic environment. *Journal of Soil and Water Conservation* **15(3)**: 211-216.

Singh SR and Verma CL (2010a) A viscous resistance model to estimate hydraulic conductivity of soil. *Proc Indian Natn Sci Acad* **76(1)**: 41-52.

Singh SR and Verma CL (2010b) A drag resistance model with an empirical factor for estimating hydraulic conductivity of soils. *Proc Indian Natn Sci Acad* **76(4)**: 189-199.

Smedma LK and Rycroft DW(1983) Land Drainage: Planning and design of Agricultural Drainage System. *Batsford, London,* 376 p.

Shani U, Hanks RJ, Bresler E and Oliverira CAS (1987) Field method for estimating hydraulic conductivity and matric potential water content relations. *Soil Sci Soc Am J* **51(2)**: 298-302.

van Beers WFJ (1970) The Auger hole method a field measurement of hydraulic conductivity of soil below water table. *Rev. ed. Bulletin 1, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands*

Warrick (1985) Point and line infiltration calculation ofwetted soil surface. *Soil Sci Soc Am J* **49(6)**: 1581-1584.

Woesten JHM and van Gennuhten MTh (1988) Using texture and after soil properties to predict the unsaturated hydraulic functions. *Soil Sci Soc Am J* **52**: 1762-1770.

Woesten JHM (1990) Use of soil survey data to improve simulation of water movements in soil. Thesis, Agricultural University, Wageningen, p.103.

Received: February 2, 2023; Accepted: May 27, 2023

Journal of Soil Salinity and Water Quality 15(1), 61-69, 2023

Development of Filtration System using Chitosan and Silica Sand as Adsorbents for Reducing Salinity of Water for Micro-Irrigation

Amarpreet Singh[2], Sunil Garg[1]*, Mukesh Siag[1] and Ritesh Jain[3]

[1]*Deptt. of Soil & Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
[2]*Ex-Student, Deptt. of Soil & Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
[3]*Deptt. of Civil Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India*
**Corresponding author E-mail: sunil1765@pau.edu*

Abstract

A study was conducted to develop filtration technique by using chitosan and silica sand as adsorbents for reducing salinity of water for irrigation purpose. Chitosan is biopolymer which is extracted by alkaline deacetylation (40–50% NaOH) of chitin. It is an abundant natural biopolymer obtained from the exoskeletons of crustaceans and arthropods which is a non-toxic copolymer consisting of b-(1,4)-2-acetamido-2-deoxy-Dglucose and b-(1,4)-2-anaino-2-deoxy-D-glucose units. The chitin is produced after crushed, washed and demineralized with 1N HCL from shrimp shell. It is widely used in agricultural fields, medicinal and removal of inorganic contaminants (e.g. trace metals) from wastewater and soil. Silica sand is also known as quartz sand and is produced from quartz stone by crushing. It is mainly the compound of silicon and oxygen and is used for adsorption purposes and glass making factories. Nanoporous silica materials have great applications in catalysis, separation and wastewater treatment because of their large surface areas, narrow pore size distribution and high adsorption capacities. The adsorbent chitosan and silica sand was able to reduce electrical conductivity (EC) by approx. 24% and 12% respectively. Optimum contact time for both adsorbents was found out to be 30 minutes.

Key words: Filtration system, Chitosan, Silica sand, Adsorbent, Electrical conductivity, Contact time

Introduction

Water is one of the significant inexhaustible assets that support life. As the population of India is growing, the use of water is also expanding at a fast pace. The significance of the groundwater resource in India can be realized by the fact that about 50% of the total irrigated area is dependent upon groundwater and about 60% of irrigated food production depends on irrigation from groundwater wells (Singh and Singh, 2002). Considerable part of groundwater in various Indian states has been reported either saline or sodic (Minhas, 1996). Sodicity and/or salinity are regular problems under irrigated agriculture particularly in areas of low precipitation and high requirement (Sumner, 1993). The saline concentration due to irrigation by saline water results in reducing soil porosity, soil permeability and hydraulic conductivity (Tedeschi and Dell'Aquila, 2005). Higher values of sodium adsorption ratio (SAR) of saline water irrigation results in clay dispersion, decreased aggregate stability, surface crusting, swelling of expandable clays and reduced tilth (Suarez *et al.,* 2006). The groundwater in many parts of southwest Punjab contains high pH (7.5-8.4), high concentration (700-2000 ppm) of dissolved salts with electrical conductivity of 1200-1600 $\mu S\ cm^{-1}$ (Sharma *et al.,* 2013).

Filtration is a common but effective process for treatment of water in comparison with other desalination technologies. A number of desalination technologies have been created on the basis of electro dialysis, membrane separation, thermal distillation, multistage flash (MSF) method, freezing, reverse osmosis (RO) etc. But these technologies are costly for agricultural use. For agricultural purposes there is a great requirement for simple and low-cost techniques for reducing water salinity (Wajima, 2013). Adsorption is right and inexpensive method for desalination for agriculture point of view. The adsorbent materials with high specific surface area made up of agricultural waste such as rice husk, coconut shells etc. Adsorption was recognized to be inexpensive and efficient for eliminating heavy metal ions, organic contaminants, and dyes from effluent waters (Imamoglu and Tekir, 2008). Many adsorbents like silica sand, activated carbon and graphene can be used for treatment of water (Tangjuank *et al.,* 2009). Activated carbon has proven for better adsorbent for the removal of organic and inorganic pollutants from aquifer water. Because of its large surface areas that varied from 500 to 1500 m^2 g^{-1} it is broadly used in the purification of water (Karnib *et al.,* 2014). The Adsorption is surface phenomenon and by this the salts are accumulated on surfaces of adsorbent. As a result, the EC and SAR values are reduced. Nasrullah *et al.* (2021) conducted experiment to prepare activated carbon from mangosteen peels (MP) waste and investigate the effect on activated carbon by adsorption of cationic methylene blue from ionic solution. Ball milled activated carbon (BMAC) was prepared by milling process of short period of 30 minutes at 350 revolutions per minute.

However, to irrigate crops with saline water of certain salt content after treatment, it is necessary to use special arrangements to apply water on field. This issue can be overcome by applying saline water through filtration strategy by using micro-irrigation system. In now days' drip irrigation, a type of micro irrigation is widely considered as the best suitable irrigation technology to use saline water of certain salt content. Various points contribute to the better performance acquired with saline water irrigation by use of drip irrigation: (i) prevent salt accumulation due to less supply of water (ii) prevent leaf burn (iii) high-frequency drip irrigation avoid the soil from drying out between irrigation events, so preventing peaks in salt concentration and concomitant high osmotic potentials (iv) salts of applied irrigation water are leaching continuously away from the wetted region and accumulate at the wetting front away from the active root zone (Nangare *et al.,* 2013).

So, the present study will examine the effectiveness of using chitosan and silica sand as an environmental-friendly adsorbent combined with micro-irrigation system will give better solution of saline water problem in affected areas. The information on development of filtration system by using chitosan and silica sand for reducing salinity for micro-irrigation is limited.

Materials and Methods

Selection of adsorbents

The adsorbents used in the study were chitosan and silica sand which were capable to improve quality of water by reducing salinity. The chitosan flakes were obtained from Marine hydrocolloids located at Kerala. These flakes were further processed in hammer mill for obtain desirable size of 0.75-1.18 mm. Silica sand used in this study was obtained from Research Farm of Department of Soil and Water Engineering, PAU.

Water quality criteria

The parameters used for determination of quality of irrigation water are as follows:

Electrical conductivity (EC)

Electrical conductivity of water is the ability of water to conduct the electric current. Salts and other chemicals are dissolved in water. The salts present in water are in form of suspended ions. These ions are positively and negatively charged.

In this study, the electrical conductivity was measured by digital instrument HANNA HI98130 as shown in Fig.2.

pH

The definition of pH is that it is a proportion of the movement of the hydrogen particle (H^+) and is accounted for as the equal of the logarithm of the hydrogen particle. As the water with a pH of 7 has 10-7 moles for every litre of hydrogen particles. This parameter is used to measure the acidity or basicity of irrigation water (less than 7.0 acidic and greater than 7.0 is basic). The normal range for pH in surface water is 6.5 to 8.5 and for groundwater 6 to 8.5.

Simulated saline water (SSW)

Simulated saline water was prepared by dissolving calculated amount of sodium chloride salt in water to get desired electrical conductivity (EC) of 5.0 dS m^{-1}.

Adsorption technique

Adsorption is surface phenomenon in which adsorbents adsorb materials, ions and substances to their surface. The particles which adsorb on surface of adsorbent are called adsorbate. Adsorption was performed by batch and column method.

Batch adsorption studies

In batch studies, orbital shaker was used for adsorption. 5, 10, 20, 30 gms of each adsorbent with 100 ml of saline water was poured in 250 ml Erlenmeyer flask and agitated on orbital shaker for 30 minutes at 60 revolutions per minute Aghakhani *et al.* (2013). The treated water was then filtered through Whatman filter paper and collected for quality analysis.

Column adsorption studies

Column studies were performed in a special developed container which was fabricated by a acrylic sheet. The dimension of container is 30 cm × 20 cm × 12 cm. The container consist of three parts as shown in Fig.1. The material container is filled with adsorbent. The simulated saline water is filled in the reservoir tank and the adsorbent is allowed to remain in contact with simulated saline water for known time. The treated water is then filtered and value of electrical conductivity is noted.

Treatments

The five contact time treatments were selected as 1, 15, 30, 60 and 120 minutes with three replications.

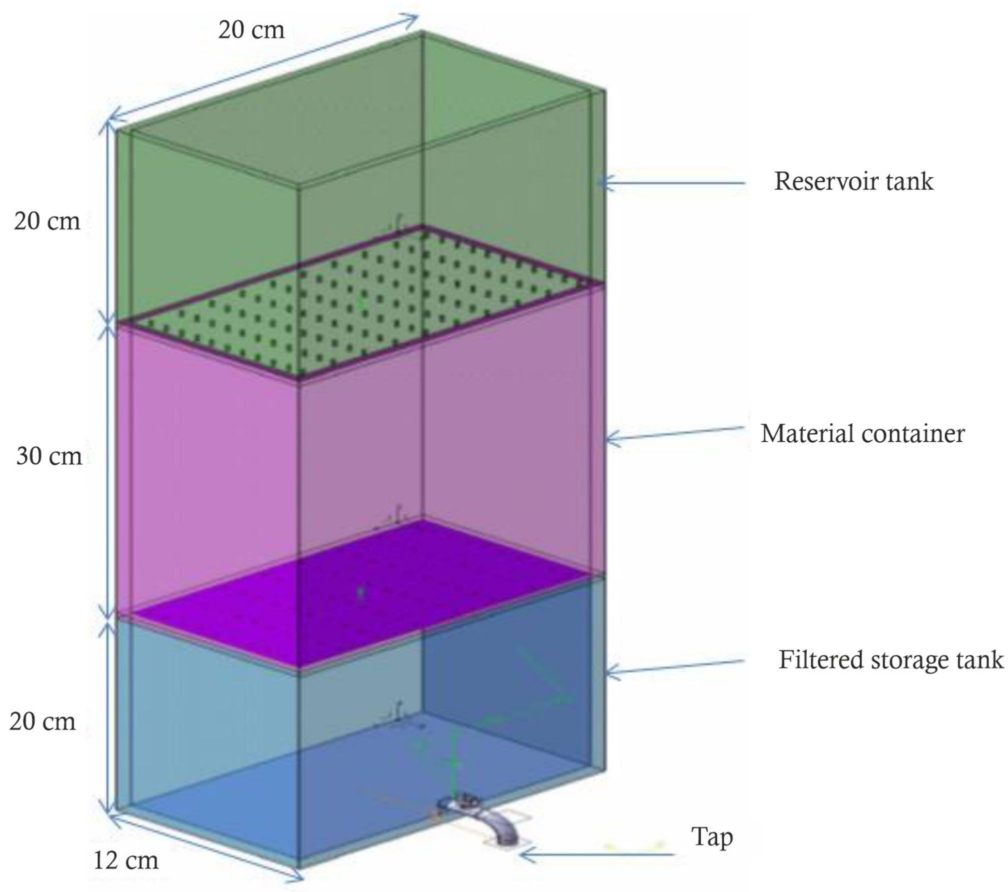

Fig. 1 Fabrication of container for column studies

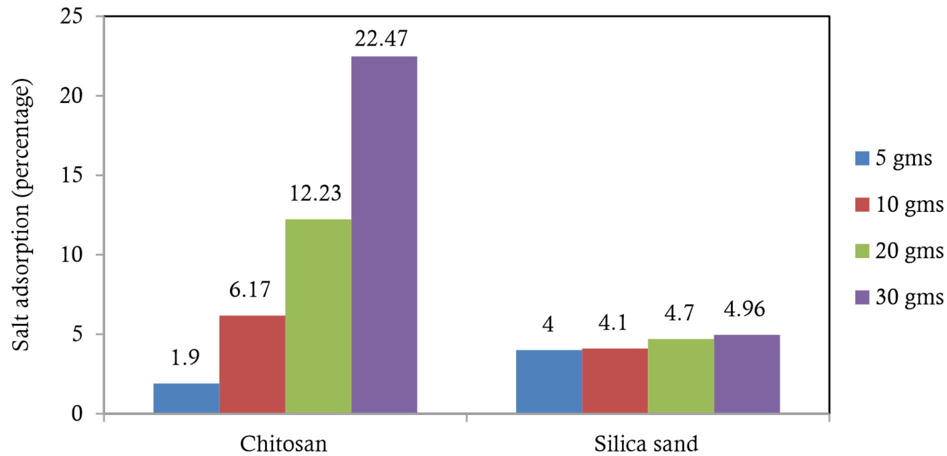

Fig. 2 Adsorbents based on batch method

Statistical analysis

The data collected from the lab experiments were subjected to statistical analysis using O.P. Sheoren Programmer developed by Computer Section, CCS HAU, Hisar. The data was statistically analysed using analysis of variance (ANOVA) techniques. The significance of differences was tested at 5 percent level.

Life cycle assessment of adsorbents.

Life cycle assessment of adsorbents chitosan and silica sand was carried out in the laboratory to see that for how many cycles or reuse adsorbents can be used maintaining almost same adsorption capacity. For this simulated saline water of known electrical conductivity was passed through adsorbent chitosan of known quantity based on batch method for optimum contact time. Same procedure was followed for batch method to find salt adsorption.

Similarly, to find life cycle of adsorbent silica sand based on column method same procedure was followed for column method to find salt adsorption.

Performance evaluation of developed filtration technique using drip irrigation

Filtration technique developed basically is a combination of batch and column method. Chitosan and silica sand was used as an adsorbent for batch and column methods respectively. Performance evaluation of developed filtration technique was carried out in two parts. First part is to find the quantity of chitosan required for desalination of known quantity of water. For this 3 kg of chitosan was taken and mixed in 10 litres of simulated saline water. The mixture was stirred continuously with the help of impeller for 60 minutes. The value of electrical conductivity (EC) was noted at different time intervals.

Results and Discussion

Adsorption by batch method

Salt adsorption by taking 5, 10, 20 and 30 grams of chitosan and silica sand

5, 10, 20 and 30 grams of chitosan and silica sand were mixed with 100 ml of simulated saline water filled in different Erlenmeyer flasks and rotated in orbital shaker for 30 min at 60 revolutions per minute. After this process the treated water was filtered through Whatman filter paper and the values of electrical conductivity (EC) and pH of water were noted by using digital instrument. Results of which are shown in Fig. 2. From the figure, it was clear that as the quantity of adsorbent is increased from 5 to 30 gms, salt adsorption increases from 1.9% to 22.47% respectively for adsorbent chitosan and 4% to 4.96% for silica sand.

Adsorption by column method

In this method simulated saline water was passed through glass container filled with adsorbent up to a height of 20 cm with contact period of thirty minutes. The treated water was then filtered through Whatman filter paper and the values of

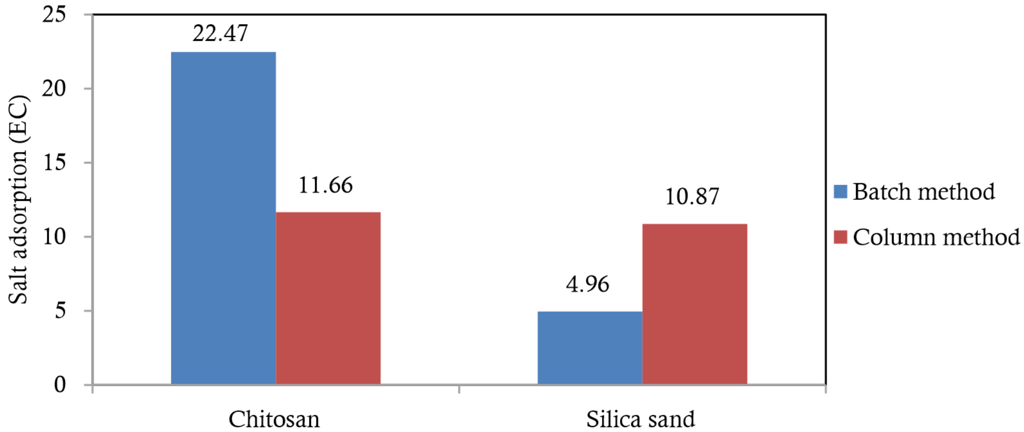

Fig. 3 Percentage of salt adsorption (EC) by adsorbents using batch and column method

electrical conductivity and pH of water were noted.

Selection of adsorbents and adsorption method for detailed adsorption studies

Selections of adsorbents using batch and column method were compared for selection of adsorption method and adsorbents for further studies as shown in Fig. 3. It was clear from Fig. 3 that both batch and column method showed better results. It was decided that chitosan will be used as adsorbent for batch method and silica sand adsorbent for column method.

Optimum contact time for adsorption by chitosan

Adsorbent chitosan was tested for determination of optimum contact time. The simulated saline water was passed through adsorbent with different contact time of 1 min, 15 min, 30 min, 60 min and 120 min respectively. Treated water was then filtered through Whatman filter paper and tested for electrical conductivity present in each sample as shown in Fig. 4. The results showed that after 30 minutes there was instant decrease in electrical conductivity from 5.0 dS m^{-1} to 3.57 dS m^{-1}. So optimum contact time for adsorbent chitosan was taken as 30 minutes asthe electrical conductivity after 30, 60 and 120 minutes was almost same. Statistical test of analysis of variance (ANOVA) design of CRD test was applied to see the significance of electrical conductivity on contact time as shown in Table 1 and Table 2. The relationship between EC and adsorbent showed a good correlation of $R^2 = 0.919$ and it followed a quadratic relationship. From the Table 1, the value of electrical conductivity and contact time significantly effect on each other. From the Table 2, critical difference (C.D.) is 0.100. Treatment

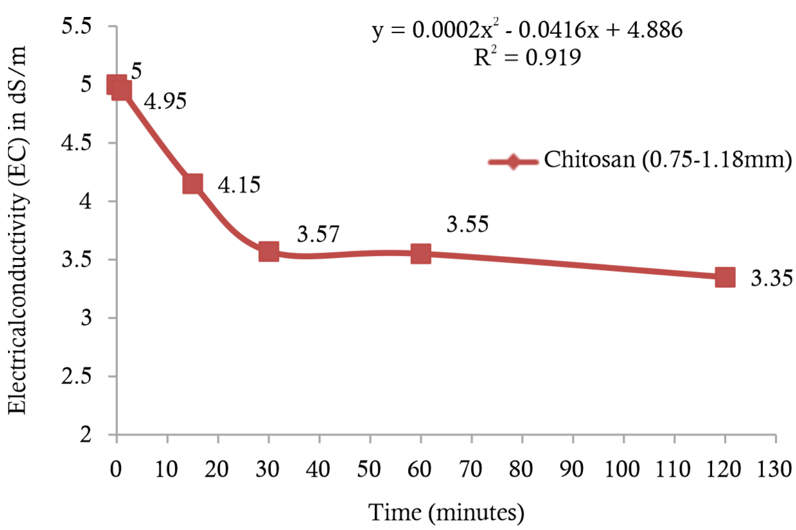

Fig. 4 EC of water by adsorbent chitosan using batch method for different contact time

Table 1. Analysis of Variance Table

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Treatment	4	5.094	1.273	430.143	0.00000
Error	10	0.030	0.003		
Total	14	5.123			

Table 2 Critical difference, standard errors and mean

Treatment	Chitosan	
	Mean	S.E
1	4.950	0.021
2	4.150	0.015
3	3.570	0.050
4	3.550	0.021
5	3.350	0.036
C.D.	0.100	
SE(m)	0.031	
SE(d)	0.044	
C.V	1.390	

(T1) is significantly different from treatment (T2) as their mean difference is more than critical value.(T1-T2 i.e 4.950-4.150 = 0.8 >0.100) But treatment T3 is not significantly differ from T4 as their mean difference 0.02 is less than calculated critical value. So, the optimum contact time was taken as 30 minutes.

Optimum contact time for adsorption by silica sand

Optimum contact time for adsorption of silica sand was carried out by passing simulated saline water for contact time of 1, 15, 30, 60 and 120 minutes. Treated water was filtered and tested for EC as shown in Fig. 5. The results showed that after 30 minutes there was instant decrease in electrical conductivity from 5.0 dS m^{-1} to 4.50 dS m^{-1}. So optimum contact time for adsorbent silica sand was taken as 30 minutes as the electrical conductivity after 30, 60 and 120 minutes was almost same. Statistical test of analysis of variance (ANOVA) design of CRD test was applied to see the significance of electrical conductivity on contact time as shown in Table 3 and Table 4. The relationship between EC and adsorbent showed a good correlation of R^2 = 0.955 and it followed a quadratic relationship. From the Table 3, the value of electrical conductivity and contact time significantly effect on each other. From the Table 4, the critical difference (C.D) value was calculated as 0.107. The treatment (T1) is significantly different from treatment (T2), (T3), (T4) and (T5) as their mean difference is greater than critical difference. But treatment (T3) and treatment (T4) are not significantly different. So, the optimum contact time for silica sand for treatment was taken as 30 minutes.

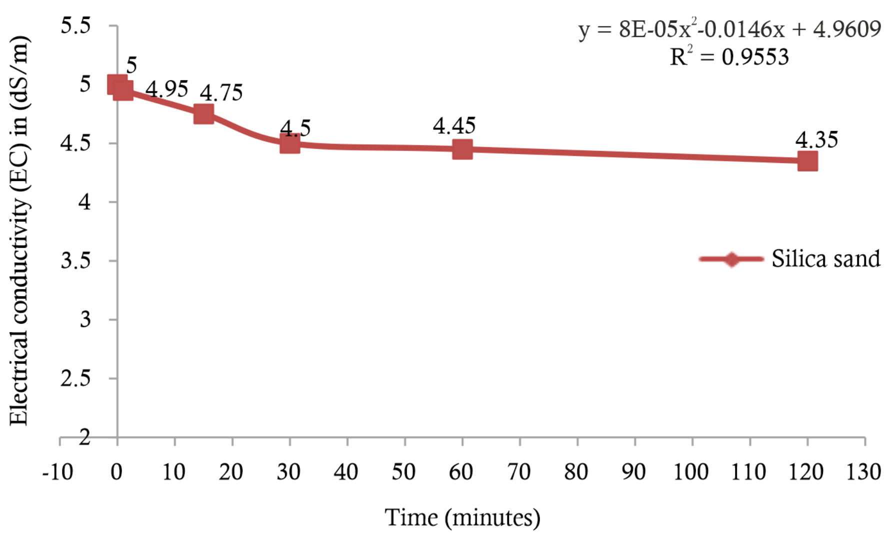

Fig. 5 EC of water by adsorbent silica sand using column method for different contact time

Table 3. Analysis of Variance Table

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
Treatment	4	0.720	0.180	53.255	0.00000
Error	10	0.034	0.003		
Total	14	0.754			

Table 4. Critical difference, standard error and mean

Treatment	Silica sand	
	Mean	S.E
1	4.950	0.015
2	4.750	0.021
3	4.500	0.046
4	4.450	0.051
5	4.350	0.015
C.D.	0.107	
SE(m)	0.034	
SE(d)	0.047	
C.V	1.264	

Life cycle assessment of adsorbents

Life cycle assessment of adsorbent chitosan and silica sand were found out.

Life cycle assessment of adsorbent chitosan

Life cycle assessment of chitosan was found out as shown in Table 5. One life cycle was taken as 30 minutes which was optimum contact time found out in batch method. From the table it was clear that after using adsorbent chitosan for six life cycles, the salt adsorption varied from 23.20% to 20.50%. After seventh life cycle, the salt adsorption reduced to 15.89% (EC: 3.65 dS m^{-1}) from 23.20% (EC: 3.35 dS m^{-1}). So, it can be concluded that adsorbent chitosan from batch studies can be reused for 6 life cycles (180 min). The same chitosan material was then washed out to remove salts adsorbed on their surface by tap water. Now, the washout chitosan can be again reused to reduced electrical conductivity.

Life cycle assessment of adsorbent silica sand

Life cycle assessment of adsorbent silica sand was found out as shown in Table 6. One life cycle was taken as 30 minutes which was optimum contact time found out in column method. From the table it was clear that after using adsorbent silica sand for six life cycles, the salt adsorption varied from 13.50% to 9.33%. After seventh life cycle, the salt adsorption reduced to 8.24% from 13.50%. So, it can be concluded that adsorbent silica sand can be reused for 6 life cycles (180 min). The same silica sand material was then washed out to remove salts adsorbed on their surface by tap water. Now, the washout silica sand can be again reused to reduced electrical conductivity.

Performance evaluation of developed filtration technique for drip irrigation system

First part is to find the quantity of chitosan required for desalination of known quantity of water. For this 3 kg of chitosan was taken and mixed in 10 litres of simulated saline water in tank. The mixture was stirred continuously with the help

Table 5. Life cycle assessment of adsorbent chitosan

S. No.	Cycles	Contact time (min)	Cumulative Contact time (min)	EC (dS m^{-1}) (initial)	EC (dS m^{-1}) (final)	Salt Adsorption percentage
1	1	30	30	4.34	3.33	23.20
2	2	30	60	4.34	3.34	23.0
3	3	30	90	4.34	3.35	22.81
4	4	30	120	4.34	3.38	22.0
5	5	30	150	4.34	3.43	20.96
6	6	30	180	4.34	3.45	20.50
7	7	30	210	4.34	3.65	15.89

Table 6. Life cycle assessment of adsorbent silica sand

S. No.	Cycles	Contact time (min)	Cumulative contact time (min)	EC (dS m^{-1}) (initial)	EC (dS m^{-1}) (final)	Salt Adsorption percentage
1	1	30	30	6.43	5.56	13.50
2	2	30	60	6.43	5.66	11.97
3	3	30	90	5.30	4.69	11.50
4	4	30	120	6.43	5.73	10.80
5	5	30	150	5.30	4.77	10.00
6	6	30	180	6.43	5.83	9.33
7	7	30	210	6.43	5.90	8.24
8	8	30	240	6.65	6.18	7.06
9	9	30	270	8.30	7.72	6.98
10	10	30	300	8.30	7.73	6.86

Table 7. Salt adsorption (EC) at different contact time using batch method

S. No.	Adsorbent	Contact time (minutes)	EC (initial) (dS m^{-1})	EC (final) (dS m^{-1})	Salt adsorption (Percent)
1	Chitosan(0.75-1.18mm)	10	5.0	4.6	8.0
2	Chitosan(0.75-1.18mm)	15	5.0	4.4	12.0
3	Chitosan(0.75-1.18mm)	30	5.0	3.8	24.0
4	Chitosan(0.75-1.18mm)	60	5.0	3.8	24.0

of impeller for 60 minutes. Performance evaluation of developed filtration system was carried out in the field using drip irrigation system.The value of electrical conductivity (EC) was noted at different time intervals as shown in Table 7. The results showed that as the contact time for adsorbent is increased from 10 min to 60 min, EC decreases from 8% to 24% respectively. EC at contact time for 30 minutes and 60 minutes is same. So, contact time of 30 minutes for salt adsorption can be taken as optimum contact time which is same contact time for results shown in Table 7.

Treated water of known EC (3.8 dS m^{-1}) was then passed through the drip filter already containing silica sand as shown in Fig. 6. The results obtained are shown in Table 8. The contact time in sand filter is managed by valve attached to the bottom of filter. The valve was opened when the contact period of desired time was fulfilled and was used for irrigation

The results showed that as the contact period of time for adsorbent is increased from 10 min to 60 min, EC decreases from 4.0% to 13% respectively. Electrical conductivity (EC) at contact time for 30 and 60 minutes is nearly same. So, contact time of 30 minutes is optimum time for salt adsorption technique. Further it is suggested that chitosan and silica sand can be used for six life cycles (180 min) and after that it can be washed with water to remove salts and again be reused.

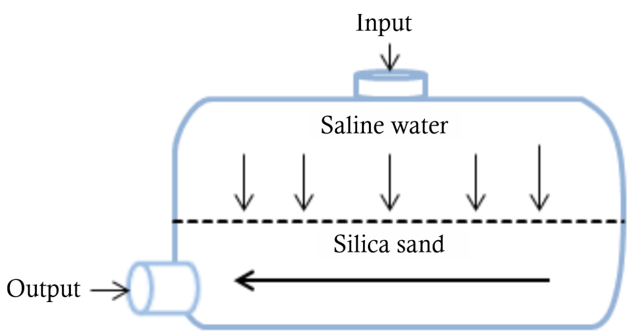

Fig. 6 Schematic diagram of filtration technique used for drip irrigation system

It can be concluded that by using a combination of batch and column method electrical conductivity (EC) of 5.0 dS m^{-1} can be reduced to 3.34 dS m^{-1} with a contact time of 30 minutes.

Table 8. Salt adsorption (EC) at different contact time using drip irrigation system

S. No.	Adsorbent	Contact time (minutes)	EC (initial) ($dS\ m^{-1}$)	EC (final) ($dS\ m^{-1}$)	Salt adsorption (Percent)
1	Silica sand	10	3.8	3.64	4.0
2	Silica sand	15	3.8	3.49	8.0
3	Silica sand	30	3.8	3.34	12.0
4	Silica sand	60	3.8	3.30	13.0

Conclusions

The adsorbent chitosan and silica sand were able to reduce electrical conductivity (EC) by approx. 24 and 12 percent respectively. Optimum contact time was found out to be 30 minutes for both the adsorbents. It can be concluded that by using a combination of chitosan and silica sand, electrical conductivity (EC) of 5.0 $dS\ m^{-1}$ can be reduced to 3.34 $dS\ m^{-1}$ with a contact time of 30 minutes. Adsorbent silica sand and chitosan can be reused for 6 life cycles (180 min). The same silica sand and chitosan material can be washed out to remove salts adsorbed on their surface by tap water and can be again reused to reduced electrical conductivity.

References

Aghakhani A, Mousavi SF and Fard BM (2013) Desalination of saline water with single and combined adsorbents. *J Desalin Water Treat* **51**: 1928-35.

Imamoglu M and Tekir O (2008) Removal of copper (II) and lead (II) ions from aqueous solutions by adsorption on activated carbon from a new precursor hazelnut husks. *Desalin* **228**: 108–13.

Karnib M, Kabbani A, Holail H and Olama Z (2014) Heavy metals removal using activated carbon, silica and silica activated carbon composite. *Energy Procedia* **50**: 113–20.

Minhas PS (1996) Effect of quality and depth of ground water table on soil salinization and crop growth. *Annu Rep CSSRI* **1**: 48-51.

Nangare DD, Singh KG and Kumar S (2013) Effect of blending fresh-saline water and discharge rate of drip on plant yield, water use efficiency (WUE) and quality of tomato in semi-arid environment. *Afr J Agric Res* **8**: 3639-45.

Nasrullah A, Khan AS, Bhat AH, Din IU, Inayat A, Muhammad N, Bakhsh EM and Khan SB (2021) Effect of short time ball milling on physicochemical and adsorption performance of activated carbon prepared from mangosteen peel waste. *Renew Energy* **168**: 723-33.

Sharma C, Mahajan A and Garg UK (2013) Assessment of arsenic in drinking water samples in south-western districts of Punjab—India. *Desalin and Water Treat* **51**: 5701–9.

Singh DK and Singh AK (2002) Groundwater situation in India: Problems and prespective. *Int J water Resour Dev* **18**: 563-80.

Sumner ME (1993) Sodic soils: New perspectives. *Aust J Soil Res* **31**: 683-750.

Suarez DL, Wood JD and Lesch S (2006) Effect of SAR on water infiltration under a sequential rain-irrigation management system. *Agric Water Manag* **86**: 150-64.

Talukdar MI and Hasnine MT (2014) Application of Chitosan-Based filtration technique for removal of heavy metals from surface water. *Int Res J Environ Sci* **3**: 5-10.

Tangjuank S, Insuk N, Tontrakoon J and Udeye V (2009) Adsorption of lead (II) and Cadmium (II) ions from aqueous solutions by adsorption on activated carbon prepared from cashew nut shells. *World Acad Sci Eng Technol* **28**: 110-6.

Tedeschi and Dell' Aquila (2005) Effects of irrigation with saline waters, at different concentrations, on soil physical and chemical characteristics. *Agric Water Manag* **77**: 308-22.

Wajima T (2013) Ion exchange properties of Japanese natural zeolite in seawater. *Anal Sci* **29**: 139-41.

Received: April 10, 2023; Accepted: June 16, 2023

Journal of Soil Salinity and Water Quality 15(1), 70-78, 2023

Biochemical and Histological Parameters in *Labeo rohita* Inhabiting Aquatic Ecosystems of Ludhiana and Muktsar Districts of Punjab

Rapneet Kaur and Navdeep Kaur*

Department of Zoology, Punjab Agricultural University, Ludhiana-141004, Punjab, India
**Corresponding author E-mail: navdeepkaur@pau.edu*

Abstract

Labeo rohita were collected from farmer's fish pond (L1) as well as village pond (L2) of Muktsar and farmer's fish pond of Ludhiana (L3) during 2019-20 in four seasons (summer, monsoon, post monsoon, winter). The protein content in liver, gills, kidneys and muscles of fish was significantly high in L3 as compared to L2 and L1 during all and most of the seasons respectively.The protein content in different organs was observed to be significantly high in L1 as compared to L2 during most of seasons. The lipid content in liver and other organs (gills, kidneys and muscles) was significantly high in L3 as compared to L1 and L2 during post monsoon + winter and all seasons respectively. The lipid content in liver as well as gills and kidneys as well as muscles was observed to be significantly high in L1 as compared to L2 during all and most of seasons respectively. The activity of AST and ALT was significantly high in liver and kidneys of both L1 and L2 as compared L3 during most of seasons. Severe histopathological lesions and alterations were observed in different organs of fish of L1 and L2 as compared to that of L3 during most of seasons. Thus biochemical an histological biomarkers in fish inhabiting ponds can be used for monitoring the water quality of aquatic ecosystems.

Key words: Aquatic ecosystems , Biochemical parameters, Biomarkers, Histological parameters, *Labeo rohita*

Introduction

Pond is a freshwater aquatic ecosystem where water is stagnant and fish ponds are controlled ponds basically used for fish farming. Fish being inhabitants of aquatic systems cannot avoid the impact caused due to deviation in physico-chemical parameters of water in the pond ecosystems (Christia and Papastergiadou, 2007; Boominathan *et al.,* 2012). Water quality has a direct effect on stability of an aquatic environment (Radhika *et al.,* 2004). The drastic rise in groundwater salinity and alkalinity problems occurred thereby have been reported in South-Western Punjab, where ground water extraction was limited due to brackish, saline and alkaline quality (Krishan *et al.,* 2014).The quality of groundwater was deteriorated due to anthropogenic activities such as industries, intensive agriculture, household waste, sewage and motor traffic at an alarming rate in most parts of the Punjab especially the South-Western districts i.e., Bathinda, Barnala, Faridkot, Ferozepur, Mansa, Moga, Muktsar and Sangrur. Groundwater from all eight districts in the Malwa region, was found to be high in heavy metal content leading to contamination (Sharma and Dutta, 2017). The district Muktsar of Punjab is facing a serious challenge of water logging and salinization (Godara, 2016).

Fishes exhibited considerable changes in their biochemical composition due to changes in the environmental conditions, nutrients availability and pollution. Carpene *et al.* (1998) illustrated the difference in biochemical parameters like total protein content and fatty acids in lateral muscle of wild and farmed gilthead seabream (*Sparus aurata*) and observed that protein content was significantly lower in wild fish due to the environmental conditions which influenced the biochemical composition of lateral muscle. Alanine transaminase/aminotransferase (ALT) and Aspartate transaminase (AST) are considered to be latent biomarkers and are often used as screening tools for the assessment of the effects of environmental stress in organisms.

Histopathology of fish tissues is an important monitoring tool, allowing the evaluation of the effect of ecological stressors (Livingstone, 2003; Lushchak, 2011). Liver, gills and kidneys are considered as the crucial organs suitable for histopathological examination in order to study xenobiotic induced toxic effects on the fish health (Paithane *et al.,* 2012). The major advantage of using histopathological biomarkers in environmental monitoring is that it allows examining specific vital organs including liver, gills and kidneys that are responsible for fundamental functions such as accumulation and bio-transformation of xenobiotics, excretion and respiration in fish.

Labeo rohita (ohu), inhabits freshwaters of South and South-East Asia and is suitable for evaluation of the level of water contamination (Ramani *et al.,* 2002). The significantly lower concentration of biomolecules (proteins, lipids) and increased activities of aspartate amino transferase, alanine amino transferase, and alkaline phosphatase in the soft tissues of *L. rohita* collected from various sites of the River Ganga from Varanasi district confirmed that *L. rohita* acted as a bioindicator of the degree of water pollution (Vaseem and Banerjee, 2016).

The objective of present study was to determine biochemical composition and histological parameters of liver, gills, kidneys and muscles of *L. rohita* inhabiting ponds of two districts of Punjab i.e. Ludhiana and Muktsar during different seasons which may act as indicators of water quality and environmental contaminants present in different ponds.

Materials and Methods

Collection and dissection of fish

A total of 72 *L. rohita* (six fish during each season from each location) were randomly collected from three locations i.e. Farmer's fish pond (L1) and village pond of Mahanbadhar village (L2) of district Muktsar and Farmer's Fish Pond of village Pamal, Ludhiana (L3) during March 2019 to February 2020 in the four seasons i.e. summer (March-June, 2019), monsoon (July-August, 2019), post monsoon (September-November, 2019) and winter (December, 2019- February, 2020). Fish were dissected and liver, gills, kidneys as well as muscles were taken out and processed for analysis of biochemical composition and histological studies.

Preparation of tissue homogenates

0.5 gram of each organ was homogenized in 2 ml of phosphate buffer (PBS: 0.1 M, pH 7.4) and cold centrifuged at 3000 r.p.m for 10 minutes, the supernatant was taken and stored at a -20°C in deep freezer for various biochemical estimations.

Analysis of biochemical composition

Total proteins content in four different tissues was estimated by method of Lowry *et al.* (1951) and total lipids were extracted by method of Folch *et al.* (1957).The content of total proteins and total lipids was expressed as mg g^{-1} of tissue. The activity of enzymes i.e. ALT and AST was assayed by calorimetric method of Reitman and Frankel (1957) as described by Bergmeyer (1974) in liver and kidney tissues and nmoles of pyruvate formed/min/ml of tissue was expressed as IU/L.

Histological studies

The liver, gills, kidneys and muscle tissues were processed for preparation of histopathological slides following procedure of Humason (1975). After fixation, the tissues were dehydrated in alcohol series followed by clearing with benzene and paraffin embedding. The blocks were prepared and paraffin section of 5-7 μm thickness were obtained on glass slide with the help of rotary microtome and stained with haematoxylin and eosin. The specific areas in slides of tissues were observed under microscope for recording the significant structural changes and the marked areas were subsequently photographed by digital camera attached with light microscope at various levels of magnifications (100X and 400 X).

Statistical analysis

The biochemical composition of fish of three locations was subjected to statistical analysis by one-way ANOVA using Statistical Analysis System (9.4) (SAS) software for finding the significance of difference with respect to different locations. "P" value of 0.05 was selected as a criterion for statistically significant differences.

Results and Discussion

Biochemical composition

Total protein and lipid content

The total protein and lipid content in liver, gills, kidneys and muscles was observed to be highest in fish of L3 followed by L1 and L2 during all the seasons (Table 1). The protein content in liver of L3 varied significantly from L2 and non-significantly from L1 during summer season and varied significantly from both L1 and L2 during and post-monsoon season. However, during monsoon and winter season protein content of all the three locations varied significantly among each other. In gills, protein content of L3 varied significantly from L2 during all the seasons and from L1 during post-monsoon and winter season. The protein content in the gills of L1 and L2 varied non-significantly from each other during summer and monsoon season and significantly during post-monsoon and winter season. In kidneys and muscles, protein content in L3 varied significantly from both L1 and L2 during all the seasons. In L1 and L2 location protein content in kidneys varied significantly from each other during summer season and non-significantly during all other seasons. The protein content in muscles of L1 and L2 also varied significantly from each other during all the seasons.

The less protein content in liver, gills, kidneys and muscles of fish of L1 and L2 as compared to L3 might be due to increased utilization of proteins to counteract the increased cellular damage may be due to variations in water quality parameters at these locations. Aier and Dutta (2018) reported that fishes i.e. *L. rohita*, *L. boga* and *Catla catla* collected from Brahmaputra river showed more protein content than Hajo pond fishes. The SDS-PAGE of their study also revealed that expression of protein band was depleted in Hajo pond fishes compared to Brahmaputra river fishes and the depletion of protein may be due to different diet and environmental condition that they adopted to the change metabolic system which might lead to degradation process like proteolysis and utilization of degraded products for increased metabolism. Meshram *et al.* (2019)

Table 1. Biochemical composition of different organs of *L. rohita* inhabiting ponds at three locations

Organ	Season	Total Protein content (mg/g)			Total Lipid content (mg/g)		
		L1	L2	L3	L1	L2	L3
Liver	Summer	76.12±2.75^{a}	71.48±0.94^{b}	84.19±1.05^{a}	20.03±0.46^{a}	20.02±0.56^{a}	21.29±0.57^{a}
	Monsoon	57.89±2.68^{b}	47.69±1.49^{c}	67.06±1.74^{a}	18.95±0.46^{a}	18.36±0.96^{a}	19.9±0.72^{a}
	Post Monsoon	44.41±1.43^{b}	41.02±1.11^{b}	67.44±1.47^{a}	14.14±0.98^{b}	13.67±0.92^{b}	17.52±0.52^{a}
	Winter	38.17±0.48^{c}	41.74±1.35^{b}	50.91±1.07^{a}	10.50±0.29^{b}	9.72±0.42^{b}	14.67±0.97^{a}
Gills	Summer	64.74±2.95^{a}	54.32±1.73^{b}	74.42±0.97^{a}	4.48±0.16^{b}	4.26±0.33^{b}	6.35±0.13^{a}
	Monsoon	39.69±1.93^{a}	36.07±1.87^{b}	47.06±1.95^{a}	5.33±0.07^{b}	4.30±0.70^{b}	5.82±0.34^{a}
	Post Monsoon	34.35±1.36^{b}	32.48±1.21^{b}	51.42±1.35^{a}	4.52±0.20^{b}	3.63±0.47^{b}	5.19±0.25^{a}
	Winter	30.17±0.30^{b}	30.51±0.76^{b}	40.42±1.18^{a}	3.51±0.15^{b}	3.36±0.76^{b}	4.59±0.47^{a}
Kidneys	Summer	55.45±0.45^{b}	46.18±1.52^{c}	58.93±0.65^{a}	13.10±0.77^{b}	12.46±0.30^{b}	16.34±0.36^{a}
	Monsoon	41.91±1.34^{b}	41.91±1.34^{b}	41.49±1.99^{a}	14.28±0.52^{b}	13.80±0.32^{b}	16.04±0.61^{a}
	Post Monsoon	29.83±1.45^{b}	28.07±1.10^{b}	42.40±1.40^{a}	11.99±0.20^{b}	11.46±0.97^{b}	13.85±0.50^{a}
	Winter	26.15±0.70^{b}	24.76±0.83^{b}	35.62±1.75^{a}	10.31 ±0.60^{b}	9.05±0.26^{c}	13.47±0.22^{a}
Muscles	Summer	96.40±2.74^{a}	84.52±1.07^{b}	101.22±1.98^{a}	20.45±0.37^{b}	19.23±0.21^{c}	20.87±0.28^{a}
	Monsoon	77.26±2.63^{b}	67.67±1.48^{c}	97.67±1.48^{a}	18.47±0.37^{b}	17.83±0.21^{b}	20.49±0.73^{a}
	Post Monsoon	63.41±2.10^{b}	62.97±0.77^{b}	88.4±1.00^{a}	15.19±0.31^{b}	11.19±0.27^{c}	18.49±0.70^{a}
	Winter	62.59±0.59^{b}	61.29±1.36^{b}	71.83±0.96^{a}	10.51±0.30^{b}	9.83±0.28^{b}	16.87±0.68^{a}

- L1 and L2 represents farmer's fish pond and village pond of Mahanbadhar village of Muktsar; L3 represents farmer's fish Pond of village Pamal of Ludhiana
- Values are Mean±SE
- Values with different superscript(a-c) along a row indicate significant difference ($p<0.05$)

reported significant decline in total protein contents of kidney of a freshwater teleost, *Oreochromis mossambicus* on Pb exposure as kidneys act as main organ of excretion and maintaining homeostasis during stress caused due to environmental contaminants. Deshmukh and Shillewar (2018) observed seasonal variations in protein content of fresh water fish *Puntius sarana* from Godavari River.

The lipid content in liver of L3 varied significantly from L1 and L2 in post monsoon and winter season and non-significantly in summer and monsoon season. The lipid content in L1 and L2 varied non significantly from each other during all the seasons in liver and gills. In gills, kidneys and muscles, lipid content of L3 varied significantly from L1 and L2 during all the seasons. The lipid content in L1 and L2 varied significantly during winter season and non-significantly during all other seasons in kidneys. In muscles, lipid content in L1 and L2 varied significantly during summer and post-monsoon season and non-significantly during monsoon and winter season. Earlier, Vutukuru (2005) reported a decline in different biochemical constituents (glycogen, total lipid and total protein levels) in liver, muscle and gills of *L. rohita* under influence of heavy metal i.e. Cr as compared to that of control fish. Kumar *et al.* (2018) also observed decrease in total lipid content in gill, muscle, liver, intestine and kidney tissue of *Anabas testudineus* which denoted the effect of metals present in the Buckingham canal effluent on lipid of tissues. Moreover, water of district Muktsar is having more salinity and earlier, Ballantyne and Jarvis (2003) reported that lipid of short nose sturgeon decreased with increase in salinity and indicate the effective utilization of lipid in osmoregulation.

Activity of AST and ALT

AST the enzyme for amino acid metabolism is responsible for reversible transfer of amino acid between glutamate and aspartate. ALT is the enzyme which is important part of alanine cycle Both AST and ALT acts as a biomarker for liver and kidney functioand their elevated levels indicate problem with liver/kidney functioning. The lowest AST and ALT activity was observed in liver and kidneys of fish from L3 followed by L1 and L2. Abei *et al.* (2013) observed that the level of AST increased in common carp on exposure to different heavy metals (Cd, Pb, Cr). Valon *et al.* (2013) revealed that the activity of ALT enzymes in fish collected in Sitnica River was significantly increased due to water pollutants in the river. Moreover, high ALT activity in fish of L1 and L2 may be due to increase in salinity level in water of district Muktsar as it has been observed that liver AST activity in rainbow trout increased with increasing salinity (Jürss, 1979).

The activity of AST in liver for L3 varied significantly from L1 and L2 during all the seasons while in L1 and L2, AST activity varied significantly in monsoon and non-significantly in all other seasons. AST activity in kidneys of fish of L3 varied non-significantly from L1 and L2

Table 2. Activity of AST and ALT in liver and kidneys of *L. rohita* inhabiting ponds at three locations

Organ	Season	Activity of AST (IU L^{-1})			Activity of ALT (IU L^{-1})		
		L1	L2	L3	L1	L2	L3
Liver	Summer	21.11±0.05^a	21.26±0.56^a	20.35±0.10^b	40.81±0.69^a	40.97±0.49^a	34.65±1.16^b
	Monsoon	34.78±1.36^b	41.27±0.75^a	30.20±1.46^c	46.91±1.16^a	49.50±1.25^a	40.73±0.68^a
	Post Monsoon	52.90±2.38^a	55.37±0.72^a	43.44±2.04^b	54.04±0.53^a	56.57±0.54^b	48.41±0.50^c
	Winter	55.77±1.46^a	56.35±0.11^a	45.60±0.61^b	59.82±1.24^a	60.62±1.76^a	41.5±0.74^b
Kidneys	Summer	10.42±1.39^a	11.85±1.06^a	5.52±0.49^b	25.71±1.01^a	26.17±1.18^a	28.05±2.226^a
	Monsoon	12.11±0.07^a	12.13±0.13^a	7.84±0.42^b	24.26±0.38^a	24.68±0.69^a	25.58±0.65^b
	Post Monsoon	14.23±0.33^a	14.42±0.58^a	10.18±0.31^b	27.68±0.77^a	28.47±0.75^a	28.22±0.73^a
	Winter	15.37±0.32^a	15.42±0.48^a	12.24±0.77^a	27.23±0.76^a	29.85±0.40^a	28.68±0.56^b

- L1 and L2 represents farmer's fish pond and village pond of Mahanbadhar village of Muktsar; L3 represents farmer's fish Pond of village Pamal of Ludhiana
- Values are Mean±SE
- Values with different superscript(a-c) along a row indicate significant difference ($p<0.05$)

during winter season and significantly during all other seasons, while in L1 and L2 the activity of AST varied non-significantly in all the seasons

The activity of ALT in liver for L3 varied non-significantly from L1 and L2 during monsoon season and significantly during all other seasons while in L1 and L2 ALT activity varied significantly in post-monsoon season and non-significantly in all other seasons. The activity of ALT in kidneys of fish of L3 varied non-significantly from L1 and L2 during summer and post-monsoon seasons and significantly during winter and monsoon seasons while in L1 and L2 ALT activity varied non-significantly in all the seasons.

Histological studies

The histomorphology of liver in *L. rohita* from three different locations was studied during four different seasons (Fig. 1). The liver of fish of L1, L2 and L3 location showed compact histo-architecture comprising of normal hepatocytes containing granular cytoplasm and nuclei and presence of sinusoids during summer, summer as

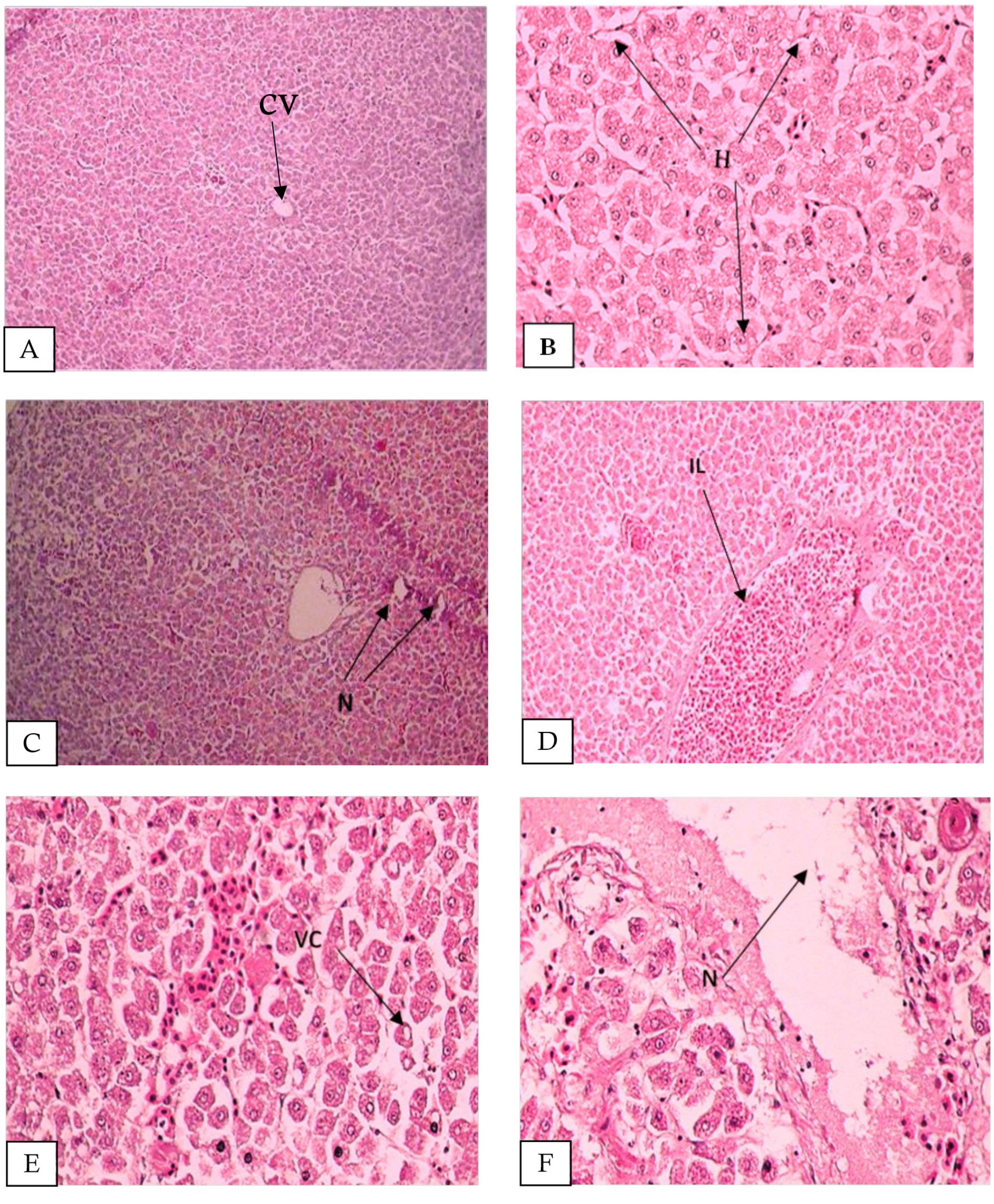

Fig. 1 T.S. of liver showing A. Normal histoarchitecture with normal hepatocytes (H) and Central Vein (CV) (100X) B. Normal histoarchitecture with granulated hepatocytes (H) (400X) C. Necrosis (N) (100X) D. Infiltration of Leucocytes (IL) (400X) E. Vacuolisation of cytoplasm (VC) (400X) F. Necrosis (N) (400X)

well as monsoon and all the four seasons respectively. The liver of L1 fish showed dilation of sinusoids during monsoon, necrosis during post monsoon season and enlargement of portal tract by mononuclear inflammation and infiltration of leucocytes, vacuolisation of cytoplasm and necrosis during winter season. The liver of L2 fish showed infiltration of leucocytes during post-monsoon and heavy leucocyte infiltration along with necrosis during winter season. Liver has a vital role in detoxification, excretion, metabolism, digestion and also storage of various substances including some that can cause toxicity to the fish. Mohammad (2009) observed abnormal structure of liver including degeneration and necrosis of the hepatocytes, vacuolar degeneration in the hepatocytes, thrombosis formation in central veins, dilation, hypertrophy and pyknosis of a nucleus in the hepatic tissues, irregular shaped nucleus and cytoplasmic vacuolation in *L. rohita* collected from contaminated water of river Ravi.

Gills are main organ of respiration in fish and are more prone to damage as they are in direct contact with the toxicants present in the water and have a large surface area. Neither of the locations had normal gills histology in any of the season (Fig. 2). The gills of fish showed haemorrhage and

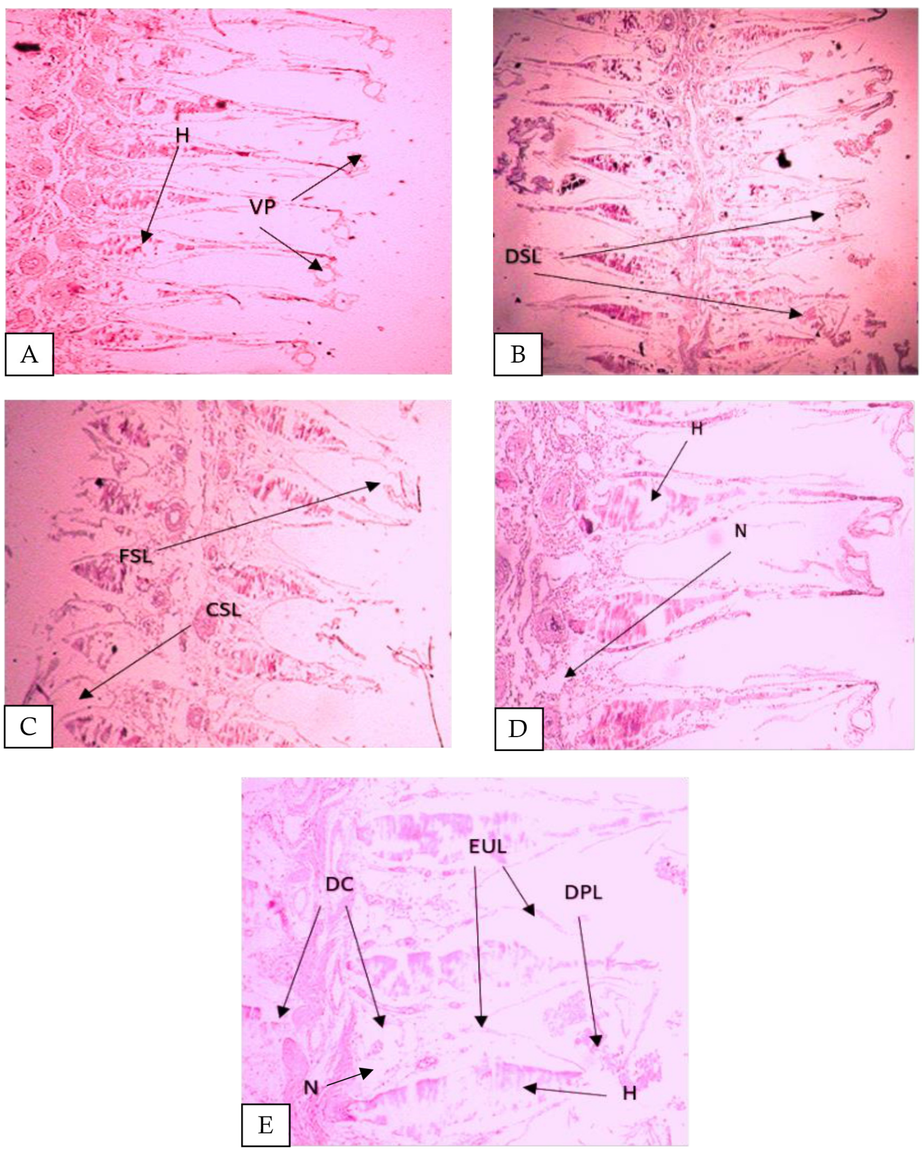

Fig. 2 T.S. of gills showing A. Haemorrhage (H) and Vasodilation in Primary lamellae (VP) (400X) B Disintegrating Secondary Lamellae (DSL) (400X)C. Fused Secondary Lamellae (FSL) and Curled Secondary Lamellae (CSL) (400X) D. Necrosis (N) and Haemorrhage (H) (400X) E. Degenerating Cartilage (DC), Epithelium uplifting (EUP), Degenerating Primary Lamellae (DPL), Haemorrhage (H) and Necrosis (N) (400X)

vasodilation in primary lamellae and disintegration of secondary lamellae during summer season, fusion and curling of secondary lamellae and necrosis alongwith haemorrhage during post monsoon season in L1 and L2 respectively. In winter season severe gill histomorphological alterations including degenerating cartilage, uplifting of epithelium, degeneration primary lamellae, necrosis and haemorrhage were observed in both L1 and L2 fish. Sultana *et al.* (2016) observed fusion of lamellae, dilation of blood vessels within gill arch, degeneration and necrosis of basal hyperplasia, dilation and rupture of marginal filaments lamellae distal hyperplasia and disorganization of lamellae within the gill filaments of fish from heavily contaminated river Ravi. Alterations like proliferation in the epithelial cells, fusion of some lamellae and epithelial lifting were defense mechanisms and it was caused by an increase in the distance between the external environment and the blood and thus serve as a barrier to the entrance of contaminants. Because of the increased distance between water and blood due to epithelial lifting, the oxygen uptake was impaired. Essien *et al.* (2013) evaluated histology of *Tilapia* exposed to mixed effluent in Okrika River, Rivers State, Nigeria and observed that gill showed vacuolar degeneration, focal areas of necrosis and aggregation of inflammatory cells between the hepatocytes. Ibrahim (2013) concluded that water quality alterations resulted in histopathological changes like haemorrhage curling and separation of secondary lamellae and necrosis in gills of *Oreochromis niloticus.*

Kidney being the vital organ involved in excretion for selective reabsorption in fishes is affected to a great extent if any toxicant is present in water for maintaining volume and pH of blood and body fluids. The toxic compounds present in filtrate affect the structure and function of organ involved in filtering as well. The normal renal histoarchitecture along with normal structure of proximal and distal convoluted tubules, Bowman's capsule and glomeruli was observed in kidneys of L3 fish during all seasons and in L1 and L2 fish during summer season (Fig. 3). However, necrosis was observed in both L1 and L2 during monsoon and post monsoon season. In winter season necrosis was observed in L1 fish and severe kidney damage including necrosis, degeneration of epithelial cells, degenerating glomeruli, degeneration proximal convoluted tubule and pyknosis in L2 fish . Chenari *et al.* (2011) observed variation in kidney histology in spotted scat, *Scatophagus argus* when exposed to abrupt salinity changes and observed that the fish kidney included significantly disoriented collecting tubules and glomeruli when subjected to higher salinity levels (10, 20 or 30 $g\ l^{-1}$) in comparison to proliferated, extensive, dense and muscular ones which retained in the kidney at 5 $g\ l^{-1}$ normal salinity level. Hussain *et al.* (2019) evaluated nephrotoxicity in *Wallago attu* and *Cirrhinus mrigala* collected from the Chenab River in an area of industrial and sewage waste disposal and observed necrosis of the hematopoietic interstitial tissue, vacuolar degeneration of renal tubules, narrowing of the tubular lumen, glomerulonephritis and renal tubular atrophy. These severe alterations were found to be related to environmental degradation, indicating the presence of stressors in freshwater.

Histology of muscle tissue of fish was observed to be normal showing various layers i.e.,

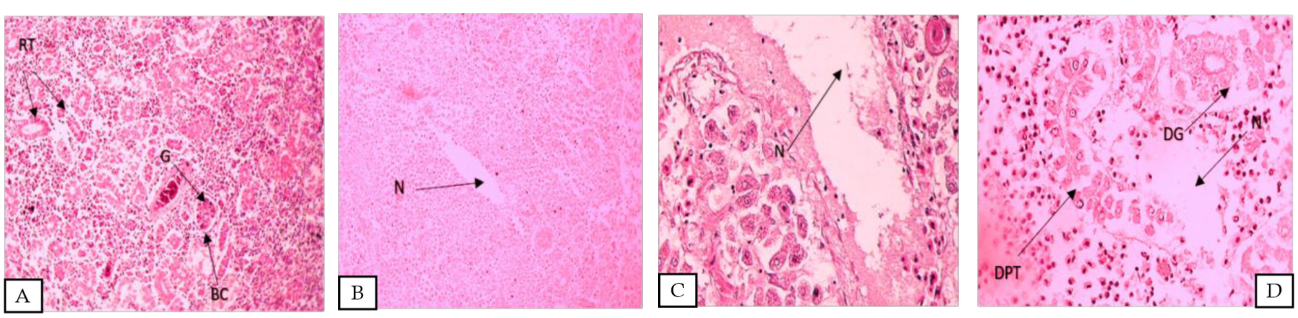

Fig. 3 T.S. of kidney showingA. Normal renal cytoarchitecture along with normal structure of renal tubules (RT), Bowman's capsule (BC) and Glomeruli (G) (100X)B. Necrosis (N) (100X)C. Necrosis (N) (400X) D. Necrosis (N), Degenerated Glomeruli (DG) and Degenerated Proximal Convoluted Tubule (DPT) (400X)

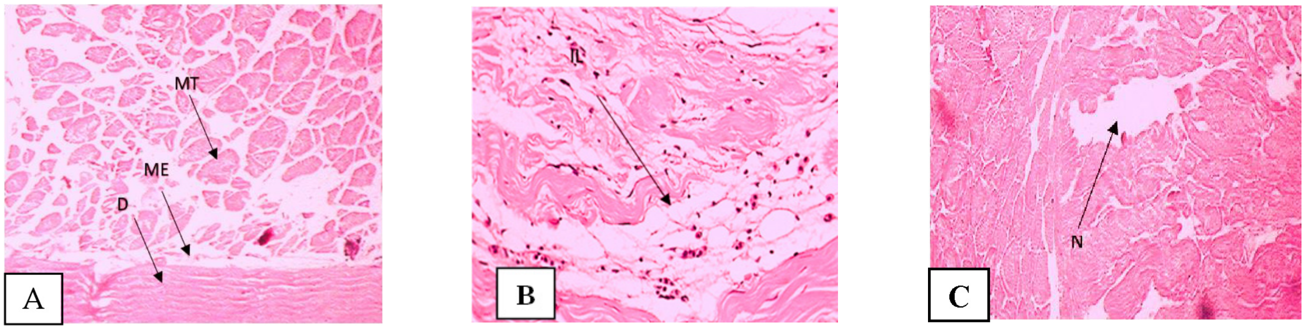

Fig. 4 T.S. of muscles showing A. Normal histology with Dermis (D), Myoepithelium (ME) and Myotomes (MT) (100X) B. Infiltration of Leucocytes (IL) (400X) C. Necrosis (N) (100X)

epidermis, dermis, myo-epithelium and normal myotomes during all seasons in L3 and during summer only in L1 and L2 (Fig. 4). The intra muscular edema and folding of dermis during monsoon season was observed in muscle tissue of L1 and L2 fish. In post monsoon further damage to muscular bundles was observed along with necrosis in both L1 and L2. In winter season infiltration of leucocytes in myoepithelium and elongated muscle bundles along with infiltration of leucocytes was observed in muscles of L1 and L2 fish respectively. Similar results of abnormal muscle histology due to contaminated environment in Cauvery river were observed which included shortening of muscle bundles, severe intra muscular edema and necrosis of muscle bundles (Dheva Krishnan and Zaman, 2012). Bhanot and Hundal (2021) found that histopathological biomarkers in fish muscles have considerable potential for measuring effect of toxicants present in wastewater on fish health.

Conclusions

The variations in biomarkers such as protein and lipid content alongwith histopathological changes in different tissues i.e. liver, gills, kidneys and muscles, activity of ALT and AST enzymes in liver and kidneys in *L.rohita* inhabiting different ponds of two districts of Punjab i.e. Ludhiana and Muktsar may be used for monitoring the water quality in aquatic ecosystems.

References

Abei Z, Hasantaban F, Khalesi MK and Babali S (2013) Effect of sublethal concentrations of cadmium, lead,and chromium on some enzymatic activities of common carp; *Cyprinus carpio*. *World Journal of Zoology* **8(1)**: 98-105.

Aier S and Dutta SP (2018) Comparative analysis of tissue protein isolated from *Labeo rohita, Labeo boga* and *Catla catla* and its expression. *International Journal of Research in Engineering, Science and Management* **1(12)**: 889-893

Ballantyne JS and Jarvis PL (2003) Metabolic responses to salinity acclimation in juvenile shortnose sturgeon *Acipenser brevirostrum. Aquaculture* **219**(1): 891-909.

Bergmeyer HU (1974) *Methods of Enzymatic Analysis*. Academic Press, Weinheim, Verlag Chemie, New York.

Bhanot R and Hundal SS (2021) Biochemical and histopathological effects in muscular tissue of carp fish (*Labeo rohita*, Hamilton 1822) following exposure to untreated and treated sewage water. *Environmental Science Pollution Research* https://doi.org/10.1007/s11356-021-13906-6

Boominathan M, Karthick B, Ali S and Ramachandra TV (2012) Spatial assessment of groundwater quality in Kerala, India. *IUP Journal of Soil and Water Sciences* **5**(1): 52-71.

Carpene E, Martin B and Libera LD (1998) Biochemical differences in lateral muscle of wild and farmed gilthead sea bream (series *Sparus aurata L.*). *Fish Physiology and Biochemistry* **19**: 229-238.

Chenari F, Morovvati H, Ghazilou A, Savari A and Ronagh MT (2011) Rapid variation in kidney histology in spotted scat *Scatophagus argus* on exposed to abrupt salinity changes. *Iranian Journal of Veterinary Research* **12(3)**: 256-261.

Christia C and Papastergiadou E (2007) Spatial and temporal variations of aquatic macrophytes and water quality in six coastal lagoons of western Greece. *Belgian Journal of Botany* **140**(1): 39-50.

Deshmukh MM and Shillewar KS (2018) Variation of protein contents in the muscle of fish *Puntius sarana (*Hamilton) from Godavari river at Nanded region, Maharashtra state. *International Journal of Life Sciences Research* **6**(3): 331-333.

Dheva Krishnan R and Zaman GMHU (2012) Cauvery river pollutants induced histopathological changes in kidney and muscle tissues of freshwater fish, *Labeo rohita* (Hamilton 1822). *Online International Interdisciplinary Research Journal* **2(5)**: 9-19.

Essien EB, Abbey BW, Chinwe N and Odeghe OB (2013) Physico-chemical evolution, gill Mda concentration and histology of Tilapia exposed to mixed effluent in Okrika River, Rivers State, Nigeria. *Journal of Environment and Earth Science* **3(2)**: 88-96.

Folch J, Less M and Sloane SGH (1957) A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry* **226**: 497-509.

Godara N (2016) A review study of groundwater quality of Malwa region, Punjab. *International Journal of Applied Research* **2(5)**: 395-398

Humason GL (1975) *Animal tissue techniques* 4th Edn. W.H. Freeman and Company San Francisco, USA

Hussain B, Fatima M, Al-Ghanim KA and Mahboob S (2019) Environmentally induced nephrotoxicity and histopathological alternations in *Wallago attu* and *Cirrhinus mrigla*. *Saudi Journal of Biological Sciences* **26(4)**: 752-757.

Ibrahim SA (2013) Effect of water quality changes on gills and kidney histology of *Oreochromis niloticus* fish inhabiting the water of Rosetta branch, River Nile, Egypt. *World Applied Sciences Journal* **26(4)**: 438-448.

Jürss K (1979) Effects of temperature, salinity, and feeding on aminotransferase activity in the liver and white muscle of rainbow trout (*Salmo gairdneri Richardson*). *Comparative Biochemisty and Physiology Part B Molecular Biology* **64(2)**: 213-218.

Krishan G, Lapworth DJ, Rao MS, Kumar CP, Smilovic M and Semwal P (2014) Natural (baseline) groundwater quality in the bist-doab catchment, Punjab, India: A pilot study comparing shallow and deep aquifers. *International Journal of Earth Sciences and Engineering* **7(01)**: 16-26.

Kumar SV, Pascal LF, Tennyson S, Pandeeswari M, Dhinamala K, Persis D, Raveen R, Arivoli S and Meeran M (2018) Changes in the biochemical profile of *Anabas testudineus* Bloch 1792 on exposure to aquatic toxicants of Buckingham canal, Chennai, Tamil Nadu, India. *International Journal of Fisheries and Aquatic Studies* **6(4)**: 81-86.

Livingstone DR (2003) Oxidative stress in aquatic organism in relation to pollution and agriculture. *Revista de Medicina Veterinaria* **154**: 427-430.

Lushchak V (2011) Environmentally induced oxidative stress in aquatic animals. *Aquatic Toxicology* **101**: 13-30.

Meshram DB, Masram SC and Baile VV (2019) Lead induced changes in protein content of kidneys, liver, muscles and ovary of Tilapia (*Oreochromis mossambicus*). *International Research Journal of Biological Sciences* **8(5)**: 17-20.

Mohammed FA (2009) Histopathological studies on *Tilapia zilli* and *Solea vulgaris* from Lake Qarun, Egypt. *Journal of Marine Sciences* **1**: 29-39.

Paithane KT, Sonawane DL, Bhandare RY and More PR (2012) Histophatological changes due to induced dimethoate in the liver of freshwater fish *Channa punctatus* from river Shivana, Aurangabad (M.S) India. *Ecoscan* **1**: 213-217.

Radhika C, Mini IG and Gangadevi T (2004) Studies on Abiotic parameters of tropical fresh water lake - Vellayani Lake, Trivandrum, Kerala. *Pollution Research* **23**(1): 49-63.

Ramani MB, Mercy TVA, Nair JR and Sherief PM (2002) Changes in the proximate composition of *Labeo rohita* (Halmiton) exposed to sub lethal concentrations of monocrotophos. *Indian Journal of Fisheries* **4(9)**: 427-432.

Reitman S and Frankel S (1957) A colorimetric method for the determination of serum glutamic oxalacetic and glutamic pyruvic transaminases. *American Journal of Clinical Pathology* **28**(1): 56-63.

Sharma R and Dutta A (2017) A study of heavy metal pollution in groundwater of Malwa Region of Punjab, India: Current status, pollution and its potential health risk. *International Journal of Engineering Research and Applications* **7(3)**: 81-91.

Sultana T, Butt K, Sultana S, Al-Ghanim KA, Mubashra R, Bashir N, Ahmed Z, Ashraf A and Mahboob S (2016) Histopathological changes in liver, gills and intestine of *Labeo rohita* inhabiting industrial waste contaminated water of river Ravi. *Pakistan Journal of Zoology* **48(4)**: 1171-1177.

Valon M, Aliko V, Sula E, Fahri G, Fatmir C, Ferizi R and Dhurata K (2013) Physiological response of fish to water pollution in Sitnica river (Kosovo). *Indian Stream Research Journal* **3**:1-5.

Vaseem H and Banerjee TK (2016) Evaluation of pollution of Ganga River water using fish as bioindicator. *Environmental Monitoring and Assessment* **188**: 444-453.

Vutukuru SS (2006) Acute effects of hexavalent chromium on survival, oxygen consumption, hematological parameters and some biochemical profiles of the Indian Major Carp, *Labeo rohita. International Journal of Environmental Research and Public Health* **2(3-4)**: 456-462.

Received: April 25, 2023; Accepted: June 16, 2023

Journal of Soil Salinity and Water Quality 15(1), 79-83, 2023

Effect of Frontline Demonstrations on Production, Productivity and Profitability of Chickpea (*Cicer arietinum*) under Saline Conditions of Rajasthan's Agro-climatic Zone IIa

HR Choudhary*, Gopichand Singh and Bhawana Sharma

Krishi Vigyan Kendra, Athiyasan, Nagaur-I, Agriculture University, Jodhpur, Rajasthan, India
**Corresponding author E-mail: hariram.agrian@gmail.com*

Abstract

Cluster Front Line Demonstrations (CFLDs) are novel approaches that provides a direct interface between researchers and farmers by involving scientists directly in the planning, execution, and monitoring of demonstrations for technologies developed by them and receiving direct feedback from farmers in the field about the crops. The cluster frontline demonstrations were conducted on chickpea crop at Bijathal and That village of Riyabadi block under Krishi Vigyan Kendra, Athiyasan, Nagaur-I during *rabi* seasons of 2020-21 and 2021-22 held. Total number of 50 CFLDs in 20 ha area were planned with the aim of showcasing the improved production technologies designed to establish the crop's potential productivity. The improved technologies package consisting use of improved variety (GNG-2144), soil treatment by *Trichoderma viride,* seed treatment with Carbendazim, mechanized sowing, integrated nutrients application, weed management, disease and pest management by Tebuconazole and Emamectin benzoate were compared with farmers' practices. Results revealed that the average yield of chickpea was observed as 1843 kg ha^{-1} in demonstration plots having improved variety as compared to local check (1460 kg ha^{-1}) which revealed 26.18% higher yield with incremental benefit: cost ratio of 0.90. The average technology gap, extension gap and technological index were found as 458 kg per ha and 19.89 percent, respectively. The results clearly indicate the positive effect of CFLDs over the existing practices to bridging the chickpea yield gap in saline soils.

Key words: Cluster frontline demonstrations, Chickpea, *Trichoderma viride,* Tebuconazole, Emamectin benzoate

Introduction

Pulses are the second most important crops after cereals in terms of agriculture, and they are also a great option for agriculture diversification and intensification in sustainable farming. India accounts for around 35% of the world's area and output of pulses and is also their greatest producer and consumer. India is the largest chickpea producing country, which is accounting for 64% of the global chickpea production (Gaur *et al.* 2010). In India, chickpea crop was grown in an area of 9.44 million hectares with the production of 10.13 million tons and the productivity of 1073 kg ha^{-1} (Anonymous, 2018-19). In Rajasthan state, chickpea crop grown in an area of 12.35 lakh hectare with production of 7.50 lakh tonnes and productivity of 607 kg ha^{-1} (Kumar and Kumawat, 2019). In Nagaur district, it occupies an area of 0.80 lakh hectares and 0.10 lakh tones production with1004 kg ha^{-1} productivity. Besides this, major abiotic stresses like low organic content in soil, low moisture content in the soil, soil salinity, seasonal drought due to low rainfall are also responsible for low productivity of the pulse crops (Dubey *et al.,* 2017). Among biotic stress, legume pod borer, *Helicoverpa armigera* (Hubner) is responsible for 50 to 60 per cent grain yield losses (Balikai *et al*., 2001).

The National Food Security Mission in India was given responsibility for the idea of cluster front line demonstrations. The major goal of frontline demonstrations at the cluster is to display newly released crop production technology and their management techniques in the farmer's field under various farming circumstances. These demonstrations are conducted under the direction of the experts of Krishi Vigyan Kendra. With the CFLD programme, new and innovative technology that has a higher output potential under a particular cropping system can gain popularity. The present study has been undertaken to evaluate the difference between demonstrated technologies vis-a-vis practices followed by the local farmers in Chickpea crop. Therefore, the effect of frontline demonstrations on production and productivity of chickpea crop has been studied in Transitional plain of Inland drainage zone (agro-climatic zone IIa) of Rajasthan.

Materials and Methods

The frontline demonstrations were conducted at 50 farmer fields in the villages Bijathal and That (Block-Riyabadi) of Nagaur district in Rajasthan during the *rabi* seasons of 2020–2021 and 2021–2022 under saline condition with 8.5 pH and 1.0 to 1.5 EC of soil. The fields were irrigated in sandy loam saline soil with low to medium fertility status under the Mungbean/ Cluster bean–Chickpea/ Fallow cropping systems. Each demonstration was conducted on an area of 0.4 ha and the same area adjacent to the demonstration plots was kept as farmer's practices. The package of improved production technologies included improved variety GNG-2144, fertilizer N:P:K:S (20:40:20:20 kg ha^{-1}) as per schedule. Soil treatment by *Trichoderma viride* @ 2.5 kg ha^{-1} (mixed with 100 kg FYM and uniformly spread), Seeds were treated with Carbendazim @ 3 g kg^{-1} seed followed by NPK consortia @ 10 ml kg^{-1} seed. Sowing of seeds was done in the first week of November every year with a seed rate of 70 kg ha^{-1} in line sowing with row to row spacing of 30 cm and 10 cm between plants. Optimum plant population was maintained in the demonstration plots. For diseases and insect management, fungicide Tebuconazole and insecticide Emamectin benzoate were used under demonstration plots. Recommended dose N and P fertilizer was applied through DAP as basal application and K and S fertilizer also applied as basal application. One hand weeding was done at 35 days after sowing for controlling weeds. The crop was harvested during third week of March after the leaves turn yellow and start dropping. The benefit-cost ratio was calculated based on gross returns. The yield data were collected from both the demonstrations and farmers' practices and their technology gap, extension gap and technology index were worked out (Samui *et al.*, 2000) as given below-

% increased yield = Demonstration yield - farmers yield × 100/farmers yield

Technology gap = Potential yield - Demonstration yield

Extension gap = Demonstration yield - Farmers yield

Technology Index = Technology gap × 100/potential yield

Results and Discussion

Technology gap analysis

The recommended package of practices and farmers existing practices were compared through survey. The main variations between farmer's practices and the demonstration package suggested that varieties, soil and seed treatment, sowing technique, sowing time, and fertilizer dosage were the major factors of technological gap. In the demonstration plots, only the inputs of the recommended practices were provided to the farmers by the KVK and all other packages and activities were timely carried out by the farmers themselves under the supervision of KVK scientists. Under farmer's practice, they sow seed of Chickpea varieties C-235, GNG-1581 and farmer own seeds at low seed rate with 40-50% of farmers followed seed treatment. As a result, the farmers selected under CFLD programme on Chickpea were provided seeds of improved chickpea variety GNG-2144. It is also observed that under farmers' practice, sowing of chickpea was done earlier to escape from water shortage for irrigation, thus leading to reduction in yield. Regarding the method of fertilization under demonstrations, all the fertilizers were drilled at the time of sowing, whereas, under farmer's practice, broadcast method of fertilization was used by the farmers. The performance and extension gap, technology gap and technology index of chickpea crop due to the adoption of improved technologies was assessed over a period of two years from 2020-21 to 2021-22 and is presented in Table 2. The economics of the data regarding cost of cultivation, gross returns, net returns, additional returns and benefit:cost ratio were analyzed and presented in Table 3.

Table 1. Details of gap analysis in chickpea

Technological practices	Recommended practice	Farmer's practice	% GAP
Variety	GNG-2144	C-235, GNG-1581, Farmer own seed	40-50
Seed rate	60-70 kg ha^{-1}	50-60 kg ha^{-1}	40-45
Seed treatment	Carbendazim @ 3 g kg^{-1} seed + NPK consortia @ 10 ml kg^{-1} seed	40-50% application	50-60
Soil treatment	*richoderma viride* @ 2.5 kg ha^{-1} mixed with 100 kg FYM	25-30% application	70-75
Method of sowing & crop geometry	Line sowing : Row × Plant (30 cm × 10 cm)	70-75% application	25-30
Nutrient Management	N:P:K:S (20:40:20:20 kg ha^{-1})	N:P (10:20 kg ha^{-1})	45-50
Weed Management	Pendimethalin 30% EC @ 0.6 kg a.i. ha^{-1} as pre-emergence + One hand weeding at 30-35 DAS	One hand weeding	35-40
Plant Protection	Pod borer- Emamectin benzoate 5% SG @ 220 g ha^{-1}, Root rot/ wilt- Soil treatment with *Trichoderma viride*@ 2.5 kg ha^{-1}, seed treatment with *Trichoderma* 10 g kg^{-1} seed and spray with Tebuconazole @ 1 ml litre^{-1}	50-60% application, Quinalphos dust @ 20 kg ha^{-1} and spray with Carbendazim 50 WP @ 0.1%	40-50

Effect on grain yield

Results revealed that average seed yield of 1892 and 1793 kg ha^{-1} were obtained in the demonstration plots of variety GNG-2144 as compared to 1475 and 1445 kg ha^{-1} in local check plot during 2020-21 and 2021-22, respectively in the villages (Table 2). The improvement in yield under CFLDs might be due to soil and seed treatments, use of bio fertilizers, timely sowing, application of recommended dose of fertilizers, proper and timely weed management and integrated pest management practices. Similarly, Kumar *et al.* (2019) also reported 83 to 1400 kg ha^{-1} grain yield of different pulse crops under demonstrations as compared to 72 to 840 kg ha^{-1} in farmer's practices. Kumar *et al.* (2018) also observed 28.57 to 30.28 per cent yield increase of chickpea crop under CFLDs in the similar dry areas.

Effect on extension gap, technology gap and technology index

The technology gap of 408 and 507 kg ha^{-1}, extension gap of 417 and 348 kg ha^{-1} and technology index of 17.74 and 22.04% was recorded in existing farmers' practices when compared with improved package of practices of chickpea during 2020-21 and 2021-22, respectively (Table 2). According to Parihar *et al.* (2018), the average extension yield gap in lentil crop was 183 kg ha^{-1} which resulted in higher grain yield under demonstrations as compared to farmers' practices. Lack of awareness of the farmers about the improved crop production technologies for better production results existence of extension yield gaps (Vedna *et al.,* 2007). The higher technology index (22.04) under CFLD plots showed the practicability of evolved technology package at the farmers' fields.

Effect on economics performance

The economic analysis of chick pea under demonstration and farmers' practice revealed that the net returns was Rs. 77046.08 and Rs. 73598.75 ha^{-1} in demonstration plots and Rs. 47756.25 and Rs. 48423.50 ha^{-1} in farmers' practices during 2020-21 and 2021-22, respectively. Benefit-cost ratio under demonstration plots was 3.97and 3.58 and control as farmers practices was 2.98 and 2.78 during 2020-21 and 2021-22, respectively (Table 3). The results further indicated that the cluster frontline demonstrations had good impact over the farming community of Nagaur district as they were motivated by the new agricultural technologies applied in the CFLD plots. Similarly, demonstrations of improved technologies at farmer's field proven best to a great extent in enhancing the production and productivity of chickpea crop (Tomar, 2010; Dayanand *et al.*, 2014; Singh *et al.,* 2017).

Table 2. Yield performance, technology gap, extension gap and technology index of Chickpea under farmer's practices and cluster front line demonstrations

FLD conducted year	Crop	Variety	No. of demonstrations	Area (ha)	Yield (q ha^{-1})			% increased yield over farmers practices	Technology gap (kg ha^{-1})	Extension gap (kg ha^{-1})	Technology index (%)
					Potential of variety	Demonstrated plot	Local checkplot				
2020-21	Chickpea	GNG-2144	25	10	23	18.92	14.75	28.27	408	417	17.74
2021-22	Chickpea	GNG-2144	25	10	23	17.93	14.45	24.08	507	348	22.04
Total/Average	50	20	23	18.43	14.60	26.18	458	383	19.89		

1 q=100 kg

Table 3. Economics of chickpea under cluster front line demonstrations

Conducted year	Cost of cultivation (Rs. ha^{-1})		Gross returns (Rs. ha^{-1})		Net returns (Rs. ha^{-1})		Additional net return over local check (Rs. ha^{-1})	B:C Ratio	
	Demonstrated plot	Local check plot	Demonstrated plot	Local check plot	Demonstrated plot	Local check plot		Demonstrated plot	Local check plot
2020-21	25915	24150	102961.08	71906.25	77046.08	47756.25	29289.83	3.97	2.98
2021-22	28560	27150	102158.75	75573.50	73598.75	48423.50	25175.25	3.58	2.78
Average	27237.50	25650	102559.92	73739.88	75322.42	48089.88	27232.54	3.78	2.88

Conclusions

The results of current study at farmers' fields indicated that the CFLDs programme is an effective tool for increasing chickpea production and productivity while also changing farmers' knowledge, attitude, and skill. The 26.18 percent average increase in yield of chickpea over the farmers' practice raised awareness and motivated other farmers to adopt the improved package of chickpea practices. These demonstrations also strengthened the bond and trust between farmers and scientists. The partner farmers of CFLDs also play an important role as source of information and quality seeds for wider dissemination of the high yielding varieties of Chickpea for other nearby farmers.

References

Anonymous (2018-19) *Agricultural Statistics at a Glance 2019*, Directorate of Economics and Statistics, Krishi Bhavan, New Delhi.

Balikai RA, Biradar AP, Yelshetty S and Teggelli RG (2001) Relative efficacy of some insecticides against chickpea pod borer, *Helicoverpa armigera*, *Karnataka Journal of Agricultural Science* **14**: 346-348.

Dayanand, Verma RK and Mehta SM (2014) Assessment of technology gap and productivity gain through frontline demonstration in chickpea. *Legume Research* **37**: 430-433.

Dubey S, Raghav RS and Singh P (2017) Enhancement of productivity for chickpea (*Cicer arietinum* L.) through front line demonstration in farmer's fields. *Legume Research* **40(2)**: 335-337.

Gaur PM, Tripathi S, Gowada CLL, Rao CVR, Sharma HC, Pande S and Sharma M (2010) Chickpea seed production manual. International Crop Research Institute for Semi Arid Tropics. pp-01.

Kumar M and Kumawat SR (2019) Knowledge level of farmers about chickpea production technology in Nagaur district of Rajasthan. *Journal of Krishi Vigyan* **8(1)**: 187-190.

Kumar S, Mahajan V, Sharma PK and Parkash S (2019) Impact of front line demonstrations on the production and productivity of moong (*Vigna radiate)*, mash (*Vigna mungo)*, rajmash (*Phaseolus vulgaris)*, lentil (*Lens culinaris)* and chickpea (*Cicer aeritinum)* under rainfed ecology in mid hills of J&K, India. *Legume Research* **42(1)**: 127-133.

Kumar U, Patel GA, Patel HP, Choudhari RP and Darji SS (2018) Impact of front line demonstration programme on the yield of chickpea (*Cicer arietinum* L.) in Patan District of Gujarat, India. *Legume Research*, DOI: 10.18805/LR-4081.

Parihar AK, Dixit GP and Gupta S (2018) Assessment of impact of frontline demonstrations in North Eastern-hill region of India. *Indian Journal of Hill Farming*, Special Issue: 40-43.

Samui SK, Maitra S, Roy DK, Mondal AK and Saha D (2000) Evaluation on front line demonstration on groundnut (*Arachis hypogea* L.). *Journal of the Indian Society of Coastal Agricultural Research* **18**: 180-183.

Singh J, Hundal RK and Dhillon BS (2017) Comparison for yield potential of chickpea in frontline demonstrations and farmer's practices in the Amritsar District of Punjab. *Current Agriculture Research Journal* **5(2)**: 239-243.

Tomar RKS (2010) Maximization of productivity for chickpea through improved technologies in farmer's field. *Indian Journal of Natural Products and Resources* **1(4)**: 515-517.

Vedna K, Kumar A, Kumar A and Bhateria S (2007) Demonstration of an effective tool for increasing productivity of rapeseed mustard in Kangra District of Himachal Pradesh. *Journal of Oilseeds Research* **33(2)**: 257-261.

Received: April 10, 2023; Accepted: June 23, 2023

Journal of Soil Salinity and Water Quality 15(1), 84-93, 2023

Impact of Differential Irrigation on Performance of Onion Cultivated With and Without Plastic Mulching

D Rajak[1], Pravin Dahiphale[2] and Mahesh Chand Singh[3]*

[1]Department of Agricultural Engineering, BAU, Ranchi-834006, Jharkhand, India
[2]Director Farm, Punjab Agricultural University, Ludhiana-141004, Punjab, India
[3]Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India
**Corresponding author E-mail: msrawat@pau.edu*

Abstract

A three-year (2015 to 2018) study was carried out to monitor the response of differential drip irrigation with and without mulching on growth, yield and water use-efficiency (WUE) of onion cultivated in sandy loam soil at Zonal Research Station, Darisai, Jharkhand, India. The experiment was laid thrice in a randomized block design with eight treatments *viz.* T_1: drip irrigation at 100% of crop evapotranspiration (ET_c), T_2: T_1 + silver black polyethylene (PE) mulch, T_3: drip irrigation at 80% of ET_c, T_4: T_3 + PE mulch, T_5: drip irrigation at 60% ET_c, T_6: T_5+ PE mulch, T_7: surface irrigation, T_8: T_7+ PE mulch. Under drip irrigation (with and without PE mulch), plant height, leaves/plant, bulb diameter and yield were recorded on higher sides as compared to surface irrigation alone or with mulch. The yield under drip irrigation (19094 kg ha^{-1}) at 80% of ET_c was recorded significantly higher when compared with surface irrigation (12039 kg ha^{-1}). The use of PE mulch with drip irrigation further enhanced the yield to 23239 kg ha^{-1}. The highest and lowest WUE were obtained as 74.76 and 20.48 kg ha^{-1} mm^{-1} under drip irrigation at 80% ET_c with PE mulch and surface irrigation, respectively. Drip irrigation at 80% of ET_c resulted in higher net income (113518.70 INR ha^{-1}) and benefit-cost ratio (B:C=1.52) in onion. Whereas, drip irrigation at 80% of ET_c with PE mulch recorded maximum net income (145719.90 INR ha^{-1}) and B:C value (1.77). Drip irrigation resulted in water saving and yield increment of about 47 and 48% as compared to surface irrigation.

Key words: Drip irrigation, PE mulch, onion, yield, WUE, benefit-cost ratio

Introduction

Onion (*Allium cepa* L.) is commercially cultivated and widely consumed as vegetable crop in India. It is an important commodity from export point of view. In India, onion occupies about 1285 thousand hectares under cultivation with total production of 23262 thousand MT with a productivity of 18.10 (MT ha^{-1}). It is an important commercial vegetable crop grown in Jharkhand, covering an area of 17.16 thousand hectares with production and productivity of 289.04 thousand MT and 16.84 MT ha^{-1}, respectively (Anon, 2018). India though ranks second in area and production, the productivity is quite low as compared to other onion producing countries like China, USA and Turkey. One of the main reasons for low productivity of onion crop is lack of awareness among the farmers about good quality seed production techniques, particularly the improved practices like drip irrigation, fertigation, etc. Flood irrigation method widely practiced in India results in inefficient use of irrigation water due to losses in evaporation, deep percolation and distribution.

Drip irrigation has proved its superiority over other conventional methods of irrigation, especially in the cultivation of fruits and vegetables due to precise and direct application of water in root zone. Numerous studies have reported significant saving of water, improved plant growth, and enhanced yields of vegetables under drip irrigation (Bhella, 1988; Bafna *et al.*, 1993; Raina *et al.*, 1999; Imtiyaz *et al.,* 2000). The use of PE mulch in vegetable production has been reported to be beneficial in controlling the weed incidence, reducing nutrient losses and improving the hydrothermal regimes of soil (Chakarborty and Sadhu, 1994; Singh, 2005).

Drip irrigation alone or in combination with plastic mulches is widely used for vegetable production, particularly for growing tomatoes, peppers and melons (Lamont, 1993). However, drip irrigation and plastic mulches are not used for onion production in Jharkhand. The benefits associated with the use of plastic mulches for vegetable production include higher yields, earlier harvests, cleaner fruits, controlling weed population, reducing the impact of falling rain drops and reducing soil erosion, regulation of soil temperature, conservation of soil moisture, and increased water and fertilizer use efficiencies (Agarwal *et al.*, 2003; Kimura *et al.*, 2014; Geisseler *et al.*, 2022). Onions produced using white-on-black mulches have higher marketable yields as compared to those cultivated on bare soil surface (Vavrina and Roka, 2000).

However, limited information is available regarding the effect of drip irrigation alone and in conjunction with polyethylene mulch as compared to surface irrigation on growth and yield of onion. Therefore, the present study was undertaken to monitor the effects of different levels of drip irrigation with and without PE mulch on growth, yield, water-use efficiency and economics of onion cultivation.

Materials and Methods

A field experiment was conducted during 2015-16, 2016-17 and 2017-18 at Zonal Research Station, Darisai, East Singhbhum, Jharkhand, India. The site is between 23°36′ N latitude and 86°54′ E longitude with an altitude of 124m above mean sea level. The mean annual rainfall and temperature of the region are 1200 mm and 28°C, respectively. The soil of the experimental site is sandy loam in texture. The major physical parameters, nutrients and water content of the soil at the study site are presented in Table 1.

Experimental treatments

The experiment was carried out in a randomized black design with eight treatments in three replicates. The treatments were as follows:

T_1: drip irrigation at 100% of ET_c

T_2: drip irrigation at 100% of ET_c + PE mulch

Table 1. Physical properties, nutrient concentration and water content of the soil at the study site

Category	Parameter	Value
Physical properties	pH	5.81
	Bulk density (g cm^{-3})	1.7
	Organic carbon (%)	48.0
Nutrient concentration (kg ha^{-1})	N	247.9
	P	51.55
	K	144.0
Moisture content (%)	At field capacity	17.79
	At wilting point	8.0

T_3: drip irrigation at 80% of ET_c

T_4: drip irrigation at 80% of ET_c + PE mulch

T_5: drip irrigation at 60% of ET_c

T_6: drip irrigation at 60% of ET_c+ PE mulch

T_7: surface irrigation

T_8: surface irrigation + PE mulch

Daily pan evaporation was recorded from the class A type USWE pan evaporimeter installed at the meteorological observatory of the station. Pan evaporation method as suggested by Mane *et al.* (2006) was used for estimating volume of water (equation 1) for 100, 80 and 60% of ET_c.

$$V = \frac{A \times E_p \times K_p \times K_c \times A_w}{U_e} \quad (1)$$

Where, V = Volume of water required for 100% of ET_c (l/day/plant), A = Crop area (m), E_p = Maximum pan evaporation (mm day^{-1}), K_p = Pan coefficient, K_c = Crop coefficient, A_w = Wetted area and U_e = Emission uniformity in decimal.

The pan coefficient value of 0.75 as suggested for USDA class A pan and the crop co-efficient for various growth stages were taken from Allen *et al.* (1998). The emission uniformity was evaluated by the method (equation 2) as suggested by Keller and Karmeli (1974).

$$U_{fe} = \frac{q_m}{q_a} \times 100 \quad (2)$$

Where, U_{fe} = Field emission uniformity (%), Q_m = Average flow rate (l h^{-1}) of emitters in the lowest quartile (1/4th) and q_a = Average flow rate (l h^{-1}) of all emitters under test

Seedling transplanting

Onion seedlings of variety 'Agri Found Dark Red'was transplanted at a depth of 3 cm by maintaining plant spacing of 15 cm × 10 cm (row to row × plant to plant).

Irrigation scheduling and fertigation

Inline laterals were laid in between the two rows of crop having emitters (at 40 cm spacing) with discharge rate of 2.40 l h^{-1}. One common irrigation was applied before transplanting for the purpose of proper establishment of crop in all the treatments. For drip irrigation treatments, the irrigation was scheduled on daily basis and the required quantity of water to be applied was computed for each day. The performance of drip irrigation was evaluated by computing the emission uniformity (EU). For surface irrigation it was scheduled at 1.0 IW/CPE ratio with 50 mm depth. The daily pan evaporation from USWB Class A pan evaporimeter was summed up and when cumulative pan evaporation (CPE) attained the value of 50 mm, the water was applied to the plots through PVC pipe. The N, P_2O_5 and K_2O fertilizers were applied at the rate of 100, 60, 60 kg ha^{-1}, respectively.

Benefit-cost analysis

For economic analysis, total seasonal cost included depreciation, interest, repairs and maintenance cost of drip irrigation set + cost of cultivation + variable cost. The income from produce for different treatments was calculated taking into account the wholesale market prices of onion. The net returns were calculated considering income from produce and total seasonal cost of production. The benefit cost ratio (B:C) was estimated dividing income obtained from produce by total cost of production for each treatment. Equations 3 and 4 were used to calculate B:C value.

$$\text{Net returns} = \text{Gross returns} - \text{cost of cultivation} \quad (3)$$

$$B:C = \frac{\text{Gross return}}{\text{Cost of cultivation}} \quad (4)$$

Data recording

Data on plant height, number of leaves per plant, days to first fruit harvest, number of fruits per plant, fruit length, fruit diameter, fruit weight, bulb diameter and bulb weight were recorded. The relationship of fruit yield of onion with different fruit parameters can be better understood by forming a mathematical expression between them, as done in the present case. WUE was computed by dividing onion yield with total water applied.

Statistical analysis

The recorded data was analyzed statistically using the analysis of variance procedure, for randomized block design at a significance level of 5%.

Results and Discussion

Performance of drip irrigation system and water saving

EU of drip irrigation system was obtained as 90%, indicating uniform water application to the crop. The water saving at 60, 80 and 100% of ET_c under drip irrigation were obtained as 57.6, 46.7 and 36.1%, respectively as compared to surface irrigation. The water saving under different treatments are presented in Table 3.

Effect of irrigation (with and without PE mulch) on plant growth parameters

The data on plant growth parameters like plant height, number of leaves per plant of onion are presented in Table 2. The plant growth was observed to be significantly superior under T_4 (drip irrigation at 80% of ET_c with PE mulch) as compared to the rest of the treatments. The mean height of plant under treatment T_4 (72.93cm) was found to be significantly higher among all other treatments, being 37.8 % higher than that obtained under surface irrigation without mulch (T_7). The plant height under T_4 treatment were recorded as 55.4 cm, 83.3 cm and 80.1 cm during 2015-16, 2016-17 and 2017-18, respectively (Fig.1). Whereas, under T_7, the plant height were as 47.8cm, 56.4 cm and 54.4 cm during 2015-16, 2016-17 and 2017-18, respectively (Fig. 1), being lowest among all treatments. The average plant height (descending order) were as 72.99 cm, 69.7cm, 66.52cm, 64.89cm, 62.79cm, 59.76 cm, 57.76 cm and 52.91cm under T_4, T_2, T_3, T_1, T_6, T_5, T_8 and T_7, respectively. Similarly, the number

Table 2. Effect of drip irrigation and PE mulch of plant height, number of leaves per plant, bulb diameter, bulb weight and yield per hectare (pooled data of three years)

Treatments	Plant height (cm)	No. of leaves plant^{-1}	Bulb diameter (cm)	Bulb weight (gm plant^{-1})	Yield (kg ha^{-1})
T_1: drip irrigation at100% of ET_c	64.89	7.92	4.97	46.50	18600
T_2: drip irrigation at 100% of ET_c + PE mulch	69.70	8.60	5.55	55.84	22335
T_3:drip irrigation at80% of ET_c	66.52	7.98	5.11	47.73	19094
T_4: drip irrigation at 80% of ET_c + PE mulch	72.93	9.20	6.08	58.07	23239
T_5: drip irrigation at60% of ET_c	59.77	7.30	4.58	41.56	16627
T_6: drip irrigation at 60% of ET_c+ PE mulch	62.79	7.62	4.73	44.66	17863
T_7: surface irrigation	52.91	6.60	4.11	30.49	12039
T_8: surface irrigation + PE mulch	57.57	7.07	4.32	37.58	14844
CD at 5%	3.91	0.56	0.49	2.70	1150

Table 3. Water applied, WUE, water saving and B: C value under different treatments (pooled data of three years)

Treatments	Water applied (mm)	Water use efficiency (kg ha^{-1} mm^{-1})	Water saving over surface irrigation (%)	Net income	B:C ratio
T_1: drip irrigation at 100% of ET_c	368.51	49.46	36.08	108829.20	1.44
T_2: drip irrigation at 100% of ET_c + PE mulch	368.51	59.64	36.08	136936.20	1.65
T_3: drip irrigation at 80% of ET_c	306.82	61.20	46.71	113518.70	1.52
T_4: drip irrigation at 80% of ET_c + PE mulch	306.82	74.76	46.71	145719.90	1.77
T_5: drip irrigation at 60% of ET_c	245.13	66.72	57.67	87416.72	1.19
T_6: drip irrigation at 60% of ET_c+ PE mulch	245.13	71.44	57.67	90913.95	1.11
T_7: surface irrigation	576.73	20.48	-	58045.00	0.98
T_8: surface irrigation + PE mulch	576.73	24.90	-	74527.24	1.16

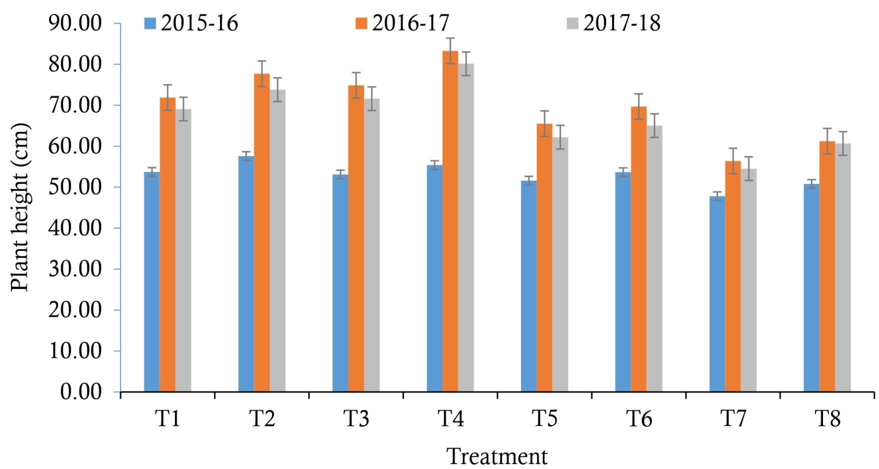

Fig. 1 Plant height during 2015-16, 2016-17 and 2017-18

of leaves per plant were recorded highest and lowest under T_4 (9) and T_7 (7), respectively. The maximum number of leaves per plant were recorded under treatment T_4 as 7, 9 and 8 during 2015-16, 2016-17 and 2017-18, respectively, whereas the lowest values were recorded under T_7 were as 6, 7 and 7 for 2015-16, 2016-17 and 2017-18, respectively (Fig. 2).

Effect of irrigation (with and without PE mulch) on onion bulb diameter

The highest (6.08 cm) and lowest (4.11 cm) bulb diameters were recorded under T_4 (drip irrigation at 80% of ET_c+PE mulch) and surface irrigation (Table 2), respectively. The year-wise bulb diameters under different treatments are presented

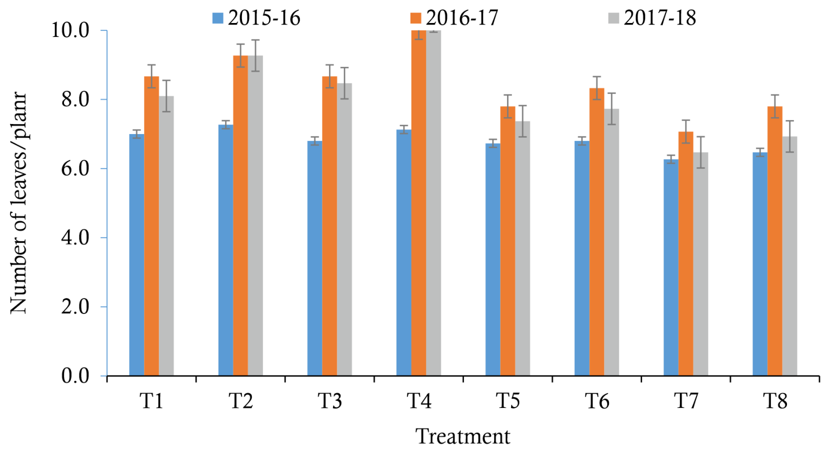

Fig. 2 Number of leaves per plant during 2015-16, 2016-17 and 2017-18

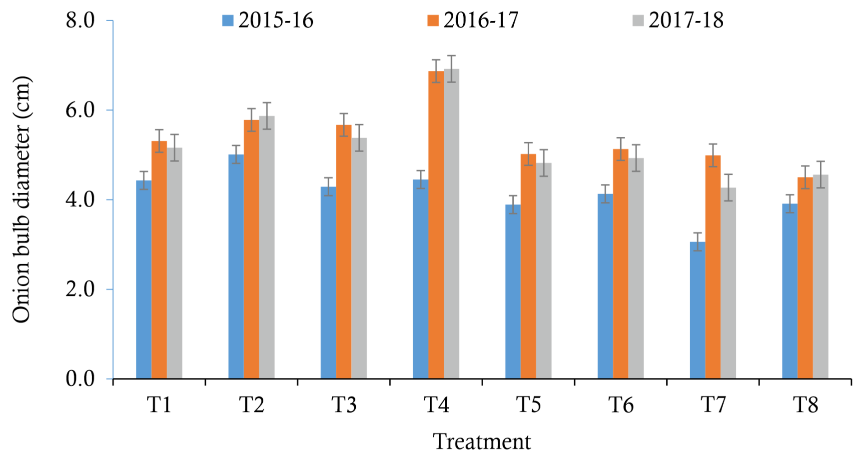

Fig. 3 Onion bulb diameter during 2015-16, 2016-17 and 2017-18

in Fig.3. The bulb diameter under T_4 for 2015-16, 2016-17 and 2017-18 were recorded as 4.45cm, 6.87cm and 6.92 cm, respectively (Fig.3). The lowest bulb diameter was observed in T_7 as 3.06 cm, 4.99 cm and 4.27 cm during 2015-16, 2016-17 and 2017-18, respectively (Fig.3). The bulb diameter was recorded to be highest under T_4, followed by T_2 and T_3 with the bulb diameter under T_1 (100% ET_c), T_3 (80% ET_c) and T_5 (60% ET_c) increased by 20.9, 24.3 and 11.4%, respectively over surface irrigation (Table 2). The increments in bulb diameter under T_2, T_4 and T_6 were recorded as 28.5, 40.7 and 9.5%, respectively over surface irrigation plus mulch (T_8). The diameter of onion bulb was significantly affected by irrigation treatments, being highest under 80% of ET_c (with PE mulch) irrigation level compared.

Effect of irrigation (with and without PE mulch) on onion bulb weight

The mean bulb weight was recorded to be maximum (58.07 gm) under T_4 (drip irrigation at 80% of ET_c+ PE mulch), being significantly higher than that obtained under surface irrigation (30.49 gm). The mean bulb weight during 2015-16, 2016-17 and 2017-18 were recorded as 53.2, 59.8 and 61.1 gm plant^{-1}, respectively under the treatment T_4, whereas for T_7 the values were 30.18, 30.82 and 30.46 gm plant^{-1} for the three respective years (Fig.4). Under T_2, the bulb weight during 2015-16, 2016-17 and 2017-18 were recorded as 56.2, 55.1 and 56.2 gm/plant, respectively. Irrespective of mulching, a significant increase in bulb weight was recorded with drip irrigation compared to surface irrigation (Table 2). Drip irrigation without mulch i.e. under T_1 (100% of ET_c), T_3 (80% of ET_c) and T_5 (60% of ET_c) recorded increased bulb weight by 52.5 and 56.5, 36.3 %, respectively over surface irrigation (Table 2). Drip irrigation plus mulch (T_2, T_4 and T_6) recorded about 48.6, 54.5 and 18.8% increase in bulb weight, respectively over surface irrigation plus mulch (T_8).

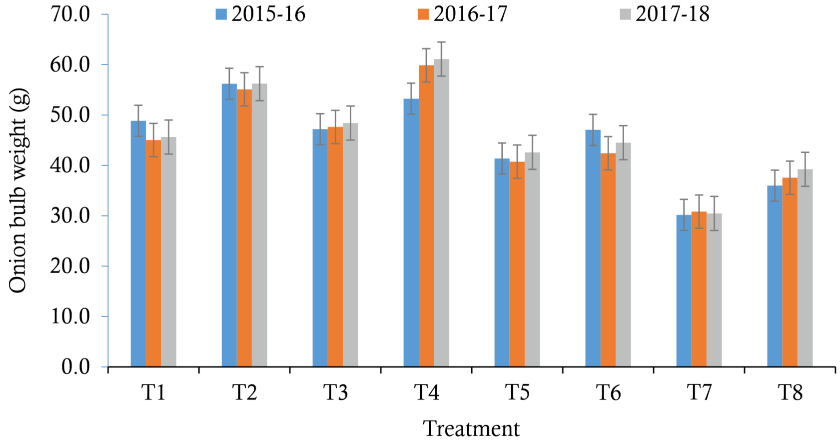

Fig. 4 Bulb weight during 2015-16, 2016-17 and 2017-18

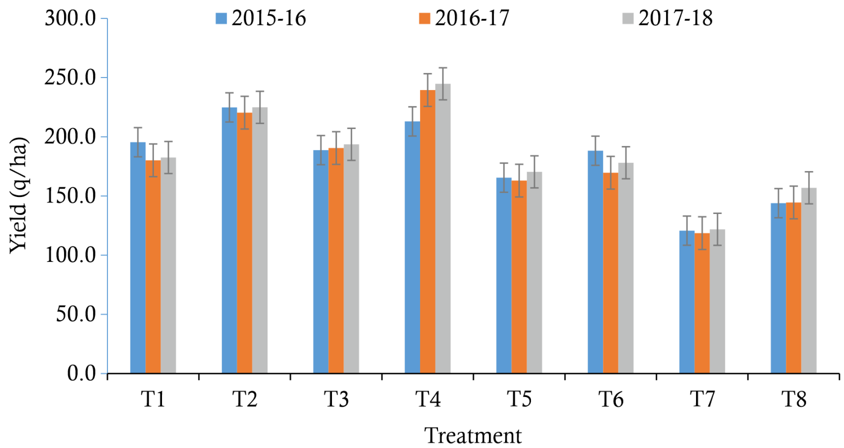

Fig. 5 Onion yield during 2015-16, 2016-17 and 2017-18

Effect of irrigation (with and without PE mulch) on onion yield

Drip irrigation at 80% of ET_c + PE mulch resulted in significantly higher yield (23239 kg ha^{-1}) than other treatments. For years 2016-17, 2017-18 and 2018-19, the onion yield under T_4 were recorded as 21297, 23946 and 24473 kg ha^{-1} with mean value of 23239 kg ha^{-1}, being highest among all the treatments (Fig.5). The lowest yield was recorded under surface irrigation with values of 12071, 11862 and 12185 kg ha^{-1} during 2016-17, 2017-18 and 2018-19, respectively with mean of 12039 kg ha^{-1}. The highest average yield was obtained under T_4, followed by T_2. The results indicated yield increments of 54.5, 58.6 and 38.1% under T_1 (100% of ET_c), T_3 (80% of ET_c) and T_5 (60% of ET_c), respectively over surface irrigation (T_7). The corresponding yield increments under T_2, T_4 and T_6 were 50.46, 56.55 and 20.34% than T_8. Application of silver black plastic mulch in surface irrigation (T_8) also helped to increase the yield by 23.30% as compared to surface irrigation without mulch (T_7). Overall, the application of PE mulch helped to increase the yield under all levels of irrigation, though the response was comparatively better under trea tment T_4 and T_2 (Table 2). Higher yield under irrigation treatments with mulch might be due to better weed control. There was complete elimination of weeds under PE mulch, whereas in the plots without mulch weeding was done manually six times during the experimentation.

Yield model of onion

A regression model was developed for predicting onion yield in relation to plant height (h), number of leaves per plant, bulb diameter (D) and bulb weight (w). The yield of onion was linearly related to h, number of leaves per plant, D and w, as described by equation (5). The results of the present study indicate higher onion yield with greater values of h, D and w and vice-versa. The

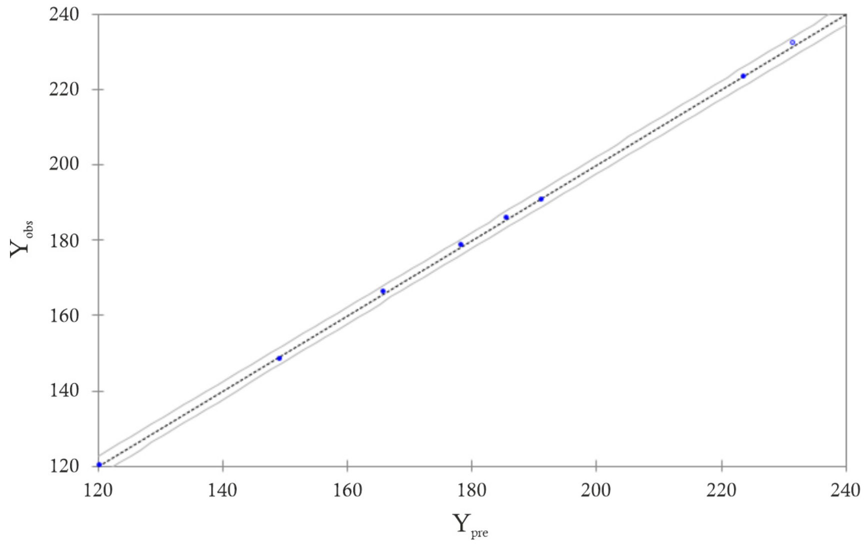

Fig. 6 Relationship between observed and predicted yields

similar relationship of yield with h, D and w is depicted by the following equation. The developed model was sufficiently accurate to predict onion yield. The plot between observed (Y_{obs}) and predicted (Y_{pre}) indicates a close association between them as shown in Fig. 6.

$$Y = 5.70606 + 0.38027*h - 6.98004*n + 3.00796*D + 4.20284*w \quad (5)$$

Effect of irrigation (with and without PE mulch) on WUE

The water applied was highest under T_7 and T_8 as compared to other treatments. During 2015-16, 2016-17 and 2017-18, the total amount of water applied under T_4 were 302.78 mm, 273.37 mm and 344.32mm, respectively with mean value of 306.86 mm (Fig. 7) and resulted in highest yield. Similarly, the quantity of water applied under T_1 as well as T_2 were 366.35 mm, 333.46 mm and 405.72 mm with mean value of 368.51 mm. Same quantity of water were applied under treatment T_3 and T_4, T_5 and T_6 and T_7 and T_8. The total amount of water applied for different levels of drip irrigation during crop period are presented in Table 3. The water applied under drip irrigation was highest for 100% ET_c (368.51 mm) followed by 80% ET_c (306.82 mm) and minimum in case of 60% ET_c (245.13 mm), whereas in surface irrigation, the amount of water applied was 576.73 mm. Drip irrigation, both with and without PE mulch recorded higher WUE as compared to surface irrigation.

Highest WUE was observed under drip irrigation at 80% of ET_c with mulch (74.76 kg

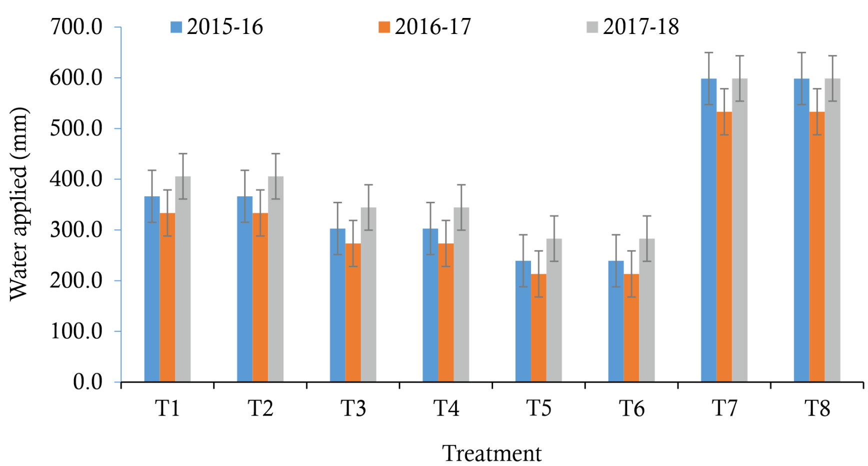

Fig. 7 Water applied for onion production during 2015-16, 2016-17 and 2017-18

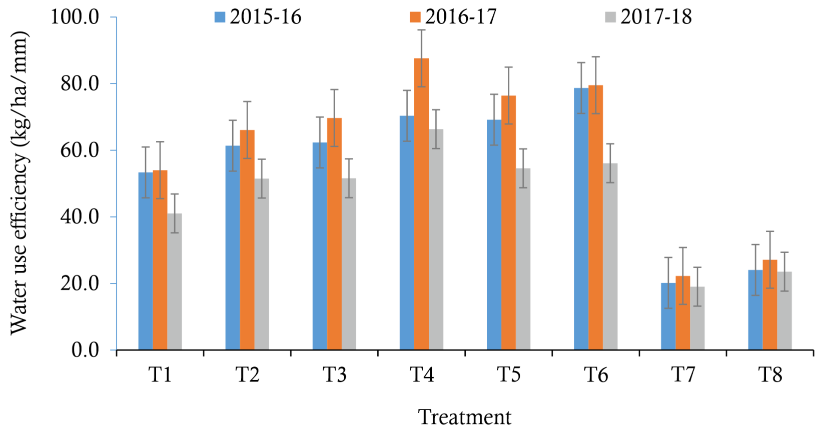

Fig. 8 Water use efficiency of onion production during 2015-16, 2016-17 and 2017-18

ha^{-1} mm^{-1}) and with drip irrigation at 60% ET_c with PE mulch (71.44 kg ha^{-1} mm^{-1}). WUE was recorded to be highest and lowest under T_4 and T_7, respectively during all the three years (2015-16, 2016-17 and 2017-18). The WUE values during 2015-16, 2016-17 and 2017-18 were 70.3, 87.6 and 66.3 kg ha^{-1} mm^{-1}, respectively with a mean value of 74.76 kg ha^{-1} mm^{-1} under T_4. Whereas, under T_7 WUE values were computed as 20.17, 22.26 and 19.02 kg ha^{-1} mm^{-1} for 2015-16, 2016-17 and 2018-19, respectively with mean value of 61.45 kg ha^{-1} mm^{-1}, being lowest among all the treatments. The WUE values under T_6 were computed as 78.68, 79.53 and 56.1 kg ha^{-1} mm^{-1} for 2015-16, 2016-17 and 2017-18, respectively with a mean value of 71.44 kg ha^{-1} mm^{-1}. Drip irrigation without mulch and surface irrigation resulted WUE values of 59.13 and 20.48 kg ha^{-1} mm^{-1}, respectively. Whereas, the WUE values for drip plus mulch and surface irrigation plus mulch were 68.61 and 24.90 kg ha^{-1} mm^{-1}, respectively. The WUE under drip irrigation was higher as compared to surface irrigation, as the rate of water loss through evaporation from soil surface was much lower due to drip method of irrigation.

Benefit-cost analysis of onion cultivation

Drip irrigation with plastic mulch registered higher net income and B:C value as compared to surface irrigation. The B:C value was computed to be highest under T_4 as 2.02 and 2.08 during 2016-17 and 2017-18, respectively (Fig. 9). Whereas, in 2015-16, the highest B:C value was obtained under T_2. The mean B:C value varied from 0.98 to 1.77, being lowest and highest under T_7 and T_4, respectively. Among different irrigation levels, drip irrigation at 80% of ET_c with PE mulch resulted in maximum net income (145719.9 INR ha^{-1}) and higher B:C value (1.77), Whereas, the lowest net income and B:C values were obtained as 58045 INR ha^{-1} and 0.98, respectively.

In the present study, drip irrigation resulted in uniform application of water to the onion crop

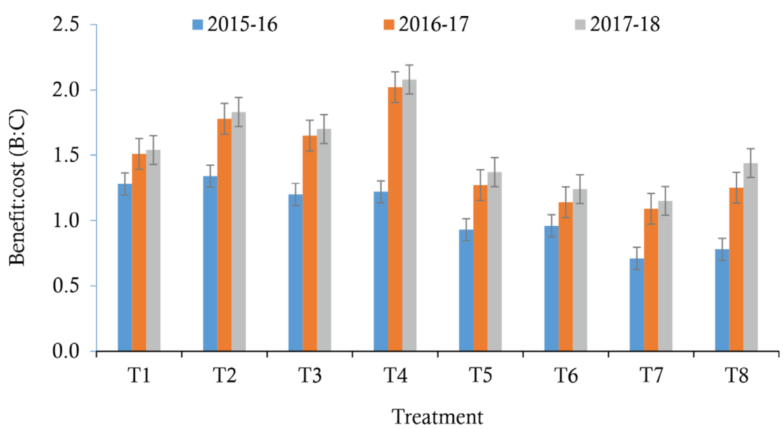

Fig. 9 B:C values of onion production during 2015-16, 2016-17 and 2017-18

with EU value of 90%. Previously, Edossa and Emana (2011) recorded the average EU value of about 89%. About 57.6, 46.7 and 36.1% saving in irrigation water were realized under 60, 80 and 100% of ET_c treatments, respectively when compared with conventional flood irrigation. Earlier Reddy *et al.* (2011) have reported 65.7, 55.2 and 44.6% water saving under drip irrigation at 60, 80 and 100% ET_c levels, respectively over surface irrigation. Bhasker *et al.* (2018) also reported about 29.4% of water saving in drip irrigation over surface irrigation for growing onion. The growth parameters (plant height and number of leaves) performed better under drip irrigation at 80% of ET_c with PE mulch as compared to the rest of the treatments. These results were in agreement with Reddy *et al.* (2011) and Bhasker *et al.* (2018). Both Reddy *et al.* (2011) and Bhasker *et al.* (2018) reported significantly higher vegetative growth in onion with drip irrigation compared to surface irrigation. Similar findings were reported by Singh *et al.* (2009) in tomato. Onion bulb diameter and fruit weight were also recorded to be highest with 80% of ET_c (with PE mulch) irrigation level compared to other irrigation levels. Reddy *et al.* (2011) also recorded the maximum bulb diameter of 6.86 cm under 80% ET_c. Similar observations were recorded by Pejic *et al.* (2011) in onion and Singh *et al.* (2009) in tomato.

The highest onion yield (23239 kg ha^{-1}) was recorded under drip irrigation at 80% of ET_c with PE mulch as compared to rest of the treatments including conventional flood irrigation. The onion yield for the three respective years were 21297, 23946 and 24473 kg ha^{-1}. The possible reasons for increased yield under drip irrigation might be the better water utilization (Manifrinato, 1974), higher uptake of nutrients (Bafna *et al.,* 1993) and excellent soil-water relationship with higher oxygen concentration in the root zone (Gornat *et al.,* 1973). Whereas, the reasons for low yield under surface irrigation might be the less availability of nutrients for crop growth due to leaching with high weed infestation (Pattanaik *et al.*, 2003), and wastage of water in deep percolation and poor aeration (Raina *et al.,* 1999). The results of the present study are in accordance with the earlier findings of Reddy *et al.* (2011) who obtained higher onion yield with drip irrigation at 80% of ET_c as compared to surface irrigation. Vavrina and Roka (2000) have also reported highest onion yield under white on black mulch than the bare ground. Besides, the developed regression model of onion yield was sufficiently accurate to predict onion yield in relation to plant height, number of leaves, fruit diameter and weight. The WUE under drip irrigation plus mulch was recorded to be 175.5% higher as compared to surface irrigation plus mulch. The higher WUE under drip irrigation, particularly at 80% ET_c (with PE mulch) as compared to surface irrigation was mainly due to lower rate of water loss through evaporation from soil surface. The results of this study confirmed the earlier findings of Pejic *et al.* (2011), Sankar *et al.* (2015) and Enchalew *et al.* (2016) who also reported highest WUE in onion cultivation under drip irrigation at 70% of ET_c. The drip irrigation at 80% of ET_c with PE mulch resulted in maximum net income with highest B:C value (1.77). The results obtained were in agreement with Reddy *et al.* (2012) and Bhasker *et al.* (2018) for onion cultivation and also with Singh *et al.* (2009) for growing tomato. This proves that an appropriate combination of drip irrigation schedule and plastic mulching, as obtained in the present case would help to improve plant growth, onion yield, water use efficiency and profits to a significant extent.

Conclusions

Drip irrigation at 80% of ET_c plus PE mulch helped to obtain the highest yield (232.39 q/ha) with maximum plant height (72.93 cm) and number of leaves per plant (9), WUE (74.76 kg ha^{-1} mm^{-1}) and B:C value (1.77). Increasing trend in yield under 80% of ET_c (with PE mulch) irrigation treatment was recorded during the study years (2015 to 2018) with yield values of 21297, 23946 and 24473 kg ha^{-1} during 2015-16, 2016-17 and 2017-18, respectively. In comparison with surface irrigation, drip irrigation proved to save a significant amount of irrigation water (about 47% saving) with about 48% enhancement in onion yield. Thus, it can be concluded that an appropriate combination of irrigation schedule and PE mulching has a great potential to improve onion yield and save a substantial amount of irrigation water.

Acknowledgements

The authors wish to acknowledge the support from the State Government for conducting this research at Zonal Research Station, Darisai, Birsa Agricultural University, Ranchi, Jharkhand, India.

References

Agarwal S, Korla BN and Raina JN (2003) Effects of mulches on soil hydrothermal regimes, weed incidence, yield and quality of Ginger. *Journal of the Indian Society of Soil Science* **51**: 65-67.

Allen RG, Pereira IS, Daes D and Smith M (1998) Crop evapotranspiration, guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No. 56**.** Rome, Italy.

Anonymous (2018) *Horticultural statistics at a glance*, pp.197-235. Available at https://agricoop.nic.in/

Bafna AM, Daftardar SY, Khade KK, Patel PV and Dhotre RS (1993) Utilization of nitrogen and water by tomato under drip irrigation system. *Journal of Water Management* **1**: 1-5.

Bhasker P, Singh RK, Gupta RC, Sharma HP, Gupta PK (2018) Effect of drip irrigation on growth and yield of onion (Allium cepaL.). *Journal of Spices and Aromatic Crops* **27**: 32-37.

Bhella HS (1988) Tomato response of trickle irrigation and black polyethylene mulch. *Journal of the American Society for Horticultural Science* **113**: 543-546.

Chakarborty RC and Sadhu MK (1994) Effect of mulch type and colour on growth and yield of tomato. *Indian Journal of Agricultural Science* **64**: 608-612.

Geisseler D, Ortiz RS and Diaz J (2022) Nitrogen nutrition and fertilization of onions (*Allium cepa* L.)-A literature review. *Scientia Horticulturae* **291**: 1-11.

Edossa DC and Emana TG (2011) Interaction effects of drip irrigation level and planting method on water use efficiency, irrigation uniformity and yield in green pepper (Capsicum annuum L.). *Philippine Agricultural Scientist* **94**: 350-358.

Enchalew B, Gebre SL, Rabo M, Hindaye B, Kedir M, Musa Y and Shafi A(2016) Effect of deficit irrigation on water productivity of onion (Allium cepa L.) under drip irrigation. *Journal of Irrigation and Drainage System Engineering* **5**: 1-4.

Gornat B, Goldberg D, Rimon D and Asher BJ (1973) The physiological effect of water quality and method of application on tomato, cucmber and pepper. *Journal of American Society for Horticultural Science* **98**: 202-205.

Imtiyaz M, Mgadla NP, Chepete B and Mothobi EO (2000) Yield and economic returns of vegetable crops under varing irrigation. *Irrigation Science* **19**: 87-93.

Keller J and Karmeli D (1974) Trickle irrigation design parameters. *Transactions of American Society for Agricultural Engineering***17**: 678-684.

Kimura Y, Okazaki K, Yanagida D and Muro T (2014) Cultivar and regional differences in the metabolite composition of onion (*Allium cepa* L.). *Scientia Horticulturae* **168**: 1-8.

Lamont Jr. WJ (1993) Plastic mulches for the production of vegetable crops. *HortTechnology* **3**: 35-39.

Mane MS, Ayare BL and Magar SS (2006) Principles of drip irrigation system, Jain Brothers, New Delhi, pp. 24 -87.

Manifrinato HA (1974) Effect of drip irrigation on soil water plant relationships. Second Int. Drip Irrigation Congress, 446- 451.

Pattanaik SK, Sahu NN, Pradhan PC and Mohanty MK (2003) Response of Banana to drip irrigation under different irrigation designs. *Journal of Agricultural Engineering* **40**: 29-34.

Pejic B, Varga JG, Milic S and Cupina B (2011) Effect of irrigation schedules on yield and water use of Onion (*Allium cepa* L.). *African Journal of Biotechnology* **10**: 2644-2652.

Raina JN, Thakur BC and Verma ML (1999) Effect of drip irrigation and polyethylene mulch on yield, quality and water-use efficiency of tomato. *Indian Journal of Agricultural Science* **69**: 430-433.

Reddy M, Ayyanagowdar MS, Nemichandrappa M, Balakrishnan P, Patil MG, Polishgowdar BS and Satishkumar U (2012) Techno economic feasibility of drip irrigation for onion (*Alluim cepa* L.). *Karnataka Journal Agricultural Science* **25**: 475-478.

Reddy M, Ayyanagowdar MS, Nemichandrappa M, Momin U, Sirajuddin M, Horaginamani and Ravichandran M (2011) Influence of drip irrigation methods on growth and yield of onion at Raichur region. *Indian Journal of Natural Science*s **11**(8): 580-587.

Sankar V, Thangasamy A and Lawande KE (2015) Effects of drip irrigation on onion (Allium cepa) seed production under western Maharashtra conditions. *International Journal of Tropical Agriculture* **33**: 621-625.

Singh R, Kumar S, Nangare DD and Meena MS (2009) Drip irrigation and black polyethylene mulch influence on growth, yield and water-use efficiency of tomato. *African Journal of Agricultural Research* **4**: 1427-1430.

Singh R (2005) Influence of mulching on growth and yield of tomato (*Lycopersicon esculentum*) in north India plains. *Vegetable Science* **32**: 55-58.

Vavrina CS and Roka FM (2000) Comparison of plastic mulch and bare-ground production and economics for short-day onions in a semitropical environment. *HortTechnology* **10**: 326-330.

Received: April 30, 2023; Accepted: June 23, 2023

Journal of Soil Salinity and Water Quality 15(1), 94-103, 2023

Biochemical Modulations Coupled with Yield of *Rabi* Maize (*Zea mays* L.) Irrigated with Treated Industrial Effluent on Vertisols

Anil R Chinchmalatpure[1*], Indivar Prasad[2], Vineeth TV[1], Shrvan Kumar[3], Sagar Vibhute[1], David Camus[1] and PC Sharma[4]

[1]ICAR-Central Soil Salinity Research Institute, Regional Research Station, Bharuch-392012, Gujarat, India
[2]ICAR-Indian Institute of Vegetable Research, Varanasi-221305, Uttar Pradesh, India
[3]ICAR-Central Arid Zone Research Institute, Jodhpur-342005, Rajasthan, India
[4]ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana, India
*Corresponding author E-mail: anil.rc@icar.gov.in

Abstract

A field experiment was conducted on *rabi* maize for 2 consecutive years on *Vertisols* to evaluate the effect of treated industrial effluents in combination with varying nitrogenous dosage as an alternative to improve crop productivity and soil characteristics. The treatments comprised of (I_1) best available water (BAW) *i.e.* treated effluent: BAW (0:1 ratio); (I_2) treated effluent and BAW (1:1 ratio); and (I_3) treated effluent i.e. treated effluent: BAW (1:0 ratio) along with combination of three nitrogen doses (N_1= 80 kg N ha^{-1}; N_2= 100 kg N ha^{-1} & N_3=120 kg N ha^{-1}). In general, treated effluent irrigation over the two years did not bring any deleterious effects on soil physico-chemical characteristics. However, electrical conductivity (EC) of the different soil layers increased with application of treated industrial effluent (I_3), but the soil pH was not affected. The application of treated effluent in combination with BAW also resulted in 1.8 times and 1.4 times higher water productivity as compared to treated effluent: BAW in 0:1 ratio and treated effluent: BAW in 1:0 ratio treatments, respectively. While treated effluent irrigation was found effective in enhancing yield of maize crop, diluted treated effluent (treated effluent: BAW in 1:1 ratio) in combination with 100 kg N ha^{-1} gave highest *rabi* maize yield (10168 kg ha^{-1}). The greenness, osmotic and ionic components of cellular response was also studied. Judicious application of treated industrial effluent in combination with optimum nitrogen source acted as an amendment to arable *Vertisol* and may be considered as an alternative option for safe disposal of this industrial waste.

Key words: Maize, Na/K ratio, Proline, Soluble sugar, Treated industrial effluent, *Vertisols*

Introduction

Exploitation of industrial and other wastewaters for agricultural practice is an age old practice that is getting renewed attention due to alarming depletion of freshwater resources in various arid and semiarid regions of the globe (Pedrero *et al.,* 2010). Good quality water is turning out to be a very scarce resource across the various semiarid and arid parts of the globe due to which our policy makers are being forced to shift their thoughts towards other sources of water that might be used cheaply and efficiently to support sustainable development (Singh *et al.,* 2012). Moreover, effluent reuse not only provides considerable quantity of irrigation water, but also paves way to preserve potable resources and minimizes the negative environmental impact related to the effluents discharge into water bodies (Agrafioti and Diamadopoulos, 2012). Moreover, proper scientific treatment of the liquid waste or effluents from industries is highly inevitable for its use in the agricultural arena with minimal detrimental effects (Khan, 2018).

Maize (*Zea mays* L.) is one among the most versatile, wide spectrum and multipurpose emerging crops having wider adaptability under diverse soil types and agro-climatic conditions and highest genetic yield potential among cereal crops (Farooq *et al.,* 2015). Maize is the staple food and feed of the tribal belts of Gujarat state, India. In Gujarat, maize is grown in an area of 460 thousand ha with a total production of 780 thousand tones and productivity of 1813 kg ha^{-1} (Kumar *et al.,* 2013). In addition, the maize based industries in the state need maize seeds in bulk for manufacturing various products such as starch, sorbitol, ethanol, poultry feed, corn oil *etc*. So, there is a tremendous growing demand for maize in the state of Gujarat. Maize is predominately a *kharif* season crop but the past few years have witnessed a tremendous boom in the adoption of *rabi* maize in the otherwise conventional maize baskets of India. In India, yield obtained during *rabi* season is invariably higher (>6 t ha^{-1}) than the *kharif* season yield (2-2.5 t ha^{-1}) due to longer duration of crop growth and least infestation of pests and diseases (Singh *et al.,* 2012).

In general, industrial effluents comprises of appreciable quantity of macro and micro nutrients which play a major constructive role in plant growth and development (Matheyarasu *et al.,* 2017) and also have been reported to enhance the bioavailability of micronutrients (Chinchmalatpure *et al.,* 2014) and reduce the requirement of fertilizers inputs (Marecos do Monte *et al.,* 1989). Application of treated industrial effluents has been reported to enhance crop yields and impart further economic benefits to farmers due to reduced need of fertilizers (Bedbabis *et al.,* 2010; Arora and Rangini, 2015). The concentration of parameters like NO_3-N, pH, available nutrient content was higher in wastewater or effluents as compared to those in control i.e. groundwater (Yaryan, 2000) or BAW (Arora and Rangini, 2015). However, the crop and soil beneficial impact of discharged effluents varies from industry to industry, and there lies the relevance of our study in analyzing the suitability of industrial effluents in crop production on *Vertisols* of highly industrialized areas of Gujarat, India. Earlier we did a preliminary study depicting the beneficial effects of treated effluents on forage yield in fodder maize, fodder sorghum and bajra in our previous studies (Annual Report, 2015-16 ICAR-CSSRI). The present study was initiated by using treated effluent as a source of irrigation along with nitrogenous fertilizer in *rabi* maize to evaluate the feasibility of the treated effluents as an alternative to improve crop productivity and soil properties. The ionic and osmotic modules of cellular response were analyzed along with morphological and yield assay to ascertain the mechanism of effluent induced crop dynamics.

Materials and Methods

The study was carried out in open field, in two years during 2016-17 and 2017-18 in the premises of Aniline-TDI (Aniline-Toluene Di Isocynate) complex of Gujarat Narmada Valley Fertilizers and Chemicals Ltd. (GNFC) in Bharuch district of Gujarat State. The experimental site is located at 21°44′16.84″ N latitude and 73°01′15.01″ E longitude. The area is characterized by semiarid climate with black cotton soils taxonomically classified as *Typic Haplusterts*. The experiment was conducted on *rabi* maize (*Zea mays* L.) with the combined application of varying doses of nitrogen in the form of urea and irrigation using treated effluent of Aniline ETP of GNFC in factorial design with three biological replications. The plots (3.0 m × 1.5 m) were prepared for fine tilth with designed layout. All other agronomic and cultural operations were done regularly during the growing season. The basic characteristics of the soil were initially analysed and it depicted a clay content ranging from 39.7 to 51.1%, cation exchange capacity (CEC) of 40.5 to 47.8 cmol(+)kg^{-1} and organic carbon content of 0.2 to 0.4%.

The treatments comprised of (I_1) best available water (BAW) *i.e.* treated effluent: BAW (0:1 ratio); (I_2) treated effluent and BAW (1:1 ratio) and (I_3) treated effluent as such i.e. treated effluent: BAW (1:0 ratio) with combinations of three nitrogen doses (N_1= 80 kg N ha^{-1}; N_2= 100 kg N ha^{-1} & N_3=120 kg N ha^{-1}). The seeds of *rabi* maize (variety SS-7077) were sown during the month of December and irrigation as well as fertilizer schedule was maintained as per the experimental design. Each plot was irrigated at 15 days interval. A total of six irrigations were given during the course of the experiment. The properties of treated effluent, diluted effluent and BAW used for irrigation are given in Table 1. The used industrial effluent has been subjected to various primary, secondary and tertiary treatments and the final discharge is characterized by pH, electrical conductivity (EC), Ca, Mg, Na, K, Cl^-, SO_4^{2-}, NH_4^+-N, NO_3-N concentration well within threshold limit.

Table 1. Analytical properties of the treated effluent, diluted effluent and best available water (BAW) used in the study

Parameter	Treated effluent	BAW	Diluted Effluent
pH	7.46	8.25	8.12
EC (dS m^{-1})	8.60	0.65	5.50
Na^+ (meq L^{-1})	66.49	2.62	39.87
K^+ (meq L^{-1})	0.15	0.08	0.13
Ca^{++} (meq L^{-1})	5.50	1.00	4.50
Mg^{++} (meq L^{-1})	3.50	1.50	2.50
Cl^- (meq L^{-1})	50.0	2.50	23.0
CO_3^{--} (meq L^{-1})	0.70	1.00	0.80
SO_4^{--} (meq L^{-1})	1.70	0.60	0.95
NH_4-N (mg L^{-1})	5.80	0.60	0.20
NO_3-N (mg L^{-1})	3.90	0.75	0.20

Soil samples in triplicates were collected during crop growth period and after the harvest of crop at two depths (0-15 and 15-30 cm) during two years for analysis of different physico-chemical properties. Soil properties like pH of saturated paste (pHs), electrical conductivity of saturated extract (ECe) were estimated using standard procedures (Richards, 1954). The pH was measured using *edge* pH & Ion Meter (Hanna instruments, India) and the EC with *N&M* EC-Meter (Hanna instruments, India). Available N was determined by the Kjeldahl method (Subbaih and Asija, 1956). P_2O_5 was determined by using the sodium bicarbonate method (Olsen *et al.,*1954). Soil available K_2O was determined in each year using standard methods by Jackson (1973).

At maturity, roots and shoots were separated. The fresh weight (FW) was immediately determined after being washed with deionized water and blotted with filter paper. Dry weight (DW) was determined after oven-drying samples at 70°C for 72 h until constant weight was achieved. The dry biomass obtained under different treatments was recorded in triplicates per plot for two consecutive years. This dry biomass was utilized for determination of fiber and ash content via standardized technique (Maynard, 1970). Yield and its attributes were recorded in terms of cob length (cm), cob weight (g), cob yield per plot (kg $plot^{-1}$), and extrapolated cob yield (kg ha^{-1}) under all treatments for two years. The water productivity was also determined during the two years by calculating the ratio of yield per plot to that of total water applied per plot. The oven-dried samples were ground to a fine powder. The concentrations of Na^+ and K^+ in the root and shoot tissues at vegetative and flowering stages were determined using flame emission photometry (Systronics Flame Photometer 128) after extraction of dry powder in 0.5% nitric acid. Total chlorophyll content was determined by using standard procedure (Arnon, 1949) at the flowering stage. Proline was quantified in the leaves at vegetative and maturity stages spectro-photometrically by the ninhydrin method as described by Bates *et al.* (1973). Soluble sugars were quantified with the anthrone reagent according to the method as described by Yemm and Willis (1954).

All data, recorded on three effluent irrigation levels and the corresponding irrigated soils, plants and crop products, during the two years, were statistically processed by analysis of variance (ANOVA). Mean values of different physiological and biochemical parameters were related by least significant difference (LSD) test at the 5% level of significance. All the results were showed as mean ± standard deviation (SD) for three replications. Moreover, data regarding effect of treatments on yield attributes were checked for homogeneity of variances using the Bartlett test (Bartlett, 1937) with a p-value of 0.05 to reject the null hypothesis. All the statistical tests were performed using SPSS.

Results and Discussion

Chemical properties of soil

Soil pH values ranged from 6.7-7.1, 6.6-7.0 and 6.6-7.0 under I_1, I_2 and I_3 treatments, respectively which were almost neutral in range. No significant variation was observed in soil pH during crop growth period and after the harvest of crop in two years. Similarly, ECe values ranged from 0.8-1.6 dS m^{-1}, 1.6 to 1.7 dS m^{-1} and 2.0 to 2.5 dS m^{-1} during crop growth period and 1.2-1.5 dS m^{-1}, 3.7 to 4.1 dS m^{-1} and 5.4 to 5.7 dS m^{-1} after harvest of crop under I_1, I_2 and I_3 treatments, respectively. In I_2 and I_3 treatments, surface soil depicted slightly higher electrical conductivity values, while I_1 had comparatively lower values (Table 2). Rusan *et al.* (2007) presented comparable results. Mojiri (2011) reported that the elevated EC of soil irrigated with

Table 2. Average value of soil EC and pH under different effluent irrigation treatments during crop growth period and after harvest of maize crop during the growing seasons*

Soil depth (cm)	Treatment					
	I_1= 0:1 (Treated Effluent: BAW)		I_2= 1:1 (Treated Effluent: BAW)		I_3= 1:0 (Treated Effluent: BAW)	
	pHs	ECe, dS m^{-1}	pHs	ECe, dS m^{-1}	pHs	ECe, dS m^{-1}
During crop growth period**						
0-15 cm	6.9	0.8	7.0	1.6	7.0	2.0
15-30 cm	7.1	1.6	6.9	1.7	6.9	2.5
After harvest of the crop						
0-15 cm	6.7	1.2	6.7	3.7	6.8	5.4
15-30 cm	6.7	1.5	6.6	4.1	6.6	5.7

*Data represents the mean of two years (2016-17 and 2017-18)

**During the crop growth period represents the mean data taken during vegetative, teaselling and maturity stages of crop growth

wastewater can be linked with the inherent higher concentration of cations such as Na and K.

Application of treated effluent did not result in significant salt build up in soils under all irrigation treatments during the crop growth period, while slight salt build up was observed in I_2 (3.7 to 4.1 dS m^{-1}) and I_3 (5.4 to 5.7 dS m^{-1}) treatments as compared to I_1 treatment (1.2 to 1.5 dS m^{-1}) (Table 2) in both the soil layers after the harvest of crop. Rain induced leaching of significant quantity of accumulated salts in to the deeper layers of the soil were reported by Lado *et al.,* (2011). Initial status of available nitrogen, phosphorus and potassium content in surface soils ranged from 146.3-181.2 kg ha^{-1}, 15.8-17.0 kg ha^{-1} and 650.0-682.8 kg ha^{-1}, respectively while after harvest, ranged from 207.0 to 263.4 kg ha^{-1}, 22.4 to 33.1 kg ha^{-1} and 709.7 to 855.3 kg ha^{-1}, respectively. There was a considerable decline in the available elemental pool in subsurface soils.

Yield attributes and water productivity

Yield and yield components of maize were significantly affected by irrigation with treated industrial effluent in two consecutive years (Table 3 and 4). Maize yield parameters like single cob weight, dry biomass yield and cob yield were found to be significantly higher in the first year under diluted treated effluent (I_2) plot followed by I_3 and I_1 plots, while I_2 was statically at par with I_3 in case of single cob weight (Table 3). In the second year, maximum cob weight and length were found under I_2N_2 treatment (217.33 g and 20.0 cm, respectively), whereas I_1N_1 and I_1N_2 treated plants displayed the least cob weight (134.00 g) and length (15.83 cm), respectively. Average values showed that maximum cob weight and length was found in I_2 (197.56 g and 18.83 cm, respectively) treatment during 2017-18 (Table 3).

Treated effluent application diluted with BAW (I_2) gave the highest cob yield (9927 kg ha^{-1}) (Table 4), signifying the possibility of using the diluted effluent for maximizing maize yield under resource limited conditions. Similar results were corroborated by Chhonkar *et al.* (2000) and Chinchmalatpure *et al.* (2014). Yield and its attributes did not show significant difference across various fertilizer treated plots, but maize yield (7746 kg ha^{-1}) was found higher under 100 kg N ha^{-1} treatment (N_2) (Table 4). In the second year, maximum cob yield was found in I_2N_2 treatment (4.79 kg $plot^{-1}$ and 8873.1 kg ha^{-1}) while I_1N_2 treated plots displayed the least yield (2.63 kg $plot^{-1}$ and 4856.6 kg ha^{-1}) (Table 4). Soil irrigated with diverse treated effluents has been reported to have higher organic carbon content as compared to normal soil which ultimately led to enhanced supply of macro and micro nutrients to arable crops contributing to sustainable yield under resource limited conditions (Chhonkar *et al.,* 2000; Lado *et al.,* 2011; Chinchmalatpure *et al.,* 2014; Matheyarasu *et al.,* 2017). Maximum dry biomass yield per plot was found in I_2N_2 treatment (6.35 kg $plot^{-1}$) while I_1N_1 treated plot showed the minimum yield (3.85 kg $plot^{-1}$). Mean value analysis indicated that maximum dry biomass

Table 3. Effect of different irrigation and nitrogen treatments on maize cob weight and length during two years of crop season

Treatments	Single cob weight (g)				Cob length (cm)			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
2016								
I_1	126.7	142.7	138.7	136.0	17.8	18.5	18.6	18.3
I_2	197.3	210.0	185.0	197.0	20.1	20.0	18.6	19.6
I_3	164.0	166.7	153.3	161.3	18.6	18.2	19.0	18.6
Mean	162.7	173.1	159.1		18.9	18.9	18.7	
	SED				SED			
Irrigation	11.922				0.434			
Nutrient	11.922 (NS)				0.434 (NS)			
Interaction	20.650 (NS)				0.751 (NS)			
CV	15.3				4.89			
2017								
I_1	134.00	141.33	142.33	139.22	17.33	15.83	17.23	16.8
I_2	185.33	217.33	190.00	197.56	18.50	20.00	18.00	18.83
I_3	153.33	157.67	169.00	160.00	18.33	17.33	18.00	17.89
Mean	157.56	172.11	172.44		18.05	17.72	17.74	
	SED				SED			
Irrigation	16.53				0.62			
Nutrient	16.53 (NS)				0.62 (NS)			
Interaction	28.63				1.08			
CV	21.18				7.41			

Table 4. Effect of different irrigation and nitrogen treatments on dry biomass and cob yield of maize during two years of crop season

Treatments	Dry biomass (g $plot^{-1}$)				Cob yield (kg ha^{-1})			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
2016								
I_1	2.76	3.93	2.56	3.09	4335	5140	4216	4564
I_2	7.10	8.81	7.34	7.75	9605	11463	8712	9927
I_3	4.90	4.62	3.71	4.41	6164	6636	5605	6135
Mean	4.92	5.79	4.54		6701	7746	6178	
				SED				
Irrigation	1.025				1002.065			
Nutrient	1.025 (NS)				1002.065 (NS)			
Interaction	1.775 (NS)				1735.627 (NS)			
CV	42.78				30.92			
2017								
I_1	3.85	4.20	4.68	4.24	6936	4856	5966	5919
I_2	5.71	6.35	5.93	5.99	7451	8873	8511	8278
I_3	4.04	3.87	4.20	4.04	8264	6470	7322	7352
Mean	4.53	4.81	4.94		7550	6733	7266	
				SED				
Irrigation	0.647				449.24			
Nutrient	0.647 (NS)				449.24 (NS)			
Interaction	0.097(NS)				778.11			
CV	28.86				13.27			

Table 5. Average water productivity of maize crop as affected by different effluent irrigation treatments during two years of crop season*

Treatments	Yield plot^{-1} (kg)	Amount of water applied plot^{-1} (m^3)	Water productivity (kg m^{-3})
I_1 Treated effluent: BAW (0:1)	2.83	3.44	0.82
I_2 Treated effluent: BAW (1:1)	4.92	3.39	1.45
I_3 Treated effluent: BAW (1:0)	3.64	3.56	1.02

*Data represents the mean value of two years

yield was found in N_3 (4.94 kg plot^{-1}) and I_2 (5.99 kg plot^{-1}) treatments (Table 4). There was non-significant interaction between irrigation and nutrient treatment (Table 4). Dry biomass content revealed that I_2 (treated effluent: BAW in 1:1 ratio) was the ideal treatment for enhanced biomass accumulation indicating that BAW and treated effluent have synergistic effect in attaining higher biological yield.

The analysis of variance showed a significant difference ($p<0.05$) in mean water productivity among the various treatments of industrial effluents. Maximum water productivity of 1.45 kg m^{-3} was noticed in I_2 treatment (treated effluent: BAW in 1:1 ratio), which may be attributed to higher biomass and crop yield under limited water usage (Table 5).

Two years yield data was pooled and data were checked for homogeneity of variances using the Bartlett test (Table 6).

Ionic, primary metabolite and osmotic alterations

Plant assay: During 2017-18, various physiological and biochemical traits were recorded during crop growth period (vegetative, flowering and maturity stages) and data were subjected to statistical analysis.

In leaves, at vegetative stage, the maximum K/Na ratio (36.10) was found in I_1N_2 treatment (Table 7), while minimum (9.30) was found in I_2N_1 treatment. In case of nitrogen treatment, on average basis K/Na ratio was maximum (23.15) under N_2 treatment in leaves during vegetative

Table 6. Two years pooled yield data analysis using Bartlett analysis test under different irrigation and nitrogen treatments

Treatments	Single Cob weight (g)	Cob Length (cm)	Biomass plot^{-1} (kg)	Yield plot^{-1} (kg)	Cob Yield (kg ha^{-1})
I_1N_1	130.30^{C}	17.58^{B}	3.31^{B}	3.04^{BCD}	5635.5^{BCD}
I_1N_2	142.04^{BC}	17.17^{B}	4.07^{B}	2.70^{D}	4998.4^{D}
I_1N_3	140.35^{BC}	17.90^{AB}	3.62^{B}	2.75^{CD}	5091.3^{CD}
I_2N_1	191.20^{AB}	19.30^{AB}	6.40^{AB}	4.61^{AB}	8528.0^{AB}
I_2N_2	213.53^{A}	20.02^{A}	7.58^{A}	5.49^{A}	10168.0^{A}
I_2N_3	187.60^{ABC}	18.30^{AB}	6.64^{AB}	4.65^{AB}	8611.9^{AB}
I_3N_1	158.60^{ABC}	18.48^{AB}	4.47^{AB}	3.89^{ABC}	7214.4^{ABC}
I_3N_2	162.20^{ABC}	17.75^{B}	4.25^{AB}	3.54^{BCD}	6553.3^{BCD}
I_3N_3	161.27^{ABC}	18.50^{AB}	3.96^{B}	3.49^{BCD}	6463.8^{BCD}
Mean	165.23	18.33	4.92	3.80	7029.4
p-Value	0.0006	0.0042	0.0014	<.0001	<.0001
CV (%)	18.47	6.21	36.95	18.57	18.57
SE(d)	17.619	0.657	1.050	0.577	0.577
#Tukey's HSD at 5%	58.535	2.1844	3.4879	1.9181*	1.9181*

#Means with at least one letter common are not statistically significant using TUKEY's Honest Significant Difference (HSD); *transformed values (for comparison purpose original mean values has been given in the table); I_1= Treated Effluent: Best available water (BAW):: 0:1; I_2= Treated Effluent: BAW:: 1:1 & I_3 = Treated Effluent: BAW:: 1:0; N_1= 80 kg ha^{-1}; N_2= 100 kg ha^{-1}: N_3= 120 kg ha^{-1}.

Table 7. K/Na ratio in leaf tissues under different effluent irrigation and nitrogen treatments at different phenological stages of maize

Treatments	Vegetative stage K/Na (µmol g^{-1} DW)				Flowering stage K/Na (µmol g^{-1} DW)				Maturity stage K/Na (µmol g^{-1} DW)			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	20.79	36.10	21.58	26.15	1.78	1.94	2.82	2.18	17.35	16.21	20.10	17.88
I_2	9.30	22.56	12.83	14.89	2.47	2.58	2.28	2.44	16.64	6.42	6.43	9.83
I_3	17.53	10.80	18.02	15.45	2.85	2.91	2.19	2.65	8.87	21.10	5.47	11.81
Mean	15.87	23.15	17.47		2.36	2.47	2.65		14.28	14.57	10.66	
						SED						
I	1.85				0.28(NS)				1.43			
N	1.85				0.28(NS)				1.43			
I × N	3.20				0.48(NS)				2.47			
CV	20.80				24.67				23.00			

I_1= Treated Effluent: Best available water (BAW):: 0:1; I_2= Treated Effluent: BAW:: 1:1 & I_3 = Treated Effluent: BAW:: 1:0; N_1= 80 kg ha^{-1}; N_2= 100 kg ha^{-1}: N_3= 120 kg ha^{-1}; NS= *non-significant*.

stage, while in case of irrigation treatment, maximum ratio (26.15) was obtained in the leaves of I_1 treatment at vegetative stage (Table 7). Treated effluent might have added some salt in to the soil which in turn reduced K uptake (Giaveno *et al.,* 2007). The flowering stage recorded maximum K/Na ratio in the leaves under I_3N_2 treatment (2.91), while minimum K/Na ratio was found in the leaves of I_1N_1 treatment (1.78). Mean value analysis showed that maximum K/Na ratio was found in the leaf tissue under N_3 (2.65) and I_3 (2.65) treatments (Table 7). Our results can further be corroborated by previous research groups who found optimum concentration of potassium and magnesium in proportionately diluted effluents for effective synthesis of pigments and other primary plant metabolites (Thambavani and Sabitha, 2011). Similar results were found in maturity stage (data not shown).

The maximum proline content (5.41 µmol g^{-1} FW) in leaves at flowering stage was found under I_3N_2 treatment, while I_1N_2 treated leaves displayed minimum content of the organic osmolyte (2.77 µmol g^{-1}) (Table 8). However, maturity stage leaves displayed maximum proline content under I_3N_3 (4.74 µmol g^{-1} FW) treatment, while minimum content was found in I_1N_1 (3.42 µmol g^{-1}) treatment. Abdel Lateef and Sallam (2015) reported that the irrigation of maize with sewage water induced a pronounced accumulation of

Table 8. Proline and chlorophyll content of leaf tissue under different effluent irrigation and nitrogen treatments at different phenological stages of maize

Treatments	Flowering stage Proline (µmol g^{-1} FW)				Maturity stage Proline (µmol g^{-1} FW)				Flowering stage Chl. (mg g^{-1} FW)			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	3.10	2.77	2.96	2.94	3.42	3.50	3.65	3.52	0.34	0.93	0.35	0.54
I_2	3.24	2.95	4.21	3.46	3.79	4.59	3.62	4.00	0.96	0.94	0.91	0.93
I_3	5.28	5.41	4.12	4.93	4.18	4.16	4.74	4.36	1.19	1.31	1.18	1.22
Mean	3.87	3.71	3.76		3.79	4.08	4.00		0.83	1.06	0.81	
						SED						
I	0.4837				0.57(NS)				0.053			
N	0.4837(NS)				0.57(NS)				0.053			
I x N	0.8378(NS)				0.98(NS)				0.092			
CV	27.11				30.53				12.51			

I_1= Treated Effluent: Best available water (BAW):: 0:1; I_2= Treated Effluent: BAW:: 1:1 & I_3 = Treated Effluent: BAW:: 1:0; N_1= 80 kg ha^{-1}; N_2= 100 kg ha^{-1}: N_3= 120 kg ha^{-1}; NS= *non-significant*.

Table 9. Total soluble sugar content of shoot and leaf tissues at flowering stage under different effluent irrigation and nitrogen treatments

Treatments	Sugar content (mg g^{-1} DW)							
	Shoot				Leaf			
	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
I_1	86.51	85.87	85.80	86.06	88.98	99.28	90.83	93.03
I_2	84.88	83.93	86.69	85.16	84.39	91.39	62.04	79.27
I_3	85.37	87.85	85.36	86.19	75.65	69.21	77.56	74.14
Mean	85.58	85.88	85.98		83.00	86.62	76.81	
	SED							
Irrigation	10.18				10.14(NS)			
Nutrient	19.18				10.14(NS)			
Interaction	17.64				17.56(NS)			
CV	9.87				26.17			

I_1= Treated Effluent: Best available water (BAW):: 0:1; I_2= Treated Effluent: BAW:: 1:1 & I_3 = Treated Effluent: BAW:: 1:0; N_1= 80 kg ha^{-1}; N_2= 100 kg ha^{-1}: N_3= 120 kg ha^{-1}; NS= *non-significant*.

proline in its root and shoot tissues. Leaf chlorophyll content during flowering stage showed an elevated content of the photosynthetic pigment in I_3N_2 treatment (1.31 mg g^{-1} FW) while minimum was found in the I_1N_1 treated leaves (0.34 mg g^{-1} FW) (Table 8). There was significant interaction between irrigation and nutrient treatments. Optimum nitrogen application (N_2) coupled with effluent helped in maintaining high chlorophyll content which reduced with increase (N_3) or decrease (N_1) in nitrogen levels (Molazem *et al.,* 2010).

At flowering stage, total soluble sugar content was measured on dry weight basis and maximum sugar content was observed in I_3N_2 and I_1N_2 treatments in shoot (87.85 mg g^{-1}) and leaf (99.28 mg g^{-1}) tissues (Table 9), while minimum was observed in the root (83.93 mg g^{-1}) and leaf (62.04 mg g^{-1}) tissues of I_2N_2 and I_2N_3 treated plants. Interestingly after flowering, there was no effect of high nitrogen on sugar content in leaf and shoot tissues. Different sources of effluent irrigation have been reported to increase the total soluble carbohydrates in maize plants (Abdel Lateef and Sallam, 2015).

The findings of the present study indicated that treated industrial effluent have the potential to be used for irrigation in combination with good quality water without a significant detrimental effect on crop and soil. Treated effluent in combination with optimum nitrogen application was found to be beneficial in enhancing the fodder quality and yield of *rabi* maize. This can be attributed to industrial effluent mediated supply of readily available essential nutrients which are directly linked to the improved fertility status of soil. Moreover, treated effluent irrigated plants maintained a lower K/Na ratio in various tissues at different phenological stages there by imparting cellular ion homeostasis. Increased availability of all essential nutrients due to the combined application of treated effluent and nitrogen fertilizer contributed to optimal uptake of these nutrients and there by supported various physiological and biochemical pathways. In short, our findings throws light on an alternative source of irrigation to conventional good quality water resources in arid and semiarid *Vertisols* where intensive agriculture is practiced and the soil and water is poor in quality. However, the knowledge on the use of industrial effluents in irrigation is still scarce and more studies are required to assess the physiological and molecular mechanism of effluent induced yield enhancement and the long-term effects on soil and plants.

Acknowledgements

The financial support in terms of consultancy project from the Aniline-ETP, Unit-II of the Gujarat Narmada Valley Fertilizers & Chemicals Ltd. (GNFC), Bharuch, Gujarat is gratefully acknowledged. (Research/Article/87/2019)

References

Abdel Latef AA and Sallam MM (2015) Changes in growth and some biochemical parameters of maize plants irrigated with sewage water. *Austin Journal of Plant Biology* **1(1)**: 1004.

Agrafioti E and Diamadopoulos E (2012) A strategic plan for reuse of treated municipal wastewater for crop irrigation on the Island of Crete. *Agricultural Water Management* **105**: 57–64.

Annual Report (2015-16) ICAR-Central Soil Salinity Research Institute, Karnal-132001, Haryana.

Arnon DI (1949) Copper enzymes in isolated chloroplasts. Polyphenoxidase in *Beta vulgaris*. *Plant Physiology* **24**: 1–15.

Arora S and Rangani DG (2015) Biochemical properties of Vertisols and performance of fenugreek (*Trigonella foenum-graecum* L.) with treated industrial effluent irrigation. *Journal of the Indian Society of Soil Science* **63(4)**: 414–22.

Bartlett MS (1937) Properties of sufficiency and statistical tests. *Proceedings of Royal Society of London* **160**: 268–82.

Bates LS, Waldren RP and Teare D (1973) Rapid determination of free proline for water-stress studies. *Plant and Soil* **39(1)**: 205–207.

Bedbabis S, Ferrara G, Ben Rouina B and Boukhris M (2010) Effects of irrigation with treated wastewater on olive tree growth, yield and leaf mineral elements at short term. *Scientia Horticulturae* **126**: 345–50.

Chhonkar PK, Datta SP, Joshi HC and Pathak H (2000) Impact of industrial effluents on soil health and agriculture- Indian experience: Part I-distillery and paper mill effluents. *Journal of Scientific and Industrial Research* **59**: 350–61.

Chinchmalatpure AR, Rao GG, Arora S, Khandelwal MK and Sharma DK (2014) Impact assessment of aniline plant treated effluent irrigation in Vertisols surrounding Bharuch. *Journal of the Indian Society of Soil Science* **62(2)**: 168–73.

Farooq M, Hussain M, Wakeel A and Siddique KHM (2015) Salt stress in maize: effects, resistance mechanisms, and management. A review. *Agronomy for Sustainable Development* **35(2)**: 461–81.

Giaveno CD, Souza RV, Souza GM and Oliveira RF (2007) Screening of tropical maize for salt stress tolerance. *Crop Breeding and Applied Biotechnology* **7**: 304–13.

Jackson ML (1973) *Soil Chemical Analysis*, Pp 498. Prentice Hall of India private Ltd, New Delhi.

Khan N (2018) Natural ecological remediation and reuse of sewage water in agriculture and its effects on plant health. *Sewage*, Zhu I(Ed). Evoqua Water Technologies, United States of America DOI: 10.5772/intechopen.75455.

Kumar R, Srinivas K and Sivaramane N (2013) Assessment of the maize situation, outlook and investment opportunities in India. *Country Report – Regional Assessment Asia (MAIZE-CRP)*, National Academy of Agricultural Research Management, Hyderabad, India.

Lado M, Bar-Tal A, Azenkot A, Assouline S, Ravina I, Erner Y, Fine P, Dasberg S and Ben-Hur M (2011) Changes in chemical properties of semiarid soils under long-term secondary treated wastewater irrigation. *Soil Science Society of American Journal* **76**: 1358–69.

Marecos do Monte, H, Silva e Sousa, M and Silva Neves, A (1989) Effects on soil and crops of irrigation with primary and secondary effluents. *Water Science and Technology* **21**: 427–34.

Matheyarasu R, Seshadri B, Kumar P, Shilpi S, Bolan NS and Naidu R (2017) The effect of wastewater irrigation rate on dry matter yield of selected field crops. *International Journal of Water and Wastewater Treatment* **3(3)**: doi http://dx.doi.org/10.16966/2381-5299.142.

Maynard AJ (1970) *Methods in Food Analysis Physical, Chemical and Instrumental Methods Of Analysis*, Pp 845. Joslyn M A(Ed). Academic Press, San Francisco, London.

Mojiri A (2011) Effects of municipal wastewater on physical and chemical properties of saline soil. *Journal of Biological and Environmental Sciences* **5(14)**: 71–6.

Molazem D, Qurbanov EM and Dunyamaliyev SA (2010) Role of proline, Na and chlorophyll content in salt tolerance of corn (*Zea mays* L.). *American-Eurasian Journal of Agricultural & Environmental Science* **9(3)**: 319–24.

Olsen SR, Cole CV, Watanabe FS and Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate, *USDA circular no. 939*, Washington, DC.

Pedrero F, Kalavrouziotis I, Alarcón JJ, Koukoulakis P and Asano T (2010) Use of treated municipal wastewater in irrigated agriculture-Review of some practices in Spain and Greece. *Agricultural Water Management* **97**: 1233–41.

Richards LA (1954) *Diagnosis and Improvement of Saline- Alkali Soils*, Pp 160. Richards L A(Ed). Government Printing Office, Washington D.C.

Rusan MJM, Hinnawi S and Rousan L (2007) Long term effect of wastewater irrigation of forage crops on soil and plant quality parameters. *Desalination* **215**: 143–52.

Singh N, Rajendran RA, Shekhar M, Jat SL, Kumar R and Kumar RS (2012) *Rabi Maize Opportunities Challenges*, 32p. Technical Bulletin No.9, Directorate of Maize Research, New Delhi.

Singh R, Verma RS and Yadav Y (2012) Use of industrial waste water for agricultural purpose: pb and cd in vegetables in Bikaner city, India. *Current World Environment* **7(2)**: 287–96.

Subbaih BV and Asija GL (1956) Rapid procedure for the estimation of available nitrogen in soil. *Current Science* **125**: 259–60.

Thambavani DS and Sabitha MA (2011) Impact of sugar mill effluent on physico-chemical profile of effected soil. *International Journal of Environmental Sciences* **5**: 49–54.

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

Yemm E and Willis A (1954) The estimation of carbohydrates in plant extracts by anthrone. *Biochemical Journal* **57**: 508–14.

Received: June 22, 2023; Accepted: June 26, 2023

Journal of Soil Salinity and Water Quality 15(1), 104-109, 2023

Sustainability of Salt Tolerant Varieties to Counter Climate Change Under Semiarid Saline Conditions of Pali, Rajasthan

Dheeraj Singh, MK Chaudhary, BR Kuri, Chandan Kumar and AS Tetarwal*

Krishi Vigyan Kendra, Central Arid Zone Research Institute, Pali-306401, Rajasthan, India
**Corresponding author E-mail: Arvind.Tetarwal@icar.gov.in*

Abstract

Expanding problems of soil salinity have become serious issues of concern in arid zone of Pali district as they affect productivity and threaten the very sustainability of agriculture. Looking to this problem CAZRI KVK made an attempt to access and improve the productivity of small farms in Pali by organizing 300 front line demonstrations (FLD) in its selected villages during 2017-20 using salt tolerant variety of wheat. Under this programme, quality seeds of improved varieties of wheat of the area were distributed to the identified farmers. In order to harness the synergy between technologies and the community participation, special emphasis was given to build farmer's capacity to produce quality produce with enhanced yield. Fine-tuning of the production technology based on the location specific conditions and resources available with the farmers enhanced the adoption rate. The results indicate higher additional returns and effective yield under demonstrations which were due to improved variety, scientific proven technology, non-monetary factors, timely operations of crop cultivation and scientific monitoring. From an initial start of 300 farmers the variety and innovation spread to 140 villages covering 790 hectares of area.

Key words: Arid region, Economics, Ffront line demonstrations, Yield gap

Introduction

Wheat (*Triticum aestivum* L.) is one of the principal cereal crops grown worldwide and one of the important staple foods of nearly 2.5 billion of world population providing almost half of all calories in the region of North Africa and West and Central Asia (Sendhil *et al.,* 2019). Being next to rice, wheat constitutes one of the key sources of protein in least developed countries and middle-income nations. India, being blessed and enriched with a diverse agroecological condition, ensuring food and nutrition security to a majority of the Indian population through production and steady supply particularly in the recent past, is the second largest producer of wheat worldwide (Sharma and Shendil, 2016). After rice, wheat holds second position in food grain crops accounting an area 31.45 million hectares (14% of global area) under cultivation and produces all-time highest output of 107.59 million tonnes of wheat grains (13.64% of world production) with a record average productivity of 3421 kg ha^{-1}. Rajasthan is the fifth largest producer of wheat where this crop cultivated in 3.12-million-hectare area and produces 10.92 million tonnes wheat with the remarkable productivity of 3501 kg ha^{-1} by contributing 9.91% in area and 10.15% in total production of the country during the year 2019-20 (Anonymous, 2020). Despite this there is a large gap in productivity of wheat in India when compared with other nations and situation is very poor if we consider wheat cultivation on problematic soils in India. Soil salinity and poor-quality ground water is a major problem of wheat cultivation in many parts of the India. Worldwide, nearly 20% of the gross cultivated area and about half of the irrigated lands are affected by soil salinity (Sattar *et al.*, 2010).

In India, about 120.40 million hectares, 37% of the total geographical area (328.73 million hectare) is affected by land degradation. About 0.2-0.4% of the total arable lands is going out of the cultivation every year due to soil salinity and water logging problem (Jabeen and Ahmad, 2012). Soil salinity is one of the major abiotic stresses which adversely affects plant growth and crop productivity (Sharma, 2015). The soils of many parts of the Rajasthan state including Pali-Marwar region severely affected by the salinity problem which is not only hampering the wheat cultivation but emerging as big challenge to nutritional and livelihood security of the area. There is need to develop improved package of practices for wheat cultivation under saline conditions for achieving the higher productivity. In this way, development of salt tolerant varieties is an effective solution to overcome the constraints of the crop production in certain saline areas (Munns and James, 2003; Kumar *et al.,* 2016). Keeping these points in view an attempt was made to study the effect of frontline demonstrations of wheat under saline soil conditions in Pali district of Rajasthan.

Materials and Methods

The field work for this research was undertaken by ICAR-CAZRI, Krishi Vigyan Kendra, Pali located at 24.75° to 26.48° North latitude and 72.78° to 74.30° East longitudes in state of Rajasthan during *rabi* season from 20017-18 to 2020-21 (4 years) in the farmers' fields of ten adopted villages of Pali district in Arid Zone of Rajasthan. For the study two blocks i.e. Rohat and Marwar junction were selectively chosen as these are the main areas where farmer obtain very low yield due to use of low yielding variety and the soil is saline with poor quality water. In total 300 frontline demonstrations in 120 ha area in different villages were conducted. In case of local check plots, existing practices being used by farmers were followed. In general, soils of the area under study were saline sandy loam to clay loam, low in fertility status. The FLDs were conducted to study the gaps between the potential yield and demonstration yield, extension gap and technology index. In the present evaluation study, the data on output of wheat cultivation were collected from FLD plots, besides the data on local practices commonly adopted by the farmers of this region at the same field were also collected. In demonstration plots, a few critical inputs in the form of quality seed, balanced fertilizers, agro-chemicals etc. were provided and non-monetary inputs like timely sowing in lines and timely weeding were also performed. Whereas, traditional practices were maintained in case of local checks. The demonstration farmers were facilitated by KVK scientists in performing field operations like sowing, spraying, weeding, harvesting etc. during the course of training and visits. From each village 30 farmers were selected thus, making a total sample size of 300 farmers. The data were collected through personal interview by designing a questionnaire. The data were collected, tabulated and analyzed by using statistical tools like frequency and percentage. Relevant information was also collected from secondary sources, including research and review papers, to supplement the interview and focus group data and to document different aspects of wheat varieties used in the frontline demonstration. The extension gap, technology gap and the technology index were worked out as per formulae given by the Samui *et al.* (2000).

Technology gap = Potential yield - Demonstration yield

Extension gap = Demonstration yield - yield under existing practice

Technology index = {(Potential yield - Demonstration yield)/Potential yield} × 100

Results and Discussion

During 2017-18 to 2020-21, ICAR-CAZRI Krishi Vigyan Kendra, Pali conducted frontline demonstrations on wheat crop using salt tolerant varieties (KRL 19, KRL 210 and KRL 213) with improved package of practices (balanced application of fertilizers (N:P:K @ 30:20:20 kg ha^{-1}), control of insect-pests at economic threshold level, enhanced knowledge and adoption of scientific practices) at farmers' fields of ten villages of Pali district. The results indicated that the use of improved varieties produced on an average additional yield of 13.84% in case of KRL 19, 19.16% in case of KRL 210 and 12.19% in case of KRL 213 as compared to local check (Kharchia wheat) whose yield was 26.65 q ha^{-1}. Within the improved varieties used in the demonstration plots, the average maximum yield was obtained from KRL 210 (32.63 q ha^{-1}), followed by KRL 213 (29.85 q ha^{-1}) and it was minimum in KRL 19 (29.50 q ha^{-1}) (Figure 1). The present findings are in close proximity with the results of Ahmad *et al.* (2005); Jakhar *et al.* (2018) and Singh *et al.* (2019b) they concluded that for increasing wheat

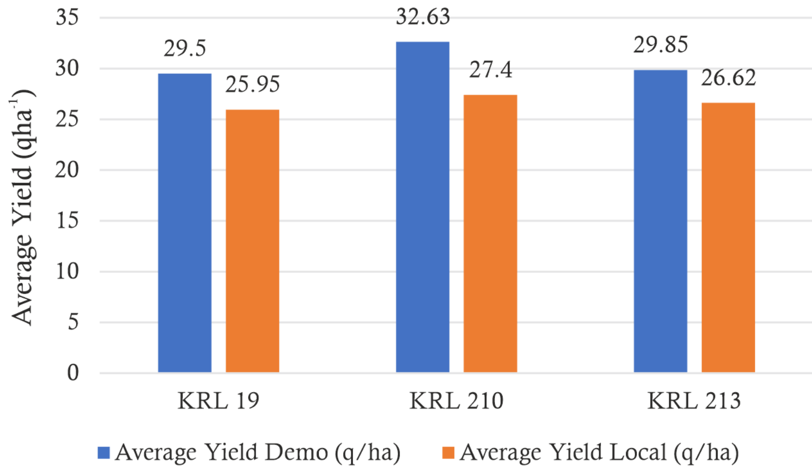

Fig. 1 Average yield of improved variety compared with local variety

productivity in salt affected area, it is necessary to make more intensive efforts for evolving suitable salt tolerant varieties of wheat like KRL 210, KRL 213, KRL 19 and KRL 2-4 which can tolerant saline (EC 5-7 ds m^{-1}) as well as alkaline soil (pH 8.7-9.3) conditions. Similar results on better plant salt tolerance, environmental adaptability and subsequent higher crop yields for tolerant genotypes in salt stress prone areas have been stated by Nikam *et al.* (2016) and Iqbal *et al.* (2015) while working with different crops under saline conditions. The year-to-year fluctuations in yield can be also explained on the basis of variations in prevailing social, economic and prevailing microclimatic condition of that particular village. Mukherjee (2003) and Singh *et al.* (2018a) has also opined that depending on identification and use of farming situation, specific interventions may have greater implications in enhancing system productivity. Yield enhancement in different crops in Front Line Demonstration has amply been documented by Haque (2000), Tiwari and Saxena (2001), Tiwari *et al.* (2003), Tomer *et al.* (2003) and Dubey *et al*. (2010). The results further indicated that the yield of wheat in the following years increased successively due to FLD which had a very good impact over the farming community of Pali district as they were motivated by the new agricultural technologies applied in the Frontline Demonstration plots (Table 1).

Table 1. Yield of wheat as influenced by improved technologies over local technology

Year	Variety	Yield (q ha^{-1})				Add. yield over local (q ha^{-1})	Increased in yield over local (%)	Ext. gap (q ha^{-1})	Tech. gap (q ha^{-1})	Tech. index (%)
		Maximum	Minimum	Mean	Local					
2017-18	KRL 19	32.5	27.2	28.9	25.7	3.2	12.45	3.2	11.1	27.75
	KRL 210	36.4	28.8	33.4	26.3	7.1	27.00	7.1	15.9	32.25
	KRL 213	31.2	27.5	30.2	25.6	4.6	17.97	4.6	13.7	31.21
2018-19	KRL 19	31.6	27.1	29.2	26.3	2.9	11.03	2.9	10.8	27.00
	KRL 210	35.1	28.0	31.9	27.3	4.6	16.85	4.6	17.4	35.29
	KRL 213	33.2	27.3	29.4	26.5	2.9	10.94	2.9	14.5	33.03
2019-20	KRL 19	34.2	28.1	30.3	27.4	2.9	10.58	2.9	9.7	24.25
	KRL 210	37.5	29.3	33.7	28.8	4.9	17.01	4.9	15.6	31.64
	KRL 213	33.4	28.2	29.5	26.9	2.6	9.67	2.6	14.4	32.80
2020-21	KRL 19	31.6	26.7	29.6	24.4	5.2	21.31	5.2	10.4	26.00
	KRL 210	35.7	28.9	31.5	27.2	4.3	15.81	4.3	17.8	36.11
	KRL 213	33.8	27.9	30.3	27.5	2.8	10.18	2.8	13.6	30.98

q=100 kg

Table 2. Economics of wheat as affected by improved production technologies over local technology

Year	Variety	Total cost of cultivation (Rs.)		Gross return (Rs ha^{-1})		Net return (Rs ha^{-1})		B: C ratio		Addi. cost of cultivation	Addi net return
		IP	FP	IP	FP	IP	FP	IP	FP	(Rs)	(Rs)
2017-18	KRL 19	25200	23300	50142	41120	24942	17820	1.99	1.76	1900	7122
	KRL 210	25350	23300	57949	42080	32599	18780	2.29	1.81	2050	13819
	KRL 213	25425	23300	52397	40960	26972	17660	2.06	1.76	2125	9312
2018-19	KRL 19	26300	24100	53728	42080	27428	17980	2.04	1.75	2200	9448
	KRL 210	26500	24100	58696	43680	32196	19580	2.21	1.81	2400	12616
	KRL 213	26750	24100	54096	42400	27346	18300	2.02	1.76	2650	9046
2019-20	KRL 19	27100	24200	58328	43840	31228	19640	2.15	1.81	2900	11588
	KRL 210	27300	24200	64873	44640	37573	20440	2.38	1.84	3100	17133
	KRL 213	27525	24200	56788	43040	29263	18840	2.06	1.78	3325	10423
2020-21	KRL 19	28800	24700	56240	39040	27440	14340	1.95	1.58	4100	13100
	KRL 210	29200	24700	62213	43520	33013	18820	2.13	1.76	4500	14193
	KRL 213	29300	24700	59843	44000	30543	19300	2.04	1.78	4600	11243

Moreover, from first year onwards, farmers co-operated enthusiastically in carrying out of Front-Line Demonstrations which lead to encouraging results in the subsequent years. More and more use of latest production technologies with high yielding and salinity tolerant varieties will subsequently change different this alarming trend of galloping extension gap. The new technologies will eventually lead to the farmers to discontinuance of old varieties with the new technology. The experiment results revealed that mean extension gap was 4.0 qha^{-1} and it ranged from 2.6 qha^{-1} to 7.1 qha^{-1} during the period of study which emphasized the need to educate the farmers through various means for the adoption of improved agricultural production technologies to reverse this trend of wide extension gap. The highest technology gap was 17.80 q ha^{-1}. However, it was observed that the average technology gap was narrowing down during last three years. The technology gap observed may be attributed to difference in the soil fertility status, agricultural practices, local climate conditions, rainfed agriculture and timeliness of availability of inputs(Singh *et al.* 2019a). Hence, variety wise location specific recommendation appears to be necessary to minimize the technology gap for yield level in different farming situations. Technology index ranged from 36.11% to 24.25% in different varieties in different years (Table 1). Lower the value of technology index, more is the feasibility of the technology demonstrated (Sagar and Chandra, 2004: Singh *et al.,* 2018b). Therefore, reduction of technology index exhibited the feasibility of technology demonstrated and confirm the finding of Sharma (2004); Singh *et al.* (2007); Patel *et al*. (2009) and Singh *et al.* (2019a) in mustard crop.

Economic analysis (Table 2) of the yield performance revealed that cost benefit ratio of demonstration plots was observed significantly higher than control plots. The cost benefit ratio of demonstrated and control plots were 2.03 and 1.73, 2.25 and 1.8 and 2.05 and 1.77 for KRL 19, KRL 210 and KRL 213 variety, respectively. Hence, favorable cost benefit ratios proved the economic viability of the intervention made under demonstration and convinced the farmers on the utility of intervention. Similar findings were reported by Sharma (2003) in moth bean , Gurumukhi and Misra (2003) in sorghum and Singh *et al.* (2020) in different crops. The data clearly revealed that the maximum increase in yield observed was during 2017-18, while maximum cost benefit ratio was observed during 2019-20. Amongst the improved varieties demonstrated the average net return (Fig. 2) was maximum in KRL 210 (INR 33,845) variety followed by KRL 213 (INR 28,531) and it was minimum in KRL 19 (INR 27,759). The variation in cost benefit ratio during different years may mainly be on account of yield performance and input output cost in that particular year. Thus, FLD obtained a significant positive result and also

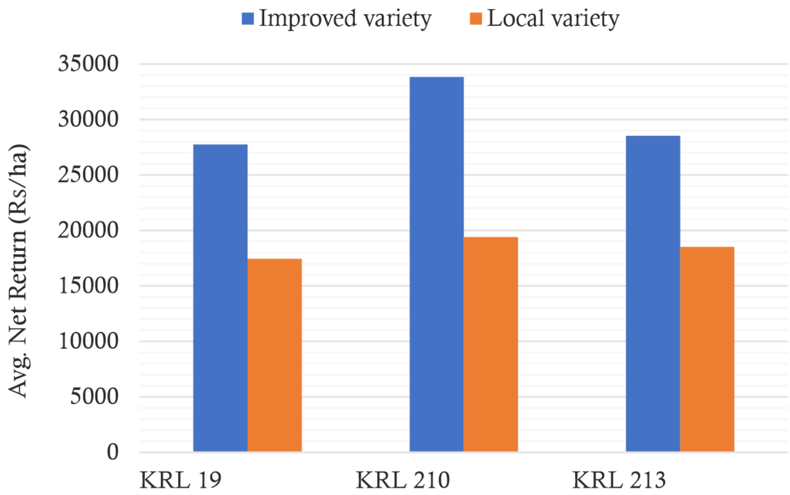

Fig. 2 Average net returns of frontline demonstration with local practice

provided the researchers an opportunity to demonstrate the productivity potential and profitability of the scientific management under field conditions (Singh *et al.,* 2018b).

Conclusions

From the above results and discussion, it can be concluded that improved varieties and skilling of the rural farmers will help immensely to increase the crop productivity. On the whole, a synergy between research-extension-policy-institutions will play an impending role to achieve the desired level of production as well as to ensure food security for future generation. Thus, it can be concluded that timely training and well framed frontline demonstration conducted under the close supervision of scientists is one of the most important tool of extension to demonstrate newly released crop production and protection technologies and its management practices in the farmers' field under different agro-climatic regions and farming situations. The realization of the expected increase in production in agriculture will only be possible with new varieties and technologies with high efficiency, high quality, resistance to biotic and abiotic stresses and by offering them to the service of the farmer through trainings and FLDs.

References

Ahmad M, Niazi B, Zaman B and Athar M (2005) Varietal differences in agronomic performance of six wheat varieties grown under saline field environment. *International Journal of Environmental Science and Technology* **2**(1): 49-57.

Anonymous (2020) Directorate of Economics & Statistics, Department of Agriculture Cooperation & Farmers Welfare, New Delhi.

Dubey S, Tripathy S, Singh P and Sharma RK (2010) Yield gap analysis of black gram production through frontline demonstration. *Journal of Progressive Agriculture* **1**(1): 42-44.

Gurumukhi DR and Mishra S (2003) Sorghum front line demonstration - A success story. *Agriculture Extension Review* **15**(4): 22-23.

Haque MS (2000) Impact of compact block demonstration on increase in productivity of rice. *Maharashtra Journal Extension Education* **19**(1): 22-27.

Iqbal MM, Murtaza G, Saqib ZA and Rashid A (2015) Growth and physiological responses of two rice varieties to applied lead in normal and salt-affected soils. *International Journal of Agriculture and Biology* **17**: 901–910.

Jabeen HN and Ahmad R (2012) Improving tolerance of sunflower and safflower during growth stages to salinity through foliar spray of nutrient solutions. *Pakistan Journal of Botany* **44**(2): 563-572.

Jakhar DS, Kumar N and Kumar S (2018) Performance of Salt Tolerant Wheat Varieties in Salt Affected Soils. *Journal of Krishi Vigyan* **6**(2): 184-186.

Kumar M, Sarangi A, Singh DK, Rao AR and Sudhishri S (2016) Response of wheat cultivars to foliar potassium fertilization under irrigated saline environment. *Journal of Applied and Natural Science* **8**(1): 429-436.

Mukherjee N (2003) Participatory Learning and Action. Concept Publishing Company, New Delhi, India. pp 63-65.

Munns R and James, RA (2003). Screening methods for salt tolerance: A case study with tetraploid wheat. *Plant Soil* **253**: 239-250.

Nikam VR, Singh RK and Chinchmalatpure A (2016) Salt tolerant varieties: A biological intervention to manage saline and sodic environment and sustain livelihoods. *Journal of Soil Salinity and Water Quality* **8**: 37–44.

Patel BI, Patel DB, Patel AJ and Vihol KH (2009) Performance of mustard in Banaskantha district of Gujarat. *Journal of Oilseeds Research* **26** (Special issue): 556-557.

Sagar RL and Chandra O (2004) Front line demonstration on sesame in West Bengal. *Agriculture Extension Review* **16**(2): 7-10.

Samui SK, Maitra S, Roy DK, Mandal AK and Saha D (2000) Evaluation of front-line demonstration on groundnut. *Journal of Indian Society of Coastal Agricultural Research* **18**(2): 180-183.

Sattar S, Hussnain T and Javaid A (2010) Effect of NaCl salinity on cotton (*Gossypium Arboreum* L.) grown on MS medium and in hydroponic cultures. *The Journal of Animal and Plant Science* **20**(2): 87-89.

Sendhil R, Kumar TMK and Singh GP (2019) Wheat Production in India: Trends and Prospects, Recent Advances in Grain Crops Research, Farooq Shah, Zafar Khan, Amjad Iqbal, Metin Turan and Murat Olgun, Intech Open, DOI: 10.5772/intechopen.86341. Available from: https://www.intechopen.com/chapters/67311

Sharma I and Sendhil R (2016) Wheat Production in India—A Decadal Synopsis. Available from: http://www.FnBnews.com

Sharma KD (2004) Impact of frontline demonstrations in adoption of improved Soybean cultivation practices. *Rajasthan Journal of Extension Education* **4**(1&2): 15-17.

Sharma OP (2003) Moth bean yield improvement through Front Line Demonstrations. *Agriculture Extension Review* **15**(5): 11-13.

Sharma R (2015) Genotypic Response to Salt Stress: I–Relative Tolerance of Certain Wheat Cultivars to Salinity. *Advances in Crop Science and Technology* **3**:192.

Singh D, Kumar C, Choudhary MK and Meena ML(2018a) Popularization of improved mustard production technology through frontline demonstration in Pali district of Rajasthan Meena, *Indian Journal of Extension Education* **54**(3): 115-118.

Singh D, Choudhary MK, Meena ML and Kumar C (2018b) Farmer field school: An innovative approach for boosting spice production in semi-arid zone, *International Journal of Seed Spices* **8**(2): 64-71.

Singh D, Choudhary MK, Meena ML and Kumar C (2019a) Farmer participatory seed production: extending the Indian experience to Africa. Conference of Agricultural Economists, September 23-26, Abuja, Nigeria

Singh D, Choudhary MK, Meena ML and Kumar C (2019b) Rain Water Harvesting for Food and Livelihood Security: A case study from Pali, India. *Open Agriculture*. **4**: 767-777. https://doi.org/10.1515/opag-2019-0071

Singh D, Choudhary MK, Meena ML (2020) Seed village programme: A practical approach for combating malnutrition and nutritional security in arid Zone, *World Review of Nutrition and Dietetics* **12**110.1159/000507513

Singh DK, Gautam US and Singh RK (2007) Study on yield gap and level of demonstrated crop production technology in Sagar district. *Indian Research Journal of Extension Education* **7**(2&3): 94-95.

Tiwari KB and Saxena A (2001) Economic Analysis of FLD of oil seeds in Chindwara. *Bhartiya Krishi Anusandhan Patrika* **16**(3&4): 185-189.

Tiwari RB, Singh V and Parihar P (2003) Role of frontline demonstration in transfer of gram production technology. *Maharashtra Journal of Extension Education* **22**(1): 19.

Tomer LS, Sharma PB, Joshi K (2003) Study on yield gap and adaptation level of potato production technology in grid region. *Maharashtra Journal of Extension Education* **22**(1): 15-18.

Received: June 5, 2023; Accepted: June 26, 2023

Journal of Soil Salinity and Water Quality 15(1), 110-114, 2023

Effect of Brackish Water on the Growth and Yield of Hydroponically Grown Cherry Tomato

Aarish Doomra[1], OP Choudhary[1]*, R Sharda[2] and MS Mavi[1]

[1]Department of Soil Science, Punjab Agricultural University, Ludhiana-141004, Punjab, India
[2]Department of Soil & Water Engineering, Punjab Agricultural University, Ludhiana-141004, Punjab, India
**Corresponding author E-mail: opc_2k@yahoo.com*

Abstract

Long-term use of saline water for irrigation deteriorates soil health. Therefore, instead of direct use of saline water for irrigation, there is a need to find the alternatives for using saline water rationally to sustain crop productivity and soil health. Growing vegetables in the nutrient film technique (NFT) in green house/poly house can be a good option to efficiently use the saline water. In this technology, hoagland solution is used to provide nutrition to the plants. A study was conducted to examine the use of different grades of saline water in the green house using nutrient film technique of for cherry tomato production. Cherry tomato was grown in the five brackish water treatments including best available water (BAW, electrical conductivity (EC) 1.5 dS m^{-1}), and saline waters having 3.0, 4.5, 6.0 and 7.5 dS m^{-1} EC at demonstration farm of Department of Soil Water and Engineering, PAU, Ludhiana. Growth parameters (plant height, number of leaves and leaf area index) and fruit parameters (yield, number of fruits and fruit weight) were measured during the study. The cherry tomato plants irrigated with nutrient solution having EC of 3.0 dS m^{-1} was found the most suitable and effective to support plant growth parameters viz. plant height, number of leaves and leaf area index and achieved higher yield (1231 g $plant^{-1}$), higher number of fruits per plant (117) and maximum fruit weight (10.5 g). It can be concluded that brackish water of 3.0 dS m^{-1} is viable option for raising cherry tomato when grown under NFT condition.

Key words: Nutrient film technique, Hoagland solution, Electrical conductivity, Cherry tomato

Introduction

In the arid and semi-arid zones of world, good quality water resources are becoming increasingly scarce. Thus, marginal quality waters which containing certain amounts of salts such as ground-water, drainage water and treated wastewater are being used to supplement surface water supplies which often leads to accumulation of salts in the soil. Improper management, irrational use of low-quality waters, high salinity and ionic composition of water sources represent serious threats to soil and environmental conditions (Gupta and Abrol, 2000; Minhas and Bajwa, 2001; Choudhary *et al.,* 2004). Salinity, measured in Electrical conductivity, is an abiotic stress that limits the production and the growth of plant. Salinity stress is considered as hyperosmotic stress as it reduces availability of water, causes water deficits and results in stunted growth. High Na^+ concentration causes inhibition of K^+ and Ca^{2+} uptake and other essential elements required for growth and development reduces productivity and may even lead to death. Salinity decreases the uptake of NO^3 ion, results from direct competition between Cl^- and NO_3^- ions by same transporter, which may induce deficiency of N in the plants (Cova, 2017). Plants can adapt to salinity in three ways: rejection of ions, the tolerance of plants to an increase in ions or by avoiding uptake of certain ions.

Cherry tomato (*Solanum lycopersicum var. cerasiforme*) is widely grown with waters having different levels of salinity. But the use of water of high salts can negatively affect the production of cherry tomatoes. Brackish water reduced the water absorption in tomato roots causing low transpiration rate and high leaf temperature. Therefore, fewer number of plants can survive under high salinity. Brackish water can also reduce fruit size and yield. The hydroponic system can be an alternative to conventional cultivation with more water use efficiency and less risks due to use of brackish waters for irrigation. The majority of crops which cannot be grown/survive on saline soils, have the ability to tolerate varying salt concentration in the hydroponic system (Donia *et al.,* 2020) because the matrix potential value in hydroponics is close to zero, which allows more water and nutrients absorption with less use of energy than those grown in soil (Santos *et al.,* 2019). Nutrient film technique (NFT) of hydroponics may help to achieve optimal growth and development as well as yield by managing the uptake of nutrients by controlling the root environment, nutritional-flow and water-flow along with other factors such as temperature, pH and electrical conductivity (EC). Hydroponics with brackish water may prove to be a good and viable alternative for fresh water which is very limited and these brackish waters can become a good asset rather than a waste resource.

Material and Methods

Study area

The field experiment was conducted during the year 2021-22 in a hi-tech greenhouse located at demonstration field of Department of Soil Water and Engineering, Punjab Agricultural University, Ludhiana. The experiment site is situated at Latitude 30°55' N and Longitude 75°54' E at 247.0 m above mean sea level.

Experimental set up

To investigate the impact of brackish water on the plant growth and yield parameters of cherry tomato, a hydroponic system using the NFT (Nutrient Film Technique) was developed. Total nine NFT systems were installed, and each NFT was fitted with seven pipes (in pyramidal shape) installed at the height of 0.8 m above the ground. The size of each NFT was 1.95 × 6.05 m and consisted of 7 number PVC pipes. The net pot in each hole has been kept 1.4 inches above the stream flow of nutrient solution. A tube of 16 mm diameter was used to supply and collect recirculated nutrient solution into the tank. Five different saline nutrition solution concentrations were taken for the crop raising that included Best Available Water (BAW) having EC of 1.5 dS m^{-1} and four saline solutions having EC of 3.0, 4.5, 6.0 and 7.5 dS m^{-1}. For growing the seedlings in the nursery in the trays, cocopeat-based soilless media was used. Cherry tomato seedlings were transplanted on 22nd October 2022 in the net pots and thereafter placed in the hydroponic system.

Preparation of Hoagland solution

The Hoagland nutritional solution was prepared in the Soil Salinity Lab, Department of Soil Science, PAU, Ludhiana. The standard composition of the Hoagland solution is demonstrated in Table 1. After every cycle of seven days, the tank was cleaned with non-saline tap water by running the system for around one hour, and simultaneously, any leakages were checked. The circulated water was removed from the tank, and it was again filled with fresh water followed by the addition of stock solution prepared as per Hoagland's solution and then brackish water was

Table 1. List of nutrients used in preparation of Hoagland solution

1.	Calcium nitrate tetra hydrate ($Ca(NO_3)_2.4H_2O$)	236 g l^{-1}
2.	Potassium nitrate (KNO_3)	101 g l^{-1}
3.	Mono potassium phosphate (KH_2PO_4)	136 g l^{-1}
4.	Magnesium sulphate hepta hydrate ($MgSO_4.7H_2O$)	246.50 g l^{-1}
5.	Trace elements	
a	Boric acid (H_3BO_3)	2.80 g
b	Manganese chloride tetra hydrate ($MnCl_2.4H_2O$)	1.80 g
c	Zinc sulphate hepta hydrate ($ZnSO_4.7H_2O$)	0.20 g
d	Copper sulphate penta hydrate ($CuSO_4.5H_2O$)	0.10 g
e	Sodium molibdate ($NaMoO_4$)	0.025 g
f	Iron Chelate (FeEDTA)	
	(i) Ethylene diaamine tetra acetic acid (EDTA. 2Na)	10.4 g
	(ii) Iron sulphate hepta hydrate ($FeSO_4.7H_2O$)	7.8 g
	(iii) Potassium hydroxide (KOH)	56 g

added to set the EC of the nutrient solution as per the treatment. The EC and pH of nutrient solution were monitored every second day using pH and EC meter to check the sensitivity of different crops to EC of their nutrient solution.

Plant growth parameters

Five tomato plants from each treatment were randomly chosen to measure their height at 15 days interval from 15, 30, 45, 60, 75 and 90 days after transplanting and so on till harvest. By using measuring tape, it was estimated from the plant's base to its top. Number of leaves of five randomly selected plants was counted at 15 days interval from 15, 30, 45, 60, and 75 days until the fruiting stage. The LAI was recorded fortnightly from 45, 60, and 75 days after transplanting till fruiting stage.

Yield and fruit parameters

Cherry tomato is harvested in accordance with the established harvest indices and the yield and its components like individual fruit weight, number of fruits per plant, and total yield per plant were recorded. Cherry tomato was harvested when the tomato changed colour to the saffron and yield was calculated for different treatments in g plant^{-1}.

Statistical design

Statistical analysis of various parameters was done by SPSS software. Data recorded for various parameters were statistically analysed as per Completely Randomized Design.

Results and Discussion

The periodic observations recorded at the progressive stages of the experiments were analysed statistically to assess the degree of variance due to the treatments.

Plant growth parameters

Plant growth parameters were affected by the salinity of nutrient solution. Plant height is the primary attribute that was affected by salinity. There was a significant difference in salinity-treated plants compared with best available water (BAW) treatment. Figure 1 illustrates the effect of the different EC treatments on the plant height (cm) of the cherry tomato over the growing period. Plants grown in nutrient solution of EC 3.0 dS m^{-1} had showed maximum plant height at most of the day intervals. Plants irrigated with 3.0 dS m^{-1} had maintained their higher plant height at 106 % than the BAW (1.5 dS m^{-1}) over 150 days of plant growth. Plants grown in nutrient solution of EC 7.5 dS m^{-1} had the minimum plant height at most of the day intervals. Plants irrigated with 7.5 dS m^{-1} had showed relative plant height from 84.8 to 66.3 % compared with BAW over different plant growth period.

Figure 2 illustrates the Effect of the different EC treatments on the number of leaves of the cherry tomato till the fruiting stage. Plants grown in nutrient solution having EC 3.0 dS m^{-1} had showed maximum number of leaves at most of the day intervals. Plants at 3.0 dS m^{-1} had improved their number of leaves from 90.8 to 117 % over 75 days of plant growth as compared with BAW

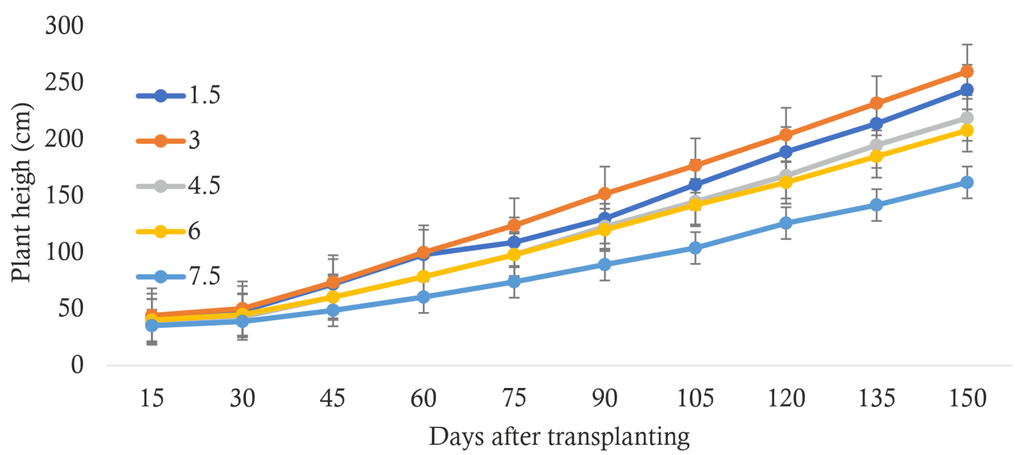

Fig. 1 Effect of different brackish water treatments on the plant height (cm) over growing period

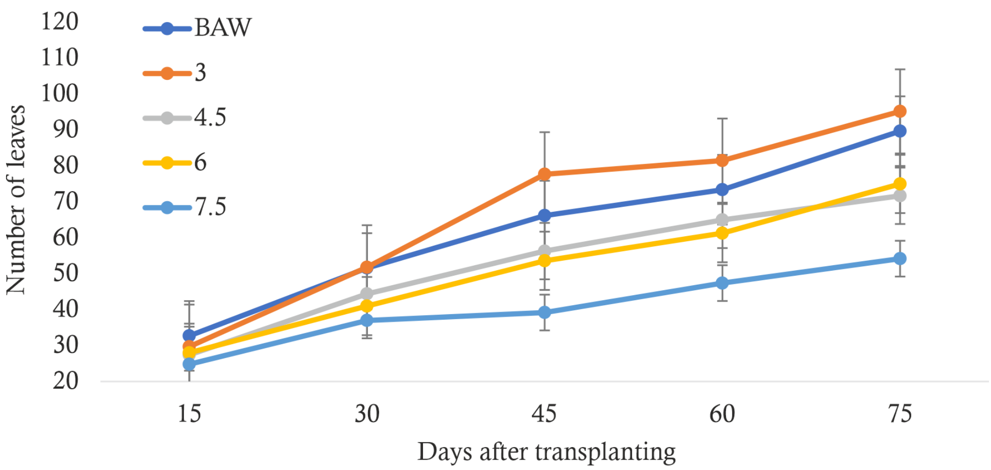

Fig. 2 Effect of different brackish water treatments on number of leaves over growing period

whereas plants receiving 7.5 dS m^{-1} water under NFT had the minimum number of leaves ranging from 75.8 to 58.5 % at different times over 75 days of plant growth relative to with the BAW treatment.

Maximum mean height (142 cm) of cherry tomato plants was recorded in the nutrient solution of 3.0 dS m^{-1} followed by BAW (EC 1.5 dS m^{-1}) treatment; both the treatments were at par. Minimum height of 88 cm was observed in the nutrient solution having 7.5 dS m^{-1} EC (Table 2). A similar result was concluded by the Habibi *et al.* (2021) and Mohammed *et al.* (2018), that an increase in the salinity is followed by a decrease in the plant height and found that salinity of nutrient solution reduces the plant height by reducing the water absorption and specific ion toxicity.

Maximum number of leaves (71.3) was counted in the plants grown in the 3.0 dS m^{-1} nutrient solution. Beyond 3.0 dS m^{-1} EC, effect of salinity was significantly observed from the plants of 4.5 dS m^{-1} to 7.5 dS m^{-1}. Similar results were found by the Furtado *et al.* (2017) in which number of leaves was also reduced with the increase in the EC of the nutrient solution. This reduction in the number of leaves might be an adjusted strategy of the plants to maintain the cellular turgor by reducing transpiration. It is evident from Table 1 that LAI is very sensitive to EC of the nutrient solution. Higher EC of nutrient solution beyond 3.0 dS m^{-1} progressively decreased the LAI of the cherry tomato. Mohamed *et al.* (2018) had also shown decreased of leaf area significantly at 100 and 150 mM NaCl due to the reduction of leaf gas exchange due to NaCl salinity stress conditions.

Yield and fruit parameters

Fruit weight, number of fruits per plant, and yield per plant were significantly affected by salinity of the nutrient solution (Table 3). Individual fruit weight and the number of fruits per plant were also significantly decreased due to high water salinity. Maximum yields of 1231 g was were obtained from the plants grown in 3.0 dS m^{-1} nutrient solution followed by 970 g in BAW treatment. Beyond 3 dS m^{-1}, fruit yield progressively and substantially decreased with

Table 2. Effect of brackish water treatments on plant growth parameters

EC treatments (dS m^{-1})	Plant height (cm)	Number of leaves	LAI
Best available water (1.5)	131 a	63.5 a	0.647 ab
3.0	142 a	71.3 a	0.703 a
4.5	117 b	53.0 b	0.523 b
6.0	114 b	50.4 b	0.447 c
7.5	88 c	39.0 c	0.403 c

Table 3. Effect of different brackish water treatments on the fruit parameters and yield

EC Treatments (dS m^{-1})	Number of fruits per plant	Fruit weight (g)	Yield (g plant^{-1})
BAW	113 ab	8.50 ab	970 b
3.0	117 a	10.5 a	1231 a
4.5	86.0 c	7.9 b	689 c
6.0	61.7 d	7.2 b	446 d
7.5	37.7 e	7.2 b	273 d

further increase in salinity of the nutrient solution. Rosadi *et al.* (2014) suggested this increase of yield in 3.0 dS m^{-1} might be due to the increase of nutrient availability and beyond that, decrease might be due to increase in osmotic and water stress in the plants due to high EC of the solution of NFT.

Increase in EC of nutrient solution beyond 3.0 dS m^{-1}, progressively reduced number of fruits and the least number of fruits (37.7) was observed in the 7.5 dS m^{-1}. It might also be due to less number of flowers during inflorescence because of reduced potassium and phosphorous uptake (Mohamed *et al.,* 2018). Maximum fruit weight (10.5 g) in the 3.0 dS m^{-1} might be due to the more uptake of water by the plants as compared with the other saline treatments. Similar results were reported by Mohamed *et al.* (2018) and they found decreased fruit weight at high salt levels in the nutrient solution decreased water potential in plants which reduces water flow into fruit and limits the rate of fruit expansion.

Conclusions

For cherry tomato productivity and fruit quality, a small increase in electrolyte concentration under the nutrient film technique (NFT) was found to be beneficial. Beyond that level, increase in the EC of the nutrient solutions in progressive decrease in yield of cherry tomato; 30% at 4.5 dS m^{-1}, 54% at 6 dS m^{-1} and 70% decline at 7.5 dS m^{-1} in comparison with the best available water tested in the study. Also plant height, number of leaves and leaf area index decreased significantly with increasing salinity of the solution of the NFT. The results of this work showed that hydroponics might allow the cultivation of cherry tomato for higher yield and better fruit quality when irrigation water is of marginal quality. However, the EC of irrigation water should not be higher than 3.0 dS m^{-1}.

References

Choudhary OP, Josan AS, Bajwa MS and Kapur ML (2004) Effect of sustained sodic and saline-sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. *Field Crops Research* **87**: 103-116.

Cova AMW, Freitas FTO, Viana PC, Rafael MRS, Neto ADA and Soares TM (2017) Content of inorganic solutes in lettuce grown with brackish water in different hydroponic systems. *Revista Brasileira de Engenharia Agrícola e Ambiental* **21**: 150-155.

Donia A, Prasad VBR, Manivannan N and Vijayalakshmi D (2020) Effect of salt stress on blackgram during seedling stage under hydroponics. *International Journal of Ecology and Environmental Sciences* **2**: 395-399.

Furtado GF, Cavalcante AR, Chaves LHG, Santos Júnior JA and Gheyi HR (2017) Growth and production of hydroponic pepper under salt stress and plant density. *American Journal of Plant Sciences* **8**: 2255-2267.

Gupta RK andAbrol IP (2000) Salinity build-up and changes in the rice-wheat system of the Indo-Gangetic plains. *Experimental Agriculture* **36**: 273-284.

Habibi N, Sediqui N, Terada N, Sanada A and Koshio K (2021) Effects of salinity on growth, physiological and biochemical responses of tomato. *Journal of International Society Southeast Asian Agricultural Science* **27**: 14-28.

Minhas PS and Bajwa MS (2001) Use and management of poor-quality waters for the rice-wheat based production system. *Journal of Crop Production* **4**: 273-305.

Mohamed M. El-Mogy, Garchery C and Stevens R (2018) Irrigation with salt water affects growth, yield, fruit quality, storability and marker-gene expression in cherry tomato. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science* **68**: 727-737.

Rosadi RAB, Senge M, Suhandy D and Tusi A (2014) The effect of EC levels of nutrient solution on the growth, yield, and quality of tomatoes (*Solanum lycopersicum*) under the hydroponic system. *Journal of Agricultural Engineering and Biotechnology* **2**: 7-12.

Santos AN, Silva EF, Silva GF, Barnabe JMC, Rolim MM and Dantas DC (2016) Yield of cherry tomatoes as a function of water salinity and irrigation frequency. *Revista Brasileira de Engenharia Agrícola e Ambiental* **20**: 107-112.

Santos JF, Filho MAC, Cruz JL, Soares TM, and Cruz AML (2019) Growth, water consumption and basil production in the hydroponic system under salinity. *Rev Ceres Viçosa* **66**: 45-53.

Received: June 5, 2023; Accepted: June 26, 2023

Journal of Soil Salinity and Water Quality 15(1), 115-126, 2023

Virus Concentration and Taqman Real-time Polymerase Chain Reaction (qPCR) Quantification of Adenoviral DNA for Detection of Sewage and Farm Wastewater-Associated Adenoviral Markers

Asima Zehra[1]* and Simranpreet Kaur[2]

[1]PhD Scholar, Centre for One Health, GADVASU, Ludhiana-141004, Punjab, India
[2]Associate Professor, Centre for One Health, GADVASU, Ludhiana-141004, Punjab, India
**Corresponding author E-mail: assimazehra@gmail.com*

Abstract

Library-independent techniques offer numerous advantages, particularly the utilization of Viral DNA as a promising microbial source tracking (MST) marker. However, the variability of genetic markers and their prevalence in populations from different geographical areas necessitate the prior characterization of MST markers' assay performance in each specific watershed before their implementation. Hence, the objective of this study was to evaluate a selected MST marker, namely adenoviruses, in faecal samples from known sources and optimize/validate virus concentration methods. Two rapid techniques for concentrating adenoviruses, including human adenoviruses (HAdV), bovine adenoviruses (BAdV), and porcine adenoviruses (PAdV), were compared in terms of their efficiency in virus recovery. In the direct extraction protocol (Protocol I), the viral genome was directly removed from the membrane, while in the adsorption-elution protocol (Protocol II), viruses were eluted using NaOH and concentrated through centrifugal ultrafiltration. No interference with the TaqMan qPCR assay was observed when processing river and tap water samples using Protocol I, and tap water samples using Protocol II. However, inhibition occurred in qPCR for river samples processed using Protocol II. The mean concentration of HAdVs (3.1×10^4 copy number) and PAdVs (2.6×10^3 copy number) was 10.47-fold and 9.51-fold higher when detected using Protocol I. All PCR markers exhibited high sensitivity and specificity, although none achieved 100% for both parameters. Despite the identification of some MST markers in hosts other than the expected ones, their abundance in the target group consistently exceeded that in non-target hosts, thus demonstrating their ability to differentiate between pollution sources.

Key words: Adenoviruses (AdVs), DNA extraction, Microbial Source Tracking, TaqMan qPCR assay, Virus Concentration

Introduction

The concept of "microbial source tracking" (MST) encompasses a range of methods and an analytical framework aimed at identifying the origin of faecal contamination in environmental waters. Various microorganisms, including the coliform group (such as *Escherichia coli*, *faecal Streptococci*, and *Enterococci*), Bacteroides species, bacteriophage, and enteric entero- and adenoviruses, are now employed for MST purposes. Molecular techniques are commonly employed in MST, which can be categorized as either library-dependent or library-independent approaches. Library-dependent techniques involve the detection of faecal sources in water samples by comparing them to a library or database of bacteria obtained from known faecal sources. On the other hand, library-independent techniques do not require the establishment of a source library database, thereby providing an alternative approach for MST analysis (Rock *et al*., 2015). These methodologies have significantly contributed to our ability to track and trace faecal contamination sources in water environments, enhancing our understanding of water quality and facilitating targeted interventions for pollution prevention and remediation.

In India, the assessment of water pollution levels often relies on the presence of coliform as a library-dependent MST marker. However, the relevance of these microbial indicators, such as *E. coli* and *Enterococci*, is questioned due to their limited association with pathogens, potential cultural biases, and uncertainties regarding their environmental origins under natural conditions (Hata *et al.*, 2013). Moreover, the effectiveness of library-dependent MST methods relies on the establishment of extensive libraries comprising isolates with diverse ribo-types, antibiotic resistance profiles, and other characteristics, as well as the application of appropriate statistical algorithms. The temporal and geographic stability of these libraries determines their applicability in specific regions. In contrast, library-independent techniques offer distinct advantages by not requiring the creation of a source library database. Instead, these techniques rely on species-specific genotypes or characteristics for MST analysis. This approach is particularly beneficial when utilizing enteric viral DNA as an MST marker, as demonstrated by studies (Wyn-Jones *et al.*, 2011). By circumventing the need for large and comprehensive libraries, library-independent methods provide a more streamlined and versatile approach to identifying and tracking faecal contamination sources in environmental waters.

Various viruses, such as coliphages, polyomaviruses, and adenoviruses, have been suggested as indicators of pathogenic enteric viruses due to their similar viral type, size, structure, and ability to survive in the environment (Barrios *et al.*, 2018). Moreover, the presence and abundance of enteric viruses and coliform/ enterococci differ across different sampling sites (Swamee *et al.*, 2017; Zehra *et al.*, 2020), necessitating the examination of viral markers in diverse geographic locations and matrices to elucidate their utility in monitoring microbial water quality (Barrios *et al.*, 2018). Furthermore, due to their small size and variable occurrence in environmental waters, viruses are challenging to detect unless they are concentrated. Additionally, the initial steps involved in capturing viruses from environmental water sources under various geological conditions, as well as the removal of PCR inhibitors from extracted genomes, pose significant challenges that hinder routine implementation (Farkas *et al.*, 2018).

In conclusion, it is recommended that prior characterization of the assay performance be conducted for each specific watershed of interest before implementing MST markers developed in a particular region. This is crucial due to the variability of multiple genetic markers and their prevalence in populations from different geographic areas (Swamee *et al.*, 2017; Zehra *et al.*, 2020). In the context of Punjab, India, this study aimed to assess the feasibility of utilizing species-specific adenoviruses as potential MST markers for monitoring surface and groundwater. Specifically, the study involved testing the selected MST marker, adenoviruses, in faecal samples from known sources, optimizing and validating virus concentration methods, and performing PCR inhibition assays to develop an effective strategy for microbial source tracking.

Material and Methods

The schematic representation outlining the methodology and workflow of this study is depicted in Figure 1.

Standards

The membrane filtering method was performed with *Enterococcus faecalis* strain ATCC 19433 and *E. coli* strain ATCC 11775 as standards; the pAdEasy vector was employed as a control for HAdV (Human Adenovirus type 2 vector plasmid procured from Dept. of Bioscience and Bioengineering, IIT Guhawati). In molecular experiments, GenBank Acc. No. MK028956 and MG673955 were employed as controls for PAdV and BAdV, respectively.

For the HAdV and BAdV/PAdV virus filtration methods, sewage and bovine/porcine wastewater samples were utilised as standards, respectively. This is done to ensure that the test sample matrix closely resembles the intricate matrix of the field samples.

Samples

Samples of primary influent sewage were obtained from two sewage treatment plants (STPs) situated in the Ludhiana and Jallandhar districts of Punjab. Bovine and porcine wastewater samples were collected from dairy farms and small-scale backyard farms, respectively, located in East Ludhiana. The samples were collected in 1-liter sterile polypropylene containers, appropriately labelled, and promptly transported to the

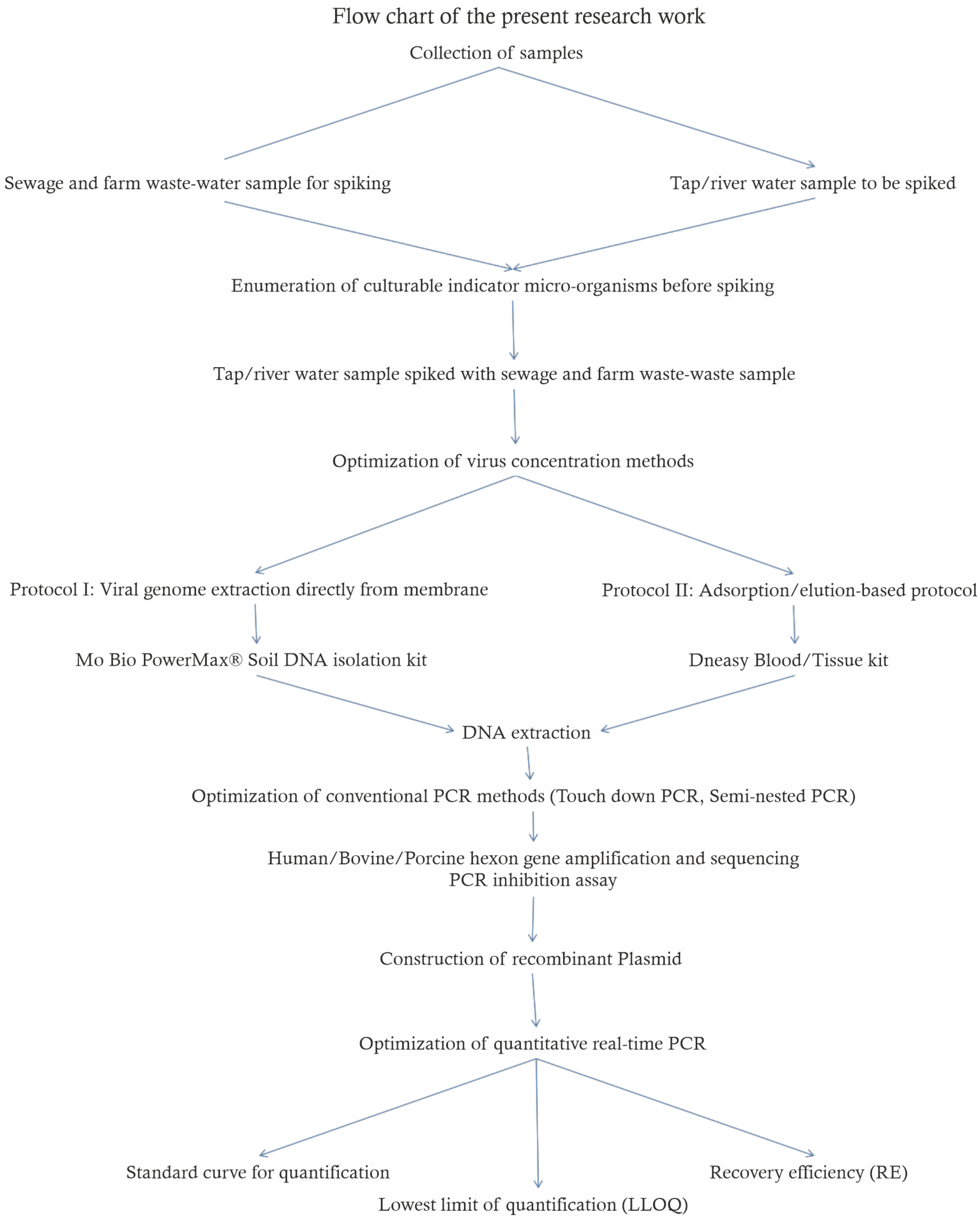

Fig. 1 The schematic representation outlining the methodology and workflow of this study

laboratory at the Centre for One Health, GADVASU, Ludhiana. The samples were refrigerated at 4 °C for less than 12 hours before being analyzed on the same day.

A 20-liter tap water sample was collected from the laboratory at the Centre of One Health, while 20-liter river water samples were collected from the upstream section of the Sutlej River.

Enumeration of culturable indicator organisms

The enumeration of *Escherichia coli* and *Enterococcus* spp. in the samples was conducted using the standard membrane filtration methods outlined by the Environmental Protection Agency (EPA) in their publications from 1997 and 2002. The analysis of samples was carried out in accordance with the minimum analytical quality control requirements specified in Protocol 1603.

Virus Concentration protocols and nucleic acid extraction

The following two virus filtration protocols were used in this study:

- *Protocol I:* Viral genome extraction directly from negatively charged membranes (McQuaig *et al.*, 2009; Ahmed *et al.*, 2015) and
- *Protocol II:* Adsorption/elution-based protocol including viruses eluted with NaOH and concentrated by centrifugal ultra-filtration (Katayama *et al.*, 2002; Ahmed *et al.*, 2015).

In this study, water samples were intentionally contaminated with sewage and farm effluent. For both protocols, 10 mL of sewage sample, porcine farm wastewater, and bovine farm wastewater were added to tap water and river water, resulting in a final volume of 1 L. Each sample was analyzed twice. The pH and turbidity of the river water were 7.8±0.2 and 6.3±0.3 NTU, respectively, while the tap water had a pH of 7.1±0.6 and turbidity of 0.5±0.2 NTU. These spiked samples were then utilized for the optimization of virus concentration protocols I and II.

In protocol I, the viral genome was directly extracted from the membranes using a MoBio PowerMax® Soil DNA isolation kit, following the manufacturer's instructions. A total of 1.5 mL of eluted DNA was collected and stored at -20 °C. The elute was further subjected to ethanol precipitation to increase the DNA concentration. In protocol II, similar to protocol I, the elute recovered in sterile 50 mL polycarbonate tubes was centrifuged at 4,750 g for 10-15 minutes to concentrate and desalt it using Amicon Ultra-15 (30 K) centrifugal filter devices from Merck Millipore Inc. The viral genome was then extracted from each concentrated sample using a DNeasy Blood/Tissue kit (Qiagen Inc.). A volume of 30-50 µL of elute was collected and stored at -20 °C until further use in downstream applications.

PCR inhibition assay

To assess the presence of PCR inhibition, decontaminated nucleic acid samples obtained from farm wastewater/sewage spiked river and tap water samples were additionally spiked with a known concentration (2.28×10^4 copy number) of *Oncorhynchus keta* DNA (Sigma Aldrich, Inc.). For comparison, 99 µL of nuclease-free water (NFW) was spiked with 1 µL of the *O. keta* DNA solution. The threshold cycle (C_t) values for *O. keta* were determined using qPCR with the NFW samples as controls. The C_t values of *O. keta* in the NFW samples were compared to those of the spiked *O. keta* in the wastewater and river water samples to assess the level of PCR inhibition. The amplification conditions and predesigned primer sequence for the Sketa 22 assay can be found in Method 1609 (Haugland *et al.*, 2005).

Nested PCR (Enzymatic amplification)

A 10 µL aliquot of extracted nucleic acid samples was subjected to semi-nested PCR and touchdown PCR analysis. For a broader range of adenoviruses, predesigned broad-spectrum primers (Sibley *et al.*, 2011) were utilized in the touchdown PCR. Additionally, semi-nested PCR was conducted for each sample using predesigned primers targeting the hexon genes of porcine adenovirus (PAdV) (Maluquer de Motes *et al.*, 2004) and bovine adenovirus (BAdV) (Hundesa *et al.*, 2006), with necessary modifications when required.

The primers for PAdV were used at a concentration of 200nM multiplied by their primer degeneracy (D) value, while the primers for BAdV were employed at a concentration of 400nM. To minimize nonspecific amplification, acetylated bovine serum albumin (Promega, Inc.) at a concentration of 0.1 µg/µL was added to the flanking reaction mixtures. The oligonucleotides used were synthesized by Eurofins Genomics, India.

To ensure the absence of contamination, negative PCR controls were implemented. Sterile NFW served as the control, and it was processed and analyzed alongside the samples during DNA extraction, PCR, and qPCR. For quality control purposes, one DNA extraction blank and one method blank were included after every four samples were analyzed, following the guidelines of EPA method 1609.

Construction of a recombinant plasmid for BAdV and PAdV controls

DNA extracted from positive controls of BAdV and PAdV using Protocol I was employed as a template for semi-nested PCR assays. The resulting amplicons, approximately 600^+ bp in size, were purified using a PCR purification kit (Promega Inc.). Subsequently, they were cloned into the pMD20T-vector using the Mighty TA-Cloning Kit (DSS Takara, India). Cloning was performed using *Escherichia coli* one-shot chemically competent cells (*E. coli* JM109, Promega Inc.), and the recombinant plasmid with inserts was extracted and purified using a plasmid miniprep kit (Promega Inc.)

The decontaminated recombinant plasmid DNA with inserts was assessed using a NanoDrop spectrophotometer (Thermo Fisher Scientific Inc.). The total DNA concentration was obtained by averaging the triplicate readings for each sample, which was then converted to an insert copy number. These extracted plasmid DNAs served as standards for the qPCR assays, with insert copy numbers ranging from 3×10^7 to 3×10^1.

Optimization of qPCR for HAdV and PAdV

TaqMan real-time PCR assays were performed using predesigned primers and probes from different studies (Staggemeier *et al.*, 2015 for AdV; Heim *et al.*, 2003 for HAdV; Wong and Xagoraraki *et al.*, 2010 for BAdV48; Hundesa *et al.*, 2009 for PAdV). The qPCR reactions for absolute quantification of viral DNA from prototype samples of HAdV-2 (pAdEasy Vector), BAdV (MG673955), and PAdV (MK028956) were optimized and conducted under identical conditions, with all reactions performed in duplicates.

For the AdV RT-PCR assay, 20 µl TaqMan qPCR mixtures were prepared using LuminoCt ready mix and 10 µl of DNA extract. The final concentration of all primers was 300 nM, and the concentration of all probes was 150 nM. Oligonucleotides were synthesized by Eurofins Genomics, India.

Plotting of standard curve

For the creation of a standard curve, the recombinant plasmid DNA was diluted in NFW to obtain concentrations ranging from 10^7 to 10^1 gene copies μl^{-1}. Five µl of each dilution was used as the template in the TaqMan qPCR assays, and each dilution was run twice. The default settings of the Roche Lightcycler® 96 for the threshold cycle (C_t) were employed for data analysis. By plotting the C_t values against the corresponding copy numbers and applying linear regression analysis, the standard curve was generated.

LLOQ of qPCR assays

The qPCR LLOQ (lower limit of quantification) was determined by preparing 10-fold sequential dilutions of standards ranging from 3×10^5 to 3×10^0 gene copies for AdVs. The lowest concentration of diluted standards that consistently produced positive results in 100% of triplicate assays was considered as the qPCR LLOQ.

Recovery efficiency (RE)

The RE (recovery efficiency) was determined using the approach described by Ahmed *et al.* (2015). The REs of HAdV and PAdV for sewage and farm wastewater spiked tap and river water were determined and compared using two virus concentration methods. To prevent qPCR contamination, viral genome extraction and qPCR setup were carried out in separate compartments of the research laboratory.

Statistical analysis

The acquired data were assessed for normality using Statistical Package for the Social Sciences (SPSS) software, and Levene's test was conducted to evaluate the hypothesis of homogeneity of variance. One-way analysis of variance (ANOVA) was performed using SPSS V24 to determine if there was a significant difference between C_t

values for *O. keta* DNA spiked NFW and tap/river water. In case of a significant difference ($p < .05$), the Tukey's significant difference test was conducted.

The difference between bacterial concentration and AdV copy numbers was calculated using unpaired t-tests after $\log_{10}$ transformation. The concentration of virus particles per sample was also $\log_{10}$ transformed, and the mean number was plotted using a 95% confidence interval (CI).

Results

Levels of faecal indicator bacterial and viral markers in farm wastewater, sewage, tap and river water (Sample characteristics)

The mean concentrations ± standard deviations of Coliform and Enterococcus counts in sewage samples from Ludhiana STP were 7.54±0.42 $\log_{10}$ CFU/100 ml, and 6.51±0.49 $\log_{10}$ CFU/100 ml, respectively. In Jallandhar STP, the corresponding values were 7.30±0.41 $\log_{10}$ CFU/100 ml for Coliform count and 6.41±0.37 $\log_{10}$ CFU/100 ml for Enterococcus count. HAdV was detected by qPCR and BAdV was detected by nested PCR in all sewage samples. Only one sample from Jallandhar STP tested positive for PAdV, with a concentration below 10 copies. This could be due to the reduced capacity and frequent direct discharge of effluent from pig farms into neighbouring bodies of water. The maximum concentrations of HAdV were 2.8×10^6 copy no./L and 1.63×10^6 copy no./L in primary influent or untreated sewage from Jallandhar STP and Ludhiana STP, respectively.

In bovine wastewater, the mean concentrations ± standard deviations of Coliform and Enterococcus counts were 7.69±0.63 $\log_{10}$ CFU/100 ml and 6.35±0.81 $\log_{10}$ CFU/100 ml, respectively. For porcine wastewater, the corresponding values were 7.86±0.82 $\log_{10}$ CFU/100 ml for Coliform count and 6.32±0.66 $\log_{10}$ CFU/100 ml for Enterococcus count. PAdVs were detected in 95% of porcine wastewater samples, with the highest concentration being 3.58×10^7 copy no./L. BAdV was detected in all samples from bovine farms when using BAdV48 primers, compared to 89.7% using broad-spectrum AtAdV primers.

No faecal indicator bacteria or viruses were detected in tap water samples. The Coliform count was 3.95±0.43 $\log_{10}$ CFU/100 ml, and the Enterococcus count was 3.13±0.73 $\log_{10}$ CFU/100 ml in river water samples, indicating lower bacterial contamination levels.

The specificity of the PCR assay

After an extensive literature review, two genome extraction kits, namely the DNeasy Blood/Tissue kit (Qiagen Inc.) and MoBio PowerSoil DNA isolation kit (MOBIO Inc.), were chosen for this study (Sidhu *et al.*, 2013; Ahmed *et al.*, 2015; García-Aljaro *et al.*, 2019). It was assumed that these kits exhibited 100% efficiency in extracting nucleic acids to determine the virus concentrations in various environmental samples. The DNA extracted during this investigation displayed a satisfactory A260/280 ratio ranging from 1.70 to 2.0, indicating high DNA quality.

To assess the specificity of the molecular assays in identifying BAdV, HAdV, and PAdV, an experimental assay utilizing semi-nested PCR was conducted. This assay successfully amplified the hexon gene of adenoviruses in the presence of other viruses present in the elute obtained from processing sewage and wastewater samples (Figure 2 and 3). The sequencing of the amplified genomic regions from field samples further confirmed the specificity of the assays. However, during the use of PAdV primers, one sample revealed a sequence of unknown origin (MT293615), suggesting potential cross-reactivity with other viruses. This particular sample was collected from a farm where cattle, porcine, and poultry were reared. Despite the presence of these markers in unexpected hosts, their abundance in the target group was consistently higher compared to the non-target group. This observation supports the reliability of these markers in differentiating between pollution sources.

qPCR standard curve and the LLOQ/sensitivity

The standard's linear range of quantification for nucleic acid extract was 3×10^7 to 3×10^1 copy no./µl and its slope ranged from -3.23 to -3.31. The

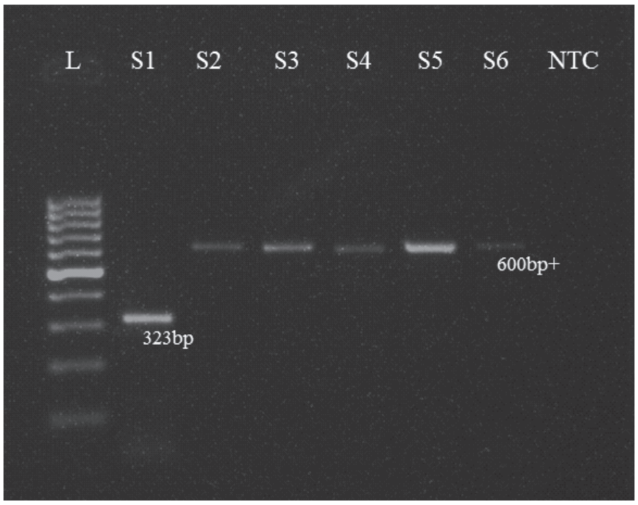

Fig. 2 Agarose gel electrophoresis of Touch-Down PCR products amplified (BAdV-323 bp and HAdV-600 bp⁺) from sewage and farm wastewater samples. Lane L: 100 bp DNA Ladder, S1-S6: Samples, NTC: No Template Control

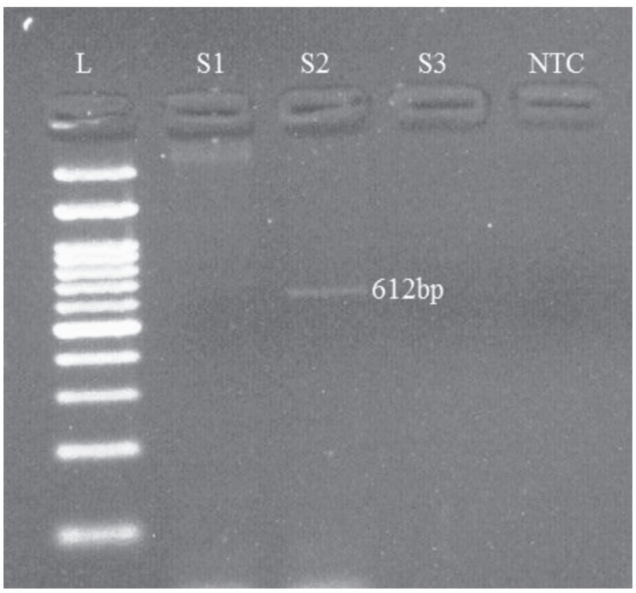

Fig. 3 Agarose gel electrophoresis of Semi-nested PCR products amplified (PAdV-612 bp) from sewage and porcine farm wastewater samples. Lane L: 100 bp DNA Ladder, S1-S3: Samples, NTC: No Template Control

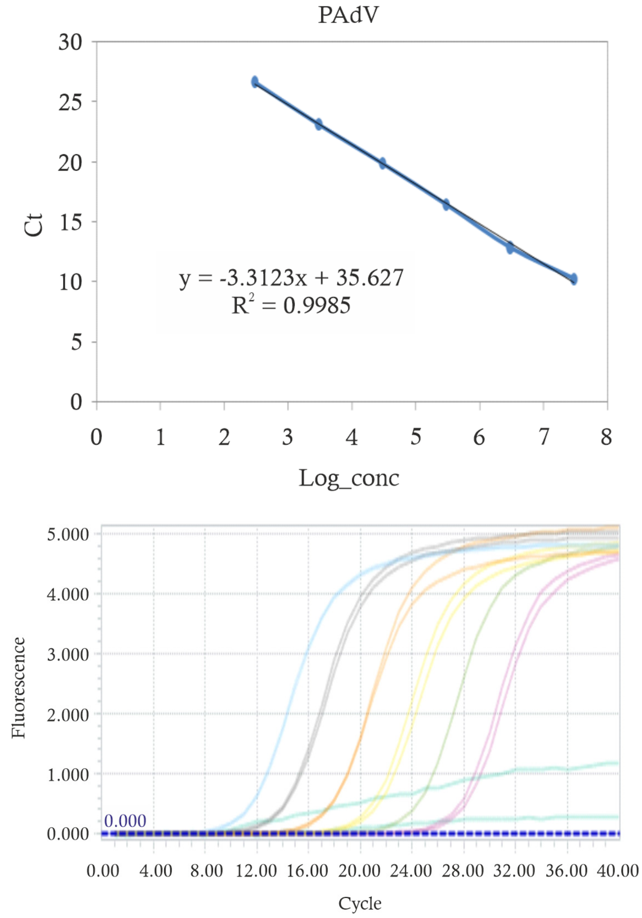

Fig. 4 Standard curve representing least square equation for quantification of PAdV and fluorescence curves representing corresponding dilutions

value of E ranged from 96 to 106% and the correlation coefficient (R^2) ranged from 0.99 to 1.0. The qPCR LLOQs were around 10 gene copies for HAdV and PAdV for all duplicate samples (Figures 4 and 5).

PCR inhibition assessment

In this study, a known concentration of 2.28×10^4 copy numbers of *O. keta* DNA was added to purified nucleic acid extracted from sewage/wastewater spiked river and tap water samples (Sketa 22 assay). The mean C_t value and standard deviation for *O. keta* spiked NFW were determined as 19.75±0.47 (Figure 6).

The C_t values of *O. keta* spiked river and tap water samples were compared to the C_t value of *O. keta* spiked NFW (Table 1). The elute volume from Protocol I was 1.5 to 2 ml, indicating a relatively low concentration of nucleic acid. To increase the DNA concentration, ethanol precipitation was performed following the manufacturer's instructions. Moreover, this elute was also tested for PCR inhibitors and compared with the C_t values of *O. keta* spiked NFW.

Comparable C_t values were observed for *O. keta* spiked sewage/wastewater spiked samples processed using Protocol I. However, the late amplification of *O. keta* DNA in nucleic acid extracts from sewage/wastewater spiked river

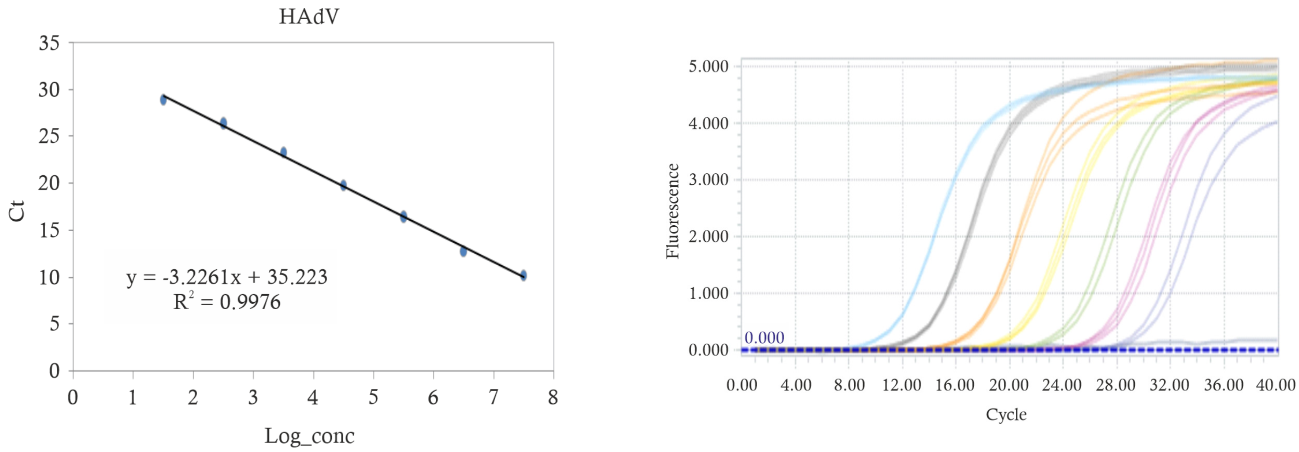

Fig. 5 Standard curve representing the least square equation for quantification of HAdV and fluorescence curves representing the corresponding dilution

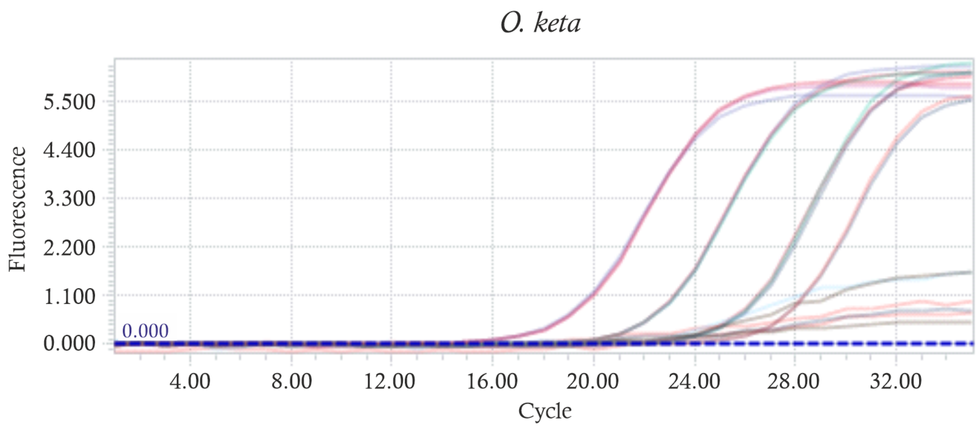

Fig. 6 Real-time fluorescence curves of *O. keta* qPCR inhibition assay (dilutions 10^5 to 10^2)

water samples obtained using Protocol II indicated the presence of PCR inhibitors. No amplification was observed in nucleic acid extracts after ethanol precipitation (Table 1).

To mitigate the effects of PCR inhibitors, the nucleic acid samples were diluted successively, and their performance was assessed again using *O. keta*. The mean C_t values and standard deviations for *O. keta* in 10-fold diluted sewage/wastewater spiked river water samples were determined as 21.30±0.39 (Protocol II, Table 1).

To test the null hypothesis, which assumes no difference between the groups, an ANOVA was performed. Levene's test confirmed the homogeneity of variance (f(6,35)=1.912, p = .106), and the ANOVA indicated a significant difference

Table 1. *O. keta* qPCR assay for the assessment of PCR inhibition in wastewater spiked river (n=6) and tap water (n=6) samples as opposed to NFW samples

			Mean C_t±SD for *O. keta* PCR assay			
Protocol	Sample type	ng DNA/ µl of extract (range)	Undiluted nucleic acid	10-fold diluted nucleic acid	Ethanol precipitation nucleic acid	100-fold diluted ethanol precipitated
I	Tap water	2.01-2.87	20.13±0.24^{ab}	-	NA	21.28±0.56^{c}
(Direct extraction)	River water	4.67-7.01	19.70±0.29^{a}	-	NA	23.33±0.28^{d}
II	Tap water	4.23-5.75	20.48±0.56^{b}	-	-	-
(Adsoption-elution)	River water	8.23-21.76	35.33±0.53	21.30±0.39^{c}	-	-

^{a,b,c,d} represents the subsets for alpha=0.05; NA- no amplification.

(f(6,35)=58.171, $p < .001$, K2=9.97). Cohen's method for effect size evaluation revealed a substantial difference between the groups, with a relatively large difference in mean scores. Post hoc comparisons using the Tukey HSD test showed that the Ct values of qPCR performed on spiked NFW, river water, and tap water extracted using Protocol I did not significantly differ from each other. However, the C_t values of undiluted river water (Protocol II), 10-fold diluted river water, and 100-fold diluted river/tap water (Protocol II and ethanol precipitation) exhibited significant differences. Based on these findings, further qPCR analysis was conducted on samples that showed no PCR inhibition, including undiluted and 10-fold diluted samples.

Recovery efficiency (RE) of AdVs from different virus concentration protocols

The mean concentrations of HAdV and PAdV in concentrated sewage spiked tap water and porcine wastewater spiked tap water samples, obtained through Protocol I, were 3.1×10^4 and 2.6×10^3, respectively. These concentrations were found to be 10.47-fold higher for HAdV and 9.51-fold higher for PAdV compared to the concentrations obtained through Protocol II (Table 2, Figure 7).

An ANOVA analysis indicated a significant difference ($p \leq .001$) in the concentrations of AdVs obtained by Protocol I compared to Protocol II. However, no statistically significant differences were observed in the AdV concentrations between tap water and river water samples within each protocol.

Interestingly, when tap water samples were spiked with the HAdV-2 standard (pAdEasy Vector) instead of sewage or porcine wastewater

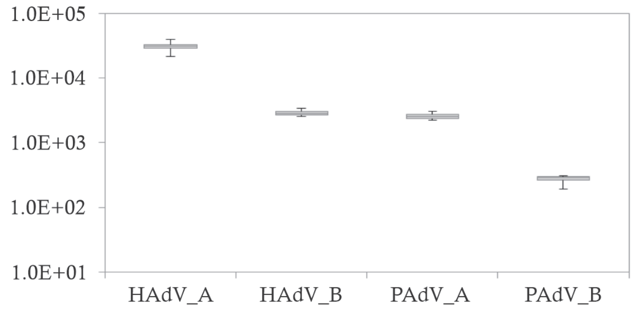

Fig. 7 Box-and-whisker plots of the concentration of gene copies of HAdV/PAdV in sewage-spiked tap water and wastewater-spiked tap water samples by protocol I and protocol II. The medians are represented by the inner box line, while the first quartile and third quartile are represented by outer box lines

spiked samples, no such concentration difference was observed. This suggests that substances present in the complex matrices of wastewater and sewage might contribute to PCR inhibition (Dalla Vecchia *et al.*, 2015).

It is worth noting that the PCR inhibition and recovery efficiency of AdVs from the two viral concentration methods were not evaluated using bovine wastewater and BAdV isolates, as qPCR could not be standardized for BAdV.

Discussion

Enteric viruses, although less prevalent in environmental waters compared to bacteria, are indicators of fecal pollution and exhibit variable distribution among the population. Unlike coliform, which may also have a soil origin, the presence of enteric viruses in ambient water is a direct indicator of faecal pollution. Adenoviruses (AdVs) are species-specific and present challenges in their detection due to the need to filter large volumes of water, typically up to 100 litres, which is impractical for field collection, transportation,

Table 2. Recovery efficiencies of HAdV and PAdV via protocol I and protocol II in quadruplicate samples

	HAdV (copy number)		PAdV (copy number)	
	Protocol I	Protocol II	Protocol I	Protocol II
01	3.09E+04	2.58E+03	2.21E+03	2.96E+02
02	3.90E+04	2.75E+03	2.68E+03	1.92E+02
03	3.08E+04	3.43E+03	2.38E+03	2.87E+02
04	2.18E+04	2.95E+03	3.08E+03	3.12E+02
Mean	3.06E+04	2.93E+03	2.58E+03	2.72E+02
StDev	7.04E+03	3.69E+02	3.83E+02	5.42E+01

and laboratory analysis. Alternative protocols involving concentration of smaller volumes (1-2 litres) through membrane filtration have been explored (Katayama *et al.*, 2002; Ahmed *et al.*, 2010), but their feasibility in Indian contexts and virus recovery efficiency require further evaluation. Moreover, most studies on microbial source tracking (MST) have focused on human sources and sewage pollution, which are significant issues in India (CPCB 2009; Kokkinos *et al.*, 2019). However, as the understanding of zoonotic infections increases, the separation of environmental pollution from animal sources is gaining importance. Therefore, this study aimed to compare the performance of two virus-concentration protocols in recovering adenoviruses from river and tap water samples spiked with raw sewage and bovine/porcine farm wastewater. This comparison aimed to identify the most effective method for processing environmental samples to detect species-specific adenoviruses as indicators of water pollution.

The complex matrices present in farm effluent and sewage can inhibit the PCR reaction, posing a challenge for effective qPCR detection of viruses (Sidhu *et al.*, 2013). To achieve accurate quantification of viral genomes in environmental samples, it is essential to remove these PCR inhibitors from concentrated water samples. However, there is limited information available in India regarding the effectiveness of viral marker recovery through virus filtration, concentration, genome extraction, purification, and quantification using TaqMan real-time PCR. Therefore, this study aimed to recreate and reproduce chosen strategies to assess their performance in different geographical locations. It has been suggested that procedures like Protocol I, which directly extracts viral genomes from membranes without the need for viral elution, may yield better recoveries (Wong *et al.*, 2012). Previous versions of Protocol I used a 500 ml sample with a 47-mm-diameter membrane (McQuaig *et al.*, 2009) or a 1 L sample with a 90-mm diameter (Ahmed *et al.*, 2015). In this study, approximately 1 L of samples were processed using a 90-mm-diameter membrane, targeting human, bovine, and porcine adenoviruses.

A disadvantage of protocol I for concentrating viruses and recovering viral genomes is that it concentrates PCR inhibitors also on the membranes. In any case, no proof of such inhibition was observed in samples prepared by protocol I and was upheld by the Sketa22 PCR assay performed in this study, which demonstrated the nonappearance of PCR inhibitors in samples handled by protocol I.

Protocol II may have experienced low recovery efficiency due to virus adhesion to HA membranes. In this approach, viruses eluted in the buffer underwent an additional concentration step using Amicon ultrafilter devices before extracting the viral genome. Previous studies have shown that Centriprep filter concentrators yielded good and consistent recovery yields (74%) for polioviruses (Haramoto *et al.*, 2010). However, for HAdV 41, only 35% recovery was achieved using Centricon filters, indicating potential loss of virus particles during the re-concentration stage (Wu *et al.*, 2011). To minimize the concentration of PCR inhibitors, the adsorption-elution method combined with ultrafilters has been supported (Sidhu *et al.*, 2013). Based on the findings of this study, qPCR assays for HAdV/BAdV and PAdV were performed on samples without PCR inhibition, including undiluted samples for protocol I and 10-fold diluted river samples for protocol II. The TaqMan qPCR assay demonstrated high sensitivity, specificity, accuracy, and speed, making it suitable for detecting adenoviral DNA in environmental samples.

In this study, the standardization of the qPCR assay for Bovine Adenoviruses (BAdVs) using a cy5-labelled TaqMan probe was not successful. This could be attributed to the high degeneracy value of the primers, which were designed to identify BAdV-types 4 to 8. Previous studies have also reported variations in fluorescence signals when using these primers, indicating potential challenges in their performance (Wong and Xagoraraki *et al.*, 2011; Hakhverdyan *et al.*, 2016). Specifically, a decrease in fluorescence was observed during amplification of the BAdV-7 serotype, which could be attributed to four mismatches present in the probe region, potentially affecting the final results. Additionally, late amplification and reduced fluorescence levels were observed for BAdV-4. These findings suggest the need for further optimization and refinement of the qPCR assay to improve its accuracy and sensitivity for detecting BAdVs.

In conclusion, this study provides valuable insights into the levels of faecal pollution indicators, the specificity of molecular assays, the sensitivity of qPCR, and the efficiency of viral recovery methods for detecting AdVs in environmental samples. These findings contribute to the understanding of water quality assessment and the potential sources of contamination, emphasizing the importance of appropriate methods for accurate detection and quantification of viral markers in environmental samples.

References

Ahmed W, Goonetilleke A and Gardner T (2010) Human and bovine adenoviruses for the detection of source-specific faecal pollution in coastal waters in Australia. *Water Research* **44**: 4662-73.

Ahmed W, Harwood VJ, Gyawali P, Sidhu JPS and Toze S (2015) Comparison of concentration methods for quantitative detection of sewage-associated viral markers in environmental waters. *Applied and Environmental Microbiology* **81(6)**: 2042-49.

Barrios M, Blanco Fernández M, Cammarata R, Torres C, and Mbayed V (2018) Viral tools for detection of faecal contamination and microbial source tracking in wastewater from food industries and domestic sewage. *Journal of Virological Methods* **262**: 79-88.

Central Pollution Control Board (2009) “Water Quality Database of Indian rivers, MoEF”. Retrieved from “Central Pollution Control Board, India, Annual Report 2008-2009” (Pdf). CPCB, Ministry of Environment & Forests, Govt of India.

Dalla Vecchia A, Rigotto C, Staggemeier R, Soliman M, Gil de Souza F and Henzel A *et al.* (2015) Surface water quality in the Sinos River basin, in Southern Brazil: tracking microbiological contamination and correlation with physicochemical parameters. *Environmental Science And Pollution Research* **22(13)**: 9899-11.

Farkas K, Cooper D, McDonald J, Malham S, de Rougemont A and Jones D (2018) Seasonal and spatial dynamics of enteric viruses in wastewater and riverine and estuarine receiving waters. *Science Of The Total Environment* **634**: 1174-1183.

García-Aljaro C, Blanch A, Campos C, Jofre J and Lucena F (2019) Pathogens, faecal indicators and human-specific microbial source-tracking markers in sewage. *Journal of Applied Microbiology* **126(3)**: 701-717.

Hakhverdyan M, Mamadatokhonova G and Belák S (2016) Development of a TaqMan Real-Time PCR assay for the rapid detection of bovine adenovirus serotypes in cattle. *Journal of Veterinary Medical Research* **3(3)**: 1051.

Haramoto E, Kitajima M, Katayama H, and Ohgaki S (2010) Real-time PCR detection of adenoviruses, polyomaviruses and torque teno viruses in river water in Japan. *Water Research* **44(6)**: 1747-52.

Hata A, Kitajima M, Katayama H (2013) Occurrence and reduction of human viruses, F-specific RNA coliphage genogroups and microbial indicators at a full-scale wastewater treatment plant in Japan. *Journal of Applied Microbiology* **114**: 545–54.

Heim A, Ebnet C, Harste G and Pring-Akerblom (2003) Rapid and quantitative detection of human adenovirus DNA by real-time PCR. *Journal of Medical Virology* **70**: 228-39.

Hundesa A, Maluquer de Motes C, Bofill-Mas S, Albinana-Gimenez N and Girones R (2006) Identification of human and animal adenoviruses and polyomaviruses for determination of sources of faecal contamination in the environment. *Applied and Environmental Microbiology* **72(12)**: 7886-93.

Haugland RA, Siefring SC, Wymer LJ, Brenner KP and Dufour AP (2005) Comparison of Enterococcus measurements in fresh water at two recreational beaches by quantitative polymerase chain reaction and membrane filter culture analysis. *Water Research* **39**.

Katayama H, Shimasaki A and Ohgaki S (2002) Development of virus concentration methods and their application to detection of enterovirus and Norwalk virus from coastal seawater. *Applied and Environmental Microbiology* **68**: 1033-39.

Kokkinos P, Katsanou K, Lambrakis N *et al.* (2019) Assessment of the Incidence of Human Adenovirus in Surface Waters of Southwest Greece: Vouraikos River as a Case Study. *Food Environ Virol* **11**: 309–313.

Maluquer de Motes C, Clemente-casares P, Hundesa A, Martin M and Girones R (2004) Detection of bovine and porcine adenovirus for tracing the source of faecal contamination. *Applied and Environmental Microbiology* **70**: 1448-54.

McQuaig SM, Scott TM, Lubasik JO, Paul JH and Harwood VJ (2009) Quantification of human polyomaviruses J C virus and B. K. virus by TaqMan quantitative PCR and comparison to other quality indicators in water and faecal samples. *Applied and Environmental Microbiology* **75**: 3379-88.

Rock Channah, Rivera Berenise, Gerba P Charles (2015) Chapter 14 - Microbial Source Tracking, Editor(s): Ian L. Pepper, Charles P. Gerba, Terry J. Gentry. Environmental Microbiology (Third Edition), Academic Press: 309-17.

Sibley DS, Goldberg TL and Pedersen AJ (2011) Detection of known and novel adenoviruses in cattle wastes via broad-spectrum primers. *Applied and Environmental Microbiology* **77(14)**: 5001-08.

Sidhu PSJ, Ahmed W and Toze S (2013) Sensitive detection of human adenoviruses from a small volume of primary wastewater samples by quantitative PCR. *Journal of Virological Methods* **187**: 395-400.

Staggemeier R, Bortoluzzi M, Heck TM, Luz BR and Fabres BR (2015) Animal and Human enteric viruses in water and sediment samples from dairy farms. *Agricultural Water Management* **152**: 135-41.

Swamee P, Misra A, Poyil R, Choudhary L, Kaur A and Chintalapati S (2017) A linear and nonlinear approach for interpretation of groundwater quality based on water quality index. *Environment, Development and Sustainability* **20(6)**: 2623-42.

Wong K and Xagoraraki I (2011) Evaluating the prevalence and genetic diversity of adenovirus and polyomavirus in bovine waste for microbial source tracking. *Applied Microbiology and Biotechnology* **90**: 1521-26.

Wong K, Fong TT, Bibby K and Molina M (2012) Application of enteric viruses for faecal pollution tracking in environmental waters. *Environment Institute* **45**: 151-64.

Wu J, Rodriguez RA, Stewart JR and Sobsey MD (2011) A simple and novel method for recovering adenovirus 41 in small volumes of source water. *Journal of Applied Microbiology* **110**: 1332-40.

Wyn-Jones AP, Carducci A, Cook N, D'Agostino M, Divizia M, Fleischer J, Gantzer C, Gawler A, Girones R, Holler C, de Roda Husman AM, Kay D, Kozyra I, Lopez-Pila J, Muscillo M, Nascimento MS, Papageorgiou G, Rutjes S, Sellwood J, Szewzyk R and Wyer M (2011) Surveillance of adenoviruses and noroviruses in European recreational waters. *Water Research* **45(3)**: 1025-38.

Zehra A, Kaur S, Singh R and Gill J (2020) Surface water quality in Punjab, India: Tracking human and farm animal-specific adenoviral contamination and correlation with microbiological and physiochemical parameters. *Water, Air, & Soil Pollution* **231(11).** doi: 10.1007/s11270-020-04892-5

Received: May 20, 2023; Accepted: June 29, 2023

Guidelines for Authors Submitting Manuscript for Publication in the "Journal of Soil Salinity and Water Quality"

The authors are advised to follow the guidelines given in the latest issue of the Journal for preparation of manuscript. They are required to submit one electronic copy through email (dagarjc@gmail.com; issswq@gmail.com) and one hard copy completed in all respects to General Secretary, Indian Society of Soil Salinity and Water Quality, Central Soil Salinity Research Institute, Kachhwa Road, Karnal-132001, Haryana, India. The receipt of manuscript as well as subsequent correspondences regarding the manuscript will be done electronically only.

Manuscript

- The article should be as concise as possible. All the full length papers should comprise of Short title, Title, Author(s)' name(s), Affiliations, email ID of corresponding author, Abstract, Key Words, Introduction, Material and Methods, Results and Discussion, Conclusions, Acknowledgements (if any), References, Tables and Figures (if any). The text under each section should throughout be 12 fonts in MSW, Times New Roman, justified with 1.5 line spacing. However in the Abstract part, text should be 11 fonts with 1.5 line spacing and should not exceed 250 words.
- The total length of article should not exceed 15 typed pages (2.5 cm. margin on each side of A4 paper) including Tables and Figures.
- All main headings should be bold in Title case with 14 fonts. However, the subheadings within each section wherever necessary should be in Sentence case bold in 12 fonts; whereas further sub-sub titles should be bold italic in 12 fonts. All main and subheadings should be aligned left.

Title Page

It should be a separate page and comprise of following:

Short Title : It should have a short title (not exceeding seven words in ordinary type; 12 font) on the top of right hand corner.

Title : It should not exceed 15 words and should reflect the contents of the paper. It should be bold in title case like "Alleviation of Sodicity Stress on Rice Genotypes by Phosphorous Fertilization".

Author(s) : Name of author(s) should be 12 fonts bold (without their official designations), aligned in center and in the title case like "AK Aggarwal and MK Tiwari".

Address : Each author's name should have number as superscript to indicate the address. The corresponding author's name should have number as superscript to indicate more than one address. The corresponding author's name should have asterisk (*) mark as superscript e.g. AK Aggarwal[*1] and MK Tiwari[2]. The address should be written in italics as shown below:

*[*1] Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal-132001, Haryana, India*

[2]Indian Institute of Soil Science, Nabibagh,, Berasia Road, Bhopal-462038, Madhya Pradesh, India.

All addresses should be complete indicating state/ province, PIN/ postal code and country etc. The email ID of corresponding author should be given after the address. The total number of pages, tables and figures of the manuscript should also be mentioned on title page.

First Page

Actual paging (on right lower corner) of the manuscript should start from this page. It should have full title of paper followed by Abstract, Key words and Introduction, etc. To ensure anonymity of the author(s), author's names and addresses should not be indicated on this page.

Abstract : Its contents should be in 11 fonts, single space and single paragraph with justified alignment.

Key words : Key words should appear just after the abstract and to be written as **Key words** (11 fonts). These may be up to 7 in alphabetic order each separated by a comma and in Sentence case. The scientific names (if any) should be italicized. e.g.

Key words : Agroforestry model, Biodrainage, Gypsum, *Oryza sativa* L., Salt tolerance

Tables and Figures

Each table and figure should have 12 fonts and be given on separate page after References part. Table 1 and Figure 1 should be written as **Table 1.** (bold) and **Fig. 1** (bold), respectively. Table caption should appear on the top of table whereas figure caption should be just below the figure. Figure caption and matter should be legible with 8-12 fonts size. The abbreviations used in Table or Figure must be explained as foot-note. Maximum size of tables and figures should be such that these can be conveniently accommodated in A4 size page. Approximate position of the tables and figures should be indicated in the text of the manuscript.

References

References should be in alphabetic and chronological order and should not be serial numbered. The author(s) names should start with surname comma after initials. If first author has two publications in a year, single author paper should appear first. Year should be bracketed. The journal names should be in full without abbreviation and should be italicized. Volume No. should be in bold. Few examples are given below:

Journal: Dagar JC, Tomar OS, Minhas PS and Kumar M (2013) Lemon grass productivity as affected by salinity of irrigation water, planting methods and fertilizer doses on a calcareous soil in a semi-arid region of northwest India. *Indian Journal of Agricultural Sciences* **83(7):** 734-738.

Book: Singh NT (2005) *Irrigation and Soil Salinity in the Indian Subcontinent- Past and Present.* Lehigh University Press, Bethlehem, USA, p 404

Book Chapter: Tyagi NK (1998) Management of salt-affected soils. In: Singh GB and Sharma BR (eds) *50 Years of Natural Resource Management Research*. Indian Council of Agricultural Research, New Delhi, India, pp 363-401.

Online Reference: Rhoades JD, Kandiah A and Mashali AM (1992) The use of saline waters for crop production-FAO irrigation and drainage paper 48. Food and Agriculture Organization, Rome. (http://www.fao.org/docrep/t0667e00.HTM.)

Conference/Symposium Proceedings: Suarez DL and Lebron I (1993) Water quality criteria for irrigation with highly saline water. In: Lieth H and Al Masoom AA (eds) *Towards the Rational Use of High Salinity Tolerant Plants*, Vol 2-*Agriculture and Forestry under Marginal Soil Water Conditions*. Proceedings of the first ASWAS Conference (December 8-15, 1990), United Arab Emirates University Al Ain, UAE. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp 389-397.

M.Sc/ Ph.D. Thesis: Ammer MHM (2004) *Molecular Mapping of Salt Tolerance in Rice.* Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

Bulletin: Abrol IP, Dargan KS and Bhumbla DR (1973) *Reclaiming Alkali Soils*. Bulletin No. 2. Central Soil Salinity Research Institute, Karnal, 58p.

Short Communication

While writing Short Communication one should focus on studies of limited scope, preliminary data, unique observations or research technique and apparatus. The length of short communication should not exceed 3 published pages. Short communication should comprise of short title, title, name (s) of author (s) with affiliations and text dealing with material and methods, results and discussion and references but there should not be any main head except of references. It should not have abstract and keywords.

Book Review

These are generally invited, however; one may send critical Book Review along with one original book for consideration by editorial board.

Units to be Followed

The international system of units (SI units) should be used throughout. Authors may consult Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) for guidance.

The terms like Nitrogen, Phosphorous, Potassium and Zinc may be denoted as N, P, K and Zn, respectively and dose expressed as kg ha^{-1} for field experiments. For pot studies, units like mg kg^{-1} or kg m^{-2} should be followed. We must avoid to use units such as q (quantal), lakh and crore.

Common Units and Symbols

time=t, metre=m, second=s, centimeter=cm, cubic centimeter=cm^3, cubic metre=m^3, degree celsius=°C, day=d, gram=g, hectare= ha ($10^4 m^2$), hour=h, kilometer=km, kilogram=kg, litre=l, megagram=Mg (tons to be given in Mg), microgram=μg, micron=μm, milimole=mmol, milliequivalent=meq, micromol=μmol, milligram=mg, milliliter=ml, minute=min, nanometer=nm, square centimeter=cm^2, square kilometer=km^2,electrical conductivity= (EC)=dS m^{-1} (deci Siemens m^{-1}), gas diffusion=g m^2 s^{-1}, water flow=m^3 $m^2 s^{-1}$, ion uptake= mol kg^{-1} of dried plant material, leaf area=$m^2 kg^{-1}$, nutrient content in plants= mg g^{-1} (dry matter basis), root density or root length density= m m^{-3}, soil bulk density= g cm^{-3}, transpiration rate=mg m^2 s^{-1}, water content of soil=kg kg^{-1}, water tension=kPa, yield (grain or forage)= Mg ha^{-1} or kg ha^{-1} , organic carbon content of soil= percent (%), cation exchange capacity of soil= cmol (p+) kg^{-1}

Style Guidelines

All soils discussed in the manuscript should be identified according to the US Soil Taxonomic System at first mention. The Latin binomial or trinomial and authority must be shown for all plants, insects, pathogens, microorganisms and animals when first mentioned. Both the accepted common name and the chemical name of any chemicals mentioned (including pesticides) must be provided. SI units must be used throughout the manuscript. Corresponding metric or English units may be added in parentheses at the discretion of the author. For spelling, Webster's *New Collegiate Dictionary* should be used as reference. If a commonly available product is mentioned, the name and the location of manufacturer should be included in parentheses after first mention. Responsibility of the facts and opinions expressed in the articles rests entirely with the author(s) and not with the journal.

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.

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. D.S. Bundela, 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; ds.bundela@icar.gov.in

For Office use only

Proposed by :

Seconded by: Admitted on General Secretary