SALINE AND SODIC IRRIGATION EFFECTS ON PERFORMANCE OF WHEAT CULTIVARS AND SOIL HEALTH

Dissertation

Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
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DOCTOR OF PHILOSOPHY
in
SOIL SCIENCE
(Minor Subject: Chemistry)

By

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(L-2012-A-40-D)

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CERTIFICATE I

This is to certify that the dissertation entitled, **“Saline and sodic irrigation effects on performance of wheat cultivars and soil health”** submitted for the degree of Ph.D. in the subject of **Soil Science** (Minor subject: **Chemistry**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Pawitar Singh (L-2012-A-40-D)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE II

This is to certify that the thesis entitled, **“Saline and sodic irrigation effects on performance of wheat cultivars and soil health”** submitted by **Pawitar Singh (L-2012-A-40-D)** to Punjab Agricultural University, Ludhiana, in the partial fulfillment of the requirements for the degree of the Ph.D. in the subject of **Soil Science** (Minor subject: **Chemistry**) has been approved by the Student’s Advisory Committee along with the Head of the Department after an oral examination on the same.

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ABSTRACT

The present investigation was conducted to observe the effects of saline and alkali irrigation water on performance of six wheat cultivars and soil health. Five levels of saline (EC 0, EC 3, EC 6, EC 9 and 12 dS m^{-1}) and four levels of alkali water (RSC 0, RSC 3, RSC 6.5 and RSC 10 me L^{-1}) were used for irrigating six wheat cultivars (KRL 210, PBW 621, HD 2967, PBW 590, PBW 658 and Berbet) during two years of research study. The results revealed that increasing salinity and alkalinity of irrigation water significantly increased soil pH , EC, SAR, ESP and soluble Na^+, Cl^- and HCO_3^- and decreased organic carbon , available nutrients (N, P, K and S) , DTPA-Zn and soluble ions (K^+, $Ca+Mg^{2+}$, SO_4^{2-}) concentration in both years. Soil physical properties such as bulk density and dispersion ratio increased with increasing salinity and alkalinity in irrigation water whereas MWD, SHC, IR and WHC decreased under these treatments. Biological soil properties (MBC, MBN, DHA and CWEC) were significantly reduced to almost 50% at highest level of salinity (EC= 12 dS m^{-1}) and alkalinity (RSC = 10 me L^{-1}) of irrigation water in 2013-14 and 2014-15. In 84 days of incubation study cumulative respiration, MBC, NH_4^+ and NO_3^- N was low under saline and alkaline irrigated soil samples which improved on addition of carbon @ 1%. Plant and yield parameters were adversely impacted due to elevated salinity and alkalinity levels of irrigation water in both years. Pooled over two years, among different cultivars the maximum grain yield was produced by PBW 658 (4.23 t ha^{-1}) at highest level of saline water (EC = 12 dS m^{-1}) and by PBW 621 (5.19 t ha^{-1}) for highest level of alkaline water (RSC = 10 me L^{-1}) whereas the minimum yield in both cases was recorded for PBW 590 (3.82 and 3.79 t ha^{-1}), respectively. Among all cultivars performance of HD 2967 was better at EC 9 dSm^{-1} and RSC 6.5 meL^{-1}, therefore can be grown without much significant loss in grain yield at respective levels but at highest level of salinity and alkalinity of irrigation water PBW 658 and PBW 621 should be preferred to get higher yield.

Keywords: Salinity, alkalinity, irrigation water levels, cultivars, grain yield, soil properties

Signature of Major Advisor **Signature of the Student**

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ਕਣਕ ਦੀਆਂ 6 ਕਿਸਮਾਂ ਦੀ ਸਹਿਣਸ਼ੀਲਤਾ ਅਤੇ ਮਿੱਟੀ ਦੀ ਸਿਹਤ ਤੇ ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਪਾਣੀ ਦਾ ਪ੍ਰਭਾਵ ਦੇਖਣ ਲਈ ਮੌਜੂਦਾ ਅਧਿਐਨ ਕੀਤਾ ਗਿਆ।ਇਹਨਾਂ 6 ਕਿਸਮਾਂ (ਕੇ.ਆਰ.ਐਲ.210, ਪੀ.ਬੀ.ਡਬਲਿਯੂ 621, ਐਚ.ਡੀ.2967, ਪੀ.ਬੀ.ਡਬਲਿਯੂ 590, ਪੀ.ਬੀ.ਡਬਲਿਯੂ 658 ਅਤੇ ਬਰਬਟ) ਦੀ 5 ਕਿਸਮ ਦੇ ਲੂਣੇ ਅਤੇ 4 ਕਿਸਮ ਦੇ ਖਾਰੇ ਪਾਣੀਆਂ ਨਾਲ ਸਿੰਚਾਈ ਕੀਤੀ ਗਈ ।2 ਸਾਲਾਂ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਪਤਾ ਲੱਗਾ ਕਿ ਪਾਣੀ ਵਿਚ ਵੱਧਦੇ ਲੂਣੇ ਅਤੇ ਖਾਰੇਪਨ ਵਾਲੀ ਮਿੱਟੀ ਦੀ ਪੀ.ਐਚ., ਈ.ਸੀ., ਐਸ.ਏ.ਆਰ, ਈ.ਐਸ.ਪੀ. ਅਤੇ ਘੁਲਣਸ਼ੀਲ ਸੋਡੀਅਮ, ਕੋਲੋਰਾਈਡ ਅਤੇ ਬਾਈਕਾਰਬੋਨੇਟ ਦੀ ਮਾਤਰਾ ਮਹੱਤਵਪੂਰਨ ਵਾਧਾ ਹੋਇਆ ।ਜਦਕਿ ਜੈਵਿਕ ਕਾਰਬਨ , ਉਪਲਬੱਧ ਤੱਤ (ਨਾਈਟਰੋਜਨ, ਫਾਰਸਫੋਰਸ, ਪੋਟਾਸ਼ੀਅਮ ਅਤੇ ਸਲਫਰ), ਡੀ.ਟੀ.ਪੀ.ਏ.ਜ਼ਿੰਕ ਅਤੇ ਘੁਲਣਸ਼ੀਲ ਪੋਟਾਸ਼ੀਅਮ, ਕੈਲਸ਼ੀਅਮ + ਮੈਗਨੀਸ਼ੀਅਮ ਅਤੇ ਸਲਫੇਟ ਦੀ ਮਾਤਰਾ ਘੱਟ ਪਾਈ ਗਈ। ਮਿੱਟੀ ਦੀ ਭੌਤਿਕ ਗੁਣਾਂ :- ਜਿਵੇਂ ਕਿ ਬਲਕ ਡੈਨਸਟੀ,ਡਿਸਪਰਸ਼ਨ ਰੇਸ਼ੋ, ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਪਾਣੀ ਦੀ ਸਿੰਚਾਈ ਕਰਨ ਤੇ ਵਧੀਆਂ ਜਦਕਿ ਐਮ. ਡਬਲਿਯੂ. ਡੀ., ਐਸ. ਐਚ. ਸੀ, ਆਈ. ਆਰ ਅਤੇ ਡਬਲਿਯੂ ਐਚ. ਸੀ. ਦੀਆਂ ਮੱਦਾਂ ਘਟੀਆਂ। ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਪਾਣੀ ਦੇ ਸੱਭ ਤੋਂ ਵੱਧ ਲੈਵਲ ਤੇ ਮਿੱਟੀ ਦੀਆਂ ਜੈਵਿਕ ਗੁਣਾਂ ਜਿਵੇ ਕਿ ਐਮ. ਬੀ. ਸੀ., ਐਮ. ਬੀ. ਐਨ., ਡੀ. ਐਚ. ਏ. ਅਤੇ ਸੀ. ਡਬਲਿਯੂ ਈ. ਸੀ. ਵਿੱਚ 50% ਘਿਰਾਵਟ ਦਰਜ ਕੀਤੀ ਗਈ।ਇਸੇ ਤਰ੍ਹਾਂ 84 ਦਿਨਾਂ ਦੀ ਇਨਕੂਬੇਸ਼ਨ ਸਮੇਂ ਦੌਰਾਨ ,ਕਮੂਲੇਟਿਵ ਰੇਸਪੀਰੇਸ਼ਨ,ਐਮ.ਬੀ.ਸੀ.,ਅਮੋਨੀਅਮ ਅਤੇ ਨਾਈਟਰੇਟ ਨਾਈਟਰੋਜਨ, ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਪਾਣੀਆਂ ਨਾਲ ਸਿੰਜਨ ਵਾਲੀ ਮਿੱਟੀ ਵਿੱਚ ਘੱਟ ਪਾਈ ਗਈ ਜਦਕਿ 1% ਕਾਰਬਨ ਪਾਉਣ ਦੇ ਨਾਲ ਇਹਨਾਂ ਗੁਣਾਂ ਵਿੱਚ ਵਾਧਾ ਦਰਜ ਕੀਤਾ ਗਿਆ।ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਵਾਲੇ ਪਾਣੀ ਵਿੱਚ ਸੱਭ ਤੋਂ ਵੱਧ ਲੈਵਲ ਤੇ ਕਣਕ ਦੀਆਂ 6 ਕਿਸਮਾਂ ਵਿੱਚੋਂ ਦੋਨੋ ਸਾਲਾਂ ਦਾ ਸਭ ਤੋਂ ਵੱਧ ਔਸਤਨ ਝਾੜ ਪੀ. ਬੀ. ਡਬਲਿਯੂ 658 (4.23 ਟਨ/ਹੈਕ:) ਅਤੇ ਪੀ. ਬੀ. ਡਬਲਿਯੂ 621 (5.19 ਟਨ/ਹੈਕ:) ਪਾਇਆ ਗਿਆ ਜਦਕਿ ਸਭ ਤੋਂ ਘੱਟ ਝਾੜ ਪੀ. ਬੀ. ਡਬਲਿਯੂ 590 (3.82 ਅਤੇ 3.79 ਟਨ/ਹੈਕ:) ਦਰਜ ਕੀਤਾ ਗਿਆ।ਕਣਕ ਦੀ ਐਚ.ਡੀ.2967 ਕਿਸਮ ਦੀ ਸਹਿਣਸ਼ੀਲਤਾ ਲੂਣੇ ਪਾਣੀ ਦੇ ਲੈਵਲ 9 ਡੀ. ਐਸ/ਮੀਟਰ ਅਤੇ ਖਾਰੇ ਵਾਲੇ ਪਾਣੀ ਦੇ ਲੈਵਲ 6.5 ਮਿਲੀਇਕੂਲੈਂਟ/ਲੀਟਰ ਸੱਭ ਤੋਂ ਵੱਧ ਪਾਈ ਗਈ ਜਦਕਿ ਲੂਣੇ ਅਤੇ ਖਾਰੇ ਵਾਲੀ ਪਾਣੀ ਦੇ ਸੱਭ ਤੋਂ ਵੱਧ ਲੈਵਲ ਤੇ ਪੀ. ਬੀ. ਡਬਲਿਯੂ 658 ਅਤੇ 621 ਦਾ ਝਾੜ ਕਣਕ ਦੀਆਂ ਬਾਕੀ ਕਿਸਮਾਂ ਨਾਲੋਂ ਵੱਧ ਪਾਇਆ ਗਿਆ।ਇਸ ਕਰਕੇ ਇਹ ਦੋਨੋਂ ਕਿਸਮਾਂ ਵੱਧ ਲੂਣੇ ਪਾਣੀ ਦੇ 12 ਡੀ. ਐਸ/ਮੀਟਰ ਅਤੇ ਖਾਰੇ ਵਾਲੇ ਪਾਣੀ ਦੇ 10 ਮਿਲੀਇਕੂਲੈਂਟ/ਲੀਟਰ ਲੈਵਲ ਤੇ ਲਗਾਈਆਂ ਜਾਣੀਆਂ ਚਾਹੀਦੀਆਂ ਹਨ।

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ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTERI

INTRODUCTION

Soil degradation through salinity and sodicity is a universal concern. Saline and sodic soils occupied 397 and 434 m ha area in the world (FAO-AGL 2000). Good quality water resources are becoming increasingly scarce for use in agriculture and are allocated with priority to domestic and industrial users. Consequently, marginal quality waters are being used for irrigation with little or no consideration of their long-term impact on soils especially in the arid and semi-arid regions. It is estimated that 60-80 million hectares are affected due to irrigation induced salinity and more land is expected to be affected due to deteriorating water quality and land clearing (Asgari *et al* 2012). It is estimated that up to 20 per cent of irrigated lands in the world are affected by different levels of salinity and sodicity (Fard *et al* 2007). In India, about 32 to 84 per cent of groundwater resources in different states are of poor quality. Groundwater surveys indicate that 40-60 per cent of the groundwater in northwestern parts of India have higher (30-50 %) residual alkalinity (Minhas and Bajwa 2001). In Punjab, out of 42 per cent poor quality ground waters, 25 per cent are saline, 69 per cent are sodic and 6 per cent are saline-sodic in nature (PRSC 2010).

Injudicious use of saline and sodic waters poses great risks to soil health due to its adverse effect on soil chemical, physical and biological properties. It also reduces crop productivity and limits the choice of crop for cultivation (Choudhary *et al* 2011a)**.** Increase in sodicity, sodium adsorption ratio (SAR) and residual sodium bicarbonate (RSC) and soluble salts in irrigation water increases pH, EC and ESP of soil. Choudhary *et al* (2010) observed that soil pH, EC and ESP of top 30 cm soil layer increased significantly with increasing RSC of irrigation water. Use of alkali water resulted in increased soil pH, SAR and ESP and which negatively impacted crop yields (Rhoades *et al* 1992). Ragab (2001) observed progressive and significant increase in soil salinity with increase in salinity of irrigation water in calcareous soil. Use of alkali waters high in carbonates and bicarbonates deteriorates soil physical properties (soil aeration and permeability, bulk density, infiltration rate, aggregate stability) due to clay dispersion, crusting and clay migration leading to clogging of pores which adversely affected crop productivity (Grattan and Oster 2003, Sharma and Minhas 2005, Minhas *et al* 2007 and Choudhary *et al* 2010).

Irrigation-induced salinity and sodicity not only have adverse affects on soil chemical and physical health but also on soil biological properties (size and activity of the microbial community). Soil microbial biomass carbon (MBC) is an important component of soil organic matter (1-3% of total organic carbon) and is a potential source of enzymes in soil. Dehydrogenase enzyme activity (DHA) reflects the total oxidative activity of microbial biomass (Nannipieri *et al* 1990). Batra and Manna (1997) observed decrease in DHA and

MBC by 87% and 68% at ECe = 40 dS/m in surface soil (0-15cm) compared with ECe = 18 dS/m, whereas in 15-30 cm soil depth it was 63% and 43% respectively at ECe = 31.4 dS/m compared with ECe = 12 dS/m. Higher salt concentrations not only kills sensitive microorganisms but also affects microbial community, soil enzymatic activities, and consequently reduce C and N transformations (Mavi *et al* 2012 and Elmajdoub and Marschner 2013). A decrease in carbon dioxide (CO_2) production, enzyme activities and microbial biomass has often been observed in salt stress field conditions (Egamberdieva*et al* 2010 and Saviozzi *et al* 2011) and under laboratory incubations (Wichern *et al* 2006, Ghollarata and Raiesi 2007, Wong *et al* 2008 and Shah and Shah 2011). Yuan *et al* (2007) observed that MBC, MBN, biomass nitrogen to total nitrogen ratio, basal respiration, potentially mineralizable nitrogen, arginine ammonification rate and FDA hydrolysis rate were all negatively correlated with EC of soil. Kaur *et al* (2008) reported MBC significantly decreased from 84.6 mg/kg in control to 19.8 mg/kg at RSC 10 me/L of alkali irrigation water in 0- 75mm soil layer and only trace of MBC were recorded in 75-150 mm soil layer at respective RSC level.

The plant response to different environmental stresses may be variable with the stage of growth at which exposure occurs (Saqib 2002). Crops differ considerably in their ability to tolerate salinity and sodicity. In addition to crops, crop cultivars also vary in tolerance to salinity and sodicity (Kuldeep Singh *et al* 2007 and Choudhary *et al* 2010). Specific effects of Na on plant can be either direct (accumulation of toxic level of sodium) or indirect (nutritional imbalance and impaired soil physical conditions). Salt tolerance of crops may also vary with their growth stage (Mass and Grieve 1994). Ranjbar (2010) reported that two wheat cultivars have different salt tolerance at different growth stages. Salinity reduces plant height, ear length, grain and straw yield, harvest index and test weight (Asha and Dhingra 2007).

Wheat (*Triticum aestivum* L.) is a moderately salt-tolerant crop (Maas and Hoffman, 1977). It is the most common field crop grown in winter on 6 m ha of Indo-Gangetic Plains (Chhuneja *et al* 2005). Effects of salinity and sodicity on wheat crop were reported by different workers (Choudhary *et al* 1996, Ahmad *et al* 2005 and Guo *et al* 2010). Because the tolerance to salinity and sodicity varies among different wheat genotypes (Munns and Tester 2008 and Choudhary *et al* 2012), research efforts need to be continued to evaluate new high-yielding wheat cultivars released from time to time for their performance under irrigation with saline and sodic waters. It will help us to identify suitable plant characteristics and thereby tolerant wheat cultivars. Keeping that in view, the present research study was conducted with the following objectives

Objectives

- To determine the effect of saline and sodic water irrigation on plant parameters and yield of different wheat cultivars
- To evaluate tissue tolerance of wheat cultivars to salinity and sodicity
- To determine the effect of different levels of salinity and residual alkalinity of irrigation water on soil health

CHAPTER-II

REVIEW OF LITERATURE

Soil salinization and alkalization mainly occurs in arid and semi arid areas and cause serious losses in agricultural productivity and pose an ecological crisis for humans. Saline soil contains mainly chlorides (Cl^-) and sulphates (SO_4^{-2}) of sodium (Na), calcium (Ca) and magnesium (Mg) as predominant salts, whereas sodic soils have carbonates (HCO_3^-) and bicarbonates, (CO_3^{-2}) of Na as major salts (Lauchli and Luttge 2002). Secondary salinization and sodification are common problems under irrigated agriculture especially in areas of low rainfall and high evaporative demand (Sumner 1995). Secondary salinization occurs as a consequence of over-irrigation caused by improper management of irrigation facilities, poor soil internal drainage condition and unsuitable quality of irrigation water and as the water table rises, salts dissolved in the ground water, reach and accumulate at soil surface thorough capillary movement.

Estimates are that about 10 m ha of irrigated land in the world suffers from secondary salinization and sodification (Szabolcs 1994). Marginal or poor quality ground waters are used for irrigation in many arid and semi-arid regions due to the absence or limited supplies of good quality waters (Choudhary *et al* 2011b).This problem of marginal or poor quality ground water is particularly acute in northwestern India, where majority of the groundwaters contain high concentrations of $NaHCO_3$ and varying soluble salt concentrations (Minhas and Bajwa 2001). In case of Punjab, these poor-quality waters are concentrated in the drier southwestern regions.Improper management of poor quality waters, without careful regard to their overall salinity and ionic composition of the irrigation water sources pose great risks to soil health (Choudhary *et al* 2004).

Soil health can be defined as the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries to sustain biological productivity, maintain quality of air and water environments and promote animal and human health (Doran *et al* 1996). The criteria for indicators of soil health relate mainly to their utility in defining ecosystem processes and integrating physical, chemical and biological properties, their sensitivity to management and climatic variations, and their accessibility to agriculture specialists, producer and policy maker (Doran and Perkin 1994). There are three main categories of soil health indicators.i.e. chemical, physical and biological. Soil pH, cation exchange capacity (CEC) , available Nitrogen (N), phosphorous (P), potassium (K), iron (Fe), copper (Cu), manganese (Mn) and zinc (Zn) and soil organic carbon are the main chemical attributes used in soil health assessment specially, when considering the soil capacity for supporting high yield crops (Kelly *et al* 2009). Soil pH is key indicator as it correlates directly with nutrient availability/solubility and also affects microbial activity (Idow *et* *al*2008). Soil organic carbon is also important indicator of soil chemical health positively correlated with crop yield (Bennett *et al* 2010). It affects important functional processes in soil such as storage of nutrients, mainly N, water holding capacity, stability of aggregates and microbial activity (Silva and Sa-mendoca 2007). The physical indictors of soil health includes bulk density, aggregates stability which are also correlated with hydrological processes like infiltration rate and water holding capacity (Schoenholtz *et al* 2000.) Soil microbial biomass and activity and soil respiration are the main biological indicators of soil heath. Soil microbial mass is the living part of soil organic matter formed by fungi , bacteria, protozoa and algae and represents an important source of plant nutrients due to its rapid cycling, being one of the main biological attributes used in soil health studies (Sicerdi *et al* 2004). In addition to microbial biomass, soil respiration has been widely used as bio-chemical indicators of soil health in either forestry or agricultural soils (Bastida *et al* 2008). Besides microbial activity and biochemical indicators, soil enzymes can also be useful indicators of soil health as they are involved in several metabolic processes and are also responsive to changes in soil use and management. Adverse effects of saline and sodic irrigation water on soil health and crop growth are discussed under the following headings:

2.1 Effect of saline water irrigation on soil health
    2.1.1 Effect on soil chemical health
    2.1.2 Effect on soil physical health
    2.1.3 Effect on soil biological health
2.2 Effect of sodic water irrigation on soil health
    2.2.1 Effect on soil chemical health
    2.2.2 Effect on soil physical health
    2.2.3 Effect on soil biological health
2.3 Effect of salinity and sodicity on crop growth
    2.3.1 Effect on growth and yield parameters
    2.3.2 Mechanism of salt tolerance
    2.3.3 Salinity and sodicity tolerance of different crops and their cultivars
    2.3.4 Performance of different wheat cultivars under salinity and sodicity

2.1 Effect of saline water irrigation on soil health

2.1.1 Effect on soil chemical health

Salinization is the accumulation of neutral salts in the soil solum or regolith to a level that impacts agricultural production, environmental health and economic welfare. Primary salinization is a natural phenomenon involving accumulation of salts through natural processes due to high salt contents in parent materials or groundwater. Secondary salinization occurs as a consequence of over-irrigation caused by improper management of irrigation facilities, poor soil internal drainage condition and unsuitable quality of irrigation water.

Long-term use of saline waters results in increased soil pH, EC and accumulation of soluble salts, creating a hostile environment in the soil rhizosphere, which adversely affects plant growth. Ghuman *et al* (2010) conducted an experiment for three years using saline water(EC = 3.2-3.5 dS/m) and found that mean soil pH and EC significantly influenced by saline water irrigation as compared to canal water (CW). They reported that soil pH increased from 8.76 to 8.91 and from 8.85 to 9.00 in 0-15 cm and 15-30 cm soil layer in plots under saline water irrigation compared withCW. They further reported that mean soil EC increased significantly from 0.50 to 0.65 dS/m in the 0-15 cm layer and from 0.40 to 0.55 dS/m in the 15-30 cm layer when plots were irrigated with saline water instead of CW. Mahdy (2011) observed effect of four levels of saline water irrigation (0.5, 4.9, 6.3 and 8.7dS/m)on soil chemical properties on sandy clay loam soil. They reported that soil EC significantly increased from 3.4 in control to 6.2, 9.1 and 12.0 dS/m at repective levels of irrigation water salinity, respectively.

In a long term experiment,Tedeschi and Aquila (2005) observed effect of saline water irrigation on pH, EC and ESP of soil. They used four levels of saline irrigation water having EC 0.5, 4.4, 8.5 and 15.7 dS/m. They reported that salinity of irrigation water affects soil pH at each soil depth (0.15 m, 0.45m and 0.75m), specially in 0.15m soil layer, where soil pH increased with increasing salinity from 7.3 to 8.0.However at deeper soil layers pH did not increased at salinity higher than 4.4 dS/m. They also found that soil ECe increased from 2 to 12 dS/m with increasing salinity of irrigation water from 4.4 to 15.7 dS/m with more accumulation of salts in deeper layers. They further concluded that ESP also increased at increasing water salinity and ESP values were similar at 0.45m and 0.75 m depth and values were significantly higher than measured at 0.15m soil depth. Similar results were also reported by Phogat *et al*(2011).They observed that average ECe for the whole 1.5 m deep profile increased by 1.8 times of the EC of saline water (8.4 dS/m) used for two years of experimental study. Zein El-Abedine *et al* (2004) also observed that soil salinity increased by 195 and 360 per cent with the use of mixed and drainage waters, respectively as compared to those soils irrigated from CW.

Effects of irrigation water salinity and leaching on chemical properties in an arid region was observed by Fard *et al* (2007). They found that as the irrigation water salinity increases, the soil salinity and SAR increases and the effects were greater for the top as compared to the lower soil layers. Similar results were also observed by Ragab *et al* (2008) in sandy and calcareous soils. They reported that SAR increased from 1.6 to 5.7 in sandy soil and from 1.4 to 6.1 in calcareous soil as salinity of irrigation water increases from 0.4 to 8.9 dS/m, respectively.

Hassanein *et al* (1993) reported that the distribution and concentration of most cations and anions increased with increasing salt concentration in irrigation water. El-Boraie (1997) also found that soluble Ca^{+2}, Mg^{+2} and Na^{+} increased in soil with increasing salinity levels of irrigation water. Ragab *et al* (2008) observed that soluble Na and Ca+Mg concentration increased with increasing salinity of irrigation water. They found that soluble Na increased from 1.6 me/L in control to 3.6, 6.2 and 11.5 me/L in sandy soils and from 3.7 me/L (control) to 7.2, 13.6 and 23.5 me/L in calcareous soil at EC 4.9 , 6.6 and 8.9 dS/m of saline irrigation water, respectively. They further concluded that soluble Ca+Mg concentration also increased from 2.1 to 8.1 me/L in sandy soil and from 14.1 to 29.6 me/L in calcareous soil as irrigation water salinity increases from 0.4 to 8.9 dS/m, respectively.

Mashali *et al* (2009)observedeffect of irrigation water salinity on some soil properties and wheat yield. They reported that soil available nitrogen (from 99 to 67 mg/kg) and phosphorous content (from 21 to 15 mg/kg) decreases as salinity of irrigation water increases. Decreasing in available N may be due to ion exchange and increased N uptake by wheat plant under soil salinity and the decrease in available P attributed to increasing soluble Ca and hence higher precipitated Ca–phosphate compounds (Mashali *et al* 1995)

2.1.2 Effect on soil physical health

The physical indicators of soil health include bulk density, aggregates stability, infiltration rate and water holding capacity. Physical and chemical properties of long term salinized soil were observed by Tedeschi and Aquila (2005). They reported effect of four levels of saline water (EC 0.5, 4.4, 8.5 and 15.7 dS/m) on soil hydraulic conductivity and bulk density at three soil depths i.e. 0.15m, 0.45m and 0.75m. They concluded that salinity moderately reduced hydraulic conductivity of soil in 4.4 dS/m irrigated plot at the deeper layers (0.45 and 0.75 m), whose values were similar to that of non-salinized control. The maximum reduction in hydraulic conductivity occurs at highest levels of salinity (EC= 8.5 and 15.7 dS/m) at all soil depths over control, respectively. The bulk density of soil also increased with salinity of irrigation water mainly in top 0.15m soil layer; however, this effect was smaller in the deeper layers.

Al-Nabulsi (2001) conducted an experiment to observed saline drainage water irrigation frequency and crop species effects on some physical properties of sandy loam soil. they reported that soil characteristics such as sorptivity, transmisivity and infiltration rate measured at 1 minute and 2 hour intervals were significantly affected by crop species (barley and alfalfa), water quality (normal water, drainage water and mixed water having EC 3.3, 8.7 and 13.6 dS/m)and irrigation frequency (7 days and 14 days). They further concluded that these soil characteristics were highest in the barley plot receiving freshwater at 7 day interval and lowest in alfalfa cropped plots receiving saline water at 14 days interval. The beneficial effect of barley on infiltration rate was attributed to more tillage during land preparation, preventing crust formation at the soil surface.

2.1.3 Effect on soil biological health

Soil microbial biomass plays an important role in maintaining or enhancing soil quality by regulating organic matter decomposition and nutrient availability, enhancing macro-aggregate formation. MBC can be used as indicator for evaluating effects of secondary salinization of soil and effect of used management practices to improve crop productivity (Pascual*et al* 2000). High salt content not only affects physical and chemical properties of soil but also biological properties. Detrimental effects of salts on microbial activity may be due to the toxicity of specific ions and because of elevated osmotic pressure. Zahran (1997) found that specific ion toxicities (e.g. Na and Cl) tended to inhibit microbial growth in saline soil.

Egamberdieva *et al* (2010) conducted an experiment to observed secondary salinity effects on soil microbial biomass. They reported that irrigation induced salinity significantly decreased MBC and percentage of organic C present as MBC by 17.9 and 41.8 % and 7.8 and 26.2 % at EC 5.6 (moderately saline) and 7.1 dS/m (strongly saline) of irrigation water, respectivelywhen compared with weakly saline water having EC = 2.3dS/m. They found that MBC was the lowest in strongly saline soil, intermediate in moderately saline soil, and the highest in weakly saline soil. They further concluded that salinity effects on MBC were more drastic (30%) between strongly and moderately saline soils than (18%) between weakly and moderately saline soils, as a result of which, the percentage of organic C present as MBC decreased (8-18%) significantly in response to soil salinity. The decrease in MBC was related to toxic effect of Na^+ and Cl^-on soil microflora (Pankhurst *et al* 2001, Sardinha *et al* 2003 and Ndour *et al* 2008) as well as due to the osmotic effect (Rietz and Haynes 2003). The positive and significant relationship of MBC with the percentage of organic C present as MBC suggests that MBC can be used as a sensitive and early indicator of changes in the availability of percentage of organic C present as MBC especially the active organic pool (Landgraf and Klose 2002).

Effects of irrigation-induced salinity and sodicity on soil microbial activity were reported by Rietz and Haynes (2003). They observed a significant negative exponential relationship between EC and MBC, the percentage of organic C present as MBC, indices of microbial activity (arginine ammonification and fluorescein diacetate (FDA) hydrolysis rates) and the activities of the exocellular enzymes such as β-glucosidase, alkaline phosphatase and arylsulphatase. They also found that potentially mineralizable N, measured by aerobic incubation, was also negatively correlated with EC, SAR and ESP. They further concluded that increasing salinity and sodicity resulted in a progressively smaller, more stressed microbial community which was less metabolically efficient.

Tripathi *et al* (2006) conducted an experiment on microbial biomass and its activities in salt affected coastal soils. They observed the average MBC, basal soil respiration and FDA hydrolyzing activity were lowest during the summer season, indicating a negative influence of soil salinity as compared to winter and monsoon season. They also reported that about 59%, 50%, and 20% variation in MBC/OC, FDHA/OC, and BSR/MBC, respectively, which are indicators of environmental stress, could be explained by the variation in ECe. They further concluded that decrease in MBC and microbial activities with a rise in salinity are probably one of the reasons for the poor crop growth in salt-affected coastal soils.Nitrogen mineralization process consists mainly in three steps: The first step is ammonification, implying degradation of the organic materials by a wide group of heterotrophic microorganisms. These organisms use the organic C for their own growth and as energy source, while part of the organic N present in decomposed organic materials is incorporated to the biomass and part is released. The ammonification process leads to NH_4^+ release, however not all the N present in decomposed organic matter is mineralized because the soil microorganisms assimilate a fraction of this N.

Carbon and nitrogen mineralization, soil enzyme activities were inhibited by high salinity. Studies have shown that ammonification is inhibited at higher salt concentration; nitrification is very sensitive to salinity, while the activity of nitrogen fixing bacteria is also inhibited (Rasul *et al* 2006 and Cantera*et al* 2006). Shah and Shah (2011) observed changes in soil microbial characteristics with elevated salinity. They found that average MBC decreased from 391 mg/kg in soils with EC of <4.0 dS/m to 209 mg/kg in soils with EC of >12 dS/m. The same trend was observed for microbial biomass N, N mineralization, nitrification, rate of CO_2 evolution and cumulative CO_2 production with respect to elevated EC.Increases in salinity have been shown to decrease soil respiration rates and the soil microbial biomass (Pathak and Rao 1998). Yuan *et al* (2007) conducted an experiment to observe microbial biomass and activity in salt affected soils. They reported that there was a significant negative exponential relationship between EC and MBC, the percentage of soil organic C present as MBC, MBN to total N ratio, basal soil respiration, FDA hydrolysis rate, arginine ammonification rate and potentially mineralizable N. The exponential relationships with EC demonstrate the highly detrimental effect that soil salinity had on the microbial community. They also found a strong negative correlation ($r = -0.82$) between MBN and soil EC.

Among the different enzymes in soils, dehydrogenase, β-glucosidase, urease and phosphatases are important in the transformation of different plant nutrients. Dehydrogenase activity reflects the total oxidative activity of the microbial biomass and being involved in central aspect of metabolism does not function extracellularly. The β-glucosidase is an important enzyme in terrestrial carbon cycle in producing glucose, which constitutes important energy source for microbial biomass (Tabatabai, 1994). Urease catalyzes the hydrolysis of urea into ammonia or ammonium ion depending on soil pH, and carbon dioxide. Among the enzymes that are involved in soil N cycling, urease is the most prominent enzyme, whereas phosphatases play an important role in transforming organic phosphorus into inorganic forms, suitable for plants.

The effects of irrigation induced salinity on the size, activity and efficiency of the soil microbial community was investigated by Rietz *et al* (2001).They reported that there was a negative relationship between MBC, microbial activity (as measured by FDA hydrolytic activity or arginine ammonification rate), the activity of enzymes involved in carbon (β-glucosidase), phosphorous (phosphatase) and sulphur (arylsulfatase) mineralization and potential N mineralization and increasing EC of soil.

Tripathi *et al* (2007) conducted an experiment on enzyme activities and microbial biomass in coastal soils of India. The study revealed that the soil microbiological and biochemical properties were adversely affected by salinity and the situation was extreme during summer season. Among different enzymes studied (β-glucosidase, urease, acid and alkaline phosphatase), dehydrogenase was more seriously affected by salinity. They further concluded that soil microbial biomass and enzyme activities are the potent driving factors for organic matter decomposition and nutrients transformation in soil, therefore, reduction in these parameters will be a limiting factor to crop production in salt affected coastal soil.

2.2 Effect of sodic water irrigation on soil health

The increase in sodicity (SAR and RSC) in irrigation water increased pH, ECe, SARe and ESP in soil. In early stages of sodic irrigation, large amounts of divalent cations are released into the soil solution from exchange sites.Long term use of sodic water for irrigation, poses a serious threat to soil health and crop productivity, mainly through increased pH, sodium saturation of soil and associated deterioration of soil physical properties such as destabilization of soil structure, deterioration of soil hydraulic properties and increased susceptibility to crusting (Shainberg *et al* 1992). Increase in ESP adversely influence soil biological properties also.

2.2.1 Effect on soil chemical health

Chemical soil health is influenced and defined by various soil chemical parameters like soil pH, EC, soil organic matter, organic carbon, CEC, N-P-K and micronutrients that are needed for plant growth. Standard soil fertility attributes (soil pH, organic carbon, available N, P, and K) are the most important factors in terms of plant growth, crop production and microbial diversity and function (Chen 1999).

Minhas and Bajwa (2001) observed increase in soil pH, EC and ESP due to the presence of ions like carbonates, bicarbonates and chloride in irrigation water. Zein El-Abedine *et al* (2004) found that the soil alkalinity increased by 175 and 280 per cent with the use of mixed and drainage waters, respectively as compared to those of soils irrigated from CW.

Choudhary *et al* (2010) observed effect of increasing RSC of irrigation water on soil pH, SAR and ESP at three soil depths (0-15, 15-30 and 30-60cm). They reported that irrigation with high RSC waters resulted in substantial increase in soilpH. The mean soil pH (0-60cm) was 7.77 under CW irrigation that increased to 8.13, 8.95 and 9.67, respectively with increasing levels of RSC to 3, 6.5 and 10me/L. Significant increase in SAR and ESP of the soil under irrigation with high RSC waters was observed at all soil depths. Mean SAR and ESP of soil increased from 2.6, 4.4, 10.4 and 17.0 and from 4.4, to 14.1, 31.2 and 56.3 % as RSC of irrigation water increased from 0 to 3, 6.5 and 10me/L, respectively. Rajpar *et al* (2004) observed that soil sodicity increased with increase in ESP levels of soil.

Minhas *et al* (2007) observed the use of alkali waters increased pH, ECe, SARe and ESP of soil compared with good quality water. The average pH values as determined at the rice harvest in first year in soils irrigated with sodic waters were about 1 unit higher than 7.8 observed in soils irrigated with good quality water. There after the pH values remained almost the same but salinity (ECe) and sodicity (SARe) continued to increase, particularly in lysimeters protected from rain. Without rainfall, the ECe (0-0.3 m) values averaged 3.18, 3.46, 3.68 and 5.13 dS m^{-1} in soils irrigated with sodic water (EC = 2.3 dS/m, RSC = 11.3 me/L, SAR=15 $mmol/L^{0.5}$) respectively; whereas values of only 2.73, 2.15, 2.91 and 3.07 dS m^{-1} were measured in soils receiving rain. The maximum values of SAR_e were observed after wheat (2002-2003) ranging from 1.6 to 2.0 and from 2.0 to 2.3 times the SAR_{iw} in soils with and without rainfall respectively. At harvest the ESP (0-0.3 m) ranged from 9.5 to 14.1 and from 21.7 to 27.6 in soils with and without rainfall respectively. Rhoades *et al* (1992) observed that use of sodic water increased soil pH, SAR and ESP and adversely affects crop yields.

Effect of alternating irrigation with sodic and non-sodic waters on soil properties and sunflower yield was studied by Choudhary *et al* (2006).They observed that soil pH after 6 years under sodic water (SW) having RSC=10me/L was 9.45, 9.51 and 9.20 in 0–0.15, 0.15–0.30 and 0.30–0.60m layers, respectively. The corresponding values under CW treatment were 8.22, 8.53 and 8.21, respectively. They also found that ESP in the SW alone treatment ranged between 37.5 and 41.8 at respective soil depths.

Chauhan *et al* (2007) observed effect of cyclic use and blending of alkali and good quality waters on soil properties, yield and quality of potato, sunflower and sesbania in a long term experiment. They observed that increase in soil pH (8.9 to 9.1), salinity (4.7 to 5.1dS/m) and sodicity (ESP = 25-41%) as a consequences of irrigation with alkali water (EC= 3.6 dS/m, RSC =15.8me/L and SAR 12.4).

Choudhary and Ghuman (2008) observed the effect of SW irrigation and its alternate use with CW in cyclic mode on soil pH, SAR and ESP for 6 years under cotton-wheat rotation. They reported that sustained irrigation with SW for 6 years significantly increased soil pH beyond the critical value of 8.5 in all the soil layers up to 0.60 m, compared with CW irrigation. They also found that irrigation with SW significantly increased SAR over that of the CW treatment, and it varied between 22.2 and 27.6 in different soil layers. They further observed that continuous irrigation with SW substantially increased ESP of the soil compared with continuous CW treatment. When SW was applied with CW in a cycle, exchangeable Na in the soil also increased at all depths, but to levels lower than those observed with continuous SW irrigation. In the SW-irrigated plots, the ESP values were similar in the 0 to 0.15 (30.5%) and 0.15 to 0.30 m (30.8%) soil layers, but were relatively higher than in the 0.30 to 0.60 m (24.2%) layer.

2.2.2 Effect on soil physical health

Some physical indicators that have been selected by Doran and Parkin (1994) for the assessment of soil health are depth of soil, topsoil or rooting depth, infiltration, soil bulk density and water holding capacity. Soil physical properties also affect nutrient availability and plant growth through the process of water movement which is influenced by soil structure. Soils deteriorated through long term use of sodic water have poor physical quality in terms of low permeability, poor water retention and transmission characteristics, poor soil structure including crusting, sealing, compaction, hardening and obstruction to tillage operations.

Sustained use of sodic and saline-sodic water for 10 years in sugarcane crop posed soil permeability problems. On average, initial infiltration rate in the 1st hour and final infiltration rate (FIR) after 24 h declined from 6.0 and 2.4 cm h^{-1} under CW treatment to 1.5 and 0.2 cm h^{-1} under sodic water and 2.4 and 0.6 cm h^{-1} under saline-sodic treatment. Singh *et al* (1992) observed that infiltration rates reduced from 22.5 to 1.8 mmh^{-1} and from 16.1 to 1.3 mmh^{-1} as SAR of water increased from 5 to 40, at EC_{iw} of 6 and 12 dS m^{-1}, respectively

Choudhary *et al* (2006) conducted an experiment for a period of 6 years on sandy loam soil to observe the effect of alternating irrigation with sodic and non-sodic waters on soil properties. At the end of sixth year of experimentation, minimum FIR (0.9 cm/h) was measured in the plots irrigated with SW and maximum (2.7 cm/ h) in plots irrigated with CW. However, when SW was used with CW in a cycle, infiltration rate increased over that of SW treatment alone; maximum increase was 155% with 2CW irrespective of the fact whether 2CW was used before or after SW(SW:2CW or 2CW:SW). When SW or 2SW preceded one CW, increase in FIR over SW alone was 89 and 72%, respectively. These results suggest that as the number of irrigations with good quality water was increased over SW applied in a cyclic mode, FIR increased over SW alone but remained lower than that under CW irrigation.

Clay dispersion, and its migration and lodging in the soil pore under SW, and to a lesser extent in other treatments involving SW, appeared to cause structural problems and decline in infiltration rate (Grattan and Oster 2003).

Hydraulic conductivity (HC) is one of the important indicator that affect the soil physical quality. HC of the soil profile in the upper soil layer is strongly affected by electrolyte concentration of soil solution and sodicity of soil (Shainberg *et al* 1992). Crescimanno *et al* (1995) observed a greater influence of ESP on soil hydraulic properties than the other soil properties like aggregate stability and susceptibility to swelling and shrinkage. The ESP values ranging from 2 to5 caused hydraulic conductivity to decrease by 25 per cent or even more and similar reduction in aggregate stability occurred at ESP ranging from 5 to 10 while swelling-shrinkage appeared to be least affected by ESP. Nayak *et al* (2004) reported that saturated hydraulic conductivity (Ks) of the vertisols decreased with increase in the ESP and increased with increase in soil electrolyte concentration. The lowest Ks of 0.009 and 0.004 cm h^{-1} were recorded in the silty clay vertisols at ESP of 13.2 and 24.2, respectively

Bulk density is an important physical parameter affecting soil quality because density is influenced by tillage and soil organisms, and density affects water infiltration and root development. Therefore, soil bulk density is an indicator of tillage, biological activity, water movement and root growth (Lewandowski and Zumwinkl 1999). Levy *et al* (2002) studied the effect of water quality and sodicity on soil bulk density and HC of soil. The conditions favoring clay swelling i.e. low EC and high ESP resulted in decrease in HC. Sansom *et al* (1998) anticipated the lower bulk density at 45 cm and 75 cm depths of soil in gypsum amended plots than sulphur amended or control plots.

Choudhary and Ghuman (2008) observed the effect of SW irrigation and its alternate use with CW in cyclic mode on the bulk density. The maximum bulk density values of 1.58, 1.63 and 1.65 Mg m^{-3} were observed in the SW-irrigated plots in 0-0.05, 0.05-0.10 and 0.10-0.15m soil layers. Significant decrease in bulk density was observed when SW and CW are used in cyclic mode. The magnitude of the decline was higher in the irrigation cycle involving more number of irrigations with CW than SW.

2.2.3 Effect on soil biological health

Biological soil health indicators include measurements of micro and macro-organisms, their activity, or byproducts. Abundance and diversity of soil microorganisms (e.g. fungi and bacteria) and fauna (e.g. earthworms, insects, and arthropods) can be used as indicator of soil biological activity because they are sensitive to anthropogenic disturbance. Soil respiration rate is an indicator of biological activity which reflects the rate of organic matter decomposition (Evanylo and McGuinn 2009).Doran and Parkin (1994) proposed some biological indicators of soil quality, including: MBC, MBN, potential mineralizable nitrogen (anaerobic incubation) and soil respiration rate. Castillo and Joergensen (2001) stated that soil biological properties play an important role as indicators of changing soil fertility and soil quality.

According to Doran and Zeiss (2000), soil organisms are the most useful indicators of sustainable land management. Microbial biomass is an important labile fraction of soil organic matter, functioning both as an agent for transformation and cycling of organic matter and plant nutrients within soil and is sink/source of plant nutrients. The high pH, exchangeable sodium and presence of soluble carbonates and bicarbonates in sodic soils and soils irrigated with sodic water not only adversely affect the physico-chemical properties of these soils and their ability to support plant growth but also profoundly influence the soil biological condition such as diversity of microbial species, their numbers and activities in soil (Rao *et al* 2004).Rietz and Haynes (2003) reported that ion toxicities and adverse pH conditions may inhibit microbial growth under sodic soil environment. The decline in MBC under sodic soil environment is due to decrease in microbial populations and their activity attributed to deterioration in physical properties of the soil,which in turn is caused by high ESP and pH (Batra and Manna 1997).

Kaur *et al* (2008) reported that long-term SW irrigation significantly decreased MBC compared with CW irrigation. Decline in MBC content under long term SW irrigation can be ascribed to a decrease in microbial populations and their activity due to higher ESP and pH and deterioration in physical quality of soil. Amending the soil with organic material maintained significantly higher MBC values (105-156 mg kg^{-1}) compared with the unamended plots (49 mg kg^{-1}) and followed the order green manure>farm yard manure>wheat straw. However, decrease in organic C content due to irrigation with SW over CW was not significant in the unamended plots. Application of gypsum did not affect organic carbon content. Organic amendments significantly increased soil organic carbon content over the unamended treatments. Application of farm yard manure resulted in maximum increase in organic carbon (0.71%) followed bygreen manure (0.51%). Organic carbon content in farm yard manuretreated plots increased by 68% compared with the unamended treatment. The corresponding increase in green manure and wheat straw treated plots were 21 and 19%, respectively.

Choudhary *et al* (2013) found that long-term irrigation with sodic water can adversely influence MBC, cold water-extractable organic carbon (CWOC) and hot water-extractable organic carbon (HWOC). Sodic water irrigation significantly decreased HWOC from 330 to 286 mg/ kg soil and CWOC from 53 to 22 mg/ kgsoil in the top 0-7.5cm soil layer. In the lower soil layer (7.5-15cm), reduction in HWOC was not significant. Application of gypsum alone resulted in a decrease in HWOC in the SW plots, whereas an increase was recorded in the SW plots with application of both gypsum and organic amendments. Nevertheless, application of gypsum and organic amendments increased the mean CWOC as compared with application of gypsum alone. CWOC was significantly correlated with MBC but did not truly reflect the changes in MBC in the treatments with gypsum and organic amendments applied. For the treatments without organic amendments, HWOC was negatively correlated with MBC (r = - 0.57) in the 0-7.5cm soil layer, whereas for the treatments with organic amendments, both were positively correlated.

Mavi *et al* (2012) observed the interactive effects of salinity and sodicity on soil respiration and dissolved organic matter dynamics in soils varying in texture. Cumulative respiration was more strongly affected by EC than by SAR. It decreased by 8% at EC 1.3 dS m^{-1} and by 60% at EC 4.0 dS m^{-1} in the sand, whereas EC had no effect on respiration in the sandy clay loam or sandy soil. The apparent differential sensitivity to EC in the two soils can be explained by their different water content and therefore, different osmotic potential at the same EC. At almost similar osmotic potential: -2.92 M Pa in sand (at EC 1.3 dS m^{-1}) and -2.76 M Pa in the sandy clay loam (at EC 4.0 dS m^{-1}) the relative decrease in respiration was similar (8-9%). Sodicity had little effect on cumulative respiration in the soils, but dissolved organic carbon (DOC), dissolved organic nitrogen (DON) and specific ultra-violet absorbance (SUVA) were significantly higher at SAR 20 than at SAR < 3 in combination with low EC in both soils.Therefore, high SAR in combination with low EC is likely to increase the risk of DOC and DON leaching in the salt affected soils, which may led to further soil degradation.

Shah and Shah (2011) reported that increasing soil salinity, combined with high soil pH, showed negative effect on all microbial indices including MBC, MBN, basal soil respiration, nitrification and net nitrogen mineralization. The soils with high salinity level showed the lowest microbial biomass and activities and thereby degrading soil biological quality. While soils with low salinity levels showed no effect on microbial indices. Microbial biomass C: N ratio was the only microbial properties which showed positive response to increasing salinity. The rate of CO_2 evolution decreased with increasing salinity levels. The effect of salinity on rate of CO_2 evolution was more pronounced during the first two days of incubation period. However, differences between soils with different salinity levels become narrower as incubations advanced to 10 days. MBC, MBN, basal soil respiration, net nitrification and net mineralization strongly affected with SAR and ESP and the relationship is depressive.

Mavi and Marschner (2012) conducted a study to assess the impact of multiple drying and wetting on microbial respiration, DOC and microbial biomass in saline and saline-sodic soils. Different levels of salinity (EC 1.5, 1.0 or 2.5 dS m^{-1}) and sodicity (SAR < 3 or 20) were induced by adding NaCl and $CaCl_2$ to a non saline/non sodic soil. Finely ground wheat straw residue was added at 20 g kg^{-1} soil as substrate to stimulate microbial activity. Drying reduced respiration more strongly at EC 2.5 than with EC 1.0. Rewetting of dry soils produced a flush in respiration which was the greatest in soils without salt addition and smallest at high salinity (EC 2.5) suggesting greater substrate utilization by microbes in soils without salts. After three drying wetting (DW) events, cumulative respiration was significantly increased by DW compared to continuously moist (CM) treatment, being 24% higher at EC1.0 and 16% higher at electrical conductivity of saturation extract (EC_e 2.5 dS m^{-1}) indicating that high respiration rates after rewetting may compensate for low respiration rates during the dry phase. The respiration rate per unit MBC was lower at EC 2.5 than at EC 1.0. Further, the size of flush in respiration upon rewetting decreased with each ensuing DW cycle being 50-70% lower in the third DW cycle than the first.

2.3 Effect of salinity and sodicity on crop growth

2.3.1 Effect on growth and yield parameters

Growth of most agricultural crops irrigated with poor quality water suffers adversely (Choudhary *et al* 2011b and Murtaza *et al* 2006).As salt concentration increases above a threshold level, both the growth rate and yield decrease progressively. Soil salinity is one of major abiotic stress affecting germination, crop growth and productivity. Salinity affects both vegetative and reproductive development which has profound implications depending on whether the harvested organ is a stem, leaf, root, shoot, fruit, fiber or grain. The most common plant response to salt stress is the reduction in growth and yield. This reduced initial growth results in smaller plants (lower leaf-area index). Salinity often reduces shoot growth more than root growth and can reduce the number of florets per ear, increase sterility and affect the time of flowering and maturity in wheat (Lauchli and Grattan 2007).

Under field conditions, germinated seedlings encounter a number of biotic and abiotic stresses. In addition to salinity, young seedlings near the soil surface are subjected to water stress, fluctuating salinities due to capillary rise and evaporation, diurnal changes in soil temperature and surface crusts(Katerji *et al* 1994). Salinity delays germination and emergence, the young salt-stressed seedlings may be more susceptible to hypocotyl and cotyledon injury or attack by pathogens (Esechie *et al* 2002). Reduction in shoot growth due to salinity is commonly expressed by a reduced leaf area and stunted shoots. Final leaf size depends on both cell division and cell elongation. Many research studies indicates that most of crops were sensitive during vegetative and early reproductive stages, less sensitive during flowering and least sensitive during the seed filling stage (Lauchli and Grattan 2007).

Salt stress causes inhibition of growth and development, reduction in photosynthesis, respiration and protein synthesis and disturbs nucleic acid metabolism. A response of photosynthesis and respiration to salinity is primarily associated with the direct effects of salinity on enzyme function and secondarily with the gas exchange and light reactions. Higher salinity levels or salt concentration in the germinating media to build up the high osmotic pressure of the solution will prevent intake of water which is necessary for germination (Kumar *et al* 2012).

Higher salt concentration cause toxic effect on embryo. It also decreased root length, callus size, coleoptile length and seedling growth, plant height, stem diameter and dry weight (Azooz *et al* 2004). At maturity, it resulted in decreased number of fertile ears, ear length, grain yield, straw yield, harvest index and test weight (Asha and Dhingra 2007). The response of plants exposed to salinity stress is a decrease in plant water potential, which reduces plant water use efficiency (Chaum *et al* 2004). The responses of wheat grain and straw yields were negatively and highly correlated with soil salinity and in particular with the mean soil salinity in the top 50 cm as reported by El-Morsy *et al*(1993). They added that the partial regression showed that most of the yield variations under soil salinity are mainly due to the total soluble salts rather than specific ions effect. Also, Zein *et al* (2003) found that wheat grain and straw yields as well as plant height, spike length, and 1000 grain weight were significantly affected by increasing irrigation water salinity. Rice and wheat yield reduced by irrigation with saline water was also reported by(Murtaza *et al* 2009). Malash *et al* (2008) observed that increase in salinity resulted in decreased leaf area index, plant dry weight, fruit yield and individual fruit weight in tomato crop.

Salinity is inimical to plant growth through specific ion toxicities, induced nutrient deficiencies and osmotic effects or a combination of these factors (Ashraf and Sarwar 2002 and Munns and James 2003). Rengaswamy (2010) showed that the specific ion effect dominates only at low salinity levels whereas; the osmotic effect becomes more important at higher salinity. Salt affected plants are stunted and may have darker green leaves which, in some cases are thicker and more succulent. Shoots growth is often suppressed more than root growth. The negative response of plants to low water potential may prevail in saline soils, while single ion toxicity or nutritional imbalance may particularly be severe in sodic soils. Excessive amount of salt entering the transpiration stream injure cells in the transpiring leaves and this reduce growth due to specific ion toxicities.

Specific ion toxicity usually associated with either excessive chloride (Cl^-) or sodium (Na^+) uptake, which affects the uptake of essential nutrient elements such as potassium (K), calcium (Ca) magnesium (Mg), phosphorous (P) and nitrate (NO_3) (Sairam *et al* 2002 and Zorb *et al* 2004). Decrease in Kand Ca uptake under salinity could be due to the antagonism of Na^+ at sites of uptake in roots, an effect of Na^+ on the K^+ and Ca^{2+} transport into the xylem. Potassiumdeficiency inevitably leads to growth inhibition because K^+, as the most abundant cellular cation, plays a critical role in maintaining cell turgor, membrane potential and enzyme activities. Blossom end rot of tomato and pepper, blackheart of celery and internal browning of lettuce are all symptoms of Ca deficiency which may occur in saline soils characterized by high sulfate levels. Increasing salinity reduced the content of free amino acids in wheat as a result of decreasing nitrate reducatase activity that plays an important role in conversion of nitrate to ammonium. An immediate effect of osmotic stress on plant growth is its inhibition of cell expansion either directly or indirectly through abscisic acid. Munns *et al* (1995) observed that initial growth inhibition in saline environment is induced by the decreased water potential of rooting medium due to osmotic effects.

Sodicity adversely affects nutrient and water uptake by plants due to poor soil structure. Adequate soil water content is often difficult to maintain in areas affected by sodicity due to water-logging at the surface. On the other hand, the formation of surface crusts reduces seed germination and plant establishment. Sodic water irrigation resulted in deterioration of soil physical properties, impact nutrient relations and thus may adversely affect yield and quality of crops (Choudhary *et al* 2004). Physical degradation of soils is manifested through increased surface crusting that impacts seedling emergence, reduced infiltration affecting water holding capacity of soil profile, increased soil strength impacting root penetration and reduced aeration resulting in anoxic conditions for roots (Choudhary *et al* 2011b). Sodic stress reflects the impact of high pH which reduces mineral element availability by precipitating Caand Mg and also inhibiting the uptake of certain other ions (Yang *et al* 2007 and Xue and Liu 2008). When soil pH increases above 9, bicarbonate and carbonate toxicity as well as deficiency of Fe, Mn, Cu, Zn and P may cause nutritional imbalances in plants (Rengaswamy 2002). Salinity dominated by Na salts not only reduces Ca availability in soils but reduces its transport and mobility to growing regions of the plant, thereby affecting the quality of both vegetative and reproductive organs (Choudhary *et al* 1996). Sekhon and Bajwa (1993) in a green house experiment studied that sustained use of sodic waters significantly decreased the dry matter yield (DMY) of rice, wheat and maize crops. As compared to CW irrigation decline in DMY under SW was much lower in rice and wheat compared to that of maize. That may be due to differences in relative salt and Na tolerance of these crops

2.3.2 Mechanism of salt tolerance

Plant responds to salinity stress through modification of different morphological, physiological and biochemical processes and anatomical changes (Tester and Davenport 2003). A variety of mechanismscontribute to salt tolerance. Resistance is the abilityof plants to adapt to salinity. It can be achieved by the ability ofgrowing cells of a plant to avoid high ion concentrations or the abilityof cells to cope with high ion concentrations. Examples ofsalt avoidance mechanisms include delayed germination or maturityuntil favorable conditions prevail; the exclusion of salt at the rootzone or preferential root growth into non-saline areas;compartmentalization of salt into and secretion from specializedorganelles such as salt glands and salt hairs; or storage in olderleaves (Yadav *et al* 2011). These tolerance mechanisms arediscussed under following headings.

2.3.2.1 Selective accumulation or exclusion of ions

Salt exclusion and inclusion, Na^+/K^+ discrimination and osmotic adjustment are recognized as different mechanisms for plants to tolerate salinity. Salt exclusion means that the plants have the ability to restrict the uptake of toxic ions into the shoot (Munns 2002). Salt inclusion is to take up large quantities of salt and to store it in the shoot, which can cause problems for many physiological and biochemical events taking place in the cell .Accumulation of excessive Na^+ causes premature senescence of leaves and hence the ability to accumulate Na^+ in leaves can serve as an important mechanism for salt tolerance (Schachtman and Munns 1992). Both glycophytes and halophytes cannot tolerate large amounts of salts in the cytoplasm and therefore under saline conditions they either restrict the excess salts in the vacuole or compartmentalize the ions in different tissues to facilitate their metabolic functions (Zhu 2003).

In general, exclusion mechanisms are effective at low to moderate levels of salinity, whereas ion accumulation is the primary mechanism used by halophytes at high salt levels, presumably in conjunction with the capacity to compartmentalize ions in the vacuole. Glycophytes limit sodium uptake, or partition sodium in older tissues, such as leaves, that serve as storage compartments which are eventually abscised. Inclusion of ions in the cytoplasm can lead to osmotic adjustment that is generally accepted as an important adaptation to salinity (Guerrier 1996). Plants are able to tolerate salinity by reducing the cellular osmotic potential as a consequence of a net increase in inorganic and solute accumulation (Serraj and Sinclair 2002). During osmotic adjustment, the cell tends to compartmentalize most of the absorbed ions in vacuoles at the same time these cells synthesize and accumulate compatible organic solutes in the cytoplasm in order to maintain the osmotic equilibrium between these two compartments (Hasegawa *et al* 2000).

2.3.2.2 Synthesis of compatible solutes

Presence of salt in the growth media often results in the accumulation of low-molecular mass compounds, termed as compatible solutes, which do not interfere with normal biochemical reactions (Zhifang and Loescher 2003). These compatible solutes include mainly proline and glycine betaine. It has been reported that proline levels increases significantly in leaves of rice, sugar beet, Brassica juncea and in the tolerant variety of sugarcane (Ghoulam *et al* 2002, Yusuf *et al* 2008, Vasantha and Rajlakshmi 2009). The increase in proline content was positively correlated to the level of salt tolerance. The proposed functions of proline under stress conditions include osmotic adjustment, protection of enzymes and membranes, as well as acting as a reservoir of energy and nitrogen for utilization during exposure to salinity (Bandurska 1993).

Exposure to saline stress results in the accumulation of nitrogen-containing compounds (NCC) such as amino acids, amides, proteins, polyamines and their accumulation is frequently correlated with plant salt tolerance (Mansour 2000). For instance, glycine betaine content has been observed to increase in green gram and peanut (Girija *et al* 2002). According to Sakamoto *et al* (1998), sub cellular compartmentation of glycine betaine biosynthesis in rice is important for increased salt tolerance. These compounds have been reported to function in osmotic adjustment, protection of cellular macromolecules, storage of nitrogen, maintenance of cellular pH, detoxification of the cells and scavenging of free radicals.

Other compatible solutes that accumulate in plants under salt stress include (a) carbohydrates such as sugars (glucose, fructose and sucrose) and starch (Kerepesi and Galiba 2000 and Parida *et al* 2002), and their major functions have been reported to be osmotic adjustment, carbon storage, and radical scavenging, (b) Polyols are reported to make up a considerable percentage of compatible solutes and serve as scavengers of stress-induced oxygen radicals and are also involved in osmotic adjustment and osmo-protection.

2.3.2.3 Control of ion uptake by roots and transport into leaves

Plants regulate ionic balance to maintain normal metabolism. For example, uptake and translocation of toxic ions such as Na^+ and Cl^- are restricted, and uptake of metabolically required ions such as K^+ is maintained or increased. Plants do this by regulating the expression and activity of K^+ and Na^+ transporters and of H^+ pump that generate the driving force for ion transport (Zhu *et al* 1993). It is well documented that a greater degree of salt tolerance in plants is associated with a more efficient system for the selective uptake of K^+ over Na^+ (Ashraf and O'Leary, 1996). It has been reported that salt tolerant barley variety maintained cytosolic Na+, ten times lower than a more sensitive variety (Carden *et al* 2003).

2.3.2.4 Changes in photosynthetic capacity under salinity

The reduction in photosynthetic rates in plants under salt stress is mainly due to the reduction in water potential. The aim of salt tolerance is, therefore, to increase water use efficiency under salinity. To this effect, some plants such as facultative halophyte (*Mesembryantheman crystallinum*) shift their C3 mode of photosynthesis to Crassulacean acid metabolism (CAM). This change allows the plant to reduce water loss by opening stomata at night, thus decreasing respiratory water loss in day time. In salt-tolerant plant species such as *Atriplex lentiformis,* there is a shift from the C3 to C4 pathway in response to salinity (Zhu and Meinzer 1999). The role of pigments particularly chlorophylls in trapping solar energy to reduce it in the carbon chains of organic photosynthates is central. The carbon fixed with the aid of chlorophyll and other pigments ultimately support the metabolic and energy reactions to be translated as growth and development.

2.3.2.5 Induction of anti-oxidative enzymes under salt stress

Plants possessefficient systems for scavenging active oxygen species that protectthem from destructive oxidative reactions and anti-oxidative enzymes are key elements in thesedefense mechanisms. Garratt *et al* (2002) has listed some of theseenzymes as catalase ascorbate peroxidase (CAT), glutathione reductase (GR), superoxidedismutase (SOD) and glutathione-S-transferase (GST). SOD that metabolizes oxygen (O_2) radicals to hydrogenperoxide (H_2O^2), thus protecting cells from damage. CAT and a variety of peroxidases catalyze thesubsequent breakdown of H_2O_2 to water and oxygen. Plants with high levels of antioxidantshave been reported to have greater resistance to this oxidativedamage. Mittova *et al* (2003) reported an increase in the activityof anti-oxidative enzymes in plants under salt stress. They found acorrelation between these enzyme levels and salt tolerance.

2.3.2.6 Salinity and induction of plant hormones

The level of planthormones, such as Abscisic acid (ABA) and cytokinins increase with high saltconcentration (Vaidyanathan *et al* 1999). ABA causes alteration in the expression of stress-induced genes whichare predicted to play an important role in the mechanism of salttolerance in rice (Gupta *et al* 1998). The inhibitory effects of NaClon photosynthesis, growth and translocation of assimilates has beenfound to be alleviated by ABA (Popova *et al* 1995).

2.3.3 Salinity and sodicity tolerance of different crops and their cultivars

Plant species differ in their salt tolerance.Crop tolerance is defined in relation to the level of root zone salinity causing yield losses. The term crop resistance is suggested to distinguish glycophyte ability to endure salinity from the tolerance of halophytes (Flowers and Yeo 1997). Francois and Maas (1999) classified wheat as moderately tolerant to soil salinity with a threshold EC of 6.0 dS/m. Salt tolerance in crops allows the more efficient use of poor quality water.

Ali *et al* (2013) conducted field study in salt affected soil to test growth and yield response of six *Brassica* cultivars. They found that out of six cultivars, two cultivars namely Dunkled and Sultan Raya (241.7 and 235.1 kg/ha) performed better as compared to other *Brassica* cultivars, because these two cultivars showed minimum Na^+accumulation in their tissues, hence these were more tolerant to salinity. Ghuman *et al* (2010) observed tolerance of three sugarcane cultivars (CoJ83, CoJ88 and CoJ89) under saline water (EC = 3.2-3.5dS/m) irrigation. They reported that across cultivars indicated that cultivar CoJ88 yielded significantly higher than CoJ83 and CoJ89. This cultivar also responded better to management interventions (cyclic use and application of FYM) than the other 2 cultivars. They suggested that CoJ88 was relatively more tolerant than other 2 cultivars to salinity. Similar results were also reported by Kuldeep-Singh *et al* (2007). They observed that tolerant sugarcane cultivar possessed a higher number of millable canes and a larger single cane weight resulting in higher cane yield in a saline water-irrigated soil (EC 3.5 –4.0 dS m^{-1}), for both planted and ratoon crops, compared to sensitive sugarcane cultivars.

Different crops and their cultivars also vary in tolerance to sodicity (Minhas and Bajwa 2001). Tolerance of a cultivar to irrigation with sodic waters (EC < 2 dS m−1, RSC > 5.0 mmolc L^{-1}) also depends upon ability of the plants to exclude Na and absorb nutritionally adequate amounts of Ca (Choudhary *et al* 1996a). Wheat and barley cultivars possessing penetrative root systems and capable of producing higher number of spikes per unit area with bolder grains could produce high yields even at an ESP of 40–50 in 0–30 cm soil developed due to long-term irrigation with sodic waters (Choudhary *et al* 1996b).Yield and fiber quality of cotton cultivars as affected by the buildup of sodium in the soils with sustained sodic irrigations under semi-arid conditions was observed Choudhary *et al* (2001). The results of this study shows that high ESP decreased plant height and seed cotton yield of the cotton cultivars, but these cultivars differed in their tolerance to sodicity stresses. The cultivars F-846, besides maintaining good plant growth (measured in terms of plant height), produced relatively heavier and number of bolls than the other cotton cultivars under thehighest ESP build up in the soils. This cultivar was also able to maintain good fiber quality whereas harmful effects of sodicity were observed on the other two cultivars. These crop specific differences can be exploited for selecting crops that can produce satisfactory yield under given level of root zone salinity and sodicity (Koyoma *et al* 2001).

Prasad *et al* (2001) observed performance of two grasses (palamrosa and lemongrass) under high RSC irrigation water. They reported that lemongrass accumulates significantly greater amount of Na in shoot tissues as compared to palamrosa and it failed to survive at high RSC after 21 months of transplanting. It suggested that palamrosa is more tolerant to irrigation water sodicity than the lemon grass. Choudhary *et al* (2010) observed better performance of tomato cultivar Punjab Chhuhara compared to Edkawi at medium and high RSC levels

2.3.4 Performance of different wheat cultivars under salinity and sodicity

Wheat, the most important cereal crop is known to be a semi tolerant crop to salinity and sodicity. Life cycle of wheat is an orderly sequence of development stage. Salinity can have a significant effect on the developmental processes that occur at a particular time. The sequence of events has been separated into three distinct but continuous developmental phases (Francois and Mass 1994). In the first phase, which encompasses the early vegetative growth stage, leaf and tiller buds are produced in the axils of the leaves and spikelet primordia is initiated. High salinity at this time reduces the number of leaves per culm and the number of tillers per plant (Mass and Grieve 1990). The differentiation of the terminal spikelet signals completion of this phase. During the second phase, the main stem and tiller culms elongate, and the final number of florets is set (Kirby 1988). Salinity stress during this phase may affect tiller survival and reduce the number of functional florets per spikelet. This phase ends with anthesis. Florets fertilization and grain filling occur during the third phase. Salinity during this phase affects seed number and seed size (Hendawy-El 2004).

Test on wheat cultivars have shown that there are inter-varietal differences for salt tolerance. Wheat genotypes that accumulate lower $Na^+$and Cl^-concentrations and higher K^+concentrations and have a high K^+ : Na^+ratio in their leaves are usually considered to be salt tolerant (Rashid *et al* 1999). Ahsan *et al*(1996) found that salt-tolerant lines had significantly lower accumulation of Na in the leaves and higher K/Na ratio than salt-sensitive lines. Hussain *et al* (2014) observed that grain yieldof sixwheat cultivars decreased by 25% at 100mM salinity over control. They reported that response of different cultivars was also different to salinity stress as cultivars ‘Lasani-08’ and ‘FSD-08’ were found to be more tolerant as compared to other cultivars.Khan *et al* (2006) conducted an experiment to observe comparative performance of sixteen wheat genotypes growing under saline water. Four salinity levels, i.e. control (1.5 dS/m), low saline (6.0 dS/m), medium saline (9.0 dS/m) and highly saline (12.0 dS/m) waters were used to irrigate wheat cultivars. They found that 16 wheat cultivars clearly show different responses to high salt concentrations with respect to nutrient assimilation. On the basis of less than 50% reduction in different growth variables, they reported five genotypes viz. LU-26s, HT-45, ESW-9525, V-8319 and Sarsabz were found tolerant, whereas Bhittai, Marvi, Chakwal-86, DS-17, Sussi (SD-66) and Zardana were reported medium tolerant. Also SD1200/51, Khirman and V-7012 medium sensitive and RWM-9313 and SH-43 were found to be sensitive wheat genotypes. They also concluded that tolerant wheat genotypes were successful in maintaining low Na and high K uptake and high K/Na ratio during experimental study.

Asgari *et al* (2012) studied salt stress effects on four wheat genotypes (Rasoul, Atrak, Kouhdasht and Tajan) growth and leaf ion **c**oncentrations at four salinity levels (EC = 3, 8, 12 and 16 dS/m). They reported that Kouhdasht and Tajan cultivars showed highest and lowest grain yield and yield components as compared to others. Leaf Na^+ and Cl^- concentrations of all genotypes increased significantly with increasing soil salinity, with the highest concentrations in Tajan, followed by Rasoul, Atrak and Kouhdasht. Highest leaf K^+ concentration and K^+: Na^+ ratio were observed in Kouhdasht, followed by Atrak, Rasoul and Tajan, respectively. They concluded that based on higher grain yield production, higher leaf K+ concentration, K+: Na+ ratio and lower leaf Na+ and Cl- concentrations, Kouhdasht and Atrak were identified as the most salt-tolerant genotypes than other 2 genotypes. Ahmed *et al* (2005) in Pakistan Punjab observed performance of six wheat varieties under saline soils (ECe= 12.7 dS/m). The reported that LU26S was most salt tolerant variety and produce higher grain weight due to its low Na^+ uptake, high K^+/Na^+ ratio, high dry weight of shoots and spikes and better grain development, whereas Punjab 85 appeared to be most salt sensitive variety under saline soils.

It was observed that difference in the salt tolerance among genotypes may also occur at different growth stages. Farooq *et al* (2008) conducted and experiment to observe comparative response of seven wheat genotypes to brackish water at seedling stage. They reported that reduction in shoot fresh weight and other growth parameters were less in SARC-1 and 8670 genotypes as compared to others in all brackish water treatments. They suggested that these genotypes had ability to perform better under different types of brackish water treatments because thay restricted uptake of Na^+ and prefereed K^+ uptake and thus maintained higher K^+/Na^+ ratio. Ranjbar (2010) also examined salt sensitivity of two wheat cultivars at different growth stages. The found that the most significant reduction of grain yield was observed in salinity imposed at emergence as compared with salinity imposed at grain filling period.

Choudhary *et al* (1996) observed that triticale (*Triticosecale sp. Wittmack*) showed greater tolerance to soil and water sodicity than bread wheat and durum wheat (*Triticum turgidum* L.) under irrigation with RSC waters. Rajpar *et al* (2004) observed that there were differences among 3 wheat cultivars in terms of performance in sodic environment. They found that cultivar Marvi was more tolerant than Sarsabz and Kiran wheat cultivars from emergence to maturity.Choudhary *et al* (2012) studied response of wheat to increasing levels of residual alkalinity in irrigation water. They found that PBW 343, PBW 550 and PBW 502 wheat cultivars responded differentially to different RSC levels of irrigation water.As tolerance of wheat crop to salinity and sodicity varies among genotypes, evaluation of new wheat cultivars for salinity and sodicity tolerance, which can efficiently utilize poor quality water for irrigation without significant reduction in yield, is very important from time to time.

CHAPTERIII

MATERIALS AND METHODS

The material and methods used in research problem entitled "**Saline and sodic irrigation effects on performance of wheat cultivars and soil health"** are discussed under following headings;

3.1 Location and climate
3.2 Field studies
3.3 Laboratory studies

3.1 Location and climate

The experimental study was carried out at the research farm of the Department of Soil Science, Punjab Agricultural University, Ludhiana (30° 56´ N, 75° 52´E 247 m above msl) for period of 2 years (2013-14 and 2014 -15) on two long-term experiments started since 2000 and 1998 on Cotton-wheat cropping system in a sandy loam soil (*Typic Ustochrept*) irrigated with different levels of saline and sodic water. The saline and sodic irrigated treatment plots were separated from each other by an un-vegetated buffer of 0.5 m width to check lateral flow of water and salts. The weather and climatic parameter recorded during *rabi* season in 2013-14 and 2014-15 were presented in Table 3.1 and 3.2.

Table 3.1: Mean monthly meteorological data recorded at Agrometeorological observatory during *rabi* 2013-14

Standard Meteorological Month	**Temperature (˚C)**			**Relative Humidity (%)**			**SSH (hr)**	**Total Rainfall (mm)**
	Max.	**Min.**	**Mean**	**Morn.**	**Even.**	**Mean**		
October-2013	31.4	20.2	25.8	90.7	49.4	70.0	5.3	36.2
November-2013	25.9	10.2	18.0	91.7	37.2	64.5	7.0	4.6
December-2013	20.0	7.4	13.7	93.5	54.8	74.1	4.9	13.2
January-2014	17.5	7.0	12.2	95.6	62.3	79.0	4.5	55.5
February-2014	19.4	8.2	13.9	93.6	62.4	78.0	8.4	36.9
March-2014	25.3	12.5	18.9	90.4	53.1	71.8	8.5	35.0
April-2014	32.7	16.6	24.7	77.4	37.2	57.3	10.1	31.0
Mean	**24.6**	**11.7**	**18.2**	**90.4**	**50.9**	**70.7**	**6.9**	**212.4**

Table 3.2: Mean monthly meteorological data recorded at Agrometeorological observatory during *rabi* 2014-15

Standard Meteorological Month	Temperature (˚C)			Relative Humidity (%)			SSH (hr)	Total Rainfall (mm)
	Max.	Min.	Mean	Morn.	Even.	Mean		
October-2014	31.2	18.9	25.0	89.0	48.0	69.0	6.0	12.9
November-2014	26.9	10.9	18.9	91.0	35.0	63.0	7.1	0.0
December-2014	17.8	7.0	12.3	94.0	65.0	80.0	4.2	42.2
January-2015	15.6	7.1	11.3	96.0	73.0	85.0	3.2	24.6
February-2015	22.2	10.5	16.3	92.9	64.8	78.8	5.6	38.6
March-2015	25.5	13.1	19.4	93.0	60.0	76.0	7.7	84.6
April-2015	32.6	19.5	26.0	74.7	49.9	59.8	8.5	29.4
Mean	**24.5**	**12.4**	**18.4**	**90.1**	**56.5**	**73.1**	**6.0**	**232.3**

3.2 Field studies

3.2.1 Experiment 1: Saline irrigation effects on performance of wheat cultivars and soil health

This experiment was carried out in a field irrigated with five levels of saline water (EC 0, 3, 6, 9 and 12 dS/m) since 2000, which consists of 30 plots having size 2m x 2m each on Cotton-wheat cropping system in a sandy loam soil. These saline water levels were maintained throughout the growth period of wheat crop by adding sodium chloride (0, 425, 850, 1275 and 1700 gm) on every irrigation. Good quality water (EC 0), used as control treatment, had EC = 0.50 dS m^{-1}. Four levels of saline water EC 3, EC 6, EC 9 and EC 12 dS m^{-1} were created by dissolving 1.77, 3.50, 5.31 and 7.08 g of NaCl per liter in good quality water, respectively. Six wheat cultivars namely KRL 210 (salt tolerant), PBW 621, HD 2967, Berbet (timely sown), PBW 590 and PBW 658 (late sown) were sown on 17th November, 2013 in saline water irrigated plots and harvested on 25th April, 2014. In 2014, these cultivars were sown on 1st November and harvested on 20th April 2015. Two sets (set 1 and set 2) of these cultivars were made consisting of three cultivars in each set. Ten lines (3 for each cultivars and the border line) were sown in each plot for set 1 and set 2. The row to row spacing of wheat crop was maintained at0.2 m. A basal dose of 165 kg urea (76 kg N ha^{-1}), 30 kg diammonium phosphate (13.8 kg P_2O_5 ha^{-1}), 30 kg murate of potash (18 kg K_2O ha^{-1}) and 10 kg zinc sulphate ha^{-1} (2.1 kg Zn ha^{-1}) was uniformly applied to all plots to meet fertilizer requirement of different wheat cultivars. Urea was applied in two splits (first at the time field preparation and second on first irrigation) and all others fertilizers were broadcast at the time of field preparation. The soil samples for this experiment were collected with an auger from five depths up to 120 cm i.e. from 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth, before sowing and after harvest of wheat cultivars in 2013-14 and 2014-15. The air dried soil samples were ground to pass through 2 mm sieve. The sieved soil samples were stored for laboratory analysis. The soil samples were analyzed for selected physical and chemical properties. Fresh soil samples from 0-15 and 15-30 cm before and after harvest of wheat crop in both years (2013-14 and 2014-15) were also taken for analyzing microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), dehydrogenase enzyme activity (DHA) and cold-water extractable carbon (CWEC).

3.2.2 Experiment 2: Sodic irrigation effects on performance of wheat cultivars and soil health

This experimental site is regularly irrigated for 18 years with four levels of sodic water having residual sodium bicarbonate (RSC) 0, 3, 6.5 and 10 me /L on Cotton-wheat cropping system before the start of investigation. Good quality used as control (RSC 0), had EC = 0.40 dS m^{-1}, RSC = 0, and sodium adsorption ratio (SAR) = 1.2. Three levels of sodic water (RSC 3, RSC 6.5 and 10me/L) were created by dissolving 0.25, 0.55 and 0.84 g of $NaHCO_3$ per liter in good quality, respectively.This research field consists of 24 plots having plot size 2m x 2.5m each. Same six wheat cultivars (KRL 210, PBW 621, HD 2967, Berbet, PBW 590 and PBW 658) which were used in experiment 1 were also sown in this experiment. In 2013, six wheat cultivars were sown on 11th November and harvested on 17th April, 2014. In 2014, wheat cultivars were sown on 5th November and harvested on 27th April, 2015. Two sets (set 1 and set 2) of six wheat cultivars were also made in this experiment with 20 cm row to row spacing. Fertilizer requirement of different wheat cultivars was met through application of 150 kg urea (69 kg N ha^{-1}), 26 kg diammonium phosphate (12 kg P_2O_5 ha^{-1}), 50 kg muriate of potash (30 kg K_2O ha^{-1}) and 10 kg zinc sulfate ha^{-1} (2.1 kg Zn ha^{-1}). Urea was applied in two splits (first at the time field preparation and second on first irrigation) and all others fertilizers were broadcast at the time of field preparation. The soil samples were collected at five depths up to 120 cm (0-15, 15-30, 30-60, 60-90 and 90-120cm), before sowing and after harvest of wheat cultivars in 2013-14 and 2014-15. These samples were analyzed for selected physical and chemical properties by different methods presented in Table 3.3. For analyzing MBC, MBN, DHA and CWEC fresh soil samples were also collected from 0-15 and 15-30 cm soil depth before and after harvest of wheat crop in both years (2013-14 and 2014-15).

3.2.3 Plant parameters and plant analysis

At tillering stage, plant height, no of tillers /m^2 and leaf area index (using Sun Scan Delta- T device) was recorded for different wheat cultivars in 2013-14 and 2014-15 for both experiments. Plant samples for mineral composition (Na, K, P and Ca) analysis were also collected at this stage. These samples were digestion in 3:1 (HNO_3: $HClO_4$) diacid mixture after proper washing and drying in oven. Samples were placed overnight for proper decomposition of plant material and then digested on a hot plate. After making volume these samples analysis of Na and K was done on flame photometer and Ca and P were determined using titration method and by spectrophotometer.

3.2.4 Yield and yield contributing parameters

Biomass, grain and straw yield of six wheat cultivars were recorded in both experiments in 2013-14 and 2014-15 and expressed as t/ha. From each plot, 10 spikes of different wheat cultivars were randomly taken at maturity to calculate spike length and to measured grain weight per spike and 1000 grain weight. Plant height and no of spikes/m ^{2} were also recorded at this stage. Grain and straw samples for determination of Na, K, P and Ca were taken at maturity and analyzed in same procedure as followed for plant samples at tillering stage. Two quality parameters .i.e. protein content and test weight for grains of different wheat cultivars were also estimated at maturity.

3.2.5 Methods determining soil properties: methods used for determining various physical, chemical and biological properties are presented in **Table 3.3**

Table 3.3: Methods used for analyzing physical, chemical and biological properties of soil

Property	Method
pH	Glass calomel electrode assembly, 1:2 soil water suspension
EC	Solubridge (Jackson 1967).
Organic Carbon (OC)	Wet digestion method (Walkley and Black 1934).
Available nitrogen	Alkaline- Permanganate Method (Subbiah and Asija 1965)
Available phosphorous	0.05M $NaHCO_3$ pH 8.5 (Olsen *et al* 1954)
Available potassium	Merwin and Peech (1950)
Available sulphur and Soluble SO_4^{-2}	Turbidimetric method (Richards 1954)
DTPA-Zn	Lindsay and Norvell (1978)
Soluble Na and K	Sodium and potassium measured in the 1:2 soil extract using Flame-photometer (Richards 1954)
Soluble Ca+Mg	Versenate method (Richards 1954)
Soluble HCO_3^- and Cl^-	Richards 1954
Exchangeable sodium percentage (ESP)	Soil samples were saturated by1 N Sodium acetate, and then washed with alcohol to get rid of water soluble fraction of Na. Then soil samples were equilibrated with 1N ammonium acetate to bring back Na in the solution from exchange complex. The Na so obtained measured for cation exchange activity (CEC) as method outlined by Richards (1954).
Sodium adsorption ratio (SAR)	SAR= Soluble $Na/(Ca^{2+}+Mg^{2+}/2)^{1/2}$
Infiltration rate	Double ring infiltrometer (Bouwer 1986).
Bulk Density	Core method (5*4 cm) (Blake and Hartge 1986).
Aggregation	Yoder (1936)
Mean weight diameter (MWD)	Kemper W D and Rosenau R C (1986)
Saturated Hydraulic conductivity	Klute and Dirkson (1986)
Water holding capacity	Richards (1954)
Soil texture	International pipette method (ISSS 1929)
Cold water extractable carbon	Ghosh 2003
Microbial biomass carbon and nitrogen	Chloroform fumigation extraction method (Vance *et al* 1987)
Dehydrogenase enzyme activity	Casida *et al* (1964)

3.2.5.1 Dehydrogenase enzyme activity

Dehydrogenase activity in soil was measured by method described by Casida *et al* (1964). Twenty gram air dried soil was mixed with 0.2 g of $CaCO_3$. Six gram of this mixture was taken in test tube in triplicate. To each tube 1 ml 3% aqueous solution of triphenyl tetrazolium chloride and 2.5 ml distilled water was added, thoroughly mixed and incubated at 37°C for 24 h.

After incubation, 10 ml methanol was added, mixed and filtrated through Whatman No 5 filter paper. Samples were repeatedly extracted with methanol till no more color could be extracted. The extracts were pooled and final volume was made to 50 ml with methanol. Absorbance was measured at 485 nm on double beam UV-Vis spectrophotometer.

Microbial Biomass Carbon

Microbial biomass C (MBC) was determined by the fumigation–extraction method (Vance *et al* 1987).

3.2.5.2.1 Fumigation

Two sets of moist incubated soil containing 5 g soil (60% water holding capacity) from each treatment were taken and one set was extracted immediately with 20 ml of 0.5 M K_2SO_4 which served as control (unfumigated). The other set was fumigated in a desiccator containing about 25 ml ethanol free chloroform in a small beaker with a fer boiling chips. The desiccators were evacuated until chloroform has boiled for 2 minutes and placed in dark at 25 ºC. After 24h, beaker of chloroform was removed and residual chloroform vapours in soil removed by repeated evacuation before extraction.

3.2.5.2.2 Extraction

For extraction, soil was transferred to a 100 ml plastic bottle, 20 ml of 0.5 M K_2SO_4 added and the bottles were shaken on an oscillating shaker for 30 min and the suspension was filtered through Whatman No. 42. To the filtrate (4 ml), add 66,7*m*M $K_2Cr_2O_7$ (1 ml) and 5 ml H_2SO_4. The mixture was allowed to cool and diluted with 20 ml distilled water added through the condenser as a rinse. The excess dichromate was determined by back titration with ferrous ammonium sulphate (33.3 *m*M) in 0.4 *M* H_2SO_4using few drops of *o*-phenanthroline monohydrate indicator.

After titration, extractable C was calculated assuming that 1 ml of 66.7 *m*M $K_2Cr_2O_7$ is equivalent to 1200 µg C and biomass C from relationship:

Biomass = 2.64 Ec

Ec is difference between C extracted from the fumigated and non-fumigated soil.

3.2.5.2 Microbial Biomass Nitrogen

Total N in the extracts was measured using the Kjeldahl method (Bremner and Mulvaney 1982 and Brookes *et al* 1985). Microbial biomass N was calculated as follows:

Microbial biomass N = EN / kEN

Where EN = (total N extracted from fumigated soils) _ (total N extracted from non-fumigated soils) and kEN = 0.54 (Brookes *et al* 1985 and Joergensen and Mueller 1996).

3.2.5.3.1 Ammonical-N and Nitrate-N

Soil samples were shaken with 2M KCl for 1 hour and filtered using Whatman filter No. 1. NH_4^+-N and NO_3^-N in the filtered extracts were determined using magnesium oxide (MgO) and Devarda's alloy (Keeney and Nelson 1982).

3.2.5.4 Cold water extractable carbon

Cold water-extractable organic carbon was determined by shaking 10 g of soil with 50 mL of distilled water for 30 min and then centrifuging for 10 min at 5000 rpm (Ghosh 2003). The organic carbon in the supernatant was measured by the dichromate digestion method (Walkley and Black 1934).

3.3 Laboratory studies

3.3.1 Experiment 3: Saline and sodic irrigation effects on carbon and nitrogen mineralization

Methodology: Soil samples (0-30 cm) for the study were collected from two ongoing long-term field experiments at the research farm of the Department of Soil Science, Punjab Agricultural University, Ludhiana. These samples were taken from three levels of each saline (EC = 0, 6 and 12 dS/m) and sodic (RSC = 0, 6.5 and 10 me /L) water treated soils. These soil samples were air-dried and passed through a 2-mm sieve and were stored at room temperature before the start of the experiment.

3.3.1.2 Treatments

The treatments consisted of three levels of saline and sodic irrigation water and two levels of carbon (0 and 1 %) which was applied through glucose.

Treatments	**Carbon (C) rates**	
Saline water levels (dS/m)	**C= 0%**	**C = 1%**
EC = 0	E_0C_0	E_0C_1
EC = 6	E_6C_0	E_6C_1
EC = 12	$E_{12}C_0$	$E_{12}C_1$
Sodic water levels(me/L)	**C= 0%**	**C = 1%**
RSC = 0	R_0C_0	R_0C_1
RSC = 6.5	$R_{6.5}C_0$	$R_{6.5}C_1$
RSC = 10	$R_{10}C_0$	$R_{10}C_1$

3.3.1.3 Incubation

After applying the amendments, 50g soil was added to PVC cores with a diameter of 4 cm and height of 5cm with a nylon mash base and packed to the bulk density of 1.49 g cm^{-3}. Soil moisture was kept at 60% of WHC by measuring core's weight regularly and adding water whenever necessary. There were four replications per irrigation water and C treatment.

The cores were placed individually into 1-L glass jars. To each jar was added a CO_2 trap containing 20 ml of 1 N sodium hydroxide (NaOH). Sealed jars were incubated in the dark at 25°C for 12 weeks and the release of CO_2 was measured daily during the first two weeks and thereafter one day interval upto 6 weeks and 2 day interval till end of experiment (12 weeks) by titrating NaOH with HCl in presence of $BaCl_2$ (Alef 1995). Separate set of cores were destructively harvested after 14 and 42 days and 84 days to determine microbial biomass C (MBC) and ammonical –N and nitrate-N. On day 0, the cores to be harvested on day 14 were placed individually into 1-L glass jars with 20 ml of 1 N NaOH and then sealed back. The remaining cores were placed in large plastic containers with loose-fitting lids. After removing, the first lot of cores from the glass jars on day 14, the cores to be sampled on day 42 and 84 were placed individually in these jars. The moisture levels in jars and plastic containers were checked twice a week by measuring weight loss, and deionised water was added when necessary to maintain constant moisture.

3.4 Statistical analyses

Data were analysed using analysis of variance (ANOVA) with CPCS1 and SAS software version 9.1 (SAS Institute Ltd., USA).

CHAPTER IV

RESULTS AND DISCUSSION

The results of experimental studies are discussed under following headings;

4.1 Experiment 1: Saline irrigation effects on performance of wheat cultivars and soil health
- 4.1.1 Effect of saline water irrigation on chemical soil health
- 4.1.2 Effect of saline water irrigation on physical soil health
- 4.1.3 Effect of saline water irrigation on biological soil health
- 4.1.4 Effect of saline water irrigation on performance of wheat cultivars

4.2 Experiment 2: Sodic irrigation effects on performance of wheat cultivars and soil health
- 4.2.1 Effect of sodic irrigation on chemical soil health
- 4.2.2 Effect of sodic irrigation on physical soil health
- 4.2.3 Effect of sodic irrigation on biological soil health
- 4.2.4 Effect of sodic irrigation on performance of wheat cultivars

4.3. Experiment 3: Saline and sodic irrigation effects on carbon and nitrogen mineralization
- 4.3.1 Effect of Saline and sodic irrigation effects on carbon and nitrogen mineralization

4.1 Experiment 1: Saline irrigation effects on performance of wheat cultivars and soil health

4.1.1 Effect of saline water irrigation on chemical soil health

4.1.1.1 Saline irrigation effects on soil pH

The data pertaining to effect of different salinity levels of irrigation water on soil pH is presented in Fig. 4.1. In general, soil pH increased significantly with increasing salinity and soil depth in both years. The magnitude of increase was higher in plots receiving 9 and 12 dS/m levels of saline irrigation water compared with plots receiving lower salinity levels (3 and 6 dS/m). In 2013-14, soil pH increased from 7.0 to 8.0 before sowing and from 7.2 to 8.1 after harvest of crop as salinity increased from 0 to 12 dS/m in surface layers , higher soil pH was observed in lower soil layers.The mean soil pH values increased from 7.56 to 8.08 before sowing and from 7.80 to 7.95 after harvest of crop as soil depth increased from 0 to 120 cm in first year.The soil pH values in next year (2014-15) were more or less similar as that of first year with increasing salinity levels. Tedeschi and Aquila (2005) observed increase in soil pH in surface soil layer from 7.3 in control to 8.1 at 15.7 dS/m irrigation water salinity level. Ragab *et al* (2008) observed significant increase in soil pH with increasing irrigation water salinity in sandy soils. Shinde *et al* (2012) reported increase in soil pH with increasing salinity under drip irrigation. Regardless of treatment, soil pH was higher at lower soil depth than surface soil layers;this may be due to movement of salts to lower layers. These results were supported by Ghuman *et al* (2010), who reported significant increase in soil pH with use of saline irrigation water compared to canal water and pH values were higher at 15-30 cm compared to 0-15 cm soil depth.

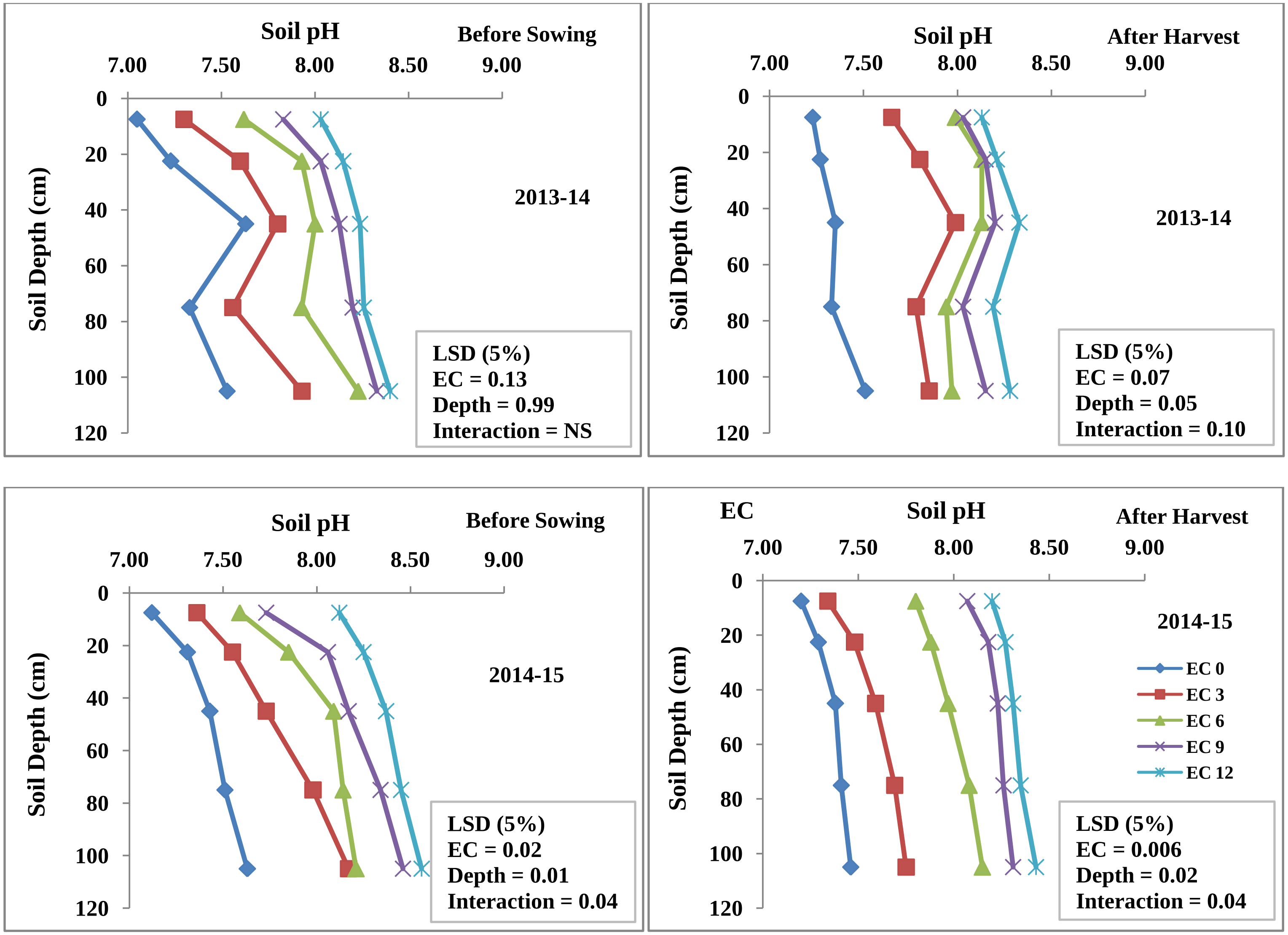


Fig. 4.1 Effect of saline irrigation water on soil pH (1:2 soil : water suspension)

Fard *et al* (2007) also reported more pH values at 15-30 cm compared to 0-15 cm soil depth. They observed that soil pH increased from 7.40 to 7.46, 7.48 at 15-30 cm and 7.24 to 7.36, 7.41for 0-15 cm at EC 4,9 and 12 dS/m levels of irrigation water salinity, respectively. Generally, more buildup of soil pH was observed at EC 3 dS/m compared to other salinity levels with increasing soil depth, which increased from around 7.2 to around 8.0 in both years except after harvest of crop in 2014-15.Regarding depth distribution, a dip in soil pH was noticed at 60-90 cm compared with 30-60 cm depth before sowing in 2013-14. The dip tended to disappear after harvesting in 2013-14. In 2014-15 however, soil pH progressively increased with increase in soil depth.The interaction effects were significant in both years except before sowing of the crop in 2013-14.

4.1.1.2 Effect of saline irrigation water on soil EC

Soil electrical conductivity **(**EC) is important indicator of soil health, which influence key soil processes. Excess salts hinder plant growth by affecting soil plant growth by affecting soil water balance.Salts also affect soil suitability, plant nutrient availability and activity of soil micro organisms.Soil EC have similar trend as that of soil pH at different salinity levels as discussed earlier in Fig.4.2. However with increased soil depth opposite trend was observed. It has been observed that soil EC increased significantly with increase in salinity of irrigation water. In 2013-14, soil salinity increased to 2.5 dS/m, when irrigated with water of 12dS/mbut it remained lower than 1.5dS/m under irrigation water salinity up to 9 dS/m salinity level. However after harvest of crop, there was buildup of soil salinity at EC 6 and 9 dS/m of irrigation water compared to before sowing, whereas at EC 12 dS/mirrigation water salinity level, not much further increase in soil salinity was observed. Fig. 4.2 depicted that in next year as well buildup of soil salinity was observed at EC 6 and 9 dS/m after harvesting compared to before sowing. However at EC 12 dS/m no notable further increase in soil salinity was observed. Nevertheless, maximum soil salinity was recorded in this treatment. This increase in soil salinity occurs due to cumulative salts build up due to irrigation with different levels of saline water irrigation. Mostafa *et al* (2012) reported that sodium concentration was gradually increased with increasing water salinity that caused increase in salinity of soil. In general,perusal of data shows that soil EC gradually decreases with soil depth from 0-15 cm to 90-120 cm in both years. These results are in agreement with Fard *et al* (2007) and Ghuman*et al* (2010), who also reported lower soil EC at 15-30 cm as compared to 0-15 cm soil depth in saline irrigated soil.

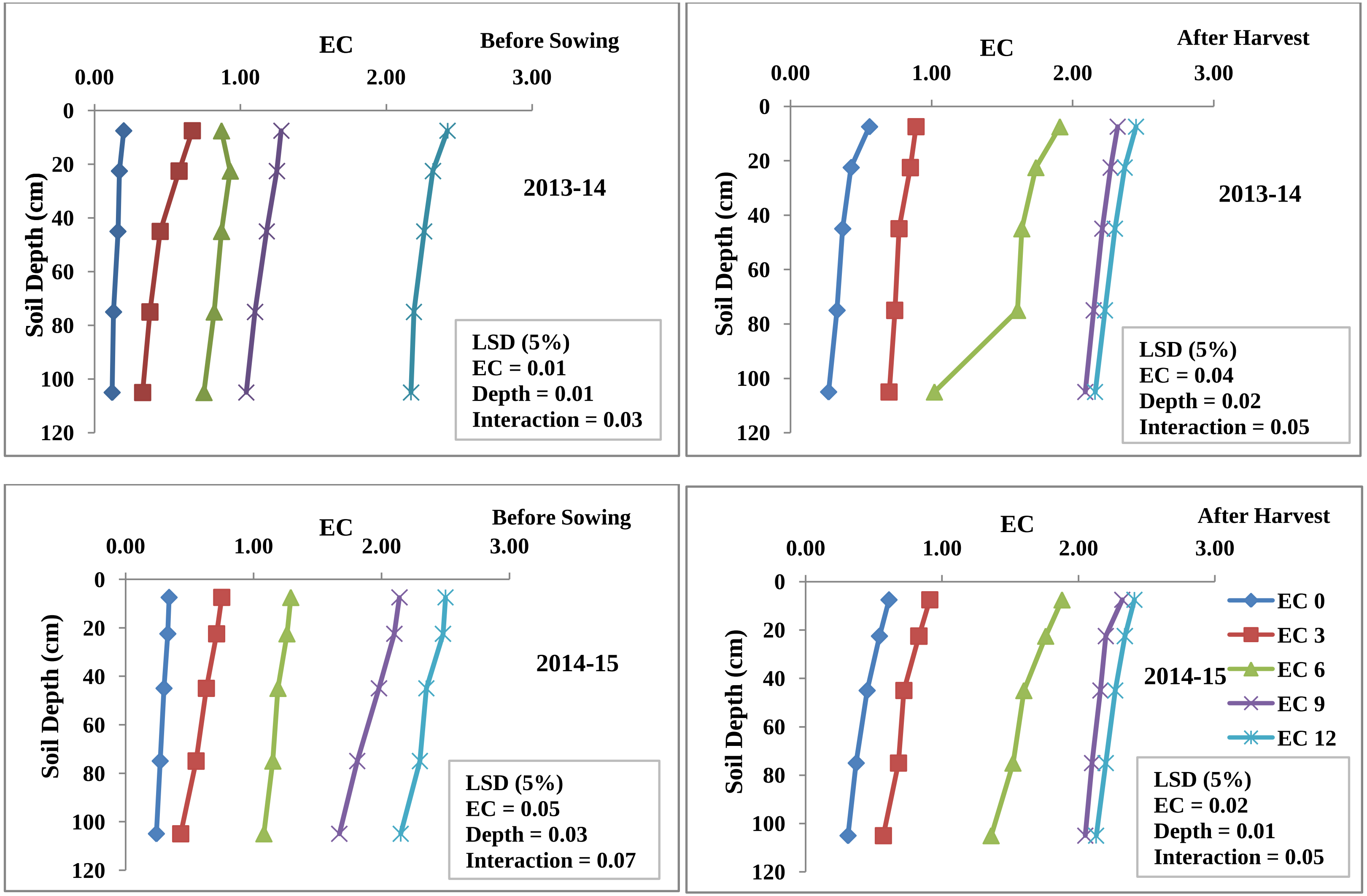


Fig. 4.2 Electrical conductivity (EC) of soil as affected by saline water irrigation (1:2 soil : water suspension; dS/m)

4.1.1.3 Effect of saline irrigation water on soilorganic carbon content

The data regarding effects of salinity on soil organic carbon (SOC) of soil profile during first and second year is presented in Table 4.1.The data revealed that SOCcontent decreased significantly with increasing salinity as compared to good quality water. Lower SOC content was observed at higher salinity water (9 and 12 dS/m) compared to lower salinity levels (3 and 6 dS/m) in both years.This reductionin SOC content may be due to less and more stressed microbial biomass present in highly saline soils (Yuan *et al* 2007). The average SOC content decreased from 3.6 to 1.7 g/kg and 3.4 to 1.6 g/kg before sowing and after harvest of wheat crop in 2013-14.In 2014-15, the mean SOC content decreased by 11.7, 29.4, 41.0 and 55.8 % before sowing and 17.2, 34.4, 44.8, and 55.2 % after harvest at EC 3, 6, 9 and 12 dS/m levels of salinity over EC 0 treatment, respectively. Yuan *et al* (2007) reported decrease in SOC content from 10.7 to 3.07 g/kg as soil salinity increased from 0.003 to 0.23dS/m.

The perusal of data presented in Table 4.1showedsignificant decrease in SOC content with increasing soil depth because most of microbial activities takes place in surface soil as compared to sub surface soil layers (15-30, 30-60, 60-90 and 90-120 cm) due to presence of high microbial biomass on soil surface. The average SOC content decreased progressively from 3.3 to 1.9 g/kg and 3.1 to 1.8g/kg before sowing and after harvest of crop in 2013-14 and from 3.3 to 1.8 g/kg before sowing and 2.7 to 1.4 g/kg after harvest of cropin 2014-15 as soil depth increased from 0-15 cm to 90-120 cm, respectively. It is evident from data that interaction effects were non-significant before sowing in 2013-14 and 2014-15, however interaction was significant afer harvest of crop in both years.

4.1.1.4 Saline irrigation water effects on soil available nitrogen

The results pertaining to available nitrogen (Av. N) content of soil as affected by irrigation water salinity is presented in Table 4.2. The data revealed that Av. N decreased significantly with increasing levels of salinity and soil depth in 2013-14 and 2014-15. However, soil was deficient in Av. N, for which sufficency range lies between 271-543 kg/ha in Punjab soils. The mean Av. N content in good quality water (EC 0) ranged from 103.9 to 124.3 kg/ha in 2013-14 and 2014-15 before sowing as well as after harvest of wheat crop. It is evident from data that mean Av. N content decreased from 109.1 in EC 0 to 74.5 kg/ha and from 103.9 (EC 0) to 68.7 kg/ha before sowing and after harvest of crop in 2013-14 ,respectively as irrigation water salinity increased from EC 0 to EC 12 dS/m. In 2014-15,mean Av. N content progressively decreased from 111.2 (EC 0) to 101.1, 87.8, 77.3, and 68.1 kg/ha before sowing and from 124.3 (EC 0) to 122.8, 97.2, 81.9 and 69.8 kg/ha after harvest of crop at EC 3, 6, 9 and 12 dS/m levels of salinity, respectively. Mashali *et al* (1995) also reported decrease in Av. N with increasing levels of irrigation water salinity. The presence of salts in soil may indirectly

Table 4.1 Saline irrigation water effect on organic carbon(g/kg) content of soil

2013-14												
Treatment / Depth	Before sowing						After harvest					
	0-15	15-30	30-60	60-90	90-120	Mean	0-15	15-30	30-60	60-90	90-120	Mean
EC 0	4.1	3.8	3.7	3.4	2.8	**3.6**	4.3	3.9	3.2	2.9	2.6	**3.4**
EC 3	3.9	3.5	3.2	2.9	2.3	**3.2**	3.7	3.3	2.6	2.4	2.1	**2.8**
EC 6	3.3	3.0	2.6	2.5	1.9	**2.6**	3.0	2.8	2.3	2.0	1.8	**2.4**
EC 9	2.6	2.3	2.1	1.8	1.5	**2.1**	2.6	2.2	1.9	1.7	1.5	**1.9**
EC 12	2.4	2.0	1.7	1.5	1.2	**1.7**	2.0	1.8	1.6	1.4	1.2	**1.6**
Mean	**3.3**	**2.9**	**2.6**	**2.4**	**1.9**		**3.1**	**2.8**	**2.3**	**2.0**	**1.8**	
LSD (5%)	EC = 0.1 Depth = 0.2 Interaction = NS						EC = 0.1 Depth = 0.2 Interaction = 0.3					
2014-15												
	Before sowing						After harvest					
Depth	0-15	15-30	30-60	60-90	90-120	Mean	0-15	15-30	30-60	60-90	90-120	Mean
EC 0	4.3	3.8	3.4	2.9	2.5	**3.4**	3.9	3.3	2.8	2.5	2.1	**2.9**
EC 3	3.9	3.5	3.0	2.5	2.2	**3.0**	3.2	2.9	2.4	1.9	1.7	**2.4**
EC 6	3.2	2.8	2.4	2.0	1.7	**2.4**	2.7	2.3	1.8	1.6	1.4	**1.9**
EC 9	2.7	2.3	1.9	1.6	1.4	**2.0**	2.1	2.0	1.5	1.3	1.2	**1.6**
EC 12	2.2	1.8	1.5	1.2	1.1	**1.5**	1.7	1.5	1.2	1.1	1.0	**1.3**
Mean	**3.3**	**2.8**	**2.4**	**2.0**	**1.8**		**2.7**	**2.4**	**1.9**	**1.6**	**1.4**	
LSD (5%)	EC= 0.2 Depth= 0.2 Interaction = NS						EC= 0.1 Depth= 0.2 Interaction = 0.4					

affect N availability through inhibition of microbial N mineralization and immobilization processes and also by increasing soil pH (Grattan and Grieve 1999). Uptake of NO_3^- also suppressed due to competiton with Cl^- in NaCl dominated salinity (Elgharably 2008).

Soil Av.N decreased significantly with increasing soil depth from 0 to 120 cm in both years. In first year, mean Av.N content decreased from 108.3 to 74.2 kg/ha and from 98.6 to 73.5 kg/ha before sowing and after harvest of crop with increase in soil depth from 0-15 cm to 90-120 cm, respectively. The corresponding decrease in second year occurred from 115.4 to 67.5 kg/ha and from 116.8 to 76.3 kg/ha.A perusal of data shows that interaction between salinity levels and soil depth for Av. N was significant for both years. In the surface soil (0-15 cm), Av. N content significantly decreased by 32.0 and 36.9 % in 2013-14 and by 39.8 and 42.8 % in 2014-15 at 12dS/m irrigation water salinity level over EC 0 before sowing and after harvest of crop.

4.1.1.5 Soil available phosphorous as affected by saline irrigation water

The available phosphorous (Av. P) was sufficient in experimental soil but decreased significantly with increasing salinity and soil depth (from 0 to 120cm). The data shows significant interaction between salinity levels and soil depth in 2013-14, however it was non-significant in 2014-15 (Table 4.3).

It is evident from datathatpercentage decrease in mean Av.P was 12.7, 26.5, 35.8 and 46.9 %before sowing and 13.9, 26.7, 39.6 and 51.6 % after harvest of crop at EC 3, 6, 9 and 12 dS/m as compared to EC 0 in 2013-14. Furthermore, as soil depth increased from 0 to 120cm, meanAv. P content decreased from 42.8 to21.1 kg/ha and from 36.0 to 19.6 kg/ha before sowing and after harvest of crop in first year. In 2014-15, mean Av. P content progressively decreased from 37.6 in EC 0 to 32.6, 28.2, 24.4 and 20.4 kg/ha before sowing and from 33.9 kg/ha (EC 0) to 29.9, 25.9,21.1 and 17.3 kg/ha after harvest of wheat at EC 3 , 6, 9 and 12 dS/m, respectively.Elgharably (2008) reported decrease in Av. P with increasing salinity.The phosphorous availability is reduced in saline soils not only because of ionic strength effects that reduced activity of phosphorous, but because of phosphorousconcentration in soil solution highly controlled by sorption processes and low solubility of Ca-P minerals (Qadir and Schubert 2002). Awad *et al* (1990) reported that with increasing NaCl salinity from 10 to 100mM in the solution culture, P activity decreased due to increased ionic strength. Mashali *et al* (2009) reported decrease in Av. P with increasing salinity of irrigation water was attributed to increased soil calcium (Ca) and hence precipitated as Ca-phosphatecompounds. These results were supported by Aslam *et al* (1996), who reported that with increasing Ca concentration, P can precipitate as poorly soluble Ca-P compounds.

Table 4.2 Effect of saline irrigation water on available nitrogen content (kg/ha) of soil

2013-14											
Treatment / Depth	**Before sowing**						**After harvest**				
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	133.7	123.3	104.5	96.2	87.8	**109.1**	120.2	113.8	103.7	94.4	87.3	**103.9**
EC 3	118.1	112.5	93.4	86.3	81.5	**98.4**	111.8	101.4	98.5	83.2	80.7	**95.2**
EC 6	103.7	98.7	86.7	78.8	72.3	**88.1**	98.2	94.3	80.9	76.3	72.5	**84.5**
EC 9	96.2	87.5	79.5	70.4	68.5	**80.4**	86.9	80.6	77.2	69.1	65.8	**75.9**
EC 12	89.9	81.5	72.5	67.4	61.2	**74.5**	75.8	73.1	70.1	63.5	61.2	**68.7**
Mean	**108.3**	**100.7**	**87.3**	**79.8**	**74.2**		**98.6**	**92.6**	**86.1**	**77.3**	**73.5**	
LSD (5%)	**EC= 0.97Depth= 0.99 Interaction = 2.21**						**EC= 1.53 Depth= 1.09 Interaction = 2.45**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	145.9	123.8	106.6	94.1	85.4	**111.2**	146.2	135.8	124.4	118.7	96.4	**124.3**
EC 3	130.4	114.5	96.5	86.6	77.5	**101.1**	133.2	127.4	116.5	98.2	88.7	**112.8**
EC 6	112.6	102.3	84.2	74.1	65.9	**87.8**	121.5	113.2	97.4	81.3	72.5	**97.2**
EC 9	99.5	88.4	75.1	65.8	57.8	**77.3**	99.4	91.3	78.7	72.1	68.4	**81.9**
EC 12	87.8	78.1	67.4	56.4	50.8	**68.1**	83.6	80.5	67.9	61.4	55.6	**69.8**
Mean	**115.4**	**101.4**	**85.9**	**75.4**	**67.5**		**116.8**	**109.6**	**96.7**	**86.4**	**76.3**	
LSD (5%)	**EC= 1.89 Depth= 1.54 Interaction = 3.45**						**EC= 1.60 Depth= 1.09 Interaction = 2.45**					

Table 4.3 Available phosphorous (kg/ha) contentas affected by salinity of irrigation water

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	55.7	46.5	40.1	33.1	28.3	**40.7**	49.8	44.5	39.8	34.1	28.5	**39.3**
EC 3	49.4	38.9	35.6	28.2	25.5	**35.5**	41.4	39.4	37.0	29.1	22.2	**33.8**
EC 6	41.5	33.4	30.7	23.7	20.1	**29.9**	36.2	33.5	32.0	23.9	18.7	**28.8**
EC 9	36.2	29.6	27.4	19.8	17.2	**26.1**	29.5	28.2	26.5	19.4	15.2	**23.7**
EC 12	31.2	24.2	23.3	15.4	14.1	**21.6**	23.1	21.5	19.8	17.1	13.5	**19.0**
Mean	**42.8**	**34.5**	**31.4**	**24.1**	**21.1**		**36.0**	**33.4**	**31.0**	**24.7**	**19.6**	
LSD (5%)	**EC= 1.4Depth= 1.3 Interaction = 2.8**						**EC= 0.8 Depth= 1.0 Interaction = 2.3**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	48.5	42.4	38.6	31.1	27.7	**37.6**	45.6	37.8	33.2	28.4	24.5	**33.9**
EC 3	41.2	37.8	34.2	26.9	23.1	**32.6**	40.9	32.4	29.8	25.5	21.2	**29.9**
EC 6	36.4	33.1	29.7	22.4	19.3	**28.2**	36.7	28.7	26.4	19.3	18.9	**25.9**
EC 9	32.1	28.5	25.2	18.5	17.6	**24.4**	29.1	24.2	20.9	16.4	15.2	**21.1**
EC 12	25.9	23.8	20.1	16.6	15.8	**20.4**	22.8	20.7	17.5	13.2	12.1	**17.3**
Mean	**36.8**	**33.1**	**29.5**	**23.1**	**20.7**		**35.0**	**28.8**	**25.6**	**20.6**	**18.4**	
LSD (5%)	**EC = 1.1 Depth = 1.7 Interaction = NS**						**EC= 2.4 Depth= 1.6 Interaction = NS**					

The perusal of data shows that significant interaction was observed for Av. P between salinity levels and soil depth in 2013-14; where, Av. P content significantly decreased by almost 50 % at EC 12 compared to EC 0 for 60-90 cm soil depth before sowing as well as after harvest of the crop.

4.1.1.6 Effect of saline irrigation water on soil available potassium

The data regarding saline irrigationwatereffect on available potassium (Av. K) in 2013-14 and 2014-15 before sowing and after harvest of wheat crop is presented in Table 4.4.Significant reduction in Av. K in 2013-14 and 2014-15 was observed with increasing levels of irrigation water salinity but no particular trend was observed with increasing soil depth in both years. Irrigationwith 12 dS/m saline water resulted in the maximum reduction in Av. K content which decreased by 30.3 and 36.4 % over EC 0 before sowing and after harvest of wheat crop in 2013-14. The corresponding decline in 2014-15was 25.3 % and 40.3 % as compared to EC 0. The decrease in Av. K may be due to inhibitingeffect of Na on K in saline water irrigated soils, which increased as salinity of irrigation water increases.

It is clear from data that interaction between salinity levels and soil depth for soil Av. K was significant in 2013-14 and 2014-15. Av. K significantly decreased by 1.5 times at 90-120 cm soil depth in 2013-14 and 1.4 times at 0-15 cm soil depth in 2014-15at EC 12 dS/m compared to EC 0 before sowing as well as after harvest of crop.

4.1.1.7 Saline irrigation water effects on soil available sulphur

Effect of different salinity levels on available sulphur (Av. S) content of soil was observed in 2013-14 and 2014-15, before sowing and after harvest of wheat crop and ispresentedin Table 4.5. The present research study revealed that mean Av. S content decreased significantly with increasing salinity as well as soil depthin both years. A perusal of data shows that meanAv. S content decreased by 14.6, 29.7, 54.3 and 66.2 % before sowing and 15.1, 29.0, 43.0 and 55.8 % after harvest of wheat crop at EC 3, 6, 9 and 12 dS/m salinity treatments over EC0 in 2013-14, respectively. Correpondingly, in 2014-15 mean Av. S content decreased from 29.8 ppm in EC 0 to 26.3, 21.8, 18.1 and 15.3 ppm and from 24.7 ppm (EC 0) to 21.6, 18.6, 15.6 and 13.6 ppm before sowing and after harvest of wheat crop, respectively. It was observed that continuous application of NaCl rich irrigation water resulted in buildup of high chloride in soil solution which competed with sulphate ions and reduceses its availability in soil.

Table 4.4 Saline irrigation water effects on available potassium(kg/ha) content of soil

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	150.2	170.5	174.8	180.4	168.0	**168.8**	196.0	167.7	149.1	154.0	144.5	**162.2**
EC 3	138.2	155.2	161.4	155.1	145.0	**151.0**	151.0	137.0	132.1	139.8	140.7	**140.1**
EC 6	137.3	142.1	144.8	125.4	140.6	**138.0**	140.6	127.8	117.9	119.9	131.5	**127.5**
EC 9	127.6	137.0	127.6	121.5	135.9	**129.9**	139.0	119.3	112.9	109.4	119.0	**119.9**
EC 12	119.6	130.0	109.3	116.8	112.4	**117.6**	127.0	105.4	95.8	94.1	92.8	**103.0**
Mean	**134.6**	**146.9**	**143.6**	**139.8**	**140.3**		**150.7**	**131.4**	**121.5**	**123.4**	**125.7**	
LSD (5%)	**EC= 1.6Depth= 1.3 Interaction = 2.9**						**EC= 1.1 Depth= 1.6 Interaction = 3.5**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	166.8	154.1	158.8	162.6	150.2	**158.5**	171.9	165.4	175.5	168.9	153.8	**167.1**
EC 3	158.4	140.7	143.5	151.8	141.6	**147.2**	158.8	148.5	161.2	141.2	138.2	**149.6**
EC 6	141.1	131.4	132.4	139.5	134.7	**135.8**	140.5	123.7	149.4	122.8	121.5	**131.6**
EC 9	130.7	124.7	121.9	127.5	125.4	**126.1**	129.4	116.4	118.7	109.4	105.3	**115.8**
EC 12	118.8	116.7	115.8	120.4	119.7	**118.3**	118.2	103.6	98.3	91.8	85.9	**99.6**
Mean	**143.1**	**133.5**	**134.5**	**140.3**	**134.3**		**143.8**	**131.5**	**140.6**	**126.8**	**120.9**	
LSD (5%)	**EC = 1.8 Depth = 1.7 Interaction = 3.8**						**EC= 1.9 Depth= 1.6 Interaction = 3.7**					

Table 4.5 Effect of saline irrigation water on available sulphur(ppm) contentof soil

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	43.6	42.6	40.1	39.1	36.0	**40.3**	41.4	37.6	36.5	34.5	31.2	**36.2**
EC 3	37.5	35.1	33.8	33.3	32.2	**34.4**	37.5	32.3	30.1	28.3	25.6	**30.7**
EC 6	31.4	29.6	28.2	27.5	24.5	**28.3**	32.2	26.6	25.4	23.1	21.4	**25.7**
EC 9	21.5	18.7	18.5	17.9	15.2	**18.4**	27.6	21.7	19.4	17.8	16.4	**20.6**
EC 12	15.9	14.4	13.5	12.4	11.6	**13.6**	21.3	19.1	16.5	12.6	10.7	**16.0**
Mean	**30.0**	**28.1**	**26.8**	**26.1**	**23.9**		**32.0**	**27.5**	**25.6**	**23.2**	**21.1**	
LSD (5%)	**EC= 0.4Depth= 0.6 Interaction = 1.2**						**EC= 1.3 Depth= 1.0 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	38.1	34.4	29.8	25.6	21.5	**29.8**	34.1	29.8	23.5	19.7	16.4	**24.7**
EC 3	35.3	30.2	24.6	22.9	18.6	**26.3**	28.2	27.1	20.2	17.5	15.2	**21.6**
EC 6	28.4	26.4	19.9	18.7	15.8	**21.8**	24.5	23.5	17.3	14.1	13.5	**18.6**
EC 9	23.8	21.9	16.5	15.2	13.2	**18.1**	20.8	18.5	14.1	12.3	12.1	**15.6**
EC 12	19.4	17.5	14.4	13.4	11.4	**15.3**	17.4	15.2	12.3	11.8	11.5	**13.6**
Mean	**29.0**	**26.1**	**21.1**	**19.2**	**16.1**		**25.0**	**22.8**	**17.5**	**15.1**	**13.7**	
LSD (5%)	**EC = 1.9 Depth = 1.4 Interaction = 3.1**						**EC= 1.8 Depth= 1.2 Interaction = 2.7**					

The data also shows significant interaction between different salinity levels and soil depth for Av. S in both years except after harvest of crop in 2013-14, where it was non-significant. It is evident from data that Av. S progressively decreased by 3 times in 2013-14 and 2 times in 2014-15 at 60-90 cm soil depth as irrigation water salinity increased from EC 0 to EC 12 dS/m

4.1.1.8 DTPA-Zn as affected by saline irrigation water

Irrigation with water having variable salinity significantly decreasesd DTPA-Zn, before sowing **as** well as after harvest of wheat crop in 2013-14 and 2014-15.It is evident from data that DTPA-Zn values were higher in magnitude for the second year compared to first year at all levels of salinity. It was observed that average DTPA-Zn decreased from 2.32 to 0.74 ppm and from1.94 to 0.79 ppm before sowing and after harvest of crop in EC 0 to EC12 treatment in 2013-14. Compared with EC 0, DTPA-Zn decreased by 3.0, 15.1, 25.2 and 34.7 % before sowing and 1.74, 10.5, 14.5 and 20.6 % after harvest of crop at EC 3, 6,9 and12dS/m, respectively in2014-15. Availability and solubility of micronutrients (Mn, Cu, Fe and Zn) is extremely low in saline soils andcrops show deficiency of these nutrients (Page *et al* 1996). The data presented in Table 4.6 revealed that DTPA-Zn also decreased with increasing soil depth in both years. The mean DTPA-Zn progressively decreased from 2.26 to 0.95 ppm and from 1.98 to 0.91 ppm before sowing and after harvest of crop in 2013-14 as soil depth increased from 0-15cm to 90-120 cm. Correspondingly in 2014-15, DTPA-Zn decreased from 3.39 to 2.78 ppm before sowing and 3.28 to 2.94 ppm after harvest of crop as soil depth increased from 0 to 120 cm.

A perusal of data showed that there was significant interaction between salinity levels and soil depth for DTPA-Zn for both years. As salinity increased from 0 to 12 dS/m at 90-120 cm soil depth, DTPA-Zn significantly decreased to 0.4 and 0.5 ppm before sowing and after harvest of crop in 2013-14, which was less than critical limit (DTPA-Zn = 0.6 ppm) for Zn deficient soils

4.1.1.9 Saline irrigation water effects on soluble potassium

Soluble K concentration in experimental soil showed decreasing trend with increasing salinity of irrigationwater, before sowing and after harvest of crop in 2013-14 and 2014-15(Table 4.7). The mean soluble Kcontent decreased from 4.5me/L in EC 0 to 3.9, 3.4, 2.9 and 1.8me/L before sowing and from 4.3 me/L (EC 0) to 3.5, 3.1, 2.4 and 1.3 me/L after harvest of crop at EC 3,6,9 and 12 dS/m , respectively in 2013-14.

Table 4.6 Effect of saline irrigation water on soil DTPA-Zn (ppm)

2013-14											
Treatment / Depth	**Before sowing**						**After harvest**				
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	3.13	2.66	2.33	1.83	1.63	**2.32**	2.70	2.33	1.90	1.50	1.30	**1.94**
EC 3	2.83	2.43	1.76	1.40	1.33	**1.95**	2.40	2.03	1.63	1.30	1.23	**1.72**
EC 6	2.36	1.90	1.33	1.03	0.80	**1.48**	1.90	1.73	1.33	1.03	0.90	**1.38**
EC 9	1.90	1.30	0.80	0.70	0.60	**1.01**	1.66	1.33	0.83	0.73	0.60	**1.03**
EC 12	1.10	0.91	0.70	0.60	0.40	**0.74**	1.26	0.90	0.63	0.63	0.53	**0.79**
Mean	**2.26**	**1.84**	**1.38**	**1.11**	**0.95**		**1.98**	**1.66**	**1.26**	**1.04**	**0.91**	
LSD (5%)	**EC= 0.10Depth= 0.12 Interaction = 0.26**						**EC= 0.08 Depth= 0.11 Interaction = 0.25**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	4.10	3.88	3.61	3.42	3.23	**3.65**	3.63	3.51	3.42	3.36	3.30	**3.44**
EC 3	3.96	3.73	3.52	3.31	3.18	**3.54**	3.57	3.46	3.37	3.28	3.24	**3.38**
EC 6	3.44	3.23	3.18	2.94	2.71	**3.10**	3.21	3.18	3.11	3.00	2.93	**3.08**
EC 9	2.89	2.78	2.70	2.68	2.60	**2.73**	3.10	3.02	2.97	2.87	2.77	**2.94**
EC 12	2.58	2.47	2.38	2.31	2.20	**2.38**	2.91	2.84	2.75	2.68	2.51	**2.73**
Mean	**3.39**	**3.22**	**3.07**	**2.93**	**2.78**		**3.28**	**3.20**	**3.12**	**3.04**	**2.94**	
LSD (5%)	**EC = 0.02 Depth = 0.01 Interaction = 0.04**						**EC= 0.02 Depth= 0.02 Interaction = 0.04**					

Table 4.7 Soluble potassium as affected by salinity of irrigation water (me/L)

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	5.0	4.6	4.4	4.3	4.0	**4.5**	5.3	4.8	4.3	3.9	3.1	**4.3**
EC 3	4.5	4.2	4.0	3.6	3.3	**3.9**	5.0	4.2	3.3	2.6	2.2	**3.5**
EC 6	4.0	3.8	3.5	3.1	2.7	**3.4**	4.3	3.7	2.9	2.5	2.1	**3.1**
EC 9	3.6	3.3	3.0	2.6	2.3	**2.9**	3.5	3.1	2.3	1.6	1.2	**2.4**
EC 12	3.0	2.4	1.6	1.2	0.7	**1.8**	2.2	1.7	1.2	0.8	0.5	**1.3**
Mean	**4.0**	**3.6**	**3.2**	**2.9**	**2.6**		**4.0**	**3.4**	**2.8**	**2.3**	**1.8**	
LSD (5%)	**EC = 0.2 Depth = 0.3 Interaction = NS**						**EC= 0.2 Depth= 0.2 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	4.8	4.5	4.3	3.9	3.4	**4.2**	6.3	5.7	5.0	4.6	4.4	**5.2**
EC 3	4.0	3.7	3.3	2.8	2.5	**3.2**	5.3	5.1	4.2	3.8	3.6	**4.4**
EC 6	3.7	3.3	2.7	2.1	1.7	**2.7**	4.9	3.5	3.0	2.7	2.3	**3.2**
EC 9	3.1	2.7	2.3	1.8	1.2	**2.2**	3.4	2.8	2.5	1.9	1.7	**2.4**
EC 12	2.6	2.2	1.5	1.1	0.6	**1.6**	3.0	2.2	1.8	1.6	1.3	**1.9**
Mean	**3.6**	**3.3**	**2.8**	**2.3**	**1.9**		**4.6**	**3.8**	**3.3**	**2.9**	**2.6**	
LSD (5%)	**EC = 0.3 Depth = 0.1 Interaction = NS**						**EC= 0.2 Depth= 0.1 Interaction = NS**					

It is evident from the data that the maximum reduction of soluble K occured at highest level of salinity water (EC =12dS/m) which was 60.0 and 69.5 % as compared to EC 0 treatment, before sowing and after harvest of wheat crop. Similarly in 2014-15, soluble K decreased by 23.8, 35.7, 47.6 and 61.9 % before sowing and 15.3, 38.5, 53.8 and 63.4 % after harvest of crop at EC 3,6,9 and 12 dS/m levels of irrigation water over control (EC 0), respectively. This decrease in soluble K level of soil may be due to higher accumulation of Na in soil irrigated with saline waters dominated with NaClthat suppressed K solubility.El-Boraie (1997) also found that soluble K decreased with increasing salinity levels. Ragab *et al* (2008) reported that soluble K significantly decreased from 0.39 to 0.26 me/L in sandy soils and from 0.84 to 0.68 in calcerous soil as irrigation water salinity increased from 0.4 to 8.9 dS/m, which were lower than values of soluble K in present reaserch study as salinity levels were higher in our experiment.

It has been observed that with increasing soil depth soluble K also decreased significantly. The average soluble K decreased from 4.0 to 2.6 me/L and 4.0 to 1.8 me/L as soil depth increased from 0 to 120cm before sowing and after harvest of crop in 2013-14. In next year, mean soluble K decreased from 3.6 to 1.9 me/L before sowing and from 4.6 to 2.6 me/L after harvest of crop at respective soil depths. Interaction between salinity levels and soil depth intervals was not significant for soluble Kin both years.

4.1.1.10 Soluble sodium as affected by salinity of irrigation water

The data presented in Table 4.8 revealed that there was significant increase in soluble Na concentration with increasing salinity before sowing and after harvest of crop in both years of research study. Soluble Na progressively increased from 0.4 (EC 0), 2.6, 4.1, 4.7 and 5.3 me/L at EC 3, 6, 9 and 12 dS/m levels of irrigation water before sowing in 2013-14. Corresponding increase in Na content after harvest was 0.5 (EC 0) to2.2, 3.8, 4.6 and 5.4 me/Lat respective water salinity levels in first year.In 2014-15, soluble Na concentration increased from 0.7 to 7.3 me/L and from 0.6 to 4.2 me/L with increase in EC 0 (control)to EC 12 (highest level of salinity) before sowing as well as after harvest of the wheat crop. This increase inNaconcentration occured due to increasing levels of NaCl in irrigation water applied to soil. Similar results were reported by Ragab *et al* (2008)who observed thatsoluble Na concentration increased by 121, 285 and 610 % in sandy soil and 94, 267 and 531 % in calcareous soilat EC 4.9, 6.6 and 8.9 dS/m of irrigation water compared to control. When results pertaining to soil depth were considered, it was found that increasing levels of salinity resulted in significant decrease in soluble Na with increasing soil depth. As soil depth increased from 0 to 120cm, mean soluble Nadecreased from 4.6 to 2.5 me/L and from 4.8 to 2.2 me/L before sowing and after harvest of wheat crop in 2013-14 and from 5.2 to 3.0 me/L before sowing and 4.4 to 1.8 me/L after harvest of crop in 2014-15.

A perusal of data shows that interaction effects for soluble Na were significant in 2013-14 and 2014-15 except before sowing of crop in 2013-14. Statistically similar values were observed at EC 6 (30-60cm) and EC 9 dS/m (60-90 cm) before sowing and at EC 6 (15-30 cm) and EC 9 dS/m (30-60 cm) after harvest of wheat crop in 2014-15, respectively.

4.1.1.11 Effect of saline irrigation water on soluble Ca + Mg

The soluble Ca + Mg concentration as influenced by different levels of saline irrigation water in 2013-14 and 2014-15 is presented in Table 4.9. It was observed that soluble Ca + Mg follow the same trend as that of soluble K (Table 4.7) i.e. decreasing with increasing levels of salinity of irrigation water. The mean soluble Ca+Mg concentration decreased significantly with increasing salinity of irrigation water except at EC3 dS/m , where no significant reduction of soluble Ca + Mg occured when compared to EC 0 treatment in both years. The average soluble Ca + Mg value decreased by 8.6, 15.2, 26.1 and 32.6 % at salinity levels of 3, 6, 9 and 12 dS/m as compared to control before sowing and by 8.8, 17.5, 29.8 and 42.1 % after harvest of crop in 2013-14 at respective levels of salinity over control. Correspondingly, in 2014-15, compared to EC 0, mean soluble Ca + Mg concentration decreased by 3.7, 13.2, 22.6 and 32.0 % and 7.6, 17.9, 30.8 and 43.5% before sowing and after harvest of wheat crop at respective levels of irrigation water. Grattan and Grieve (1999) reported that Ca activity decraeses in salt affected sooils due to ion interactions, precipitation and increase in ionic strength, thereby decreasing Ca available to plants

The data also revealed that soluble Ca + Mg decreased significantly with increasing soil depth from 0 to 120 cm in both years. Non-significant interaction between different salinity levels and soil depth was observed for soluble Ca + Mg in 2013-14 and 2014-15.

Table 4.8 Soluble sodium (me/L) as affected by salinity of irrigation water

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.6	0.5	0.4	0.3	0.2	**0.4**	0.8	0.5	0.4	0.3	0.2	**0.5**
EC 3	4.1	2.9	2.4	2.1	1.7	**2.6**	3.7	2.3	2.0	1.8	1.3	**2.2**
EC 6	5.5	4.3	4.0	3.6	3.1	**4.1**	5.5	4.2	3.7	2.9	2.6	**3.8**
EC 9	6.2	5.0	4.7	4.3	3.5	**4.7**	6.5	5.1	4.5	3.8	3.1	**4.6**
EC 12	6.9	5.6	5.1	4.9	4.0	**5.3**	7.5	6.0	5.2	4.5	3.9	**5.4**
Mean	**4.6**	**3.7**	**3.3**	**3.0**	**2.5**		**4.8**	**3.6**	**3.2**	**2.7**	**2.2**	
LSD (5%)	**EC = 0.4 Depth = 0.3 Interaction = NS**						**EC= 0.2 Depth= 0.3 Interaction = 0.6**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.9	0.8	0.7	0.6	0.5	**0.7**	0.8	0.6	0.5	0.5	0.3	**0.6**
EC 3	3.8	3.7	3.4	2.9	2.2	**3.2**	3.9	2.6	2.3	1.9	1.7	**2.5**
EC 6	5.2	4.9	4.2	3.7	3.3	**4.2**	5.0	3.5	3.0	2.3	2.0	**3.2**
EC 9	6.9	6.2	5.9	4.5	3.9	**5.4**	5.7	4.1	3.5	2.7	2.3	**3.7**
EC 12	8.8	8.1	7.7	6.6	5.3	**7.3**	6.3	4.8	4.0	3.1	2.8	**4.2**
Mean	**5.2**	**4.7**	**4.4**	**3.7**	**3.0**		**4.4**	**3.1**	**2.7**	**2.1**	**1.8**	
LSD (5%)	**EC = 0.2 Depth = 0.3 Interaction = 0.6**						**EC= 0.5 Depth= 0.2 Interaction = 0.5**					

Table 4.9 Effect of saline irrigation water on soluble Ca+Mg (me/L)

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.53	0.47	0.45	0.42	0.40	**0.46**	0.65	0.60	0.57	0.55	0.49	**0.57**
EC 3	0.50	0.44	0.42	0.38	0.35	**0.42**	0.60	0.57	0.53	0.47	0.41	**0.52**
EC 6	0.48	0.40	0.39	0.35	0.32	**0.39**	0.56	0.52	0.48	0.43	0.34	**0.47**
EC 9	0.42	0.35	0.34	0.32	0.28	**0.34**	0.49	0.43	0.42	0.39	0.30	**0.40**
EC 12	0.38	0.33	0.30	0.29	0.25	**0.31**	0.41	0.38	0.33	0.30	0.25	**0.33**
Mean	**0.46**	**0.40**	**0.38**	**0.35**	**0.32**		**0.54**	**0.49**	**0.46**	**0.43**	**0.36**	
LSD (5%)	**EC = 0.08 Depth = 0.06 Interaction = NS**						**EC= 0.05 Depth= 0.06 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.60	0.58	0.57	0.51	0.45	**0.53**	0.48	0.44	0.39	0.36	0.32	**0.39**
EC 3	0.56	0.54	0.53	0.47	0.43	**0.51**	0.47	0.41	0.37	0.29	0.28	**0.36**
EC 6	0.51	0.49	0.52	0.43	0.39	**0.46**	0.43	0.37	0.31	0.24	0.23	**0.32**
EC 9	0.48	0.45	0.47	0.37	0.32	**0.41**	0.38	0.34	0.27	0.19	0.17	**0.27**
EC 12	0.43	0.40	0.40	0.33	0.27	**0.36**	0.33	0.28	0.23	0.15	0.13	**0.22**
Mean	**0.52**	**0.49**	**0.49**	**0.42**	**0.37**		**0.42**	**0.37**	**0.31**	**0.25**	**0.22**	
LSD (5%)	**EC = 0.04 Depth = 0.05 Interaction = NS**						**EC= 0.07 Depth= 0.05 Interaction = NS**					

4.1.1.12 Sodium adsorption ratio of soil as affected by saline irrigation water

Sodium adsorption ratio (SAR) is an indicator of amount of sodium relative to Ca + Mg and is considered an index of Na hazard. Data in Fig. 4.3 showed that SAR increased significantly with increasingsalinitylevels in 2013-14 and 2014-15. In genral SAR values in the surface layer (0-15cm) increased at EC 9 and 12 dS/m in both years, whereas values were around 10 at EC6 dS/m. In first year not much increase in SAR values were observed after harvet of the crop over those before sowing as depicted in Fig 4.3. In 2014-15, before sowing at EC 12, where SAR values in 0-15 cm soil depth reached upto 20 however after the harvest values again decreased to about15. It was observed that the SAR of the soil progressively increased due to addition of Nathrough saline irrigation waters, which resulted in significant increase in Na in proportion to Ca+Mg resulting in substaintial increase in SAR in both years. Mahdy (2011) reported that SAR increased from 5.29 to 8.27 with increasing salinity of irrigation water from 0.5 to 8.70 dS/m. Fig. 4.3 also depicted that with increasing soil depth SAR values decreased in all treatments. This decrease was sharp at 15-30 cm soil depth, whereas at lower soil layers decrease in SAR values were gradual in both years. Similar results were reported by Fard *et al* (2007) that as irrigation water salinity increased the soil salinity and SAR increases and effects were more in surface as compared to sub surface soil layers. Interaction between different salinitylevels and soil depth for SAR was non-significant in both years.

4.1.1.13 Saline irrigation water effect on exchangeable sodium percentage of soil

The data pertaining to effect of saline irrigation water on exchangeable sodium percentage **(**ESP) of soil in 2013-14 and 2014-15 is presented in Fig 4.4. A perusal of data shows that ESP of soil follows the same trend as that of observed for SAR i.e. increased with salinity and decreased with soil depth in both years.Tedeschi and Aquila (2005) also reported increase in ESP with increasing salinity of irrigation water. The ESP of soil ranged from 2.2 to 32.2 % before sowing and after harvest at different salinity levels and soil depth of crop in 2013-14 and 2014-15. Fig 4.4 shows buildup of ESP at EC 9dS/m after harvest compared to before sowing in 2014-15, however at EC 12 dS/m no further increase in ESP was observed. ESP values were higher in 0-15 cm soil depth, which decreased uniformly with increasing soil depth. These higher values can be attributed to accumulation of salts to surface layer through capillary action. These results were supported by Shinde *et al* (2012), who observed higher ESP values at soil surface those to lower soil layers with saline water for drip irrigation.

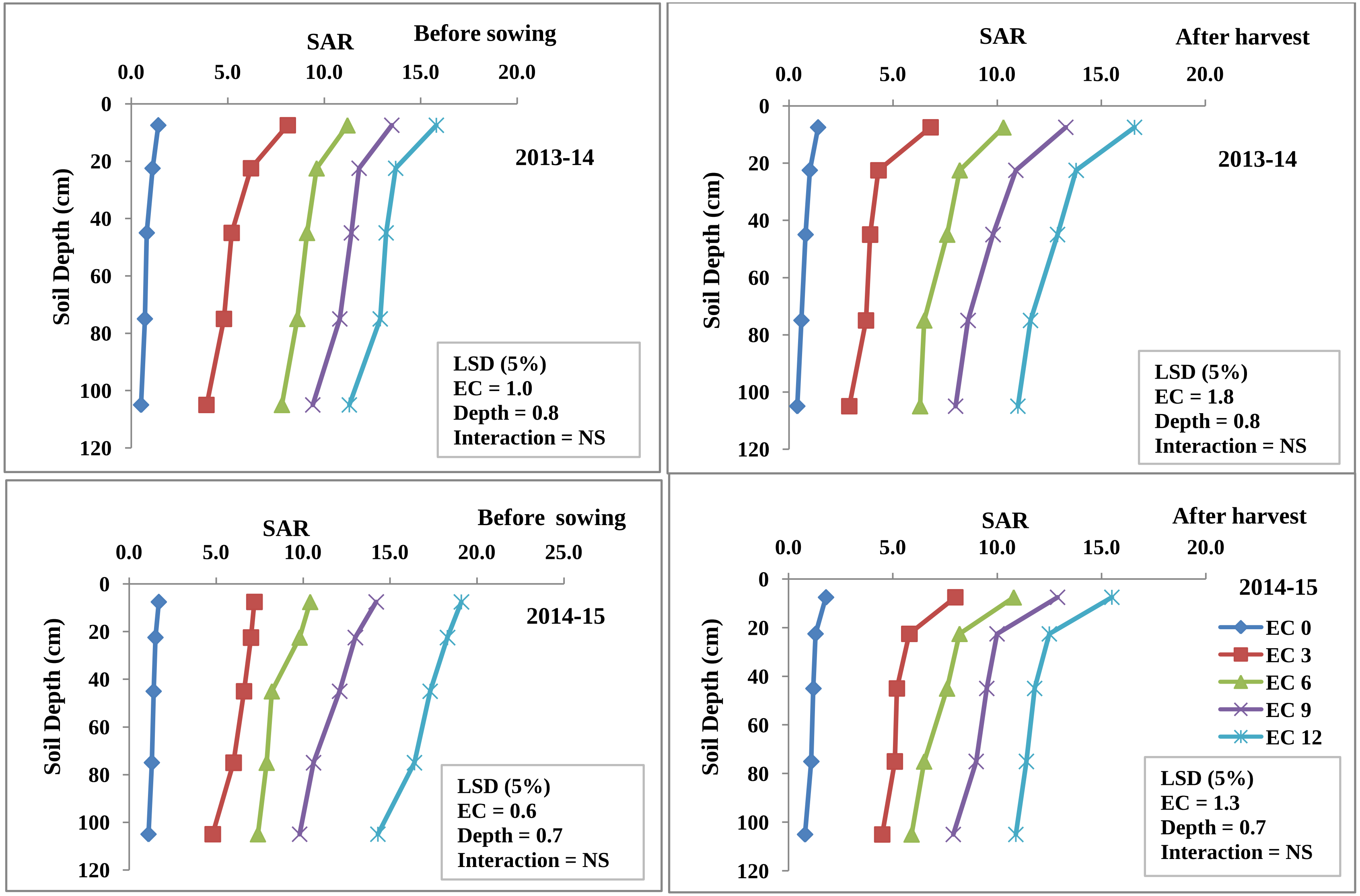


Fig 4.3 Sodium adsorption ratio (SAR) of soil as affected by saline irrigation water

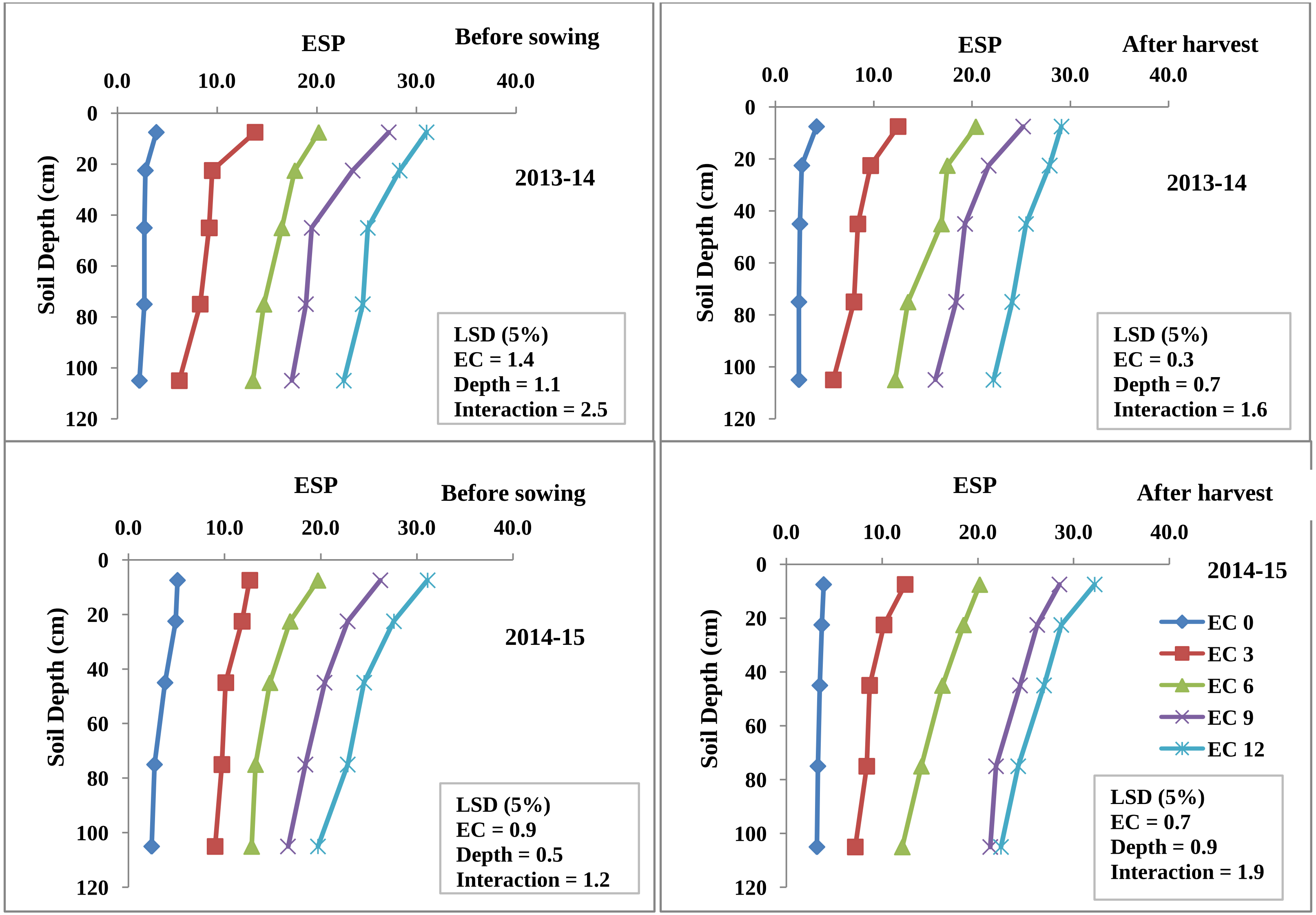


Fig 4.4 Saline irrigation water effects on exchangeable sodium percentage (ESP) of soil

4.1.1.14 Effect of saline irrigation water on soluble bicarbonate

Soluble bicarbonate (HCO_3^-)concentration as affected by salinity of irrigation water during first and second year is presented in Table 4.10. The data showed that soluble HCO_3^- concentration decreased significantly with increasing salinity and soil depth. This decreaseis observed due to dominance of NaCl salt in salinity water which increased Cl^- ions concentration, as a result of which soluble HCO_3^- concentration decreased in soil solution. Average soluble HCO_3^- decreased from 1.9 to 0.9me/L and2.0 to 0.8 me/L in 2013-14 as salinity increased from 0 to 12 dS/m of irrigation water before sowing and after harvest of wheat crop.In 2014-15,relative to EC 0 treatment, soluble HCO_3^-concentrations decreased by 66 and 39 % at EC 12 dS/m before sowing and after harvest of crop. When data pertaining to soil depth was considered, it was found that soluble HCO_3^-decreased from 1.9 to 1.0 me/L before sowing and 2.0 to 1.0 me/L after harvest of crop as soil depth increased from 0 to 120cm in 2013-14, while in next year, it decrease occured from 1.9 to 1.4 me/L and from 1.7 to 1.2 me/L before sowing and after harvest of wheat crop with increase in soil depth from 0to 120 cm.

Significant interaction effects between salinity and soil depth for soluble HCO_3^- was observed for 2013-14 (before sowing) and 2014-15 (after harvest). It was observed that soluble HCO_3^-concentration decreased by 0.7-1.0 unit before sowing in 2013-14 and from 0.4-0.5 unit after harvest in 2014-15 at all salinity levels as soil depth progressively increased from 0-15 cm to 90-120 cm.

4.1.1.15 Soluble chloride as affected by salinity of irrigation water

Soluble chloride (Cl^-) as affected by saline irrigation water in 2013-14 and 2014-15 is depicted in Table 4.11. These results revealed that soluble chloride concentration significantly increased with salinity of irrigation water in both years. However for soil depth, opposite trend was observed. The mean soluble Cl^-concentration increased from 0.4 to 2.1, 3.4, 3.8, and 4.9 me/L as salinity of irrigation water increased from 0 to 3, 6, 9 and 12 dS/m, respectively before sowing of crop and from 0.4 to 1.7, 3.4, 4.3 and 4.6 me/L, respectively after harvest of crop 2013-14. In 2014-15, Cl^- concentration increased from 0.3 to 1.9, 2.3, 3.6 and 4.8 me/L at EC 0, 3, 6, 9 and 12 dS/m levels of irrigation water before sowing and corresponding values after harvest of crop were 0.3 to 1.8, 3.2, 4.2 and 5.4 me/L. This increase in concentrationof soluble Cl^- is due to addition of NaCl through saline irrigation water.Increase in soluble chloride concentration with increasing salinity was reported by Mahdy (2011) , who observed solubleCl^-concentration increased from 13.05 to 26.18 mmol/L at EC 8.7 dS/m compared to control. Earlier, Ragab *et al* (2008) also reported significant increase in soluble Cl^-concentration in sandy and calcareous soilwith increasing irrigation water salinity.

Table 4.10 Effect of saline irrigation water on soluble bicarbonate (HCO_3^-) (me/L)

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	2.4	2.2	1.9	1.7	1.5	**1.9**	2.6	2.4	2.0	1.7	1.5	**2.0**
EC 3	2.2	1.9	1.7	1.4	1.2	**1.7**	2.3	2.1	1.8	1.4	1.4	**1.8**
EC 6	1.9	1.7	1.4	1.2	0.9	**1.4**	2.1	1.8	1.6	1.2	1.0	**1.5**
EC 9	1.6	1.4	1.2	0.9	0.7	**1.2**	1.7	1.4	1.2	0.9	0.7	**1.2**
EC 12	1.2	1.1	0.8	0.7	0.5	**0.9**	1.3	1.0	0.8	0.7	0.5	**0.8**
Mean	**1.9**	**1.6**	**1.3**	**1.2**	**1.0**		**2.0**	**1.7**	**1.4**	**1.2**	**1.0**	
LSD (5%)	**EC = 0.07 Depth = 0.05 Interaction = 0.10**						**EC= 0.3 Depth= 0. 2 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	2.3	2.2	2.2	2.0	1.9	**2.1**	2.1	1.9	1.8	1.7	1.6	**1.8**
EC 3	2.2	2.1	2.0	1.8	1.7	**2.0**	1.9	1.7	1.6	1.6	1.4	**1.6**
EC 6	2.0	2.0	1.9	1.6	1.6	**1.8**	1.7	1.5	1.4	1.4	1.2	**1.4**
EC 9	1.7	1.7	1.6	1.4	1.3	**1.5**	1.5	1.4	1.3	1.2	1.1	**1.3**
EC 12	1.1	1.0	0.8	0.5	0.5	**0.7**	1.3	1.2	1.2	1.0	0.8	**1.1**
Mean	**1.9**	**1.8**	**1.7**	**1.5**	**1.4**		**1.7**	**1.5**	**1.4**	**1.3**	**1.2**	
LSD (5%)	**EC = 0.09 Depth = 0.06 Interaction = NS**						**EC= 0.04 Depth= 0.03 Interaction = 0.07**					

Table 4.11 Soluble chloride (Cl^-) (me/L) as affected by salineirrigation water

2013-14												
Treatment / Depth	**Before sowing**						**After harvest**					
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.6	0.5	0.4	0.3	0.2	**0.4**	0.5	0.5	0.3	0.3	0.1	**0.4**
EC 3	2.8	2.4	2.0	1.9	1.4	**2.1**	2.2	1.9	1.6	1.4	1.1	**1.7**
EC 6	4.6	3.7	3.3	2.9	2.5	**3.4**	4.1	3.8	3.5	3.0	2.7	**3.4**
EC 9	5.0	4.2	3.5	3.3	2.9	**3.8**	5.2	4.8	4.3	3.7	3.3	**4.3**
EC 12	5.7	5.4	5.1	4.4	3.8	**4.9**	5.6	5.3	4.6	4.0	3.6	**4.6**
Mean	**3.7**	**3.2**	**2.9**	**2.6**	**2.2**		**3.5**	**3.2**	**2.8**	**2.5**	**2.1**	
LSD (5%)	**EC =0.1 Depth = 0.2 Interaction = 0.5**						**EC= 0.3 Depth= 0.2 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.5	0.4	0.3	0.2	0.1	**0.3**	0.5	0.4	0.3	0.2	0.2	**0.3**
EC 3	2.6	2.3	1.9	1.5	1.1	**1.9**	2.5	1.9	1.8	1.5	1.3	**1.8**
EC 6	3.0	2.8	2.2	1.8	1.6	**2.3**	4.0	3.5	3.5	2.7	2.4	**3.2**
EC 9	4.5	4.3	3.7	3.0	2.5	**3.6**	5.1	4.7	4.1	3.8	3.2	**4.2**
EC 12	6.0	5.8	4.6	4.2	3.3	**4.8**	6.2	6.0	5.5	4.9	4.4	**5.4**
Mean	**3.3**	**3.1**	**2.6**	**2.1**	**1.7**		**3.7**	**3.3**	**3.0**	**2.6**	**2.3**	
LSD (5%)	**EC = 0.3 Depth = 0.2 Interaction = 0.5**						**EC= 0.5 Depth= 0.3 Interaction = 0.6**					

They observed that soluble chloride concentration increased progressively from 2.28 to 5.84, 8.26 and 12.91me/L in sandy soil and from 12.54 to 12.34, 26.83 and 33.21 me/L in calcareous soilas salinity of irrigation water increased from 0.43 dS/m(control) to 4.85, 6.60 and 8.86 dS/m, respectively. Meansoluble chloride concentration decreased from 3.7 to 2.2 me/L and from 3.5 to 2.1 me/L before sowing and after harvest in 2013-14 and from 3.3 to 1.7 me/L before sowing and 3.7 to 2.3 me/L after harvest oof cop in 2014-15 as soil depth incaresd from 0 to 120 cm. Decrease in soluble chloride with increasing soil depth is due to surface applied salts through irrigation water and also due toupward movement of salts to soil surface through evaporation process which resulted in increased concentration of soluble chloride in the surface than sub-surface soil layers.

It is evident from data that significant interaction effects were observed for soluble chloride in first and second year of research study except after harvest of crop in 2013-14. as soil depth progressively increased from 0-15 cm to 90 to 120 cm, soluble chloride concentration decresed approximately by 2 unit at EC 9 dS/m salinity level before sowing as well as after harvest of crop in 2014-15.

4.1.1.16 Effect of saline irrigation water on soluble sulphate

It was observed that soluble sulphate (SO_4^{-2}) follows similar trend as that of bicarbonates i.e. it decreased with increasing salinity and soil depth. Mean soluble SO_4^{-2}concentration decreased from 2.1 to 0.8 me/L and 1.9 to 0.6 me/ L before sowing and after harvest of crop as salinity increased from 0 to 12 dS/min 2013-14.With increasing soil depth from 0 to 120 cm, averagesoluble SO_4^{-2} concentration decreased from 2.9 to 0.8 me/L before sowing and 1.9 to0.9 me/L after harvest of crop.Compared to EC 0, mean soluble SO_4^{-2} decreased by 65.2 and 57.5 % at EC 12 dS/m salinity level before sowing and after harvest of crop in 2014-15. Likewise souluble SO_4^{-2} concentrationdecreased from 2.5 to 0.8 me/L and 3.2 to 0.3 me/L before sowing and after harvest of crop as soil depth increased from 0 to120 cm. A perusal of data showedsignificant interaction between salinity levels and soil depth in 2013-14 after harvet of wheat crop.Statistically similar values of soluble sulphate were observed at EC 6 (0-15 cm) and EC 3 dS/m (15-30 cm) salinity levels.

4.1.2 Effect of saline irrigation water on soil physical health

The results related to soil physical properties asaffected by salinity of irrigation water are presented in Table 4.13. Six soil physical properties such as bulk density, mean weight diameter, saturated hydraulic conductivity, infiltration rate, dispersion ratio and water holding capacity were measured for top 15 cm soil depth for both years. In genral, saline water irrigationhas non-significant effect on soil physical properties (except dispersion ratio).

Table 4.12Soluble sulphate (SO_4^{-2}) (me/L) as affected by saline irrigation water

2013-14											
Treatment / Depth	**Before sowing**						**After harvest**				
	0-15	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	3.6	2.1	1.9	1.7	1.4	**2.1**	2.8	2.0	1.8	1.6	1.4	**1.9**
EC 3	3.4	1.8	1.6	1.4	1.2	**1.9**	2.5	1.8	1.6	1.4	1.1	**1.7**
EC 6	3.1	1.5	1.3	1.1	1.0	**1.6**	1.8	1.7	1.5	1.2	1.0	**1.5**
EC 9	2.6	1.1	0.8	0.5	0.3	**1.1**	1.5	1.4	1.2	1.0	0.7	**1.2**
EC 12	2.0	0.9	0.6	0.4	0.2	**0.8**	1.2	0.7	0.5	0.3	0.2	**0.6**
Mean	**2.9**	**1.5**	**1.2**	**1.0**	**0.8**		**1.9**	**1.5**	**1.3**	**1.1**	**0.9**	
LSD (5%)	**EC = 0.2 Depth = 0.1 Interaction = NS**						**EC= 0.03 Depth= 0.02 Interaction = 0.05**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	3.5	2.8	2.3	1.8	1.3	**2.3**	4.3	3.9	3.3	2.7	2.1	**3.3**
EC 3	2.9	2.4	1.9	1.5	1.1	**1.9**	3.7	3.5	2.5	2.3	1.6	**2.7**
EC 6	2.5	2.0	1.6	1.2	0.8	**1.6**	3.4	3.1	1.9	1.8	1.3	**2.3**
EC 9	2.1	1.7	1.1	0.9	0.5	**1.3**	2.7	2.6	1.5	1.4	0.9	**1.9**
EC 12	1.5	1.0	0.7	0.4	0.3	**0.8**	2.2	2.0	1.1	1.0	0.6	**1.4**
Mean	**2.5**	**1.9**	**1.5**	**1.2**	**0.8**		**3.2**	**3.0**	**2.1**	**1.8**	**1.3**	
LSD (5%)	**EC = 0.2 Depth = 0.1 Interaction = NS**						**EC= 0.3 Depth= 0.2 Interaction = NS**					

Table 4.13Soil physical health as affected by salinity of irrigation water

Treatment	Bulk density (Mg/m^3)	Mean weight diameter (mm)	Saturated hydraulic conductivity (cm/hr)	Infiltration rate (cm/hr)	Dispersion ratio	Water holding capacity
2013-14						
Before sowing						
EC 0	1.33	0.90	0.28	2.6	0.344	36.6
EC 3	1.34	0.88	0.27	2.5	0.358	35.8
EC 6	1.36	0.87	0.26	2.4	0.388	34.1
EC 9	1.37	0.86	0.25	2.2	0.437	32.4
EC 12	1.40	0.84	0.22	1.8	0.480	31.2
LSD (5%)	**NS**	**NS**	**0.03**	**NS**	**0.007**	**NS**
After harvest						
EC 0	1.39	0.87	0.25	2.3	0.337	37.9
EC 3	1.42	0.86	0.24	2.2	0.346	36.6
EC 6	1.44	0.84	0.23	2.1	0.361	35.4
EC 9	1.46	0.82	0.22	1.9	0.380	33.1
EC 12	1.47	0.80	0.20	1.9	0.415	31.5
LSD (5%)	**NS**	**NS**	**NS**	**NS**	**0.007**	**NS**
2014-15						
Before sowing						
EC 0	1.30	0.88	0.26	2.4	0.352	37.3
EC 3	1.32	0.87	0.25	2.4	0.364	36.2
EC 6	1.36	0.85	0.24	2.2	0.397	34.5
EC 9	1.37	0.84	0.22	2.1	0.447	32.1
EC 12	1.40	0.82	0.20	2.0	0.475	30.4
LSD (5%)	**0.05**	**NS**	**NS**	**NS**	**0.02**	**3.7**
After harvest						
EC 0	1.37	0.85	0.23	2.2	0.344	37.1
EC 3	1.38	0.85	0.22	1.9	0.359	36.6
EC 6	1.39	0.83	0.21	1.9	0.374	35.3
EC 9	1.42	0.81	0.20	1.7	0.423	33.2
EC 12	1.44	0.79	0.18	1.6	0.441	30.7
LSD (5%)	**NS**	**NS**	**NS**	**NS**	**0.01**	**NS**

For dispersion ratio, effects were significant in both years before sowing and after harvest of crop , whereas for saturated hydraulic conductivity results were significant at EC 9 and 12 dS/m before sowing in 2014-15. In case of bulk density and water holding capacity significant difference were observed in 2014-15 before sowing of crop compared to EC0. Water holding capacity declined significantly at EC 9 and EC 12dS/m, while up to EC 6 differences were nonsignificant. However for bulk density significant increase occurred from EC 6 dS/m onwards.

4.1.3Effect of saline irrigation water on soil biological health

Soil microflora plays an important role in maintaining / enhancing soil quality by regulating organic matter decomposition and nutrient availability, enhancing macro-aggregate formation. Microbial parameters are sensitive indicators of changes in soil quality in response to management practices or environmental stress (Islam and Weil 2000 and Wong *et al* 2008). Soil microbial communities and their activity are greatly influenced by salinity because microbial processes in soils control ecological function and soil fertility (Rietz and Haynes, 2003). Therefore in present research study effect of different levels of saline irrigation water on dehydrogenase enzyme activity, microbial biomass carbon, microbial biomass nitrogen, and cold water extractable were observed at 0-15 cm and 15-30 cm soil depth and discussed under the following headings.

4.1.3.1 Dehydrogenase enzyme activity

Dehydrogenase enzyme has critical role in substrate oxidation and can be used as a measure of microbial metabolism rates in soils (Alef and Nannipieri 1995).. The data in Table 4.14 revealed that DHA decreased significantly with increasing levels of irrigation water salinity during both years of research study. The data shows that mean DHA progressively decreased from 29.4 to 26.8, 22.0, 18.8 and 14.4µg/TPF/hr/g soil before sowing and from 32.2 to 30.0, 24.2, 20.4, and 14.3 µg/TPF/hr/gsoil after harvest of wheat crop with increase in salinity of irrigation water from 0 to 3, 6, 9 and 12 dS/m in 2013-14. Similarly, in the next year (2014-15), compared to EC 0, mean DHA decreased by 7.8, 21.2, 42.8 and 51.0 % and 8.4, 27.5, 43.3 and 55.5 % at EC 3, 6, 9 and 12 dS/m salinity levelsbefore sowing and after harvest of wheat crop. Decrease in dehydrogenase activity may be due tolower microbial biomass (Garcia *et al*1994). Batra and Manna (1997) observed that DHA decreased significantly from 48.8µg/TPF/hr/gsoil to 21.5 µg/TPF/hr/gsoil as salinity of soil saturation extract (ECe) increased from 28dS/m to 40.8 dS/m in 0-15 cm soil layer. Similar results were also reported by Tripathi *et al* (2007) who observed that DHA activity decreased by 17.6 & 26.1 %, 41.5 & 44.4 % and 55.8 & 74.4 % during monsoon, winter and summer season at ECe6.9 dS/m over control.

Table 4.14: Effect of saline irrigation water on dehydrogenase enzyme activity (µg/TPF/hr/ g soil)

2013-14						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	31.3	27.5	**29.4**	35.4	29.1	**32.2**
EC 3	28.5	25.2	**26.8**	32.6	27.4	**30.0**
EC 6	24.2	19.8	**22.0**	27.1	21.3	**24.2**
EC 9	20.7	16.9	**18.8**	22.1	18.6	**20.4**
EC 12	16.5	12.3	**14.4**	16.0	12.6	**14.3**
Mean	**24.3**	**20.3**		**26.6**	**21.8**	
LSD (5%)	**EC= 1.7Depth= 1.1 Interaction = NS**			**EC= 4.0 Depth= 2.5 Interaction = NS**		
2014-15						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	32.8	28.5	**30.6**	33.2	26.2	**27.2**
EC 3	30.3	26.1	**28.2**	29.8	23.5	**24.9**
EC 6	26.5	21.6	**24.1**	25.1	19.3	**19.7**
EC 9	19.7	15.3	**17.5**	21.3	13.5	**15.4**
EC 12	14.9	11.8	**13.4**	15.0	9.9	**10.3**
Mean	**24.8**	**20.6**		**24.9**	**18.5**	
LSD (5%)	**EC= 3.3 Depth= 2.1 Interaction = NS**			**EC= 2.6 Depth= 1.6 Interaction = NS**		

They reported that more reduction in DHA in summer season due to lesser microbial biomass due to soil desiccation and increased salinity.

Table 4.14also described that DHA was lower at 15-30 cm relative to 0-15 cm in 2013-14 and 2014-15. The mean DHA decreased from 24.3 to 20.3 µg/TPF/hr/g soil and from 26.6 to 21.8 µg/TPF/hr/gsoil before sowing and after harvest of wheat crop in 2013-14 and from 24.8 to 20.6 µg/TPF/hr/g soilbefore sowing and from 24.9 to 18.5 µg/TPF/hr/gsoil after harvest of crop in second year in 15-30 cm soil depth compared with 0-15 cm soil layer. Interaction effects for DHA was non-significant for both years.

4.1.3.2 Microbial biomass carbon as affected by salinity of irrigation water

Effect of different salinitylevels on microbial biomass carbon **(**MBC) was observed at two soil depth (0-15cm to 15-30 cm) before sowing and after harvest of wheat crop in 2013-14 and 2014-15(Table 4.15). The data revealed that mean MBC significantly decreased with increasing levels of irrigation water salinity and soil depth in both years. Compared to control (EC 0), correspondingly mean MBC decreased by 15.5, 26.7, 40.2 and 50.2% before sowing and 21.7, 35.2, 48.7 and 55.7 % after harvest of wheat crop at EC 3, 6, 9 and 12 dS/m salinity levels in 2013-14, respectively. In 2014-15, mean MBC decreased from 239.4 mg/kg in controlto 194.9, 157.8, 125.2 and 109.2 mg/kg and from 230.8 mg/kg (control) to 180.7, 152.7, 118.9 and 99.6 mg/kg before sowing and after harvest of wheat crop. Decrease in MBC was related to toxic effects of Na and Cl on soil microflora (Pankhurst *et al* 2001 and Ndour *et al* 2008) as well as due to osmotic effects (Rietz and Haynes 2003).

Table 4.15 Effect of saline irrigation water on microbial biomass carbon (mg/kg)

2013-14						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	228.4	180.3	**204.5**	242.5	218.4	**230.5**
EC 3	190.2	155.4	**172.7**	185.7	175.2	**180.4**
EC 6	165.3	134.5	**149.8**	158.3	140.3	**149.3**
EC 9	131.5	112.8	**122.2**	127.6	108.7	**118.1**
EC 12	119.1	84.5	**101.8**	113.9	89.9	**101.9**
Mean	**166.9**	**133.5**		**165.6**	**146.5**	
LSD (5%)	**EC= 7.7Depth= 4.9 Interaction = 10.9**			**EC= 2.9 Depth= 1.8 Interaction = 4.1**		
2014-15						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	248.3	230.5	**239.4**	236.4	225.2	**230.8**
EC 3	198.5	191.3	**194.9**	187.5	173.8	**180.7**
EC 6	163.2	152.4	**157.8**	166.8	138.5	**152.7**
EC 9	135.8	114.6	**125.2**	127.3	110.6	**118.9**
EC 12	119.7	98.8	**109.2**	111.5	87.7	**99.6**
Mean	**173.1**	**157.5**		**165.9**	**147.2**	
LSD (5%)	**EC= 5.1 Depth= 3.2 Interaction = 7.2**			**EC= 4.8 Depth= 3.0 Interaction = 6.8**		

Egamberdieva *et al* (2010) observed decrease in MBC from 347to 202 mg/kg as soil salinity increased from 2.3 to 7.1 dS/m. Shah and Shah (2011) also reported that MBC decreased from 391 to 209 mg/kg in saline soils having EC less than4dS/m to EC more than12 dS/m.The data presented inTable 4.15 revealedthat MBC also decreased from 166.9 to 133.5 mg/kg and 165.6 to 146.5 mg/kg in 2013-14 and from 173.1 to 157.5 mg/kg and from 165.9 to 147.2mg/kg in 2014-15 in15-30 cm soil depth compared to 0-15cm, before sowing and after harvest of crop, respectively. The data showed that significant interaction was observed for MBC between different salinity levels and soil depth during first and second year of research study. It was observed MBC values were statistically at par for EC 6 (15-30 cm) and EC 9dS/m (0-15 cm)before sowingin 2013-14 and at EC 9 (15-30cm) andEC 12dS/m (0-15 cm)harvest of crop in 2014-15.

4.1.3.3 Saline irrigation water effect on microbial biomass nitrogen

The data regarding saline irrigation water effect on microbial biomass nitrogen (MBN) in 2013-14 and 2014-15 at soil depths 0-15cm and 15-30cm is given in Table 4.16.It is evident from data that MBN follows the similar trend as that of MBC with increasing salinity of irrigation water.

Table 4.16Effect of saline water irrigation on microbial biomass nitrogen (mg/kg)

2013-14						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	88.1	72.2	**80.1**	97.5	82.9	**90.2**
EC 3	67.5	58.8	**63.1**	73.4	64.2	**68.8**
EC 6	44.3	40.5	**42.4**	51.2	47.4	**49.3**
EC 9	36.0	28.7	**32.4**	35.3	32.9	**34.1**
EC 12	25.5	22.0	**23.7**	26.1	24.2	**25.1**
Mean	**52.3**	**44.4**		**56.7**	**50.3**	
LSD (5%)	**EC= 5.4 Depth= 3.4 Interaction = NS**			**EC= 3.1 Depth= 2.0 Interaction = 4.4**		
2014-15						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	91.4	79.7	**85.6**	94.4	80.4	**87.4**
EC 3	70.2	66.8	**68.5**	78.5	59.5	**69.0**
EC 6	56.4	38.6	**47.5**	55.6	42.2	**48.9**
EC 9	37.9	29.9	**33.9**	29.3	24.8	**27.1**
EC 12	25.1	21.7	**23.4**	22.2	18.6	**20.4**
Mean	**56.2**	**47.4**		**56.0**	**45.1**	
LSD (5%)	**EC= 3.4 Depth= 2.2 Interaction = 4.9**			**EC= 2.1 Depth= 1.3 Interaction = 3.0**		

The data showed that mean MBN decresed from 80.1 to 23.7 mg/kg and from 90.2 to 25.1 mg/kg before sowing and after harvest of crop as salinity increased from EC0 to EC12 dS/m in 2013-14. In 2014-15, corresponding decrease occurred from 85.6 to 23.4 mg/kg and 87.4 to

20.4 mg/kg at respective salinity levels. Shah and Shah (2011) reported decrease in MBN from 113.8 (EC<4dS/m) to 24.8 mg/kg (EC> 12 dS/m) in saline soils. Earliar, Yuan *et al* (2007) alo reported decrease in MBN from 32.8 to 17.4 mg/kg as soil salinity increased from 0.32 to 5.2 mS/m. It was observed that MBN also decreased significantly from 0-15 to 15-30 cm soil depth in both years.Mean MBN decresed from 52.3 to 44.4 mg/kg before sowing and from 56.7 to 50.3 mg /kg after harvest of crop in 2013-14 as soil depth increased from 0-15cm to 15-30 cm. Corresponding decrease in MBN occurred from 56.2 to 47.4 mg/kg and 56.0 to 45.1 mg/kg in 2014-15 at repective soil depths.

Table 4.17Effect of saline irrigation water on cold water extractable carbon (mg/kg)

2013-14						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	68.6	54.3	**61.4**	64.8	56.1	**60.4**
EC 3	66.3	50.1	**58.2**	60.2	53.5	**56.8**
EC 6	56.5	43.6	**50.1**	47.3	45.3	**46.3**
EC 9	41.2	34.5	**37.8**	36.4	32.2	**34.3**
EC 12	32.1	28.5	**30.3**	29.2	26.7	**27.9**
Mean	**52.9**	**42.2**		**47.6**	**42.7**	
LSD (5%)	**EC= 3.9Depth= 2.4 Interaction = 5.5**			**EC= 4.5 Depth= 2.8 Interaction = NS**		
2014-15						
Treatment / Depth	**Before sowing**			**After harvest**		
	0-15	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
EC 0	72.6	56.1	**64.3**	66.0	51.3	**58.6**
EC 3	59.4	51.0	**55.2**	61.8	48.6	**55.2**
EC 6	52.7	42.6	**47.6**	50.4	39.2	**44.8**
EC 9	46.2	31.7	**38.9**	43.7	32.5	**38.1**
EC 12	35.1	25.4	**30.2**	35.9	27.1	**31.5**
Mean	**53.2**	**41.4**		**51.5**	**39.7**	
LSD (5%)	**EC= 3.0 Depth= 1.9 Interaction = NS**			**EC= 3.9 Depth= 2.5 Interaction = NS**		

A perusal of data shows that significant interaction was observed for MBN between salinity levels and soil depth in both years except before sowing of crop in 2013-14. The MBN values significantly decreased by same magnitude i.e. 3.4 and 3.6 at EC 12 dS/m salinity level as soil depth increased from 0 to 30 cm before sowing as well as after harvest of crop in 2014-15.

4.1.3.4 Cold water extractable carbon as affected by salinity of irrigation water

The data revealed that cold water extractable carbon (CWEC) significantly decreased with increasing levels of salinity (Table 4.17). Lower CWEC values were observed for 15-30 cm soil layercompared with surface layer. Mean CWEC decreased from 61.4 to 30.3 mg/kg as salinity levels increased from EC 0 to EC 12 dS/m and from 52.9 to 42.2 mg/kg at 15-

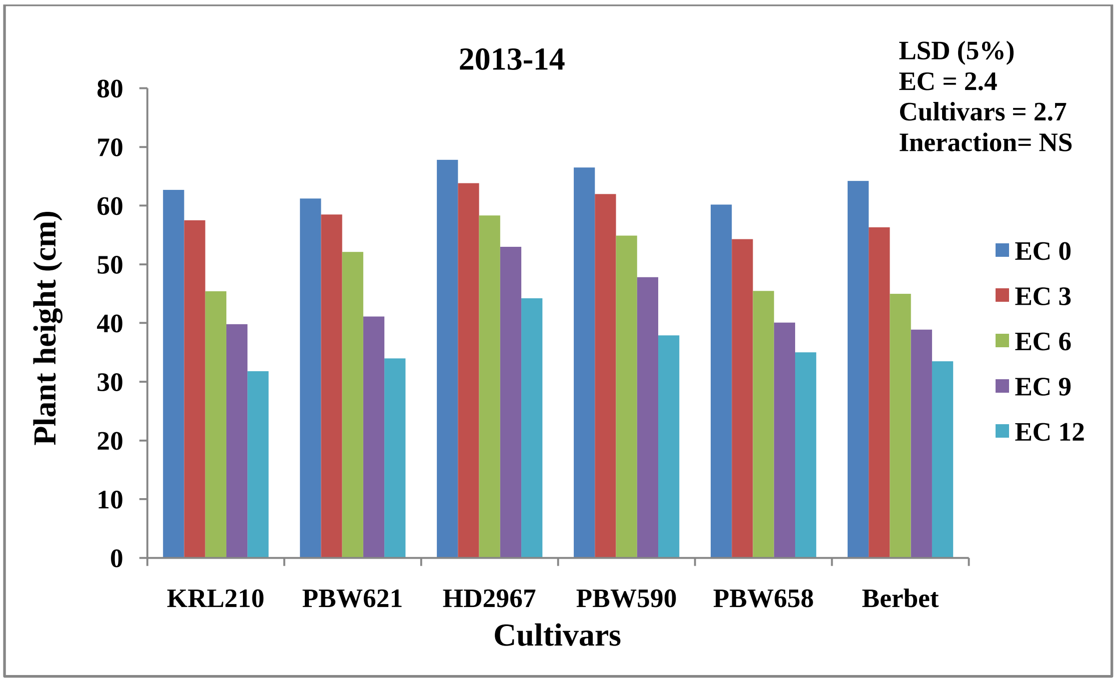
30cm soil depth compared with 0-15cm before sowing of crop in 2013-14, respectively. Corresponding decrease in CWEC values after harvest of crop takes place from 60.4 to 27.9 mg/kg and from 47.6 to 42.7mg/kg at respective salinty levels and soil depths. Mean CWEC decreased from 64.3 mg/kg in control (EC 0) to 55.2, 47.6, 38.9 and 30.2 mg/kg before sowing and from 58.6 mg/kg (EC 0) to 52.2, 44.8, 38.1 and 31.5 mg/kg at EC 3, 6, 9 and 12 dS/m after harvest of wheat crop in 2014-15. Significant interaction was observed for CWEC between different salinity levels and soil depth before sowing in 2013-14 where CWEC values significantly decreased by approximately 50% at EC 12 dS/m compared to EC 0 for both soil depths (0-15 cm and 15-30 cm).

4.1.4 Effect of saline irrigation water on performance of wheat cultivars

Effect of different levels of irrigation water salinity plant parameters i.e. plant height , number of tillers /m^2 and leaf area index and mineral composition (Na, K, P and Ca) in whole plant was determined at tillering stage for six wheat cultivars namely KRL 210, PBW621, HD2967, PBW658 and Berbet in 2013-14 and 2014-15. The results pertaining to these plant parameters and mineral composition is discussed under the following headings.

4.1.4.1 Plant height

Plant height is an index of growth and development of the plant over a period of time. The data pertaining to effect of salinity levels on plant height of six wheat cultivars at tillering stage is depicted in Fig. 4.5. It was observed that plant height decreased significantly with increasing irrigation water salinity in all the wheat cultivars, although magnitude of decrease varias among wheat cultivars at different salinity levels in both years. Maximum plant height was observed in EC 0 treatment for cultivar HD2967 followed by PBW 590, whereas minimum was reported at EC 12dS/m salinity level for KRL210 (salt tolerant) in 2013-14. In the next year, maximum plant height was observed for cultivar Berbet followed by KRL210 in control and minimum in PBW658 at EC 12dS/m. Maximum reduction in mean plant height of different wheat cultivars occurs at highest levels of water salinity (EC =12dS/m) which decreased by 43.4 and 45.1 % in 2013-14 and 2014-15 as compared to control. In a pot experiment, Kumar *et al* (2012) reported that as salinity increased from 0 to 12 dS/m average plant height of eightwheat cultivars deceased significantly from 60.8 cm to 43.2 cm, respectively. The presence of salts in soil solution decreases osmotic potential of soil, creating water stress and makes it difficult for plant to absorb water and nutrients the necessary for growth (Munns 1993). Saqib *et al* (2006) also observed that soil salinity reduces plant growth through osmotic effect in first phase and later on due to salt toxicity (e.g. Na and Cl).



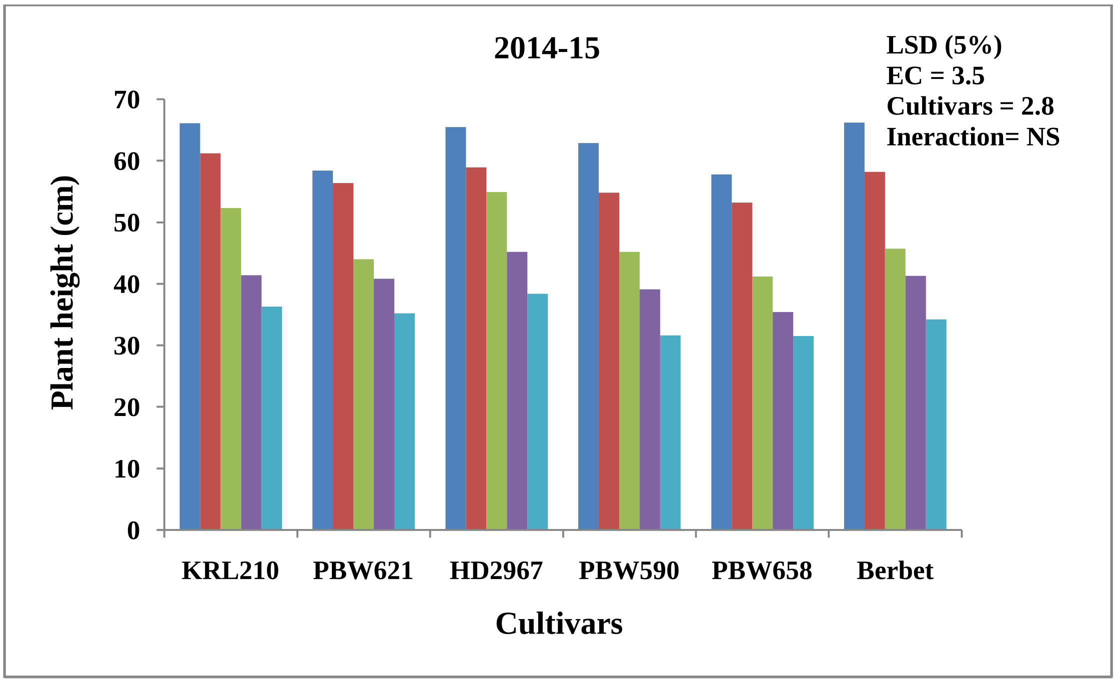


Fig. 4.5 **Effect of saline water irrigation on plant height (cm) of wheat cultivars at tillering stage**

Among different wheat cultivars plant height varied from 31.8 to 67.8 cmin 2013-14 and ranged from 31.5 to 65.5 cm in 2014-15. There was no interaction robserved for plant height between different salinity levels and wheat cultivars in both years

4.1.4.2 Number of tillers/m^2

Tillering has great agronomic significance in cereals since it may partially or totally compensate difference in plant number after crop establishment. The data on number of tillers/m^2 of wheat cultivars as affected by differentsalinity levels at tillering stage during 2013-14 and 2014-15 is presented in Table 4.18.It is evident that number of tillers/m^{2}of wheat cultivars decreased significantly with increasingwatersalinity levels in both years.Compared to control, mean number of tillers/m^2 were decreased by 3.3, 7.1, 12.0 and 22.1 % in 2013-14 and 3.9, 8.5, 18.1 and 28.7 % in 2014-15 at EC 3, 6, 9 and 12 dS/m salinity levels, respectively.Nicolas *et al* (1994) found that salt stress during tiller emergence can inhibit their formation and can cause their abortion at later stages.Salinity significantly decreased tiller number and their appearance in wheat (Mass and Poss 1989).Hendaway *et al* (2005) reported that tiller number of 13wheat cultivars reduced by 22, 28 and 37.5 % at 50,100 and 150 mM NaCl salinity as compared to control.

Table 4.18: Effect of saline water irrigation on no. of tillers/m^2 of wheat cultivars at tillering stage

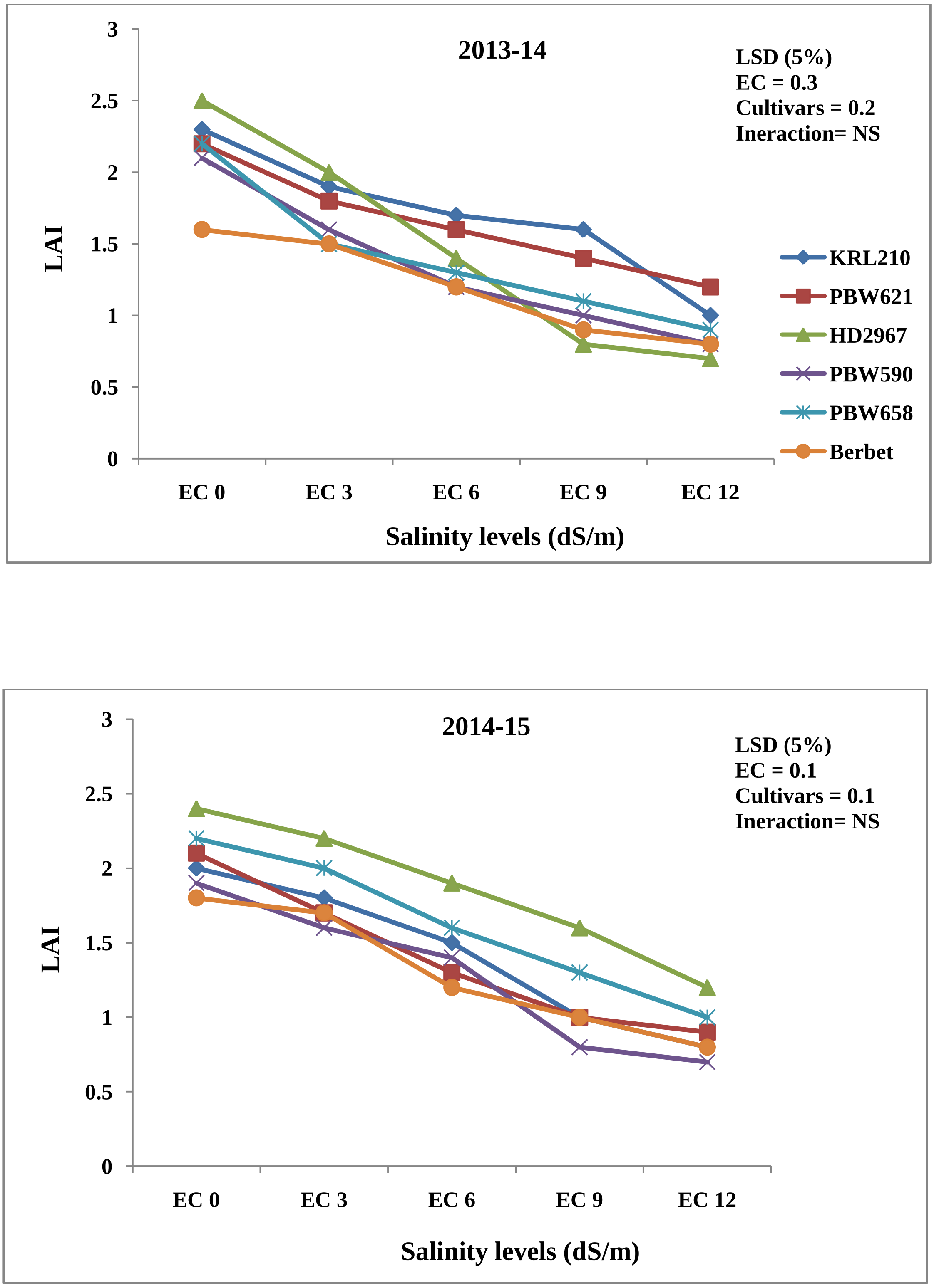
2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	341	318	328	305	338	322	**325**
EC 3	329	310	315	297	320	311	**314**
EC 6	309	304	307	287	312	291	**302**
EC 9	293	288	295	273	290	278	**286**
EC 12	251	260	265	248	253	242	**253**
Mean	**305**	**296**	**303**	**283**	**303**	**288**	
LSD (5%)	**EC= 3.9 Cultivar= 3.8 Interaction = 8.4**						
2014-15							
EC 0	351	325	338	310	336	328	**331**
EC 3	330	319	318	304	327	319	**318**
EC 6	311	298	304	281	310	312	**303**
EC 9	276	285	280	261	278	245	**271**
EC 12	235	240	248	221	242	231	**236**
Mean	**300**	**293**	**297**	**275**	**297**	**291**	
LSD (5%)	**EC= 1.5 Cultivar= 2.2 Interaction = 5.0**						

Eugene *et al* (1994) reported that as salinity increased above 7.5 dS/m, most of secondary tillers of moderately tolerant genotypes were eliminated and numbers of primarily tillers for salt sensitive genotypes were greatly reduced. The data revealed that among different wheat cultivars, maximum decrease at each salinity level was observed in PBW 590 cultivar having minimummean value for both years. The maximum and minimum relative decrease was observed in KRL 210 and PBW 621 cultivars at each salinity level compared to control. Number of tillers/m^2 for cultivars HD 2967 and PBW 658 decreased by more or less same magnitude at different salinity levels and have statistically similar mean values in 2013-14 and 2014-15. Interaction effectswere significant for number of tillers/m^2 in both years.

4.1.4.3 Effect of saline water irrigation on leaf area index of wheat cultivars at tillering stage

Leaf area index is defined as total one sided area of photosynthetic tissues per unit ground surface area.The leaf area index (LAI)of different wheat cultivars at different salinity levels were recorded at tillering stage in 2013-14 and 2014-15.The Fig. 4.6depicted thatLAI of six wheat cultivars significantly decreased with increasing irrigation water salinity.

In first year, decresed was observed for mean LAI from 2.5 to 0.8 for all cultivars with increasing salinity of irrigation water . Maximum decline occurred for cultivar HD 2967 (2.5 to 0.7) followed by Berbet (1.6 to 0.8) at EC 12 dS/m over control. Likewise in second year, decreasing trend was same but maximum reduction of LAI was observed for cultivar PBW 590 (1.9 to 0.7) followed by Berbet (1.8 to 0.8) and PBW621 (2.1 to 0.9). Increasing salinitydecreased rate of leaf expansion, as a result of which total leaf area of plant is reduced. Hendawy *et al* (2005) reported that leaf area of different wheat cultivars decreased by 8, 19 and 28 % at 50,100 and 150 mM NaCl salinityas compared to control. Out of six wheat cultivars, maximum decreased in LAI of cultivar HD 2967 (20, 44, 68 and 72%) was reported at each salinity level in first year, whereas for second year this trend was observed for cultivar PBW621 (19, 38, 52.3 and 57 %).



2013-14
LSD (5%)
EC = 0.3
Cultivars = 0.2
Ineraction= NS

2014-15
LSD (5%)
EC = 0.1
Cultivars = 0.1
Ineraction= NS

Fig. 4.6 Saline irrigation watereffects on leaf area index (LAI) of wheat cultivars at tillering stage

4.1.4.4 Mineral composition of wheat cultivars at tillering stage

Mineral composition (Na, K, P and Ca) of whole plant of six wheat cultivars was determined at tillering stage in 2013-14 and 2014-15 and is discussed under following headings;

4.1.4.4.1 Effect of saline irrigation water on plant sodium content of wheat cultivars at tillering stage

Irrigation with different levels of saline water significantly increased plant sodium (Na) content in six wheat cultivars at tillering stage in 2013-14 and 2014-15 (Table 4.19). It is evident from data that mean plant Na content increased from 0.078 % in control to 0.094, 0.122, 0.144 and 0.167 % at EC 3, 6, 9 and 12 dS/m salinity levels in 2013-14. The corresponding values of plant Na content in 2014-15 were 0.078, 0.097, 0.120, 0.143 and 0.164 % at respective levels of water salinity. Increase of Na^+ concentration in plant tissue is one of the primary plant responses to salinity stress (Schachtman and Munns 1992 and Meneguzzo *et al* 2000). Khan *et al* (2006) reported increases in leaf Na content in 16 wheat cultivars which ranged from 0.9 to 2.90% as salinity increased from 0 to 12 dS/m but the magnitude of increase was higher compared to present research study. It might be due to dilution factor as Na content of whole plant was determined in this case. Mahdy (2011) also reported increase in shoot Na content increased from 10 g/kg to 40 g/kg as irrigation water salinity increased from 0.5 to 8.70 dS/m.

Mean plant Na content in normal irrigation water (EC0) tends to remain constant over time with an average of 0.078 %. Out of six wheat cultivars Na content of PBW 621 and Berbet increased with same magnitude from EC 6 to EC 12dS/m salinity level in 2013-14.Whereas in 2014-15, cultivars KRL 210 and PBW621 have more or less similar increase from EC 6 to EC 9dS/m salinity level but at EC 12 dS/m higher values were recorded for KRL 210 than PBW621.

It has been observed that maximum average plant Na content was reported in cultivar PBW 658 (0.138 % and 0.131 %), whereas as minimum was observed in salt tolerant cultivar KRL210 (0.105% and 0.112%) in 2013-14 and 2014-15. Significant interaction was observed for plant Na content between different salinity levels and wheat cultivars in 2014-15.

Table 4.19 Effect of saline irrigationwateron plant sodium content (%) of wheat cultivars at tillering stage

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.055	0.066	0.080	0.088	0.094	0.082	**0.078**
EC 3	0.076	0.085	0.093	0.102	0.115	0.093	**0.094**
EC 6	0.105	0.123	0.118	0.130	0.132	0.121	**0.122**
EC 9	0.133	0.146	0.132	0.141	0.162	0.149	**0.144**
EC 12	0.156	0.164	0.159	0.176	0.187	0.164	**0.167**
Mean	**0.105**	**0.117**	**0.116**	**0.127**	**0.138**	**0.122**	
LSD (5%)	**EC= 0.02 Cultivar= 0.008 Interaction = NS**						
2014-15							
EC 0	0.062	0.074	0.095	0.092	0.086	0.072	**0.078**
EC 3	0.077	0.093	0.103	0.101	0.112	0.096	**0.097**
EC 6	0.115	0.115	0.115	0.123	0.130	0.127	**0.120**
EC 9	0.140	0.136	0.130	0.155	0.153	0.144	**0.143**
EC 12	0.165	0.152	0.147	0.172	0.174	0.169	**0.164**
Mean	**0.112**	**0.114**	**0.118**	**0.127**	**0.131**	**0.121**	
LSD (5%)	**EC= 0.004 Cultivar= 0.007 Interaction = 0.01**						

4.1.4.4.2 Plant potassium content of wheat cultivars as affected by salinity of irrigation water at tillering stage

The data regarding effect of saline irrigationwateron plant potassium (K) content in 2013-14 and 2014-15 at tillering stage is presentedin Table 4.20. The data revealed that plant K content significantly decreased with increasing levels of saline irrigation water during both years of study. Compared to EC 0 treatment, mean plant K content decreased by 6.8, 16.3, 27.8 and 40.1 % in 2013-14 and by 5.4, 14.1, 21.6 and 33.1 % in 2014-15 at EC 3,6, 9 and 12dS/m salinity levels**.**

Table 4.20 Effect of saline water irrigation on plant potassium content (%) of wheat cultivars at tillering stage

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.137	0.145	0.134	0.152	0.163	0.150	**0.147**
EC 3	0.132	0.138	0.121	0.145	0.151	0.137	**0.137**
EC 6	0.128	0.112	0.112	0.123	0.135	0.130	**0.123**
EC 9	0.105	0.095	0.101	0.110	0.114	0.113	**0.106**
EC 12	0.087	0.072	0.081	0.090	0.101	0.098	**0.088**
Mean	**0.117**	**0.112**	**0.110**	**0.124**	**0.132**	**0.126**	
LSD (5%)	**EC= 0.003**		**Cultivar= 0.009**		**Interaction = NS**		
2014-15							
EC 0	0.128	0.152	0.131	0.162	0.164	0.151	**0.148**
EC 3	0.121	0.147	0.124	0.153	0.158	0.141	**0.140**
EC 6	0.116	0.133	0.112	0.142	0.143	0.121	**0.127**
EC 9	0.103	0.118	0.106	0.133	0.128	0.108	**0.116**
EC 12	0.093	0.103	0.095	0.118	0.102	0.087	**0.099**
Mean	**0.112**	**0.130**	**0.113**	**0.141**	**0.139**	**0.122**	
LSD (5%)	**EC= 0.004**		**Cultivar= 0.005**		**Interaction = NS**		

Khan *et al* (2006) reported that leaf K content of 16 wheat cultivars decreased from 2.24 to 1.61 % as salinity increased from 0 to 12 dS/m. Flower and Hajibagheri (2001) reported that NaCl salinity decreased K^+ concentration in many plant species. Higher concentration and accumulation of Na^+ and Cl^- ions to toxic levels in leaves reduced K^+ concentration due to decreased water potential of rooting medium and interfering metabolic processes viz. photosynthesis, protein synthesis etc. (Ibrahim 2003). Reduction in K uptake by crop plants with increasing salinity levels had been reported by numerous studies (Izzo *et al* 1993, Perez-Alfocea *et al* 1996 and Velu and Shrivastwa 2000).

With increasing water salinity levels from 0 to12dS/m, cultivar PBW621 showed higher reduction at each salinity level in 2013-14, wheras for 2014-15 two cultivars (KRL 210 and HD 2967) shows this trendat each salinity level. Maximum accumulation of average plant K content was observed in cultivars PBW 658 (0.132 %) in 2013-14 and PBW 590 (0.141 %) in 2014-15, whereas the minimum content of mean plant K was reported in cultivar HD 2967 (0.110 %) for first year and in KRL 210 (0.112 %) for the second year of study, respectively.The reduction in K uptake in plants by Na^+ is a competitive process and occurs regardless of whether the solution is dominated by Na^+ salts of Cl^- or SO_4^{-2} , however plant species may differ in reduction magnitude (Grattan and Grieve, 1999).Interaction effects were non-significant for plant K content in 2013-14 and 2014-15.

4.1.4.4.3 Plant Na/ K ratio as affected by salinity of irrigation water

Plant Na/K ratio as affected by different salinity levels in 2013-14 and 2014-15 is presented in Table 4.21. It is evident from data that plant Na/K ratio significantly increased with increasing levels of saline irrigation water. The average plant Na/K ratio increased from 0.53 in EC 0 to 0.68, 0.99, 1.38 and 1.97 at EC 3, 6, 9 and 12 dS/m levels of salinity in 2013-14. Corresponding increase in 2014-15 was from 0.52 (EC 0) to0.69, 0.96, 1.25 and 1.65 at respective salinity levels.

Table 4.21 Effect of saline irrigation water on plant Na/ K ratio of different wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.40	0.49	0.59	0.58	0.58	0.54	**0.53**
EC 3	0.57	0.62	0.76	0.70	0.76	0.68	**0.68**
EC 6	0.82	1.09	1.06	1.05	1.01	0.94	**0.99**
EC 9	1.29	1.57	1.32	1.28	1.46	1.33	**1.38**
EC 12	1.87	2.34	2.04	1.99	1.90	1.67	**1.97**
Mean	**0.99**	**1.22**	**1.15**	**1.12**	**1.14**	**1.03**	
LSD (5%)	**EC = 0.32 Cultivar = 0.12 Interaction = NS**						
2014-15							
EC 0	0.48	0.49	0.71	0.50	0.52	0.47	**0.52**
EC 3	0.64	0.63	0.84	0.66	0.71	0.69	**0.69**
EC 6	0.99	0.87	1.06	0.86	0.90	1.06	**0.96**
EC 9	1.44	1.15	1.25	1.16	1.20	1.34	**1.25**
EC 12	1.79	1.47	1.53	1.47	1.74	1.96	**1.65**
Mean	**1.06**	**0.92**	**1.07**	**0.93**	**1.01**	**1.10**	
LSD (5%)	**EC= 0.14 Cultivar= 0.09 Interaction = 0.19**						

Out of six wheat cultivars,the maximum plant Na/K ratio was observed in cultivar PBW 621andthe minimum in KRL 210in 2013-14. For second year, the maximumplant Na/K ratio was reported for Berbet and the minimum in PBW621. Interaction effects forplant Na/K ratio were significant in 2014-15.

4.1.4.4.4 Effect of saline irrigation water on plant phosphorous content of wheat cultivars at tillering stage

The data presented in Table 4.22 revealed that plant phosphorous (P) content significantly decreased with increasing salinity of irrigation water in 2013-14 and 2014-15 expect at EC 3dS/m level of irrigation water. The data shows that magnitude of plant P was higher in second year compared to first year. Mean plant P content decreased from 0.32 % in EC 0 to 0.26, 0.20, 0.14 and 0.10 % at EC 3, 6, 9 and 12dS/m salinity levels in 2013-14 and from 0.42 % (EC 0) to 0.38, 0.34, 0.30 and 0.25 % in 2014-15 at respective salinity levels.In most of cases, salinity decrease concentration of phosphorous in plant tissue (Sharpley *et al* 1992).

Table 4.22 Saline irrigation watereffecton plant phosphorous content (%) of wheat cultivars at tillering stage

2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.29	0.26	0.31	0.38	0.36	0.37	**0.32**
EC 3	0.25	0.21	0.26	0.29	0.28	0.31	**0.26**
EC 6	0.18	0.15	0.20	0.23	0.22	0.26	**0.20**
EC 9	0.11	0.09	0.14	0.18	0.16	0.19	**0.14**
EC 12	0.09	0.07	0.10	0.14	0.11	0.10	**0.10**
Mean	**0.18**	**0.15**	**0.20**	**0.24**	**0.22**	**0.25**	
LSD (5%)	**EC= 0.06 Cultivar= 0.02 Interaction = NS**						
2014-15							
EC 0	0.48	0.39	0.46	0.32	0.40	0.49	**0.42**
EC 3	0.45	0.36	0.42	0.27	0.37	0.43	**0.38**
EC 6	0.40	0.32	0.39	0.23	0.33	0.38	**0.34**
EC 9	0.35	0.28	0.36	0.18	0.29	0.34	**0.30**
EC 12	0.30	0.23	0.31	0.14	0.25	0.30	**0.25**
Mean	**0.39**	**0.31**	**0.38**	**0.22**	**0.32**	**0.39**	
LSD (5%)	**EC= 0.05 Cultivar= 0.04 Interaction = NS**						

Further exploration of results described that average plant P content of different wheat cultivars varied from 0.15 to 0.25% and 0.22- 0.39 % for first and second year of reserachl study. Fageria *et al* (2011) reported that under salt stress P uptake varies with plant genotypes.However, non-significant interaction between salinity levels and wheat cultivars was observed for plant P content in 2013-14 and 2014-15.

4.1.4.4.5Influence of saline water irrigation on plant calcium content of wheat cultivars at tillering stage

It was observed that the plant calcium (Ca) content follows the same trend as that of plant P content at different salinitylevels i.e. decreased with increasing salinity of irrigation water. The data revealed that the plant Ca content decreased by 14.2, 35.7, 50.0 and 64.2 % in 2013-14 and 16.6, 41.6, 58.3 and 66.7 % in 2014-15 at EC 3, 6, 9 and 12dS/m salinity levelsover control (Table 4.23). Plant acquisition and utilization of necessary nutrient particulary K^+ and Ca^{+2} impair under saline conditions affecting growth and productivity of plants (Zhu 2003).

Table 4.23 Effect of saline water irrigation on plant calcium content (%) of wheat cultivars at tillering stage

2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.012	0.011	0.021	0.013	0.013	0.015	**0.014**
EC 3	0.009	0.010	0.018	0.011	0.010	0.012	**0.012**
EC 6	0.007	0.008	0.015	0.009	0.008	0.009	**0.009**
EC 9	0.006	0.007	0.011	0.006	0.006	0.008	**0.007**
EC 12	0.043	0.005	0.009	0.004	0.004	0.006	**0.005**
Mean	**0.007**	**0.008**	**0.015**	**0.009**	**0.008**	**0.010**	
LSD (5%)	**EC= 0.002 Cultivar= 0.001 Interaction = NS**						
2014-15							
EC 0	0.012	0.011	0.014	0.013	0.012	0.014	**0.012**
EC 3	0.008	0.009	0.012	0.011	0.009	0.011	**0.010**
EC 6	0.007	0.006	0.009	0.009	0.007	0.009	**0.007**
EC 9	0.005	0.004	0.007	0.006	0.005	0.007	**0.005**
EC 12	0.004	0.003	0.005	0.004	0.004	0.006	**0.004**
Mean	**0.007**	**0.006**	**0.009**	**0.008**	**0.007**	**0.009**	
LSD (5%)	**EC= 0.0005 Cultivar= 0.0007 Interaction = NS**						

Calcium in plant leaves decreased due to inhibition by salt of symplastic xylem loading of Ca in roots, leading to reduced Ca status in growing regions of leaves (Neves-Piesten and Bernstan 2005). The data shows that mean plant Ca content of different wheat cultivars ranged from 0.007 to 0.015% in 2013-14 and 0.006 to 0.009 % in 2014-15. Furthermore, interaction effects for plant Ca content were non-significant for first and second year of research study.

4.1.5 Yield, yield attributes, mineral composition and quality parameters of differentwheat cultivars as affected by saline irrigation water at maturity

4.1.5.1 Saline irrigation water effect on plant height of different wheat cultivars at maturity

The data pertaining to plant height of different wheat cultivars as affected by different salinity levels at maturity was recorded in 2013-14 and 2014-15 is presented in Table 4.24.Although, more plant height was recorded at maturity, compared to tillering stage but increasing salinity significantly decreased plant height of wheat cultivars during both years of study. Islam *et al* (2011) observed that salinity stress resulted in lower turgidity in cell and produced shorter plants. The mean plant height of wheat cultivars decreased by 3.3, 10.1, 14.5 and 19.2 % in 2013-14 and 4.8, 10.7, 16.8 and 24.1 % in 2014-15 at EC 3, 6, 9 and 12 dS/m salinitylevels as compared to control. Under saline conditions, plant growth is usually reduced by reducing leaf elongation, enlargement and division of cells in the leave (Allen *et al* 1985). It was observed that mean plant height of different wheat cultivars ranged from 71.2 to 78.3 cm in 2013-14 and from 71.9 to 78.1 cm in 2014-15 at different levels of salinity.

Among six wheat cultivars, themaximum plant height was observed in KRL 210 in both years, whereas the minimum was recordedfor PBW 590 in 2013-14 and HD 2967 in 2014-15, respectively. Non-significant interaction was observed for plant height between salinity levels and wheat cultivars in 2013-14 and 2014-15.

Table 4.24 Saline water irrigation effects on plant height (cm) of different wheat cultivars at maturity

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	82.9	78.2	81.1	79.6	80.8	83.6	**81.0**
EC 3	81.7	75.8	77.6	75.4	78.8	80.8	**78.3**
EC 6	76.7	72.6	70.1	70.3	70.8	76.5	**72.8**
EC 9	76.6	68.3	67.6	68.4	65.4	69.2	**69.2**
EC 12	74.0	66.1	65.4	62.6	60.6	63.9	**65.4**
Mean	**78.3**	**72.2**	**72.3**	**71.2**	**71.3**	**74.8**	
LSD (5%)	**EC= 1.9 Cultivar= 2.5 Interaction = NS**						
2014-15							
EC 0	86.1	85.0	82.1	82.9	83.4	86.2	**84.3**
EC 3	83.2	81.2	78.3	80.8	79.8	77.9	**80.2**
EC 6	77.3	76.0	72.6	77.2	75.2	73.0	**75.2**
EC 9	73.7	71.1	66.1	73.7	68.3	67.5	**70.1**
EC 12	70.0	68.5	60.4	60.3	62.7	61.6	**63.9**
Mean	**78.1**	**76.4**	**71.9**	**75.0**	**73.9**	**73.3**	
LSD (5%)	**EC= 2.9 Cultivar= 3.5 Interaction = NS**						

4.1.5.2 Number of Spikes/m^2

Number of spikes/m^2 of different wheat cultivars were significantly decreased with increasing salinity of irrigation water in both years (Table 4.25). The average number of spikes/m^2 of wheat cultivars decreased from 311 in control to 285, 271,252 and 228 at EC 3, 6, 9 and 12 dS/m levels of salinity in 2013-14. In 2014-15 corresponding values were 327 (EC 0) to 298, 269, 256 and 228 at respective salinity levels. The data revealed that maximum reduction in average number of spikes/m^2 occurs at highest level of salinity (EC=12dS/m) which decreased by 26.6 and 30.2 % over control in 2013-14 and 2014-15. Houshmand*et al* (2005) reported that for eight wheat cultivars average number of spikes/m^2 decreased from 507 to 430 in saline soil (EC= 3.8 dS/m) as compared to normal soil (EC=1.1 dS/m).Ahmad *et al* (2005) also reported decrease in number of spike/plant for six wheat cultivars under saline soil as compared to normal soil.

Table 4.25 Number of spikes/ m^{2}of different wheat cultivars as affected by salinity of irrigation water

2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	321	315	318	285	319	310	**311**
EC 3	283	281	291	271	296	284	**285**
EC 6	266	265	275	266	278	274	**271**
EC 9	251	248	258	243	258	251	**252**
EC 12	221	228	248	226	230	220	**228**
Mean	**269**	**268**	**278**	**258**	**276**	**267**	
LSD (5%)	**EC = 6.2**	**Cultivar = 4.4**		**Interaction = 9.7**			
2014-15							
EC 0	328	325	348	310	322	328	**327**
EC 3	297	302	317	284	290	295	**298**
EC 6	272	270	267	261	275	269	**269**
EC 9	256	253	261	248	268	250	**256**
EC 12	215	220	240	232	227	235	**228**
Mean	**273**	**274**	**287**	**267**	**276**	**275**	
LSD (5%)	**EC = 5.5**	**Cultivar = 3.6**		**Interaction = 8.1**			

Maximum meannumber of spikes /m^2 were reported in cultivar HD 2967 (278 and 287) followed by PBW658 (276) in both years , whereas minimum in PBW 590 (258 and 267) cultivar in respective years. Among different wheat cultivars, maximum reduction in number of spikes/m^2 at highest salinity level was observed for KRL 210 in 2013-14 and

Berbet in 2014-15. Number of spikes/m^{2}of KRL 210 and PBW621 almost decreased by same magnitude and have same mean valuesin both years.

The perusal of data shows that significant interaction was observed for number of spikes/m^2 between salinity levels and wheat cultivars during first as well second year of research study where number of spikes/m^2 was statistically at par at EC 9 for cultivars PBW 621 and EC 12 dS/m levelfor HD 2967 in 2013-14 and at EC 6 for PBW 590 and 9 dS/m levels of salinity for cultivars HD 2967 in 2014-15, respectively

4.1.5.3 Spike length

Effects of different levels of saline water irrigation on spike length of six wheat cultivars along with statistically analysis in 2013-14 as well 2014-15 were presented in Table 4.26. It has been observed that spike length of different wheat cultivars was significantly decreased with increased salinity levels expect at EC 3dS/m in 2014-15. It is evident that maximum reduction in average spike length occurs at salinity level of 12 dS/m in 2013-14 and 2014-15, which decreased by 18.9 % and 20.2 % over control. Kumar *et al* (2012) reported that average ear length of eight wheat cultivars decreased from 10.8to 7.1 cm as salinity increased from 0 to 12dS/m. Ahmad *et al* (2005) for six wheat cultivars average spike length of these cultivars decreases from 9.8 to 8.4 cm in saline soil (ECe =12 dS/m) as compared to normal soil (ECe =1.9 dS/m.)

Table 4.26 Spike length (cm) of different wheat cultivars as affected by saline water irrigation

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	8.8	8.9	9.3	9.7	9.6	10.4	**9.5**
EC 3	8.4	8.3	9.0	9.6	9.5	9.9	**9.1**
EC 6	8.0	7.5	8.6	9.2	9.1	9.8	**8.7**
EC 9	7.7	7.0	8.0	8.8	8.4	9.5	**8.2**
EC 12	7.5	6.7	7.6	8.0	7.5	9.2	**7.7**
Mean	**8.1**	**7.7**	**8.5**	**9.1**	**8.8**	**9.8**	
LSD (5%)	**EC = 0.3**	**Cultivar = 0.4**		**Interaction = NS**			
2014-15							
EC 0	8.3	9.5	9.7	9.8	9.4	10.1	**9.4**
EC 3	8.1	9.0	9.3	9.4	9.2	9.8	**9.1**
EC 6	7.7	8.6	8.7	9.1	8.8	9.6	**8.7**
EC 9	7.2	8.0	8.1	8.5	8.4	9.2	**8.2**
EC 12	6.5	7.4	7.5	7.8	7.7	8.5	**7.5**
Mean	**7.6**	**8.5**	**8.6**	**8.9**	**8.7**	**9.5**	
LSD (5%)	**EC = 0.4**	**Cultivar = 0.5**		**Interaction = NS**			

Among different wheat cultivars maximum mean spike length was observed in cultivars Berbet in 2013-14 as well as 2014-15, whereas minimum was reported in PBW 621 for first year and in KRL 210 for second year of experimental study. Non-significant interaction effects were observed for spike length for both years.

4.1.5.4 Grain weight/spike

The results pertaining to grain weight/spike of wheat cultivars at different salinity levels during 2013-14 and 2014-15are presented in Table 4.27. It is evident that grain weight/spike significantly decreased with increase in salinity of irrigation water in both years. The mean grain weight/ spike decreased by 18.8, 31.8, 39.4 and 50.0 % and 8.3, 16.6, 29.1 and 41.6 % at EC 3, 6, 9 and 12 dS/m levels of salinity as compared to EC 0 with maximum reduction occuring at the highest level of salinity in 2013-14 and 2014-15. Ahmad *et al* (2005) reported that average grain weight /spike of six cultivars decreased from 2.4 to 1.7 in saline soils (ECe=12 dS/m) as compared to normal soil (ECe = 1.9 dS/m).Similar results were also reported by Houshmand *et al* (2005), who reported that average grain weight/ spike of eight wheat cultivars decreased from 2.1 in normal soil (EC = 1.1 dS/m) to 0.6 g in saline soil (EC= 3.8dS/m).The data revealed that for different wheat cultivars grain weight/ spike varied from 1.0 to 2.6 g and from 1.3 to 2.6 g in 2013-14 and 2014-15 at different salinity levels.

Table 4.27 Effect of saline water irrigation on grain weight per spike (g) of wheat cultivars

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	2.6	1.9	2.3	1.7	2.5	2.1	**2.2**
EC 3	2.0	1.6	1.8	1.5	2.0	1.8	**1.8**
EC 6	1.8	1.6	1.7	1.2	1.5	1.4	**1.5**
EC 9	1.3	1.2	1.2	1.1	1.2	1.0	**1.2**
EC 12	1.0	1.1	1.2	1.0	1.4	1.1	**1.1**
Mean	**1.7**	**1.5**	**1.6**	**1.3**	**1.7**	**1.5**	
LSD (5%)	**EC = 0.2**	**Cultivar = 0.2**		**Interaction = NS**			
2014-15							
EC 0	2.5	2.3	2.5	2.6	2.2	2.5	**2.4**
EC 3	2.0	2.2	2.4	2.3	2.1	2.4	**2.2**
EC 6	1.9	2.0	2.2	1.9	2.0	2.1	**2.0**
EC 9	1.8	1.7	2.0	1.6	1.8	1.7	**1.7**
EC 12	1.5	1.4	1.7	1.3	1.6	1.4	**1.4**
Mean	**1.9**	**1.9**	**2.1**	**1.9**	**1.9**	**2.0**	
LSD (5%)	**EC = 0.2**	**Cultivar = NS**		**Interaction = NS**			

The mean grain weight/spike among different wheat cultivars was at par in 2014-15. Non-significant interaction was observed for grain weight/spike between salinity levels and wheat cultivars in both years.

4.1.5.5 Effects of irrigation water salinity on thousand grain weight of wheat cultivars

Effect of saline irrigation water on thousand grain weight (TGW) of six wheat cultivars was observed in 2013-14 and 2014-15 and presented in Table 4.28. Data shows that TGW decreased significantly at all levels of salinity expect at EC 3 dS/m relative to EC 0 treatments in 2014-15. Salinity stress at grain filling stages can cause a decrease in photosynthesis, mobilization to grains and thereby decreasing grain weight (Sadeghipour 2008).

It has been observed that TGW decreased from 41.1g in EC 0 to 39.7, 38.8, 38.2 and 36.4 g at EC 3, 6, 9 and 12 dS/m salinity levels in 2013-14. Corresponding decrease in 2014-15 occured from 44.1 g (EC 0) to 42.8, 40.9, 39.7 and 37.4 g. Houshmand *et al* (2005) also reported decrease in TGW of eight wheat cultivars from 44.5 to 21.3 g in saline soil (EC= 3.8dS/m) compared to normal soil (EC = 1.1 dS/m)

Table 4.28 Thousand grain weight (g) of wheat cultivars as affected by salinity of irrigation water

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	39.2	41.5	40.6	39.4	41.2	44.9	**41.1**
EC 3	38.0	38.2	39.6	38.3	39.7	44.9	**39.7**
EC 6	37.7	37.5	39.2	36.7	38.4	43.5	**38.8**
EC 9	36.6	37.2	38.6	36.5	37.7	43.2	**38.2**
EC 12	35.2	35.1	36.5	35.1	35.7	40.5	**36.4**
Mean	**37.3**	**37.9**	**38.9**	**37.2**	**38.5**	**43.4**	
LSD (5%)	**EC = 0.9**		**Cultivar = 1.3**		**Interaction = NS**		
2014-15							
EC 0	44.8	43.0	44.0	43.2	44.5	45.2	**44.1**
EC 3	43.9	42.5	41.9	42.4	42.0	44.6	**42.8**
EC 6	42.5	39.0	38.1	41.8	40.7	43.1	**40.9**
EC 9	41.1	37.9	37.6	40.5	38.8	42.6	**39.7**
EC 12	38.3	36.2	36.5	39.0	36.3	38.2	**37.4**
Mean	**42.1**	**39.7**	**39.6**	**41.3**	**40.5**	**42.7**	
LSD (5%)	**EC =1.6**		**Cultivar = 1.9**		**Interaction = NS**		

Among different wheat cultivars, maximum TGW was observed in Berbet for both years, whereas minimum was observed for PBW 590 in 2013-14 and for HD 2967 in 2014-15 respectively.The severe inhibitory effect of salts on different genotypes may be due to the differential completion in carbohydrates supply between vegetative growth and constrained its distribution to developing spikes and lead to reduction in the viability of pollens under stress condition and therefore, resulting in the failures of seed set (Abdullah *et al* 2001). The maximum and minimum relative decrease was observed for PBW 621 and Berbet in 2013-14 and PBW 658 and PBW 590 in 2014-15. Non-significant interaction was observed for TGW between salinity levels and wheat cultivars in 2013-14 and 2014-15.

4.1.5.6 Total biomass

Effect of different salinity levels on biomass of wheat cultivars was recorded in 2013-14 and 2014-15 and is discussed in Table 4.29. It was observed that average biomass in control was 13.30 t/ha while it was 12.50, 11.87, 11.20 and 9.91 t/ha at EC 3, 6, 9 and 12 dS/msalinitylevels,respectively across two years. Reduction in biomass of wheat cultivars may be due to extra energy utilization for osmotic accumulation which is much more ATP-consuming for osmotic adjustments (Wyn and Jones and Gorham 1993). According to Munns(2002) salt stress decreased growth in most of plants and these plants are unable to produce their maximum biomass.The percentage relative decrease of biomass was 93.9, 89.2, 84.2 and 74.5 % atEC 3, 6, 9 and 12 dS/msalinity levelsover control across two years.

Table 4.29Influence of saline irrigation water on biomass (t/ha) of wheat cultivars

2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	14.02	13.88	14.89	11.27	13.66	12.08	**13.29**
EC 3	12.37	13.58	13.00	11.15	12.71	11.29	**12.35**
EC 6	11.78	12.72	12.36	11.01	12.58	10.70	**11.85**
EC 9	11.54	10.59	10.66	11.63	12.09	10.70	**11.20**
EC 12	9.68	9.82	10.15	10.36	9.74	9.57	**9.88**
Mean	**11.87**	**12.12**	**12.21**	**11.08**	**12.16**	**10.87**	
LSD (5%)	**EC = 0.39**		**Cultivar = 0.34**		**Interaction = 0.75**		
2014-15							
EC 0	13.80	14.08	14.69	11.05	13.85	12.34	**13.30**
EC 3	12.58	13.67	13.00	11.55	12.97	12.07	**12.64**
EC 6	11.98	12.52	12.16	11.01	12.72	10.90	**11.88**
EC 9	11.21	10.38	10.79	11.58	12.28	10.90	**11.19**
EC 12	9.88	9.62	10.09	10.41	9.95	9.66	**9.93**
Mean	**11.89**	**12.05**	**12.14**	**11.12**	**12.36**	**11.17**	
LSD (5%)	**EC = 0.11**		**Cultivar = 0.12**		**Interaction = 0.27**		
Pooled data							
EC 0	13.91	13.98	14.79	11.16	13.76	12.21	**13.30**
EC 3	12.48	13.63	13.00	11.35	12.84	11.68	**12.50**
EC 6	11.88	12.62	12.26	11.01	12.65	10.80	**11.87**
EC 9	11.38	10.49	10.73	11.61	12.19	10.80	**11.20**
EC 12	9.78	9.72	10.12	10.39	9.85	9.62	**9.91**
Mean	**11.88**	**12.09**	**12.18**	**11.10**	**12.26**	**11.02**	
LSD (5%)	**EC = 0.18**		**Cultivar = 0.17**		**Interaction = 0.39**		

Among different wheat cultivars maximum average biomass was observed in cultivar HD 2967 and PBW 658 in 2013-14 and 2014-15, whereas minimum was observed in cultivar Berbet and PBW 590 in respective years. Interaction between two factors (salinity levels and wheat cultivars) for biomass was significant for first and second year of research study.

4.1.5.7 Grain yield of wheat cultivars as affected by salinity irrigationwater

The data pertaining to effect of saline irrigation water on grain yield of different wheat cultivars in 2013-14 and 2014-15 is presented in Table 4.30. It was evident from data that grain yield significantly decreased at all levels of salinity except at EC 3dS/m level in 2013-14. It was observed that grain yield decreased from 5.18 t/ha in EC 0 to 5.01, 4.72, 4.35 and 3.99 t/ha at EC 3, 6, 9 and 12dS/m salinity levels across two years. Similar findings were reported by Phogat *et al* (2011). They observed significant decrease in grain yield of wheat crop from 5.53 to 3.73 Mg/ha in 2003 and from 4.51 to 2.58Mg/ha in 2004 as salinity of irrigation water increasesd from 0.4 to 8.4 dS/m, respectively. Houshmand *et al* (2005) also reported significant effects of salinity on grain yield reduction.

Table 4.30 Grain yield (t/ha) of wheat cultivars as influenced by saline water irrigation

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	5.35	5.06	5.27	4.75	5.32	5.17	**5.15**
EC 3	5.12	4.82	5.06	4.67	5.14	4.95	**4.96**
EC 6	4.90	4.74	4.96	4.29	4.82	4.65	**4.73**
EC 9	4.44	4.39	4.54	4.08	4.47	4.16	**4.35**
EC 12	3.87	3.92	4.05	3.89	4.26	3.91	**3.98**
Mean	**4.74**	**4.58**	**4.78**	**4.34**	**4.80**	**4.57**	
LSD (5%)	**EC = 0.22 ,Cultivar = 0.26 , Interaction = NS**						
2014-15							
EC 0	5.22	5.16	5.37	4.85	5.54	5.07	**5.20**
EC 3	5.16	5.02	5.25	4.74	5.32	4.87	**5.06**
EC 6	4.80	4.64	4.93	4.34	5.01	4.59	**4.71**
EC 9	4.36	4.43	4.49	4.23	4.47	4.16	**4.35**
EC 12	3.91	4.05	4.17	3.75	4.19	3.88	**3.99**
Mean	**4.69**	**4.66**	**4.84**	**4.38**	**4.91**	**4.51**	
LSD (5%)	**EC = 0.14 ,Cultivar = 0.09 , Interaction = NS**						
Pooled data							
EC 0	5.29	5.11	5.32	4.80	5.43	5.12	**5.18**
EC 3	5.14	4.92	5.16	4.71	5.23	4.91	**5.01**
EC 6	4.85	4.69	4.95	4.32	4.92	4.62	**4.72**
EC 9	4.40	4.41	4.52	4.16	4.47	4.16	**4.35**
EC 12	3.89	3.99	4.11	3.82	4.23	3.90	**3.99**
Mean	**4.71**	**4.62**	**4.81**	**4.36**	**4.85**	**4.54**	
LSD (5%)	**EC = 0.12 ,Cultivar = 0.14 , Interaction = NS**						

The data shows that percentage relative decrease in grain yield was 96.7, 91.1, 84.0 and 77.0% at EC 3, 6, 9 and 12 dS/m salinity levels over control across two years. The decrease in grain yield due to salinity can be attributed to low germination and reduction in number of spikes and spikelets (Mass *et al* 1996 and Singh and Chatrath 2001). Saqib *et al* (2006) also reported that grain yield and yield components of wheat are negatively affected by salinity.

The perusal of data shows that grain yield of different wheat cultivar ranged from 3.87 to 5.35 t/ha and 3.75to 5.54 t/ha in 2013-14 and 2014-15.At EC 9 dS/m, performance of PBW 658 and HD 2967 in absolute grain yield was similar and higher than other cultivars but cultivar PBW621 produced 86 % relative yield compared to 84% for cultivar HD 2967 and 82% for PBW 658, whereas salt tolerant KRL 210 (83%) was on par with these cultivars (based on relative yield). However, at EC 12 dS/m , cultivar PBW 658 produced significantly higher grain yield (4.23 t ha^{-1}) than cultivar HD 2967 (4.11 t/ ha) and PBW621 (3.99 t/ ha). Salt tolerant KRL 210 (3.89t/ ha) and Berbet (3.90t/ ha) was on par at respective salinity level. The interaction between salinity levels and different wheat cultivars for grain yield was non-significant across two years.

4.1.5.8 Effect of saline irrigation water on straw yield of wheat cultivars

Irrigation with different salinity levels resulted in significant decrease in straw yield of six wheat cultivars in both years as presented in Table 4.31. The mean straw yield decreased from 8.13t/ha in control to 7.49, 7.15, 6.86 and 5.92 t/ha at EC 3, 6, 9 and 12 dS/m salinity levels across two years. The parcentage relative decrease in straw yield of wheat cultivars was 92.1, 87.9, 84.4 and 72.8 % at EC 3, 6, 9 and 12 dS/m salinity levelsas compared to control in two years . Zein *et al* (2003) reported that grain and straw yield were significantly affected by increasing irrigation water salinity. El-Morsy *et al* (1993) also observed that grain and straw yield were negatively correlated with soil salinity.

When results pertaining to straw yield among wheat cultivars were considered, it was observed that maximum average straw yield was recorded for cultivars PBW 621 and minimumfor cultivar Berbet across two years. Significant interaction effects were observed for straw yield in both years.

Table 4.31Saline irrigation water effect on straw yield (t/ha) of wheat cultivars

2013-14							
Cultivars							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	8.67	8.82	9.62	6.52	8.34	6.91	**8.15**
EC 3	7.25	8.76	7.94	6.48	7.57	6.34	**7.39**
EC 6	6.88	7.97	7.40	6.72	7.76	6.04	**7.13**
EC 9	7.10	6.20	6.12	7.55	7.61	6.54	**6.85**
EC 12	5.81	5.90	6.10	6.47	5.48	5.66	**5.90**
Mean	**7.14**	**7.53**	**7.43**	**6.74**	**7.35**	**6.30**	
LSD (5%)	**EC = 0.22**	**Cultivar = 0.28**	**Interaction = 0.64**				
2014-15							
EC 0	8.59	8.92	9.32	6.19	8.32	7.27	**8.10**
EC 3	7.47	8.66	7.75	6.81	7.65	7.21	**7.59**
EC 6	7.18	7.88	7.23	6.67	7.72	6.31	**7.16**
EC 9	6.86	5.94	6.36	7.39	7.88	6.74	**6.86**
EC 12	5.97	5.57	5.92	6.65	5.76	5.79	**5.94**
Mean	**7.21**	**7.39**	**7.31**	**6.74**	**7.46**	**6.66**	
LSD (5%)	**EC = 0.02**	**Cultivar = 0.03**	**Interaction = 0.08**				
Pooled data							
EC 0	8.63	8.87	9.47	6.36	8.33	7.09	**8.13**
EC 3	7.36	8.71	7.85	6.65	7.61	6.78	**7.49**
EC 6	7.03	7.93	7.32	6.70	7.74	6.18	**7.15**
EC 9	6.98	6.07	6.24	7.47	7.75	6.64	**6.86**
EC 12	5.89	5.74	6.01	6.56	5.62	5.73	**5.92**
Mean	**7.18**	**7.46**	**7.38**	**6.75**	**7.41**	**6.48**	
LSD (5%)	**EC = 0.10**	**Cultivar = 0.14**	**Interaction = 0.32**				

4.1.5.9 Harvest Index of wheat cultivars as affected by salinity of irrigation water

Harvest index indicates magnitude of allocation of dry matter from leaves and stem to grains (Solanki 2009). The data related to harvest index as influenced by the different levels of salinity in 2013-14 and 2014-15 is presented in Table 4.32. The non- significant relationship of harvest index with salinity levels and different wheat cultivars was observed for first and second year of experimental study. The average harvest index ranged from 0.39-0.40 at different salinity levels in 2013-14 and 2014-15. It was observed that interaction effects for harvest index were also non- significant in both years.

Table 4.32 Harvest indexof wheat cultivars as affected by salinity of irrigation water

2013-14							
	Cultivars						
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.38	0.36	0.35	0.42	0.39	0.42	**0.39**
EC 3	0.41	0.35	0.39	0.42	0.40	0.44	**0.40**
EC 6	0.41	0.37	0.39	0.39	0.38	0.43	**0.39**
EC 9	0.38	0.41	0.43	0.35	0.38	0.39	**0.39**
EC 12	0.40	0.40	0.40	0.38	0.44	0.41	**0.40**
Mean	**0.39**	**0.38**	**0.39**	**0.39**	**0.39**	**0.42**	
LSD (5%)	**EC = NS**		**Cultivar = NS**		**Interaction = NS**		
2014-15							
EC 0	0.37	0.36	0.36	0.44	0.40	0.41	**0.39**
EC 3	0.41	0.36	0.40	0.40	0.41	0.40	**0.39**
EC 6	0.40	0.37	0.40	0.39	0.39	0.42	**0.39**
EC 9	0.39	0.42	0.41	0.36	0.36	0.38	**0.39**
EC 12	0.39	0.42	0.41	0.35	0.42	0.40	**0.40**
Mean	**0.39**	**0.39**	**0.39**	**0.39**	**0.39**	**0.40**	
LSD (5%)	**EC = NS**		**Cultivar = NS**		**Interaction = NS**		

4.1.6. Mineral composition (Na, K, P and Ca)of wheat cultivar at maturity

Mineral composition (Na, K, P and Ca) of grain and straw samples of six wheat cultivars was determined to observe the effect of different salinity levels in 2013-14 and 2014-15 and results pooled over two years are discussed under following headings;

4.1.6.1 Grain sodium content

Increase in levels of saline irrigation water significantly increased grain Na content in six wheat cultivars acroos two years (Table 4.33). It is evident that average grain Na content increased from 0.050 % to 0.064, 0.074, 0.084 and 0.096 % at EC 3, 6, 9, and 12 dS/m salinity levels over EC 0 treatment. Ragab *et al* (2008) reported increase in grain Na uptake from 47.5 to 56.0 mg/pot in sandy soil and from 80.1 to 115.4 mg/pot in calcareous soil with increase in irrigation water salinity from 0.43 to 8.9 dS/m.

Table 4.33 Grain sodium and potassium content (%) and Na/K ratio of wheat cultivars as influenced by salinity of irrigation water pooled over two years

Grain Na (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.030	0.041	0.047	0.058	0.064	0.059	**0.050**
EC 3	0.048	0.064	0.062	0.070	0.073	0.066	**0.064**
EC 6	0.065	0.076	0.071	0.078	0.081	0.078	**0.074**
EC 9	0.072	0.088	0.083	0.086	0.087	0.089	**0.084**
EC 12	0.085	0.100	0.098	0.098	0.099	0.098	**0.096**
Mean	**0.060**	**0.074**	**0.072**	**0.078**	**0.081**	**0.078**	
LSD (5%)	**EC = 0.002, Cultivar = 0.005, Interaction= NS**						
Grain K (%)							
EC 0	0.078	0.090	0.084	0.087	0.085	0.090	**0.086**
EC 3	0.071	0.076	0.076	0.081	0.078	0.084	**0.078**
EC 6	0.061	0.070	0.065	0.065	0.064	0.068	**0.065**
EC 9	0.048	0.056	0.054	0.054	0.056	0.062	**0.054**
EC 12	0.040	0.047	0.044	0.038	0.043	0.048	**0.043**
Mean	**0.059**	**0.068**	**0.064**	**0.065**	**0.065**	**0.070**	
LSD (5%)	**EC = 0.005, Cultivar = 0.004, Interaction= NS**						
Grain Na/K ratio							
EC 0	0.39	0.47	0.56	0.67	0.76	0.66	**0.58**
EC 3	0.70	0.84	0.85	0.90	0.94	0.81	**0.83**
EC 6	1.09	1.09	1.10	1.19	1.29	1.14	**1.15**
EC 9	1.57	1.57	1.59	1.60	1.65	1.47	**1.58**
EC 12	2.27	2.18	2.26	2.69	2.31	2.14	**2.30**
Mean	**1.20**	**1.23**	**1.27**	**1.41**	**1.39**	**1.24**	
LSD (5%)	**EC = 0.15, Cultivar = 0.14, Interaction= NS**						

It was observed that meangrain Na content among wheat cultivars ranged from 0.060 to 0.081 % in two years at different levels of salinity. It has been observed that maximum average grain Na content was reported in cultivar PBW 658 (0.081 %), whereas as minimum was observed in cultivar KRL210 (0.060 %) across two years. Non-significant interaction between salinity levels and wheat cultivars was observed for grain Na in two years.

4.1.6.2 Grain potassium content

The data pertaining to effect of saline water irrigation on grain K content pooled over two yearsis presented in Table 4.33. Mean grain K content decreased by 9.3, 24.4, 37.2 and 50.0 % at EC 3, 6, 9 and 12dS/m salinity levels as compared to EC 0 across two years. The decrease in K content was due to presence of excessive Na in growth medium (antagonistic effect) (Sarwar and Ashraf 2005). Ragab *et al* (2008) reported that increasing irrigation water salinity from 0.43 to 8.9 dS/m resulted in significant decrease grain K uptake from 231.7 to 186.7 mg/pot in sandy soil and from 458.5 to 309.2 mg/pot in calcareous soil.

The maximum average grain K was observed in cultivars Berbet and minimum in KRL210 for two years. The interaction effects for grain K content were non-significant.

4.1.6.3 Na/K ratio in grains of different wheat cultivars under saline irrigation water

It was observed that Na/K grain ratio significantly increased with increasing salinity levelsover two years. The Na/K grain ratio increased from 0.58 to 0.83, 1.15, 1.58 and 2.30 as salinity of irrigation water increased from 0 to 3, 6, 9 and 12 dS/m levels over two years. Among different wheat cultivars maximum and minimum Na/K ratio was observed in PBW 590 and KRL 210. Interaction effects for Na/K grain ratio were non-significant across two years

4.1.6.4Grain phosphorous content

The pooled data presented in Table 4.34 revealed that grain P content significantly decreased with increasing salinity of irrigation water. Average grain P content decreased from 0.21 % (EC 0) to 0.18, 0.15, 0.12 and 0.10 % at EC 3, 6, 9 and 12dS/m salinity levels over two years. The results revealed that average plant P content of different wheat cultivars varied from 0.12 to 0.20%. Non-significant interaction between salinity levels and wheat cultivars was observed for grain P content over two years.

Table 4.34 Effect of saline irrigation wateron grain phosphorous and calcium content(%) of wheat cultivars

Grain P (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.20	0.17	0.20	0.27	0.22	0.23	**0.21**
EC 3	0.18	0.15	0.17	0.23	0.19	0.20	**0.18**
EC 6	0.16	0.13	0.14	0.20	0.15	0.18	**0.15**
EC 9	0.13	0.10	0.10	0.17	0.13	0.15	**0.12**
EC 12	0.10	0.08	0.07	0.14	0.11	0.11	**0.10**
Mean	**0.15**	**0.12**	**0.13**	**0.20**	**0.16**	**0.17**	
LSD (5%)	**EC = 0.02 ,Cultivar = 0.01 , Interaction= NS**						
Grain Ca (%)							
EC 0	0.009	0.013	0.011	0.011	0.011	0.012	**0.011**
EC 3	0.009	0.011	0.010	0.010	0.009	0.010	**0.009**
EC 6	0.007	0.009	0.008	0.009	0.007	0.009	**0.008**
EC 9	0.005	0.006	0.007	0.007	0.006	0.007	**0.006**
EC 12	0.004	0.005	0.005	0.005	0.005	0.005	**0.005**
Mean	**0.007**	**0.009**	**0.008**	**0.008**	**0.007**	**0.008**	
LSD (5%)	**EC = 0.001 ,Cultivar = 0.001 , Interaction= NS**						

4.1.6.5 Grain calcium content of different wheat cultivars as affected by salinity ofirrigation water

It was observed that the graincalcium Ca content follows the same trend as that of grain P i.e. decreasing with increasing salinity of irrigation water. Grain Ca content decreased by 18.1, 27.3, 45.4 and 54.5 % as compared to control (EC 0) over two years (Table 4.34).The decrease in Ca uptake under salinity could be due to antagonism effect of Na at sites of uptake in roots, which affects Ca transport into xylem (Hendawy 2004)

It was observed that grain Ca content for all cultivars was on par over two years.Interaction effects for grain Ca content were non-significant across two years.

4.1.6.6 Straw sodium content

The data presented in Table 4.35 revealed that straw Na content significantly increased with increasing salinity of irrigation water over two years. It is evident that mean straw Na content increased from 0.065 % in EC 0 to 0.082, 0.099, 0.121 and 0.141 % in 2013-14 and from 0.063 % (EC 0) to 0.081, 0.098, 0.120 and 0.140 % at EC 3, 6, 9 and 12dS/m salinity levels, respectively. With increasing salinity from 0 to 12 dS/m, maximum increase in straw Na content of cultivar PBW 658 was observed at each salinity level, while minimum increase observed for KRL 210 across two years. The average straw Na content of different wheat cultivars varied from 0.083 to 0.118%.

Table 4.35 Straw sodium and potassium content(%) and Na/ K ratio of wheat cultivars under saline irrigation water pooled over two years

Straw Na (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.037	0.047	0.068	0.073	0.085	0.071	**0.063**
EC 3	0.064	0.069	0.088	0.088	0.099	0.082	**0.081**
EC 6	0.080	0.093	0.098	0.106	0.113	0.101	**0.098**
EC 9	0.111	0.119	0.109	0.120	0.137	0.125	**0.120**
EC 12	0.125	0.141	0.130	0.142	0.158	0.144	**0.140**
Mean	**0.083**	**0.094**	**0.098**	**0.106**	**0.118**	**0.104**	
LSD (5%)	**EC = 0.003 ,Cultivar = 0.005 , Interaction = 0.011**						
Straw K (%)							
EC 0	0.111	0.120	0.115	0.116	0.140	0.128	**0.121**
EC 3	0.100	0.108	0.104	0.105	0.129	0.116	**0.110**
EC 6	0.086	0.101	0.094	0.089	0.116	0.108	**0.099**
EC 9	0.078	0.089	0.087	0.083	0.102	0.094	**0.089**
EC 12	0.068	0.084	0.072	0.068	0.088	0.080	**0.076**
Mean	**0.089**	**0.100**	**0.094**	**0.092**	**0.115**	**0.105**	
LSD (5%)	**EC = 0.005 ,Cultivar = 0.006 , Interaction = NS**						
Straw Na/K ratio							
EC 0	0.33	0.40	0.59	0.63	0.61	0.56	**0.52**
EC 3	0.64	0.64	0.87	0.84	0.77	0.70	**0.74**
EC 6	0.93	0.92	1.06	1.21	0.98	0.94	**1.00**
EC 9	1.43	1.36	1.27	1.53	1.36	1.33	**1.38**
EC 12	1.91	1.68	1.86	2.12	1.82	1.86	**1.88**
Mean	**1.05**	**1.00**	**1.13**	**1.27**	**1.11**	**1.07**	
LSD (5%)	**EC = 0.12 ,Cultivar = 0.09 , Interaction = NS**						

4.1.6.7 Straw potassium content

The data revealed that mean straw K content decreased by 9.1, 18.2, 26.4 and 37.2 % at EC 3, 6, 9 and 12 dS/m salinity levels as compared to control(EC 0)(Table 4.35). The maximum and minimum straw K content was observed for PBW 658 and KRL 210 over two years. Interaction between salinity levels and wheat cultivars for straw K content was non-significant across two years.

4.1.6.8 Straw Na/K ratio

The data regarding to straw Na/K ratio as affected by different levels of saline irrigation water in both yearsis presented in Table 4.35. It is evident that straw Na/K ratio follows same trend as that of grain Na/K ratio (Table 4.33) i.e. significantly increased with increasing salinity of irrigation water. The average straw Na/K ratio increased from 0.52 in EC 0 to 0.74, 1.00, 1.38 and 1.88 at EC 3, 6, 9 and 12 dS/m salinity levels across two years.Out of six wheat cultivars maximum straw Na/K ratio was observed in cultivar PBW590 while minimum in PBW 621 over two years.

4.1.6.9 Effect of saline irrigation water on straw phosphorus content of wheat cultivars

The data on plant, grain and straw P content shows that P content decreased with advancement of crop age, which indicates that P from straw translocated into grains and utilized it for growth of plants (dilution factor) (Fageria 2011). The data revealed that straw P decresed from 0.12 to 0.10, 0.08, 0.06 and 0.05 % at salinity levels of 3, 6, 9 and 12dS/m as compared to contro (EC 0)**.**Ragab *et al* (2008) reported decrease in straw P uptake from 104.2 to 88.5 mg/pot in sandy soil and from 424.6 to 311.8 mg/pot in calcareous soil as irrigation water salinity increased from 0.43 to 8.9 dS/m.

Table 4.36 Effect of saline irrigation wateron straw phosphorous and calcium content (%) of wheat cultivars

Straw P (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.12	0.11	0.12	0.11	0.15	0.13	**0.12**
EC 3	0.10	0.10	0.11	0.10	0.13	0.12	**0.10**
EC 6	0.08	0.08	0.08	0.08	0.11	0.09	**0.08**
EC 9	0.06	0.06	0.06	0.06	0.09	0.07	**0.06**
EC 12	0.05	0.04	0.04	0.06	0.07	0.23	**0.05**
Mean	**0.08**	**0.07**	**0.08**	**0.08**	**0.11**	**0.13**	
LSD (5%)	**EC = 0.012 ,Cultivar = 0.017, Interaction = NS**						
Straw Ca (%)							
EC 0	0.015	0.013	0.013	0.011	0.015	0.013	**0.013**
EC 3	0.013	0.011	0.012	0.008	0.013	0.011	**0.011**
EC 6	0.010	0.009	0.009	0.007	0.011	0.009	**0.009**
EC 9	0.007	0.007	0.007	0.005	0.008	0.007	**0.006**
EC 12	0.005	0.005	0.006	0.004	0.006	0.005	**0.005**
Mean	**0.010**	**0.009**	**0.009**	**0.007**	**0.011**	**0.009**	
LSD (5%)	**EC = 0.001 ,Cultivar = 0.001 , Interaction = NS**						

Among different wheat cultivars, average straw P content varied from 0.07 to 0.13 % over two years. The interaction between salinity levels and wheat cultivar for straw P content was non-significant.

4.1.6.10Effect of saline irrigation wateron straw calcium content of wheat cultivars

It was observed that straw Ca content follows similar trend as that of straw P but values were less in magnitude for straw Ca content. Average straw Ca content decreased from 0.013 % in EC 0 to 0.011, 0.009, 0.006 and 0.005 % at EC 3, 6, 9 and12 dS/m levels of irrigation water salinity (Table 4.36). Reduction in Ca concentration due to salinity was also reported by Meneguzzo *et a*l (2000).The average straw Ca content among different cultivars ranged from 0.004 to 0.019 % in 2013-14 and varied from 0.007to 0.011 % over two years.

4.1.7 Quality parameters

The effect of different salinity levels on two grain quality parameters .i.e. protein content (%) and test weight (kg/hl) were determined in 2013-14 and 2014-15 and results are discussed under following headings:

Table 4.37 Effect of saline irrigation wateron protein content (%) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	10.8	12.4	12.6	12.7	12.5	11.7	**12.1**
EC 3	10.8	11.8	11.6	12.5	12.4	11.6	**11.8**
EC 6	10.3	11.0	11.6	12.1	11.9	11.4	**11.3**
EC 9	10.3	10.9	10.7	12.0	10.6	11.3	**11.0**
EC 12	10.3	10.9	10.7	12.0	10.6	11.3	**10.9**
Mean	**10.5**	**11.4**	**11.5**	**12.3**	**11.6**	**11.5**	
LSD (5%)	**EC = 0.54**		**Cultivar = 0.42**		**Interaction = NS**		
2014-15							
EC 0	11.2	11.4	11.7	11.9	11.8	11.5	**11.6**
EC 3	10.9	11.1	10.9	11.6	11.8	11.3	**11.3**
EC 6	11.0	10.8	10.8	11.1	11.4	11.2	**11.0**
EC 9	10.7	10.8	10.1	10.7	11.2	10.5	**10.8**
EC 12	10.6	10.6	10.1	10.4	11.0	9.9	**10.4**
Mean	**10.8**	**10.9**	**10.7**	**11.1**	**11.5**	**11.0**	
LSD (5%)	**EC = NS**		**Cultivar = NS**		**Interaction = NS**		

4.1.7.1 Protein content

The data pertaining to protein content of different cultivars as affected by irrigation water salinity for both years is presented in Table 4.37. The protein content of different wheat cultivars decreased significantly at EC 6, 9 and 12 dS/m salinity levels in 2013-14, whereas non-significant results were obtained for salinity levels and six wheat cultivars in 2014-15. The average protein content decreased by 2.5, 6.6, 9.1 and 10.0 % in 2013-14 and 2.6, 5.1, 6.9 and 10.3 % in 2014-15 at EC 3, 6, 9 and 12 dS/m salinity levels as compared to control.

Among different wheat cultivars average protein content varied from 10.5 to 12.3 % with minimum and maximum value observed for cultivars KRL 210 and PBW 590 during first and from 10.7 to 11.5 %with minimum and maximum value observed for cultivars HD 2967 and PBW 658 for second year. For different wheat cultivars protein content was statistically at par in 2014-15. Non-significant interaction was observed between salinity levels and wheat cultivars for protein content for both years.

Table 4.38 Influence of saline irrigation wateron test weight (kg/hl) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	78.0	78.2	77.7	78.0	76.5	77.6	**77.6**
EC 3	78.0	77.8	76.8	77.8	76.3	77.0	**77.3**
EC 6	77.8	77.2	76.2	76.7	76.3	76.5	**76.7**
EC 9	77.2	77.0	76.5	76.5	76.0	74.6	**76.6**
EC 12	76.6	76.8	75.8	76.5	74.3	75.8	**75.9**
Mean	**77.4**	**77.4**	**76.6**	**77.1**	**75.9**	**76.7**	
LSD (5%)	**EC = 0.76**		**Cultivar = 0.62**		**Interaction = NS**		
2014-15							
EC 0	79.8	78.6	78.0	79.0	77.8	79.1	**78.7**
EC 3	79.3	78.3	78.2	78.6	77.6	78.6	**78.4**
EC 6	79.0	77.2	77.0	78.3	76.8	77.5	**77.6**
EC 9	78.6	76.3	76.8	78.1	75.8	77.3	**77.2**
EC 12	76.3	75.8	76.1	77.8	75.1	76.6	**76.3**
Mean	**78.6**	**77.2**	**77.2**	**78.4**	**76.6**	**77.8**	
LSD (5%)	**EC = 0.68**		**Cultivar = 0.70**		**Interaction = NS**		

4.1.7.2 Test weight

Thedata presented in Table 4.38revealed that test weight of different wheat cultivars progressively decreased with increasing salinity levels except at EC 3 dS/m in 2013-14 and 2014-15. Average test weight decreased from 77.6 to 75.9 kg/hl in first year and from 78.7 to 76.3 kg/hl in second year of research study, as salinity increased from EC0 to EC12 dS/m levels, respectively. Kumar *et al* (2012) also reported decrease in test weight of eight wheat cultivars with increasing salinity of irrigation water.Non-significant interaction was observed between salinity levels and wheat cultivars for test weight during first and second year of reserach study.

4.2 Experiment 2: Sodic irrigation effects on performance of wheat cultivars and soil health

4.2.1 Effect of Sodic irrigation on chemical soil health

4.2.2 Effect of Sodicirrigation onphysical soil health

4.2.3 Effect of Sodic irrigation on biological soil health

4.2.4 Effect of Sodicirrigation on performance of wheat cultivars

4.2 Experiment 2: Sodic irrigation effects on performance of wheat cultivars and soil health

4.2.1 Effect of Sodic irrigation on chemical soil health

4.2.1.1 Effect of Sodic irrigationwater on soil pH (1:2 soil: water suspension)

The results pertaining to effect of sodic irrigation water on soil pH in 2013-14 and 2014-15 before sowing and after harvest of wheat crop were depicted in Fig 4.7 It was observed that increasing RSC levels of irrigation water significantly increase soil pH during first as well as second year of experimental study. High soil pH values were reported in 0 - 30cm soil layer, as compare to lower soil layers before sowing and after harvest of crop in 2013-14. This can be occurred due to restricted downward movement of water and salt into the lower layers because of higher soil dispersion (Josan*et al* 1998). Similar results were reported by Choudhary and Ghuman (2008). They reported that soil pH values were higher in 0-30cm soil layer, than in 30-60cm soil layer, when irrigated with sodic water as compare to canal water for six year under cotton wheat rotation.

Furthermore, in next year, higher soil pH values were observed at 15-30 cm as compared to 0-15 cm soil layer at all levels of sodic water irrigation which again deceases in lower layers. As the salt concentration in soil solution increases, Ca^{2+} precipitates as $CaCO_3$ and, to a lesser extent as $CaSO_4$, leaving preponderance of Na^+ in soil solution that subsequently induces Na adsorption on the cation exchange sites and increases soil pH. These results were in accordance with Murtaza *et al* (2006), who reported higher soil pH value at 30 to 60cm soil depth as compared to 0-30cm as a result of accumulation of Na^+ through its movement from upper depths.

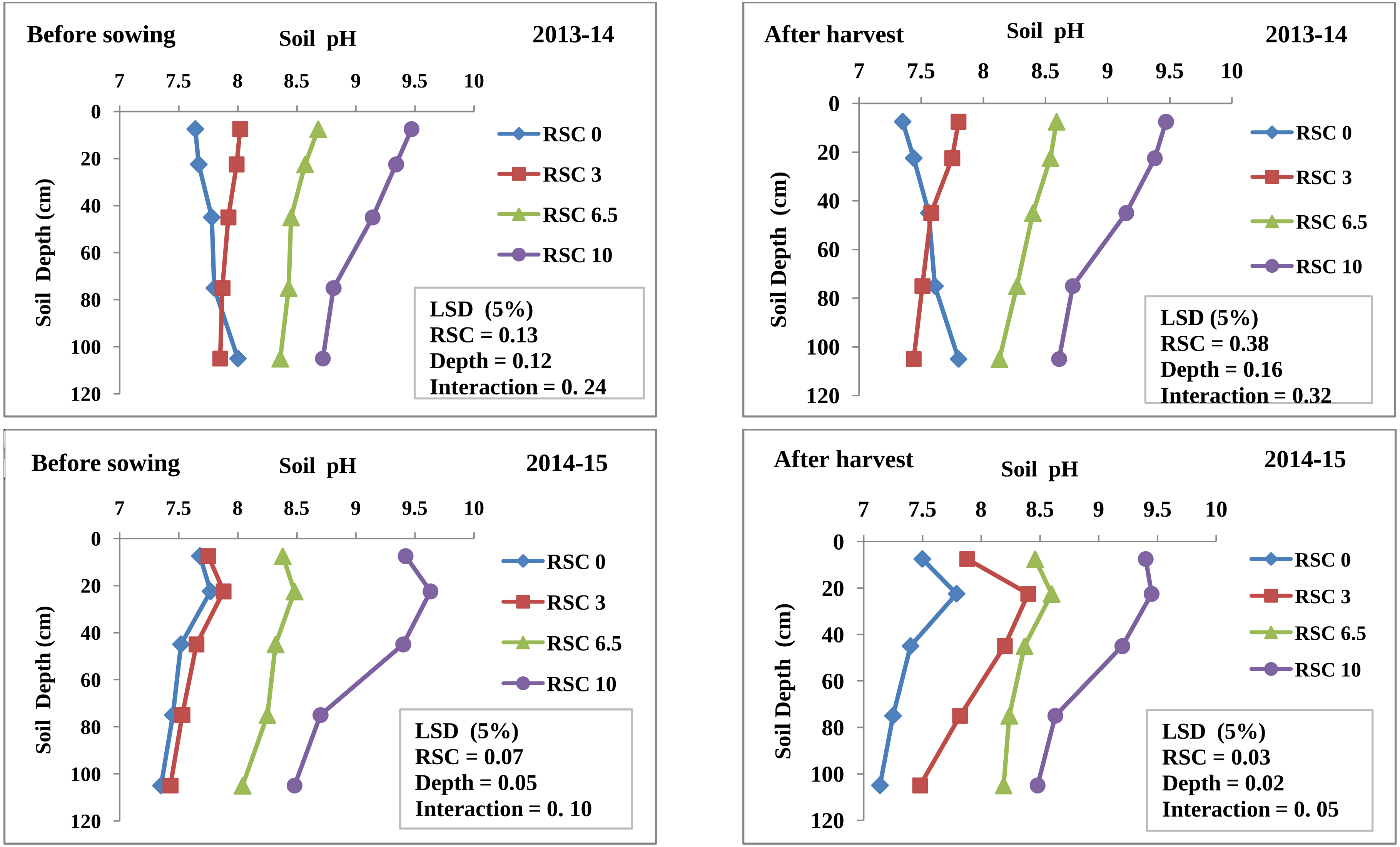


Fig. 4.7 Effect of Sodic irrigationwater on soil pH (1:2 soil: water suspension)

4.2.1.2 Effects of sodic irrigation water in soil EC (1:2 Soil: water suspension)

The data pertaining to effect of sodic irrigation water on soil electrical conductivity (EC) with increasing levels of residual sodium bicarbonate (RSC) in irrigation water, before sowing and after harvest of crop in 2013-14 and 2014-15 was presented in Table 4.39. The data revealed that soil EC significantly increased with increasing sodicity of irrigation water during first as well as second year of experimental study. It was observed that soil EC increased from 0.208 dS/m in control to 0.248, 0.388 and 0.464 dS/m at RSC 3, 6.5 and 10me/L levels of irrigation water, before sowing and from 0.211 dS/m (control) to 0.308, 0.430 and 0.656 dS/m after harvest of crop at respective RSC levels in 2013-14. Similarly in 2014-15, corresponding values were 0.216, 0.254, 0.368 and 0.514 dS/m before sowing and 0.228, 0.340, 0.463 and 0.699 dS/m after harvest of crop at RSC 3, 6.5 and 10me/L levels of irrigation water, respectively.

Although soil EC increased with increasing RSC water, but it was less than 1 dS/m in all treatment, which does not adversely affect plant growth and yield of wheat cultivars. Further exploration of results described that soil EC decreases with increase in soil depth in 2013-14 as well as 2014-15. The perusal of data shows that soil EC decrease from 0.425 to 0.228 dS/m before sowing and from 0.548 to 0.284 dS/m after harvest of crop as soil depth increases from 0-15cm to 90-120cm in 2013-14. Likewise, in 2014-15, corresponding decrease occurs from 0.395 to 0.282 dS/m and 0.515 to 0.347 dS/m before sowing and after harvest of crop at respective soil depths. The data shows that as soil depth increases, there is significant decrease in soil EC i.e. surface soil layer have more EC than lower layers in both years. This occurs due to fact that movement of salt was hindered to lower soil layer, salts tend to accumulate at the surface mainly due to evaporation process and resulted in higher EC in surface soil layer as compared to sub surface soil layers. It has been observed that interaction of two factors (RSC level and soil depth) was significant for soil EC in 2013-14 as well as 2014-15.

4.2.1.3 Effects of sodic irrigation water on organic carbon of soil

The results presented in Table 4.40 revealed that soil organic carbon (SOC) significantly decreased with increasing sodicity of irrigation water as well as soil depth for 2013-14 and 2014-15, before sowing and after harvest of wheat crop. It was observed that SOC decreased by 11.1, 22.2 and 33.3% before sowing and 11.7, 26.4 and 47.1% after harvest of crop at RSC 3, 6.5 and 10 me/L levels of sodic irrigation water as compared to control in 2013-14. Furthermore, as soil depth increases from 0-15 cm to 90-120cm, mean OC decreased from 3.1 to 1.6 g/kg and 3.3 to 2.2 g/kg before sowing and after harvest of wheat crop in respective year. Kaur *et al* (2008) also observed that SOC decreased from 0.424 % to 0.405 % at RSC 10me/L of irrigation water as compared to control.

Table 4.39 Effect of sodic irrigation water on soil EC (dS/m) (1:2 soil: water suspension)

2013-14											
	Before sowing						**After harvest**				
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	0.276	0.230	0.213	0.190	0.130	**0.208**	0.300	0.240	0.203	0.170	0.143	**0.211**
RSC 3	0.330	0.273	0.243	0.223	0.173	**0.248**	0.480	0.363	0.290	0.230	0.176	**0.308**
RSC 6.5	0.473	0.443	0.393	0.343	0.290	**0.388**	0.593	0.470	0.413	0.363	0.313	**0.430**
RSC 10	0.629	0.510	0.460	0.410	0.320	**0.464**	0.820	0.753	0.660	0.543	0.503	**0.656**
Mean	**0.425**	**0.364**	**0.327**	**0.291**	**0.228**		**0.548**	**0.456**	**0.391**	**0.326**	**0.284**	
LSD (5%)	**RSC = 0.02 Depth = 0.01 Interaction = 0.04**						**RSC = 0.02 Depth = 0.01 Interaction = 0.04**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	0.270	0.255	0.212	0.183	0.163	**0.216**	0.284	0.246	0.220	0.207	0.184	**0.228**
RSC 3	0.290	0.283	0.261	0.238	0.198	**0.254**	0.438	0.398	0.354	0.281	0.231	**0.340**
RSC 6.5	0.410	0.373	0.320	0.390	0.350	**0.368**	0.533	0.517	0.436	0.424	0.407	**0.463**
RSC 10	0.612	0.564	0.500	0.476	0.420	**0.514**	0.804	0.785	0.724	0.617	0.567	**0.699**
Mean	**0.395**	**0.369**	**0.323**	**0.321**	**0.282**		**0.515**	**0.486**	**0.433**	**0.382**	**0.347**	
LSD (5%)	**RSC = 0.02 Depth = 0.01 Interaction = 0.02**						**RSC = 0.001 Depth = 0.002 Interaction = 0.004**					

Table 4.40 Effect of sodic irrigation water on organic carbon (g/kg) of soil

2013-14												
	Before sowing						After harvest					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	3.6	3.0	2.7	2.3	2.0	**2.7**	4.2	3.7	3.4	3.0	2.7	**3.4**
RSC 3	3.3	2.7	2.4	2.1	1.6	**2.4**	3.6	3.3	2.9	2.7	2.4	**3.0**
RSC 6.5	2.9	2.5	2.1	1.7	1.4	**2.1**	2.8	2.4	2.6	2.5	2.1	**2.5**
RSC 10	2.5	2.2	1.8	1.5	1.3	**1.8**	2.5	2.1	1.8	1.6	1.3	**1.8**
Mean	**3.1**	**2.6**	**2.2**	**1.9**	**1.6**		**3.3**	**2.9**	**2.7**	**2.5**	**2.2**	
LSD (5%)	**RSC = 0.1 Depth = 0.2 Interaction = NS**						**RSC = 0.2 Depth = 0.1 Interaction = NS**					
2014-15												
	Before sowing						After harvest					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	4.0	3.7	3.3	3.0	2.6	**3.3**	3.8	3.6	3.3	2.9	2.6	**3.3**
RSC 3	3.8	3.4	3.0	2.6	2.0	**2.9**	3.5	3.4	3.1	2.6	2.1	**2.9**
RSC 6.5	3.3	2.9	2.7	2.1	1.6	**2.5**	3.0	2.8	2.6	2.3	2.0	**2.6**
RSC 10	2.7	2.3	1.9	1.6	1.4	**1.9**	2.5	2.3	2.0	1.7	1.5	**2.0**
Mean	**3.5**	**3.0**	**2.7**	**2.3**	**1.9**		**3.2**	**3.0**	**2.8**	**2.4**	**2.1**	
LSD (5%)	**RSC = 0.1 Depth = 0.2 Interaction = NS**						**RSC = 0.2 Depth = 0.1 Interaction = NS**					

It is evident from data that average OC decreased from 3.3 g/kg in control to 2.9, 2.5 and 1.9 g/kg at RSC 3, 6.5 and 10 me/L levels of irrigation water, before sowing and from 3.3g/Kg (RSC 0) to 2.9, 2.6 and 2.0 g/kg after harvest of crop at respective RSC levels in 2014-15. Similarly, with increasing soil depth (from 0-15cm to 90-120 cm); mean OC decreased from 3.5 to 1.9 g/kg and from 3.2 to 2.1 g/kg before sowing and after harvest of crop in respective year. This decrease in soil OC may be due to fact that at higher sodicity, conditions were becoming increasingly detrimental to microbial community and this was demonstrated by decline in percentage of organic carbon present as microbial biomass carbon (Rietz and Haynes 2003). Interaction between RSC levels and soil depth for SOC was non-significant in both years.

4.2.1.4 Effect of sodic irrigation water on soil available nitrogen

The data regarding effect of increasing levels of sodic irrigation water on soil available nitrogen (Av. N) in first and second year of experimental study was discussed in Table 4.41. The data revealed that mean Av. N decreased by 11.3, 21.0 and 30.8% before sowing and 13.5, 24.8 and 32.7 % after harvest of crop at RSC 3,6.5 and 10me/L levels of irrigation water over control in 2013-14. The mean Av. N decreased from 94.3 to 62.5 kg/ ha before sowing and from 92.6 to 61.6 kg/ha after harvest of the crop in 2014-15. Change in properties of soil solution and exchangeable ions which have osmotic and ion-specific effects that can produce imbalance in plant nutrients including deficiencies of several nutrients (Mengel and Kirkby 2001). Another reason for decrease in Av. N is to high soil pH, which enhance NH_3 volatilization in sodic soils. Nitrogen availability is also affected by Cl, which inhibits NO_3^- uptake and often present at high concentration in sodic soils (Gratten and Grieve, 1999). These results were also supported by Yaduvanshi and Swarup (2005). They observed marginal improvement in soil available nitrogen status in treatments receiving farm yard manure and press mud, under sodic water irrigation (RSC=8.5 me/L) used for more than 8 years to irrigate field as compared to control. They ascribed this decrease may be due to leaching, volatilization and immobilization losses occurs in sodic soils.

Further exploration of data depicts that Av. N decreased from 111.7 to 52.1 kg/ha before sowing and 90.4 to 60.31 kg/ha after harvest of crop in 2013-14 as soil depth increased from 0 to120 cm. The corresponding values in 2014-15 decreased from 100.9 to 57.5 kg/ha and from 95.1 to 58.9 kg/ha before sowing and after harvest of wheat crop.Significant interaction results were observed between RSC levels of irrigation water and soil depth for Av. N in both years. Statistically similar values of Av. N was observed at RSC 6.5 (60-90 cm)and 10 me/L (30-60cm) levels of irrigation water before sowing in 2013-14. In 2014-15,

Table 4.41 Effect of sodic irrigation water on available nitrogen (kg/ha) of soil

2013-14											
	Before sowing						**After harvest**				
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	130.1	105.9	75.7	74.9	68.2	**90.9**	103.6	102.4	94.1	88.4	77.9	**93.3**
RSC 3	116.5	91.1	75.6	68.2	51.4	**80.6**	97.7	89.9	77.8	72.7	65.4	**80.7**
RSC 6.5	105.9	80.4	68.5	56.7	47.5	**71.8**	84.5	75.8	70.2	67.9	51.9	**70.1**
RSC 10	94.5	75.7	56.7	46.5	41.2	**62.9**	75.6	68.9	66.7	56.4	46.1	**62.7**
Mean	**111.7**	**88.3**	**69.1**	**61.6**	**52.1**		**90.4**	**84.2**	**77.2**	**71.3**	**60.3**	
LSD (5%)	**RSC = 0.8 Depth = 1.0 Interaction = 2.1**						**RSC = 0.6 Depth = 0.9 Interaction = 1.9**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	120.3	103.4	94.3	81.3	72.3	**94.3**	116.9	104.1	89.2	82.2	71.1	**92.6**
RSC 3	106.3	96.4	84.2	71.4	61.1	**83.9**	99.3	85.4	74.3	72.3	64.0	**79.1**
RSC 6.5	91.5	78.6	72.4	62.6	51.3	**71.3**	83.9	78.7	67.1	64.3	56.5	**70.1**
RSC 10	85.4	68.4	61.6	51.8	45.1	**62.5**	80.3	68.3	60.4	55.3	44.0	**61.6**
Mean	**100.9**	**86.7**	**78.2**	**66.8**	**57.5**		**95.1**	**84.1**	**72.7**	**68.5**	**58.9**	
LSD (5%)	**RSC = 1.8 Depth = 1.7 Interaction = 3.5**						**RSC = 1.3 Depth = 1.8 Interaction = 3.7**					

statistically similar values of Av. N were observed at RSC 3 (60-90 cm) and 6.5 me/L (30-60 cm) before sowing and at RSC 6.5 (90-120cm) and 10 me/L (60-90 cm) levels of sodic irrigation water.

4.2.1.5 Effect of sodic irrigation water on soil available phosphorus

It was observed that mean Av. P in control was 37.8 kg/ha while it was 31.3, 21.0 and 16.8 kg/ha at RSC 3, 6.5 and 10 me/L levels of sodicity before sowing and corresponding values after harvest were 33.2, 28.4, 23.7 and 18.5 kg/ha at respective levels of irrigation water in 2013-14(Table 4.42).In 2014-15, Av. P content decreased from 35.2 to 20.6 kg/ha before sowing and from 32.6 to 18.1 kg/ha at RSC 10 me/L level of irrigation water as compared to control. The reduction in phosphorus availability in sodic environment is primarily due to reason that P occurring as NaOH-P and HCl-P is strongly adsorbed compounds and consequently results in reduced P availability (Curtin *et al* 1992). These results were also supported by Yaduvashi and Swarup (2005), who reported decrease in soil available P status due to P fixation in sodic soils. Lower availability of phosphorous is also related to higher soil pH values, which further increased with increasing RSC levels in irrigation water as compared to good quality water (RSC 0)in the present research study.

The perusal of data shows that increasing soil depth from 0-15cm to 90-120cm, also resulted in significant decreased in Av. P from 33.6 to 20.3 kg/ha before sowing and from 32.2 to 19.7 kg/ha after harvest of crop in 2013-14. Similar trend was also observed for next year, where it decreased from 33.1 to 23.7 kg/ha and 30.5 to 20.2 kg/ha before sowing and after harvest of crop as soil depth increased from 0-15cm to 90-120cm. Non-significant interaction was observed for Av. P between RSC levels and soil depth in in both years, expect before sowing of crop for first year.

Table 4.42 Effect of sodic irrigation water on available phosphorous (kg/ha) of soil

2013-14											
	Before sowing						**After harvest**				
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	46.5	43.7	34.5	32.9	31.4	**37.8**	40.2	37.1	33.9	30.7	24.5	**33.2**
RSC 3	37.4	35.2	31.0	28.7	24.3	**31.3**	36.3	31.8	28.5	23.7	22.1	**28.4**
RSC 6.5	28.8	24.2	20.8	17.4	14.1	**21.0**	29.6	26.4	23.6	20.4	18.6	**23.7**
RSC 10	21.8	19.1	18.0	13.6	11.6	**16.8**	22.9	20.3	19.6	16.1	13.8	**18.5**
Mean	**33.6**	**30.5**	**26.1**	**23.1**	**20.3**		**32.2**	**28.9**	**26.4**	**22.7**	**19.7**	
LSD (5%)	**RSC =1.1 Depth = 1.1 Interaction = 2.2**						**RSC = 1.2 Depth = 1.5 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	42.7	37.3	33.4	32.9	29.7	**35.2**	38.9	36.3	32.7	28.7	26.3	**32.6**
RSC 3	36.1	34.4	27.6	26.4	25.7	**30.1**	34.3	30.7	27.3	24.5	22.4	**27.8**
RSC 6.5	29.3	28.6	24.8	22.9	21.6	**25.4**	26.7	25.4	23.4	20.1	18.6	**22.9**
RSC 10	24.2	23.1	19.6	18.4	17.8	**20.6**	21.9	19.8	18.5	16.7	13.7	**18.1**
Mean	**33.1**	**30.8**	**26.4**	**25.1**	**23.7**		**30.5**	**28.1**	**25.5**	**22.4**	**20.2**	
LSD (5%)	**RSC = 1.2 Depth = 1.7 Interaction = NS**						**RSC = 1.2 Depth = 1.5 Interaction = NS**					

4.2.1.6 Effect of sodic irrigation water on soil available potassium

The results pertaining to available potassium (Av. K) as affected by sodic irrigation water for 2013-14 and 2014-15 were presented in Table 4.43. The data revealed that Av. K significantly decreased with increasing RSC levels of irrigation water and soil depth for first and second year. Mean Av. K decreased from 128.9 to 108.6 kg/ha and 142.4 to 94.9 kg/ha before sowing and 151.4 to 128.2 kg/ha and 156.6 to 131.1 kg/ha after harvest of crop as RSC levels of irrigation water increased from 0 to 10 me/L and soil depth from 0-15 cm and 90-120 cm in 2013-14 respectively. Likewise in 2014-15, mean Av. K content in control was reported to be 137.4 kg/ha which decreased to 128.5, 115.0 and 107.6 kg/ha at RSC 3, 6.5 and 10me/L levels of sodicity before sowing of wheat crop. The corresponding values after harvest of crop were 123.3, 116.5, 114.3 and 103.2 kg/ha at respective RSC levels of irrigation water.

It is evident from data that as soil depth increased from 0-15cm to 90-120cm, mean Av. K decreased from 156.1 to 104.6 kg/ha and from 127.4 to 106 kg/ha before sowing and after harvest of crop in 2014-15. A perusal of data shows that interaction between RSC levels and soil depth was significant for Av. K for first and second year of experimental study. It was observed that Av. K was statistically at par at RSC 3 for soil depth 60-90 cm and 6.5 me/L levels of irrigation water at soil depth 30-60 cm before sowing in 2013-14. Statistically similar values of Av. K was observed at RSC 3 (90-120 cm) and 6.5 me/L (60-90 cm) levels of sodicity before sowing and after harvest of wheat crop.

4.2.1.7 Effect of sodic irrigation water on soil available sulphur

Effect of different levels of sodic irrigation water on available sulphur (Av. S) content was observed in 2013-14 and 2014-15, before sowing and after harvest of crop and discussed in Table 4.44. It was observed that Av. S decreased significantly with increasing sodicity of irrigation water and soil depth. The mean Av. S content decreased by 23.1, 47.0 and 65.8 % and by 13.1, 30.4 and 45.8 % before sowing and after harvest of crop in 2013-14 and decreased by 17.1, 30.4 and 43.5 % before sowing 11.2, 26.1 and 38.9 % after harvest of crop at RSC 3, 6.5 and 10 me/L levels of sodicity as compared to control in 2014-15.

Table 4.43 Effect of sodic irrigation water on available potassium (kg/ha) of soil

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	151.2	140.5	138.2	114.1	100.6	**128.9**	162.2	161.8	146.8	142.3	144.3	**151.4**
RSC 3	145.3	125.3	117.3	109.4	94.2	**118.3**	160.4	142.4	138.2	128.4	134.3	**140.7**
RSC 6.5	143.5	115.8	117.1	108.5	93.3	**115.6**	154.4	141.3	129.5	120.1	126.7	**134.4**
RSC 10	129.4	113.3	108.0	100.9	91.3	**108.6**	149.5	138.0	120.1	114.6	118.8	**128.2**
Mean	**142.4**	**123.8**	**120.2**	**108.2**	**94.9**		**156.6**	**145.8**	**133.6**	**126.3**	**131.1**	
LSD (5%)	**RSC = 1.2 Depth = 1.0 Interaction= 2.0**						**RSC = 2.5 Depth = 0.9 Interaction= 1.9**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	171.8	137.6	127.1	126.6	124.2	**137.4**	132.2	123.5	123.1	120.4	117.4	**123.3**
RSC 3	162.4	134.6	122.7	113.1	109.7	**128.5**	130.9	122.3	111.5	110.6	107.3	**116.5**
RSC 6.5	151.5	116.9	105.0	108.3	93.1	**115.0**	128.9	120.1	108.5	107.3	106.6	**114.3**
RSC 10	139.0	109.7	104.6	93.3	91.6	**107.6**	117.8	112.3	100.2	92.9	92.6	**103.2**
Mean	**156.1**	**124.7**	**114.9**	**110.3**	**104.6**		**127.4**	**119.5**	**110.8**	**107.8**	**106.0**	
LSD (5%)	**RSC = 1.5 Depth = 1.7 Interaction = 3.4**						**RSC = 1.7 Depth = 1.8 Interaction = 3.6**					

Table 4.44 Effect of sodic irrigation water on available sulphur (ppm) of soil

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	43.6	35.3	34.7	31.3	30.5	**35.1**	40.4	37.5	33.2	28.6	25.1	**32.9**
RSC 3	38.0	27.7	27.6	21.3	20.3	**27.0**	36.1	31.7	29.1	25.5	20.9	**28.6**
RSC 6.5	28.1	20.1	17.5	14.2	13.3	**18.6**	28.5	26.1	23.8	19.4	16.8	**22.9**
RSC 10	12.1	12.6	12.3	11.7	11.3	**12.0**	23.1	21.5	18.5	15.2	11.1	**17.8**
Mean	**30.4**	**23.9**	**23.0**	**19.6**	**18.8**		**32.1**	**29.2**	**26.1**	**22.2**	**18.4**	
LSD (5%)	**RSC = 1.3 Depth = 0.9 Interaction = 1.9**						**RSC = 0.5 Depth = 0.9 Interaction= NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	51.6	42.4	38.6	30.4	27.6	**38.1**	37.6	35.8	32.3	26.6	24.2	**31.3**
RSC 3	44.2	33.7	31.3	26.2	22.8	**31.6**	34.5	32.4	28.3	23.3	20.6	**27.8**
RSC 6.5	34.3	30.4	28.6	20.1	19.1	**26.5**	28.9	25.5	22.7	19.8	18.5	**23.1**
RSC 10	26.3	24.1	22.1	18.6	16.5	**21.5**	25.2	20.7	18.6	16.5	14.3	**19.1**
Mean	**39.1**	**32.7**	**30.2**	**23.8**	**21.5**		**31.5**	**28.6**	**25.5**	**21.5**	**19.4**	
LSD (5%)	**RSC = 1.4 Depth = 1.9 Interaction = 3.7**						**RSC = 2.2 Depth = 1.5 Interaction = NS**					

The perusal of data shows that mean Av. S content at depth 0-15cm was 30.4 ppm which decreased to 23.9, 23.0, 19.6 and 18.8 ppm at depth intervals 15-30, 30-60, 60-90 and 90-120cm before sowing of crop in 2013-14. The corresponding values after harvest of wheat crop were 32.1, 29.2, 26.1, 22.2 and 18.4 ppm in respective year. Likewise in 2014-15, mean Av. S decreased from 45.1 to 21.5 ppm and from 31.5 to 19.4 ppm before sowing and after harvest of crop as soil depth increased from 0 to 120cm. Interaction between RSC levels and soil depth for Av. S was non-significant after harvest of crop for both years and significant before sowing of crop in both years.

4.2.1.8 Effect of sodic irrigation water on soil available DTPA-Zn

The results related to effect of RSC irrigation water on soil DTPA-Zn in 2013-14 and 2014-15 were presented in Table 4.45. These results revealed that significant reduction in DTPA-Zn occur with increasing sodicity of irrigation water in 2013-14 and 2014-15 respectively expect after harvest of crop in 2013-14 where sodic water irrigation have no significant effect on DTPA-Zn. It was observed that mean DTPA-Zn decreased from 2.3 ppm in RSC 0 to 1.9, 1.6 and 1.1 ppm before sowing and from 2.1 ppm (control) to 2.0, 1.9 and 1.6 ppm after harvest of crop at RSC 3, 6.5 and 10 me/L levels of irrigation water in 2013-14. In 2014-15, DTPA-Zn decreased from 3.3 to 1.3 ppm and from 3.3 to 2.0 ppm before sowing and after harvest of wheat crop at RSC 10me/L level as compared to control. The sodic soil and sodic environment have low organic matter and crops grown on these soils suffer from specific in toxicities (Na, Cl and B) and deficiencies (Ca, K and Zn) (Tahir *et al* 2012). Low solubility of Zn in sodic soils is also attributed to increased soil pH (Naidu and Rengasemy). These results were similar to findings of Yaduvanshi and Swarup *et al* (2005), who reported decreased in DTPA-Zn with use of sodic irrigation water (RSC=8.4 me/L) which might have been due to adsorption /immobilization of added Zinc in high pH.

The perusal of data show that DTPA-Zn decreased significantly with increasing soil depth expect before sowing of crop in 2013-14 where DTPA-Zn have no particular trend with increasing soil depth. DTPA-Zn decreased from 3.0 to 2.0 ppm and from 3.4 to 1.9 ppm before sowing and after harvest of crop as soil depth increased from 0 to 120cm in 2014-15. Non-significant interaction was observed for DTPA-Zn between RSC levels of irrigation water and soil depth in first and second year of experimental study.

Table 4.45 Effect of sodic irrigation water on soil DTPA-Zn (ppm)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	4.0	2.1	1.7	1.7	2.2	**2.3**	4.9	3.5	0.8	0.6	0.5	**2.1**
RSC 3	4.0	1.5	1.4	0.9	1.6	**1.9**	4.9	3.4	0.7	0.5	0.4	**2.0**
RSC 6.5	3.9	0.8	0.7	0.8	1.6	**1.6**	4.9	3.3	0.7	0.4	0.3	**1.9**
RSC 10	3.7	0.7	0.3	0.6	0.3	**1.1**	4.4	2.7	0.5	0.2	0.2	**1.6**
Mean	**3.9**	**1.3**	**1.0**	**1.0**	**1.4**		**4.8**	**3.2**	**0.7**	**0.4**	**0.3**	
LSD (5%)	**RSC = 0.2 Depth = 0.5 Interaction= NS**						**RSC = NS Depth = 0.7 Interaction= NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	3.8	3.5	3.3	3.0	2.8	**3.3**	4.1	3.8	3.4	2.9	2.5	**3.3**
RSC 3	3.4	3.2	2.9	2.7	2.5	**2.9**	3.7	3.5	3.0	2.6	2.1	**2.9**
RSC 6.5	2.8	2.6	2.4	2.2	1.9	**2.4**	3.1	2.7	2.4	2.2	1.8	**2.4**
RSC 10	2.0	1.7	1.3	1.0	0.8	**1.3**	2.8	2.3	2.0	1.7	1.3	**2.0**
Mean	**3.0**	**2.7**	**2.5**	**2.2**	**2.0**		**3.4**	**3.0**	**2.7**	**2.3**	**1.9**	
LSD (5%)	**RSC = 0.1 Depth = 0.2 Interaction = NS**						**RSC = 0.2 Depth = 0.3 Interaction = NS**					

4.2.1.9 Effect of sodic irrigation water on soluble potassium

The soluble potassium (K) as affected by sodicity of irrigation water, before sowing and after harvest of crop in 2013-14 and 2014-15 was presentedin Table 4.46. The data revealed that soluble K significantly decreased with increasing RSC levels of irrigation water and soil depth. The soluble K decreased from 2.36 to 0.26 me/L and 2.07 to 0.91me/L as sodicity increased from 0 to 10 me/L levels of irrigation water before sowing and after harvest of crop in 2013-14. Furthermore, it decreased from 1.32 to 1.23, 1.08, 0.97 and 0.69 me/L before sowing and from 1.96 to 1.70, 1.45, 1.20 and 1.02 me/L after harvest of crop in 2013-14 as soil depth increases from 0-15cm to 90-120cm, respectively. It is evident from data that soluble K decreased from 2.29 in control to 1.23, 0.54 and 0.31 me/L and from 1.89 (control) to 0.84, 0.51 and 0.18 me/L before sowing and after harvest of crop at RSC 3, 6.5 and 10me/L levels of irrigation water in 2014-15.

Further investigation of data depicts that soil K decreased from 1.38 to 0.74 me/L before sowing and from 1.22 to 0.61 me/L after harvest of crop as soil depth increased from 0-15cm to 90-120cm in 2014-15. The perusal of data shows that interaction effects of RSC levels and soil depth were significant for soluble K for first and second year of research study.

4.2.1.10 Effect of sodic irrigation water on soluble sodium

The data presented in Table 4.47 revealed that soluble sodium (Na) significantly increased as sodicity of irrigation water increases; however with increasing soil depth no peculiar trend was observed during first as well as second year of experimental study. the present investigation study shows that soluble Na increased from 4.9 to 16.4 me/L before sowing and 5.4 to 19.7 me/L after harvest of crop in 2013-14 as RSC levels of irrigation water increased from 0 to 10 me/L. Likewise in next year soluble Na increased from 5.7 me/L in control to 7.5, 12.8 and 23.4 me/L and from 5.6 me/L (control) to 6.3, 10.8 and 18.0 me/L before sowing and after harvest of crop at RSC levels 3, 6.5 and 10 me/L levels of sodicity. This increase occurs due to regular use of sodic water to irrigate experimental soil.

It is evident from data that with increasing soil depth soluble Na have no particular trend, however in first year, soluble Na increased up to 60-90 cm soil depth then shows decreasing trend; whereas in second year it increase up to 15-30 cm soil depth and then decreased up to 90-120cm soil depth. Significant interaction was observed between RSC levels and soil depth for soluble Na for 2013-14 and 2014-15. It was observed that soluble Na was statistically at par at RSC 6.5 and 10me/L for soil depth 60-90 and 90-120 cm before sowing of crop in 2013-14.

Table 4.46 Effect of sodic irrigation water on soluble potassium (me /L)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	2.81	2.71	2.39	2.20	1.70	**2.36**	2.93	2.46	1.93	1.62	1.41	**2.07**
RSC 3	1.58	1.46	1.23	1.06	0.55	**1.17**	2.30	1.89	1.70	1.48	1.20	**1.71**
RSC 6.5	0.54	0.47	0.44	0.42	0.36	**0.45**	1.46	1.34	1.25	0.95	0.85	**1.17**
RSC 10	0.35	0.30	0.27	0.22	0.17	**0.26**	1.16	1.10	0.91	0.77	0.62	**0.91**
Mean	**1.32**	**1.23**	**1.08**	**0.97**	**0.69**		**1.96**	**1.70**	**1.45**	**1.20**	**1.02**	
LSD (5%)	**RSC = 0.04 Depth = 0.03 Interaction= 0.07**						**RSC = 0.26 Depth = 0.12 Interaction = 0.23**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	2.76	2.45	2.31	2.19	1.78	**2.29**	2.43	2.23	1.66	1.58	1.54	**1.89**
RSC 3	1.62	1.58	1.19	1.13	0.60	**1.23**	1.28	0.93	0.75	0.67	0.58	**0.84**
RSC 6.5	0.72	0.62	0.53	0.46	0.38	**0.54**	0.80	0.63	0.48	0.36	0.29	**0.51**
RSC 10	0.41	0.38	0.31	0.25	0.20	**0.31**	0.39	0.22	0.13	0.11	0.05	**0.18**
Mean	**1.38**	**1.25**	**1.08**	**1.01**	**0.74**		**1.22**	**1.01**	**0.75**	**0.68**	**0.61**	
LSD (5%)	**RSC = 0.03 Depth = 0.02 Interaction = 0.04**						**RSC = 0.05 Depth = 0.03 Interaction = 0.07**					

Table 4.47 Effect of sodic irrigation water on soluble sodium (me /L)

2013-14											
	Before sowing						**After harvest**				
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	3.2	4.8	5.5	5.6	5.7	**4.9**	4.2	4.7	5.5	6.1	6.4	**5.4**
RSC 3	5.1	5.7	7.2	7.8	7.8	**6.7**	5.1	5.3	5.7	6.5	9.8	**6.4**
RSC 6.5	10.5	11.5	12.1	13.2	14.2	**12.3**	14.3	15.2	15.7	17.3	17.8	**16.0**
RSC 10	17.5	17.4	17.1	14.1	15.7	**16.4**	21.8	19.5	19.2	18.7	19.2	**19.7**
Mean	**9.0**	**9.8**	**10.4**	**10.2**	**10.8**		**11.4**	**11.2**	**11.5**	**12.2**	**13.3**	
LSD (5%)	**RSC = 0.2 Depth = 0.1 Interaction= 0.4**						**RSC = 0.3 Depth = 0.1 Interaction= 0.2**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	3.6	7.1	6.3	6.0	5.4	**5.7**	4.2	6.4	6.0	5.8	5.5	**5.6**
RSC 3	6.4	8.5	8.2	7.2	6.8	**7.5**	6.4	8.4	6.3	5.6	4.9	**6.3**
RSC 6.5	13.5	15.6	13.4	11.4	9.9	**12.8**	11.9	13.5	11.3	9.7	7.5	**10.8**
RSC 10	26.5	28.3	24.8	19.8	17.5	**23.4**	20.7	21.4	18.5	15.6	13.7	**18.0**
Mean	**12.5**	**14.9**	**13.2**	**11.1**	**9.9**		**10.8**	**12.4**	**10.5**	**9.1**	**7.9**	
LSD (5%)	**RSC = 0.4 Depth = 0.5 Interaction = 1.0**						**RSC = 0.6 Depth = 0.4 Interaction = 0.8**					

4.2.1.11 Effect of sodic irrigation water on soluble Ca + Mg

The soluble Ca + Mg concentration as influenced by different levels of sodic irrigation water, before sowing and after harvest of crop in 2013-14 and 2014-15 was presented in Table 4.48. It is clear from data that **i**rrigation with increasing RSC levels significantly decreased soluble Ca + Mg. The data shows that soluble Ca + Mg mean value decreased by 28.3, 60.3, 66.0 % before sowing and 26.9, 46.4 and 55.3 % after harvest of crop in 2013-14 as compared to control. Similarly in 2014-15, soluble Ca + Mg mean value decreased from 5.5 me/L in control to 5.1, 4.7 and 4.2 me/L and from 5.2 me/L (control) to 4.1, 3.6 and 2.5 me/L before sowing and after harvest of crop at RSC 3, 6.5 and 10 me/L levels of irrigation water.

The perusal of data shows that Soluble Ca + Mg significantly decreased with increased soil depth in second year; however, it decreased up to 60-90cm again increases at 90-120 cm soil depth in first year of research study. When results pertaining to interaction effects were considered , it was found that significant interaction was observed for soluble Ca + Mg between RSC levels and soil depth for first and second year of research study, expect after harvest of crop in 2014-15 where it was reported to be non-significant. It was observed that soluble Ca + Mg was statistically at par at RSC 6.5 and 10 me/L levels of irrigation water for soil depth 15-30 and 30-60 cm before sowing as well as after harvest of crop in 2013-14.

4.2.1.11 Effect of sodic irrigation water on SAR

The Fig 4.8 depicted effect of sodic irrigation water on sodic absorption ratio of soil. It was observed that SAR significantly increased with increasing levels of RSC in irrigation water 2013-14 as well as 2014-15. The SAR increased up to 0-30cm soil depth and then shows decreasing trend with increases in soil depth at all levels of sodic water irrigation before sowing and after harvest in 2013-14. This can be attributed due to decreases in permeability of soil upon irrigation with high RSC waters and resulting higher SAR (Oster 2004). These results were supported by Choudhary *et al* 2007, who reported significant increases in SAR under irrigation with high RSC water in 0-30cm soil layers compared to 30-60cm at higher RSC irrigation water.

Further exploration of results revealed that in 2014-15, higher SAR values were observed in 15-30 cm as compare to surface soil layer (0-15 cm) which further deceases in lower soil depths up to 120 cm at different RSC levels of irrigation water. Similar results were also reported by several workers (Chauhan *et al* 2007, Minhas and Bajwa 2007, Choudhary *et al* 2012).

Table 4.48 Effect of sodic irrigation water on soluble Ca+Mg (me /L)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	5.8	5.5	5.2	5.0	5.1	**5.3**	6.4	5.5	5.2	4.7	6.3	**5.6**
RSC 3	5.3	5.1	3.2	2.5	3.0	**3.8**	5.8	5.1	3.1	2.8	4.1	**4.2**
RSC 6.5	2.4	2.1	1.9	1.5	2.7	**2.1**	4.1	3.4	2.7	2.2	2.7	**3.0**
RSC 10	1.8	1.9	2.0	1.3	2.4	**1.8**	2.5	2.9	3.2	1.8	2.4	**2.5**
Mean	**3.8**	**3.6**	**3.0**	**2.5**	**3.3**		**4.7**	**4.2**	**3.5**	**2.9**	**3.8**	
LSD (5%)	**RSC = 0.2 Depth = 0.1 Interaction= 0.3**						**RSC = 0.1 Depth = 0.2 Interaction= 0.3**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	6.1	5.8	5.4	5.2	5.1	**5.5**	5.8	5.3	5.0	4.9	4.7	**5.2**
RSC 3	5.7	5.2	5.1	4.9	4.5	**5.1**	5.0	4.2	4.0	3.8	3.3	**4.1**
RSC 6.5	5.3	4.9	4.8	4.6	3.9	**4.7**	4.3	4.0	3.7	3.4	3.0	**3.6**
RSC 10	4.8	4.6	4.4	3.8	3.5	**4.2**	3.0	2.8	2.7	2.3	2.0	**2.5**
Mean	**5.5**	**5.2**	**4.9**	**4.6**	**4.2**		**4.5**	**4.0**	**3.9**	**3.6**	**3.2**	
LSD (5%)	**RSC = 0.05 Depth = 0.06 Interaction = 0.13**						**RSC = 0.3 Depth = 0.7 Interaction = NS**					

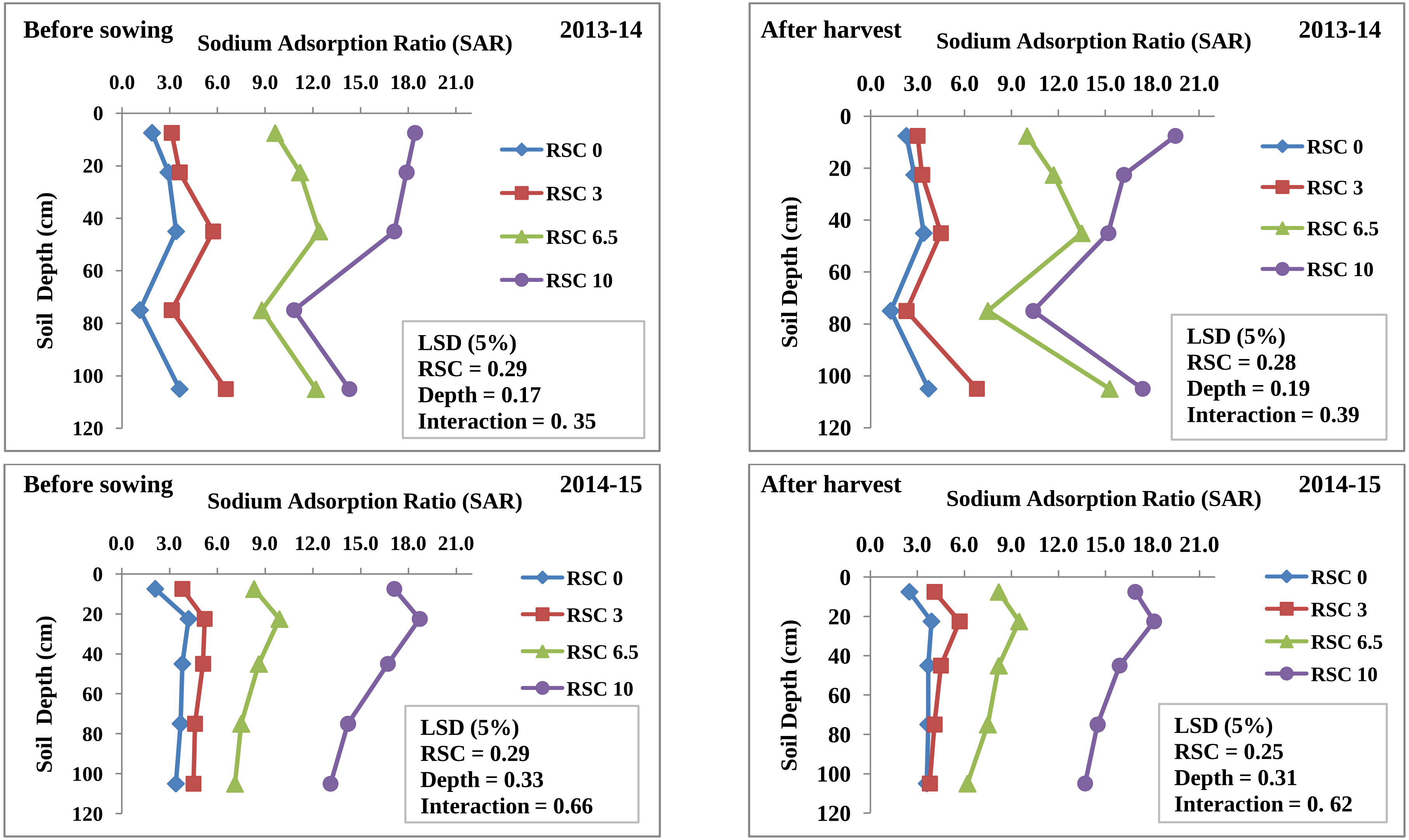


Fig. 4.8 Effect of sodic irrigation water on sodium adsorption ratio (SAR) of soil

4.2.1.11 Effect of sodic irrigation water on ESP

Effect of sodic irrigation water on ESP of soil, before sowing and after harvest of wheat crop in 2013-14 and 2014-15 was depicted in Fig.4.9. It was evident from figure that ESP follows same trend as that of SAR during first as well as second year of research study. It was observed that soil ESP increase significantly with increases in RSC levels of irrigation water in 2013-14 as well 2014-15, before sowing and after harvest of crop. It is clear from Fig 4.9 that soil ESP values were higher in 0-15cm as compared to 15-30cm soil layer at higher RSC levels. Higher ESP values were caused by increase soil dispersion and accumulation of sodium carbonate and bi carbonate in surface layers because of evapo-concentration (Gratten and Oster 2003 and Choudhary *et al* 2006). Similar results were also reported by Choudhary *et al* (2012).

In 2014-15, results revealed that higher soil ESP values in sub surface soil layer as compare to surface layers, before sowing and after harvest of crop at all levels of sodic water irrigation, which may be due to accumulation of sodium in lower layers.

4.2.1.14 Effect of sodic irrigation water on soluble bicarbonate

Long term use of sodic water resulted in high build up of carbonates and bicarbonates in soils. Table 4.49 clearly shows that bicarbonate concentration significantly increased as RSC levels of irrigation water increased in 2013-14 as well as in 2014-15.This increased may be due to constantly addition of $NaHCO_3$ to soil through RSC irrigation water . It was observed that mean bicarbonate concentration increased from 5.2 me/L in control to 5.8, 6.8 and 7.9 me/L before sowing and from 7.3 me/L (control) to 8.8, 11.4 and 14.6 me/L after harvest of crop in 2013-14 at RSC 3,6.5 and 10 me/L levels of irrigation water. Similarly, in 2014-15, mean bicarbonate concentrationincreased from 5.1 to 12.5 me/L and from 5.3 to 14.0 me/L before sowing and after harvest of crop as RSC of irrigation water increases from 0 to 10me/L, respectively.

The data also revealed that with increasing soil depth (0 to 120 cm) mean bicarbonate concentrationhave no particular trend in 2013-14 , however it decreases with increase in soil depth in 2014-15. The perusal of data shows that interaction between RSC levels and soil depth was found to be significant for soluble bicarbonate in 2013-14 as well as 2014-1 except after harvest of crop n 2014-15, where this interaction was observed to be non significant. Statistically similar results were observed at RSC 6.5 and 10me/L at depths 15-30 and 30-60 cm and at same RSC levels for depth 60-90 and 90-120 cm, before sowing of crop in 2013-14 as well as 2014-15.

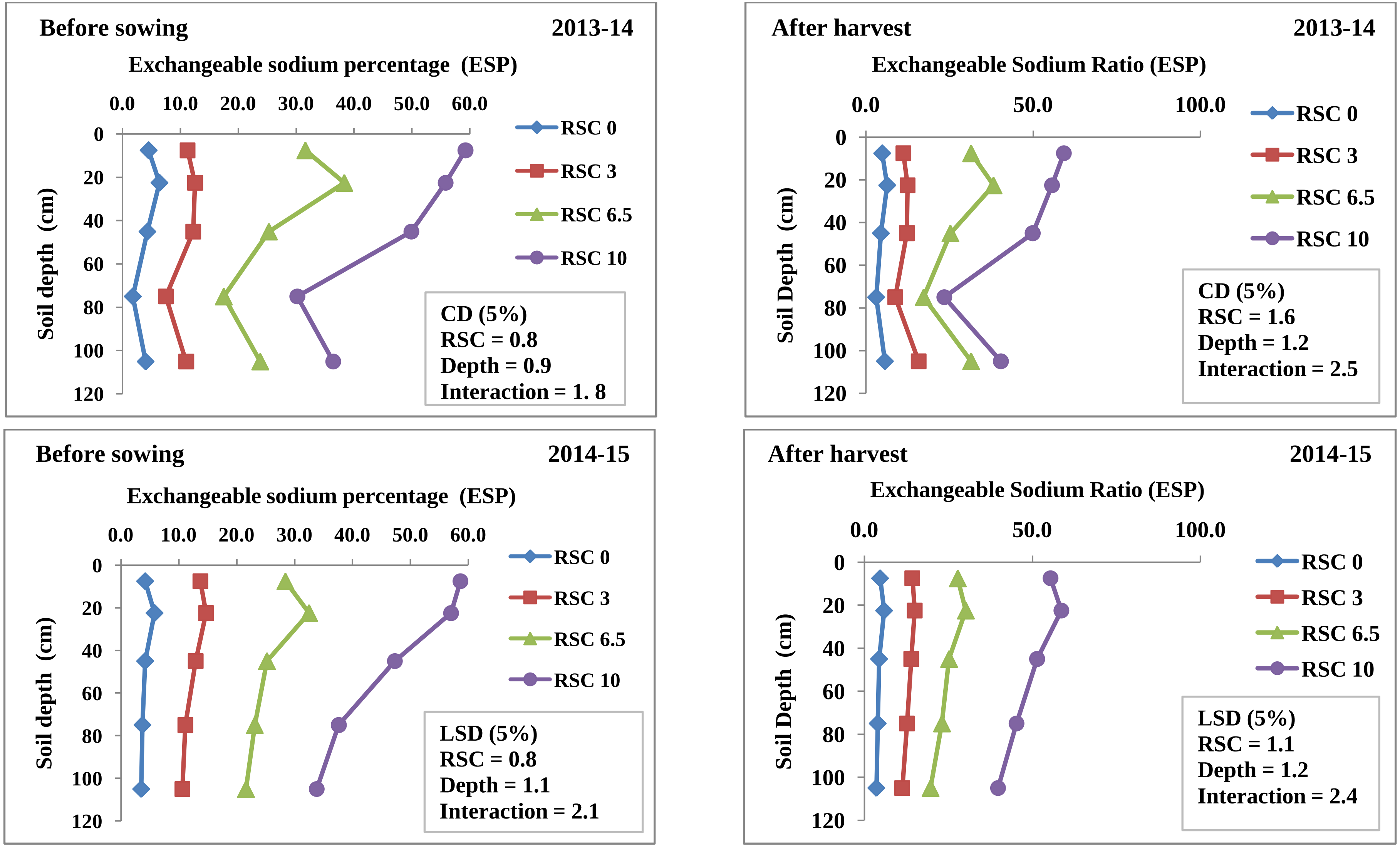


Fig 4.9 Effect of sodic irrigation water on exchangeable sodium percentage (ESP) of soil

Table 4.49 Effect of sodic irrigation water on soluble bicarbonate (HCO_3^-) (me /L)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	7.2	5.2	3.8	4.7	5.2	**5.2**	8.4	8.2	8.4	6.1	5.3	**7.3**
RSC 3	8.1	5.3	4.5	5.1	5.6	**5.8**	10.4	8.7	8.5	7.1	9.2	**8.8**
RSC 6.5	10.1	5.8	6.6	6.0	5.7	**6.8**	12.4	9.2	13.6	7.6	14.4	**11.4**
RSC 10	11.2	6.5	7.8	7.6	6.4	**7.9**	15.0	16.8	14.6	8.4	18.1	**14.6**
Mean	**9.1**	**5.7**	**5.6**	**5.8**	**5.7**		**11.6**	**10.8**	**11.3**	**7.3**	**11.7**	
LSD (5%)	**RSC = 0.3 Depth = 0.5 Interaction= 1.1**						**RSC = 0.4 Depth = 0.7 Interaction= 1.3**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	6.6	6.0	5.2	4.4	3.7	**5.1**	6.5	6.1	5.5	4.6	4.0	**5.3**
RSC 3	8.3	7.1	6.5	5.7	4.9	**6.5**	9.8	9.2	8.7	8.0	7.2	**8.6**
RSC 6.5	12.8	11.4	10.1	8.8	7.0	**10.0**	12.5	11.8	11.0	10.6	9.8	**11.2**
RSC 10	16.5	14.2	12.0	10.2	9.4	**12.5**	15.8	15.1	14.1	13.2	12.1	**14.0**
Mean	**11.1**	**9.7**	**8.5**	**7.3**	**6.3**		**11.2**	**10.6**	**9.8**	**9.0**	**8.2**	
LSD (5%)	**RSC = 1.0 Depth = 0.6 Interaction = 1.2**						**RSC = 0.9 Depth = 0.5 Interaction = NS**					

4.2.1.15 Effect of sodic irrigation water on soluble chloride

The data pertaining to effect of sodic water irrigation on soluble chloride (Cl^-) in 2013-14 and 2014-15 before sowing and after harvest of crop was presented Table 4.50**.** It was observed that increasing RSC levels of irrigation water significantly reduced Cl^- concentration which may be due to competition between HCO_3^- and Cl^- ions. The data revealed that soluble Cl^- concentration decreased from 6.6 me/L in control to 5.5, 4.6 and 3.5 me/L before sowing and from 8.3me/L (control) to 6.6, 5.6 and 3.8 me/L after harvest of crop at RSC 3, 6.5 and 10 me/L levels of irrigation water in 2013-14. Similarly in next year, mean soluble Cl^- was 7.0 me/L in control which decreased to 5.6, 5.0 and 4.5 me/L at RSC 3, 6.5 and 10me/L levels of irrigation water before sowing and corresponding values after harvest were 7.8, 7.2, 6.5 and 5.8 at respective RSC levels.

Further exploration of results depicts that soluble Cl^- also significantly decreased with increasing soil depth from 0-15cm to 90-120cm during first as well as second year of experimental study. The perusal of data shows that soluble Cl^- mean value decreased from 7.1 me/L to 3.4 me/L before sowing and 7.2 to 5.0 me/L after harvest of crop in 2013-14 as soil depth increased from 0-15 cm to 90-120 cm. The corresponding decrease in 2014-15 takes place from 6.2 to 4.7 me/L and 9.0 to 4.8 me/L before sowing and after harvest with increasing soil depth. Non significant interaction was observed for soluble Cl^- between RSC levels and soil depth in 2013-14 as well as 2014-15.

4.2.1.16 Effect of sodic irrigation water on soluble sulphate

It was observed that soluble sulphate (SO_4^{-2}) follows same trend as that of soluble Cl^- i.e. decreased with increasing sodicity and soil depth during first as well as second year of research study Table 4.51. The mean soluble SO_4^{-2} concentration decreased from 1.38 to 0.43 me/L and 1.59 to 0.58 me/L before sowing and after harvest of crop in normal water irrigation to highest level of sodic water irrigation (RSC=10me/L) in 2013-14 however, with increasing soil depth from 0-15cm to 90-120cm, mean soluble SO_4^{-2} decreased from 1.34 to 0.39 me/L before sowing and 2.12 to 0.51 me/L after harvest of crop in respective year. Similarly in next year, soluble SO_4^{-2} concentration decreased by 24.3 and 21.5% before sowing and after harvest at RSC 10me/L of irrigation water over control. Furthermore, the mean soluble SO_4^{-2} concentration decreased from 0.99 to 0.51 and 0.99 to 0.38me/L before sowing and after harvest of crop as soil depth increased from 0-15cm to 90-120 cm in 2014-15.

A perusal of data shows that significant interaction was observed for soluble SO_4^{-2} between RSC levels and soil depth in 2013-14 and 2014-15 expect after harvest of wheat crop in 2014-15, where this interaction was observed to be non-significant. It was found that soluble SO_4^{-2} was statistically at par at RSC 6.5 and 10me/L levels of irrigation water for soil depth 30-60cm and 60-90cm before sowing and for 0-15 cm and 15-30 cm soil depth after harvest of crop at respective RSC levels in 2013-14.

Table 4.50 Effect of sodic irrigation water on soluble chloride (Cl^-) (me /L)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	8.5	7.2	6.4	5.9	5.0	**6.6**	9.4	9.1	8.4	7.7	6.8	**8.3**
RSC 3	7.6	6.0	5.6	4.5	4.1	**5.5**	7.9	7.5	6.2	6.1	5.6	**6.6**
RSC 6.5	6.8	5.3	4.7	4.0	2.6	**4.6**	6.4	5.9	5.6	5.3	4.8	**5.6**
RSC 10	5.7	4.1	3.3	2.7	1.9	**3.5**	4.9	4.5	3.6	3.2	2.7	**3.8**
Mean	**7.1**	**5.6**	**5.0**	**4.2**	**3.4**		**7.2**	**6.7**	**5.9**	**5.5**	**5.0**	
LSD (5%)	**RSC = 0.5 Depth = 0.4 Interaction= NS**						**RSC = 0.5 Depth = 0.4 Interaction = NS**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	7.8	7.5	7.1	6.5	6.1	**7.0**	10.3	9.2	7.5	6.3	5.9	**7.8**
RSC 3	6.4	6.0	5.8	5.3	4.8	**5.6**	9.3	8.4	6.9	6.1	5.2	**7.2**
RSC 6.5	5.7	5.4	5.0	4.6	4.2	**5.0**	8.6	7.6	6.5	5.5	4.5	**6.5**
RSC 10	5.2	4.8	4.5	4.0	3.9	**4.5**	8.0	6.8	5.8	4.8	3.9	**5.8**
Mean	**6.2**	**5.9**	**5.6**	**5.1**	**4.7**		**9.0**	**8.0**	**6.6**	**5.7**	**4.8**	
LSD (5%)	**RSC = 0.2 Depth = 0.1 Interaction = NS**						**RSC = 0.1 Depth = 0.3 Interaction = NS**					

Table 4.51 Effect of sodic irrigation water on soluble sulphate (SO_4^{-2}) (me /L)

2013-14												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	2.30	1.89	1.43	0.72	0.57	**1.38**	3.30	2.06	1.05	0.86	0.67	**1.59**
RSC 3	1.51	1.45	0.86	0.62	0.48	**0.98**	2.50	1.27	1.11	0.77	0.54	**1.24**
RSC 6.5	0.84	0.69	0.52	0.42	0.29	**0.55**	1.90	0.81	0.78	0.63	0.45	**0.91**
RSC 10	0.73	0.44	0.40	0.36	0.22	**0.43**	0.80	0.68	0.58	0.48	0.38	**0.58**
Mean	**1.34**	**1.11**	**0.80**	**0.53**	**0.39**		**2.12**	**1.20**	**0.88**	**0.68**	**0.51**	
LSD (5%)	**RSC = 0.05 Depth = 0.04 Interaction= 0.08**						**RSC = 0.03 Depth = 0.02 Interaction= 0.05**					
2014-15												
	Before sowing						**After harvest**					
Depth	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
RSC 0	1.12	1.01	0.75	0.65	0.58	**0.82**	1.13	0.74	0.46	0.49	0.44	**0.65**
RSC 3	1.05	0.87	0.69	0.59	0.56	**0.75**	1.05	0.71	0.67	0.64	0.50	**0.71**
RSC 6.5	0.99	0.82	0.62	0.56	0.48	**0.67**	0.96	0.85	0.74	0.53	0.42	**0.70**
RSC 10	0.81	0.75	0.53	0.51	0.42	**0.62**	0.85	0.73	0.54	0.30	0.18	**0.51**
Mean	**0.99**	**0.86**	**0.65**	**0.58**	**0.51**		**0.99**	**076**	**0.56**	**0.49**	**0.38**	
LSD (5%)	**RSC = 0.07 Depth = 0.08 Interaction = NS**						**RSC = 0.002 Depth = 0.003 Interaction = 0.005**					

4.2.2 Effect of sodic irrigation water on physical soil health

The results pertaining to effects of sodic irrigation water on physical soil health of soil in 2013-14 as well as 2014-15 was presented in Table 4.52. These physical properties includes bulk density, mean weight diameter (MWD), saturated hydraulic conductivity (SHC), infiltration rate (IR), dispersion ratio (DR) and water holding capacity (WHC), which were adversely affected by sodic water irrigation. It was observed that continuous irrigation with sodic water resulted in increase in soil bulk density and dispersion ratio, while all other physical properties (MWD, SHC, IR and WHC) decrease significantly. Bulk density and dispersion ratio increased from 1.54 to 1.73 Mg/m^3 and 0.350 to 0.630 before sowing and from 1.47 to 1.69 Mg/m^3 and 0.351 to 0.635 after harvest of crop in 2013-14 as RSC levels increased from 0 to 10me/L. Likewise in 2014-15, this increase takes place from 1.50 to 1.74 Mg/m^3 for bulk density and 3.361 to 0.627 for dispersion ratio before sowing and from 1.49 to 1.66 Mg/m^3. And 0.356 to 0.621 after harvest of crop as sodicity increase from 0 to 10 me/L respectively. The increase in bulk density was due soil compaction with sodicity. Soil compaction increased due to dispersive action of exchangeable sodium on soil collide and altering the pore size distribution. (Gratten and Oster, 2003) similarly increase in dispersion ratio was due to the addition of dispersing cation sodium through long term irrigation.

The perusal of data shows that MWD and WHC deceased by 16.4 and 17.3 % and 28.8 and 28.7 % at RSC 10me/L level over control, before sowing and after harvest in 2013-14. Contrary to this in 2014-15 it decreased by 15.2 and 17.9 % and 29.3 and 27.2 % at RSC 10me/L of irrigation water as compared to control before sowing and after harvest of crop. Eltarif and Gharaibeh (2007) also found that mean weight diameter decrease with increase in soil exchangeable sodium percentage. High level of Na also leads to structural changes which affect water and air movement, and ultimately water holding capacity of soil. Further exploration of data depicts that soil water transmission properties were adversely affected by increasing sodicity of irrigation water. Nayak *et al* (2004) reported that SHC of vertisols decreased with increases in ESP and soil electrolyte concentration. The data revealed that SHC and IR of soil decreased by 64.5 % and 58.6 % and 62.9 and 57.1 % in 2013-14 and corresponding values in 2014-15 were 60.6 and 55.5 % and 56.0 and 57.6 % at RSC 10 me/L as compared to control.

Table 4.52Effect of sodic irrigation water onphysical soil health

Treatment	**Bulk density (Mg/m^3)**	**Mean weight diameter (mm)**	**Saturated hydraulic conductivity (cm/hr)**	**Infiltration rate (cm/hr)**	**Dispersion ratio**	**Water holding capacity (%)**
2013-14						
Before sowing						
RSC 0	1.54	0.97	0.31	2.7	0.350	37.4
RSC 3	1.61	0.94	0.26	2.0	0.424	33.5
RSC 6.5	1.67	0.87	0.17	1.5	0.536	30.2
RSC 10	1.73	0.81	0.11	1.0	0.630	26.6
LSD (5%)	**0.03**	**0.05**	**0.04**	**0.4**	**0.010**	**7.1**
After harvest						
RSC 0	1.47	0.92	0.29	2.8	0.351	38.6
RSC 3	1.53	0.87	0.25	2.4	0.435	35.1
RSC 6.5	1.60	0.80	0.19	1.8	0.567	31.4
RSC 10	1.69	0.76	0.12	1.2	0.635	27.5
LSD (5%)	**0.06**	**0.07**	**0.04**	**0.5**	**0.021**	**6.5**
2014-15						
Before sowing						
RSC 0	1.50	0.92	0.33	2.5	0.361	36.7
RSC 3	1.58	0.87	0.28	2.0	0.468	33.1
RSC 6.5	1.64	0.82	0.19	1.6	0.578	29.6
RSC 10	1.74	0.78	0.13	1.1	0.627	26.1
LSD (5%)	**0.04**	**0.09**	**0.05**	**0.4**	**0.025**	**4.6**
After harvest						
RSC 0	1.49	0.89	0.27	2.6	0.356	39.2
RSC 3	1.55	0.84	0.24	2.3	0.458	36.1
RSC 6.5	1.61	0.79	0.18	1.7	0.560	32.4
RSC 10	1.66	0.73	0.12	1.1	0.621	28.5
LSD (5%)	**0.02**	**0.01**	**0.07**	**0.3**	**0.021**	**5.8**

4.2.3 Effect of sodic irrigation water on biological soil health

Microbial biomass and water extractable pools of soil organic carbon are considered sensitive indices that characterize changes in biological conditions cause by soil management practices. Therefore in present study, dehydrogenase enzyme activity microbial biomass carbon and nitrogen and cold water extractable carbon biological parameters were observed under sodic irrigation treatment.

4.2.3.1 Effect of sodic irrigation water on dehydrogenase enzyme activity

Dehydrogenase enzyme activity (DHA) reflects the total oxidative activity of microbial biomass (Nannipieri *et al* 1990) i.e. involved in central aspects of metabolism. The results pertaining to effect of increasing RSC levels of irrigation water on DHA in 2013-14 and 2014-15, before sowing and after harvest of crop were presented in Table 4.53. It is evident from data that DHA significantly decreased with increasing levels of sodic irrigation water in 2013-14 and 2014-15. The mean DHA decreased by 20.3, 38.5 and 53.4 % and 23.7, 43.0 and 58.9 % before sowing and after harvest of crop at RSC 3, 6.5 and 10me/L levels of irrigation water as compared to control in 2013-14. Similarly in 2014-15, mean DHA decreased from 39.8 µ g/TPF/hr/g in control to 33.1, 25.7 and 18.5µg/TPF/hr/g at RSC 3, 6.5 and 10me/L levels of sodicity before sowing and from 38.1µg/TPF/g (control) to 30.0, 24.2 and 16.8 µg/TPF/hr/g at respective RSC levels after harvest of crop. Reitz and Hayns (2003) observed that irrigation induced sodicity depressed the enzyme activity because sodicity exhibit unique structural problems resulting from soil physical processes such as slaking, swelling and dispersion of clay, which in turn cause degradation of soil structure (Boivin *et al* 2004 and Tejada and Gonzalez2005) thereby adversely affecting soil microbial community and thereby dehydrogenase enzyme activity. The present investigation study reveals that DHA also significantly decreased with increasing soil depth expect before sowing of crop in 2013-14, where it was non-significant. The mean DHA decreased from 28.1 to 24.2 µg/TPF/hr/g and from 32.1 to 24.1µg/TPF/hr/g before sowing and after Harvest of crop in 2013-14 as soil depth increased from 0-15cm to 15-30cm. Likewise in 2014-15, corresponding values decreased from 32.4 to 26.1 µg/TPF/hr/g before sowing and from 30.2 to 24.3 µg/TPF/hr/g after harvest of crop from surface soil layer to sub surface soil layer, respectively. In general, more DHA in surface soil was observed as compared to sub-surface soil because microbial activity was more in top soil than below soil layers. It was observed that non-significant interaction was reported for DHA between RSC levels of irrigation water and soil depth in 2013-14 and 2014-15.

Table 4.53 Effect of sodic irrigation water on dehydrogenase enzyme activity (µg/TPF/hr/ g soil)

2013-14						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	38.6	34.1	**36.3**	44.5	37.4	**40.9**
RSC 3	30.1	27.7	**28.9**	36.3	26.2	**31.2**
RSC 6.5	24.2	20.5	**22.3**	27.1	19.6	**23.3**
RSC 10	19.3	14.6	**16.9**	20.4	13.3	**16.8**
Mean	**28.1**	**24.2**		**32.1**	**24.1**	
LSD (5%)	**RSC = 5.8, Depth = NS, Interaction =NS**			**RSC = 5.2, Depth = 3.6 , Interaction =NS**		
2014-15						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	43.5	36.2	**39.8**	41.0	35.2	**38.1**
RSC 3	36.6	29.5	**33.1**	33.7	26.3	**30.0**
RSC 6.5	28.5	22.9	**25.7**	27.6	20.8	**24.2**
RSC 10	21.3	15.7	**18.5**	18.5	15.1	**16.8**
Mean	**32.4**	**26.1**		**30.2**	**24.3**	
LSD (5%)	**RSC = 2.3 , Depth = 1.6 , Interaction =NS**			**RSC = 2.7 , Depth = 1.9 , Interaction = NS**		

4.2.3.2 Effect of sodic irrigation water on microbial biomass carbon

Long term irrigation with sodic water significantly decreased microbial biomass carbon (MBC) in surface and sub surface soil layers in 2013-14 as well as 2014-15 (Table 4.54). The data revealed that mean MBC was 245.1 mg/kg in control, while it was 223.1, 190.0 and 156.3 mg/kg at RSC 3, 6.5 and 10me/L levels of sodicity before sowing of crop and corresponding values after harvest of crop were 249.3, 220.1, 179.7 and 141.6 mg/kg at respective RSC levels in 2013-14. Furthermore in 2014-15 mean MBC decreased by 9.7, 26.2 and 37.0 % and 10.8, 25.0 and 39.3 % at RSC 3, 6.5 and 10me/L levels over control before sowing and after harvest of crop. The decrease in MBC occurs because under sodic conditions, toxicities of Na and other accompanying ions (Cl^- and HCO_3^-), along with high soil pH inhibits microbial growth (Zahran 1997).

The data presented in Table 4.54 showed that MBC significantly decreased with increasing soil depth in 2013-14 as well as 2014-15. The mean MBC decreased from 211.1 to 196.1 mg/kg and from 202.4 to 192.9 mg/kg at soil depth 0-15 to 15-30cm before sowing and after harvest of crop in 2013-14, whereas corresponding MBC at respective soil depths in 2014-15 were 204.2 and 198.1mg/kg and 197.3 and 179.6mg/kg before sowing and after harvest of crop. Further exploration of data depicts that interaction effects of two factors (RSC levels and soil depth) were found to be significant for MBC expect before sowing of crop in 2013-14 and 2014-15, where interaction was observed to be non-significant. Kaur *et al* (2008) also reported significantly lower MBC in soil irrigated with sodic water as compared to good quality water.

Table 4.54 Effect of sodic irrigation water on microbial biomass carbon

2013-14						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	251.5	238.7	**245.1**	258.3	240.1	**249.3**
RSC 3	230.1	215.9	**223.1**	221.8	218.5	**220.1**
RSC 6.5	198.7	181.3	**190.0**	183.1	176.3	**179.7**
RSC 10	164.2	148.5	**156.3**	149.5	133.6	**141.6**
Mean	**211.1**	**196.1**		**203.2**	**192.2**	
LSD (5%)	**RSC = 4.5 , Depth = 3.2 , Interaction = NS**			**RSC = 4.2 , Depth = 2.9 , Interaction = 5.8**		
2014-15						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	255.5	236.6	**246.1**	240.5	223.5	**232.0**
RSC 3	225.3	218.7	**222.0**	219.3	194.6	**206.9**
RSC 6.5	183.6	179.1	**181.4**	178.7	169.3	**174.0**
RSC 10	158.8	151.1	**154.9**	150.4	130.8	**140.6**
Mean	**205.8**	**196.4**		**197.3**	**179.6**	
LSD (5%)	**RSC = 5.6 , Depth = 3.9 , Interaction = NS**			**RSC = 5.1 , Depth = 3.6 , Interaction = 7.2**		

4.2.3.3 Effect of sodic irrigation water on microbial biomass nitrogen

The results pertaining to effect of increasing sodic irrigation water levels on microbial biomass nitrogen (MBN) in 2013-14 as well as 2014-15, before sowing and after harvest of wheat crop were presented in Table 4.55. It is clear from data that MBN follows same trend as that of MBC i.e. decreasing with increasing RSC levels of irrigation water during first as well as second year of experimental study. The mean MBN decreased from 105.4 mg/kg (control) to 91.5, 66.1 and 42.4 mg/kg at RSC 3, 6.5 and 10 me/L levels of sodicity and from

89.8 to 62.8 mg/kg at soil depths 0-15 to 15-30cm before sowing of crop in 2013-14. The corresponding values after harvest of wheat crop were 108.8, 91.7, 69.4 and 41.3 mg/kg at respective RSC levels and soil depth for same year.

Furthermore in 2014-15 mean MBN was 95.1mg/kg in control which decreased to 78.2, 61.6 and 44.3 mg/kg at RSC level 3, 6.5 and 10me/L before sowing of crop and from 111.4mg/kg (control) to 92.9, 73.4 and 47.8mg/kg at respective levels of sodicity. Likewise, the mean MBN decreased from 81.7 to 57.9 mg/kg and from 96.9 to 65.6 mg/kg before sowing and harvest of crop as soil depth increases from 0-15 to 15-30cm in 2014-15. It is evident from data that non-significant interaction results were obtained for MBN between RSC levels and soil depth expects before sowing in 2014-15, where MBN was statistically at par at RSC 3 and 6.5 me/L levels of irrigation water for soil depth 0-15cm and 15-30cm.

Table 4.55 Effect of sodic irrigation water on microbial biomass nitrogen

2013-14						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	120.4	90.3	**105.4**	118.5	99.2	**108.8**
RSC 3	111.8	71.2	**91.5**	97.2	86.2	**91.7**
RSC 6.5	76.9	55.3	**66.1**	77.3	61.5	**69.4**
RSC 10	50.3	34.5	**42.4**	45.4	37.2	**41.3**
Mean	**89.8**	**62.8**		**84.6**	**71.0**	
LSD (5%)	**RSC = 5.9, Depth = 4.2 , Interaction = 8.5**			**RSC = 4.4, Depth = 3.1 , Interaction = NS**		
2014-15						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	107.6	82.5	**95.1**	126.5	96.2	**111.4**
RSC 3	88.8	67.7	**78.2**	110.1	75.8	**92.9**
RSC 6.5	74.3	48.8	**61.6**	88.7	58.1	**73.4**
RSC 10	56.1	32.5	**44.3**	62.5	32.5	**47.8**
Mean	**81.7**	**57.9**		**96.9**	**65.6**	
LSD (5%)	**RSC = 5.2 , Depth = 3.7 , Interaction = NS**			**RSC = 5.3 , Depth = 3.7 , Interaction = NS**		

4.2.3.4 Effect of sodic irrigation water on cold water extractable carbon

The data presented in Table 4.56 revealed that cold water extractable carbon(CWEC) significantly decreased with increasing levels of RSC irrigation water as well as soil depth. The mean CWEC decreased by 18.7, 28.8 and 56.2 % and 15.5, 35.0 and 58.7 % at RSC 3,6.5 and 10 me/L levels of irrigation water over control before sowing and after harvest of crop in 2013-14. On the other hand in 2014-15 it decreased by 14.1, 34.7 and 56.1 % and 15.9, 36.8 and 62.1 % at respective RSC levels over control before sowing and after harvest of crop. These results are conformity with finding of Choudhary *et al* (2013). They reported that CWEC deceased by 66.7 % at RSC 10me/L of irrigation water as compared to canal water treatment. It was observed that CWEC was significantly higher in 0-15 cm soil layer than15-30 cm layer in 2013-14 as well as 2014, as microbial activity was more in surface soil than sub-surface soil. The data further shows that CWEC decreased from 56.1 to 39.3 mg/kg and 61.6 to 36.8 mg/kg before sowing and after harvest of crop in 2013-14 and from 59.1 to 42.4 mg/kg and 55.1 to 37.1 mg/kg in 2014-15 before sowing and after harvest of crop as soil depth increases from 0-15 cm to 15-30cm respectively. When results pertaining to interaction effects were considered, it was observed that RSC levels and soil depth, shows significant interaction for CWEC in 2013-14 as well as 2014-15. It was observed that CWEC was statistically at par at RSC 3 and 6.5 me/L levels of irrigation water for soil depth 0-15cm and 15-30cm before sowing and at RSC 6.5 and 10 me/L for respective soil depth after harvest of crop in 2014-2015.

Table 4.56 Effect of sodic irrigation water on cold water extractable carbon (mg/kg)

2013-14						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	76.5	52.3	**64.4**	81.4	53.9	**67.7**
RSC 3	61.1	43.5	**52.3**	72.1	42.3	**57.2**
RSC 6.5	55.6	36.2	**45.8**	58.6	29.3	**44.0**
RSC 10	31.3	25.1	**28.2**	34.1	21.7	**27.9**
Mean	**56.1**	**39.3**		**61.6**	**36.8**	
LSD (5%)	**RSC = 3.2 , Depth = 2.3 , Interaction = 4.6**			**RSC = 2.2 , Depth = 1.5 , Interaction = 3.1**		
2014-15						
	Before sowing			**After harvest**		
Depth	**0-15**	**15-30**	**Mean**	**0-15**	**15-30**	**Mean**
RSC 0	79.2	58.4	**68.8**	76.3	52.8	**64.5**
RSC 3	66.5	51.7	**59.1**	62.1	46.2	**54.2**
RSC 6.5	52.7	37.2	**44.9**	52.5	28.9	**40.7**
RSC 10	38.1	22.4	**30.2**	29.6	20.5	**25.1**
Mean	**59.1**	**42.4**		**55.1**	**37.1**	
LSD (5%)	**RSC = 2.1 , Depth = 1.5 , Interaction = 3.1**			**RSC = 2.6 , Depth = 1.8 , Interaction = 3.7**		

4.2.4 Effect of sodic irrigation water on performance of wheat cultivars

4.2.4.1 Effect of sodic irrigation water on plant height of wheat cultivars at tillering stage

The data related to plant height of different wheat cultivars at tillering stage as influenced by sodic water irrigation in 2013-14 as well as 2014-15 was presented in Table 4.57.The data revealed that plant height of different wheat cultivars decreased significantly with increasing sodicity of irrigation water. In 2013-14, mean plant height decreased by 4.8, 9.9 and 26.7 % at RSC 3, 6.5 and 10me/L levels of irrigation water as compared to control. Contrary to this, in next year of research study average plant height decreased from 57.3 cm in control to 53.5, 47.7 and 39.6 cm at RSC 3, 6.5 and 10me/L levels of sodicity. Almost similar findings were reported by Murtaza *et al* (2006,) who reported decreased in plant height of wheat crop from 96.5cm in control to 92.8 cm receiving saline sodic water (EC=3.3 dS/m and RSC= 5.25 me/L). It is evident from data that mean plant height tends to remain constant over time with an average of 56.3cm as there are no effects of sodic irrigation water.

Further exploration of data revealed that among different wheat cultivars maximum average plant height was observed for cultivar KRL 210 whereas minimum in HD 2967 for first as well as second year of experimental study. It has been observed that non-significant interaction was reported for plant height between RSC levels and wheat cultivars in 2013-14, however in 2014-15 this interaction was found to be significant, where statistically same plant height was observed for cultivars PBW 621at 6.5 me/L and HD 2967 at RSC 10me/L levels of sodic irrigation water in 2013-14.

4.2.4.2 Number of tillers/m^2 of different wheat cultivars as affected by sodic water irrigation at tillering stage

The data presented in Table 4.58 revealed that number of tillers/m^2 wheat cultivars significantly decreased with increasing sodicity of irrigation water in 2013-14 as well as 2014-15. The average number of tillers/m^2 decreased from 370 in control to 356, 330 and 308 at RSC 3, 6.5 and 10me/L levels of sodicity in 2013-14 and from 365 (control) to 350, 330 and 303 in 2014-15 at respective RSC levels in 2014-15. These results were similar to findings of Murtaza *et al* (2006), who observed decreased in no. of tillers/m from 493 in control to 414 at saline sodic water (EC=3.3 dS/m, RSC = 5.3 me/L).

Table 4.57 Effect of sodic irrigation water on plant height (cm) of wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	63.8	56.4	45.6	54.6	61.2	50.5	**55.3**
RSC 3	61.3	50.5	43.0	52.0	60.8	48.3	**52.6**
RSC 6.5	57.4	47.9	42.4	49.2	56.3	45.7	**49.8**
RSC 10	47.9	35.5	34.4	41.2	43.8	40.2	**40.5**
Mean	**57.6**	**47.6**	**41.3**	**49.3**	**55.5**	**46.1**	
LSD (5%)	**RSC= 4.1 Cultivar= 2.6 Interaction = NS**						
2014-15							
RSC 0	68.1	57.7	48.7	55.8	62.7	50.6	**57.3**
RSC 3	68.5	50.3	43.6	52.1	60.6	46.2	**53.5**
RSC 6.5	57.7	42.8	40.3	51.0	50.4	44.5	**47.7**
RSC 10	41.0	33.0	32.1	43.3	45.3	42.9	**39.6**
Mean	**58.8**	**45.9**	**41.2**	**50.5**	**54.7**	**46.1**	
LSD (5%)	**RSC= 1.3 Cultivar=1.5 Interaction = 2.9**						

Out of six wheat cultivars maximum average no of tillers/m^2 were retained by HD 2967 (349) followed by Berbat (346) whereas minimum was observed in PBW 590 (330 and 346) for 2013-14 and 2014-15. It is evident from data that number of tillers /m^2 of different wheat cultivars ranged from 307 to 378 in 2013-14 and varied from 296 to 375 in 2014-15 at different levels of sodic irrigation water. Furthermore, significant interaction was observed for number of tillers /m^2 between RSC levels and wheat cultivars for bothyears. Statistically similar valuesof number of tiller/m^2 were observed for cultivars HD 2967 and PBW 590 at RSC 3 and 6.5 me/L levels of irrigation water in 2013-14 and 2014-15.

Table 4.58 Number of tillers/m^2 of different wheat cultivars as affected by sodic water irrigation at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	365	376	378	356	373	371	**370**
RSC 3	357	360	365	340	359	358	**356**
RSC 6.5	318	333	340	321	332	340	**330**
RSC 10	297	307	312	306	313	314	**308**
Mean	**334**	**344**	**349**	**330**	**344**	**346**	
LSD (5%)	**RSC = 3.4**	**Cultivar= 2.9**		**Interaction = 5.8**			
2014-15							
RSC 0	355	375	371	352	370	365	**365**
RSC 3	341	358	356	337	356	350	**350**
RSC 6.5	323	329	338	318	337	338	**330**
RSC 10	288	296	314	298	310	312	**303**
Mean	**327**	**340**	**345**	**326**	**343**	**341**	
LSD (5%)	**RSC = 4.5**	**Cultivar= 4.9**		**Interaction = 9.9**			

4.2.4.3 Sodic irrigation water effects on leaf area index (LAI) of different wheat cultivars at tillering stage

The leaf area index (LAI) of different wheat cultivars at different sodicity levels was recorded at tillering stage during first and second year of experimental study (Table 4.59). The data revealed that LAI of different wheat cultivars significantly decreased at RSC 6.5 and 10me/L levels of irrigation water in 2013-14 as well as 2014-15. It is evident from data that mean LAI in normal irrigation treatment tends to remain constant over time as there are no effects of sodic water irrigation. The present results study revealed that LAI of different wheat cultivars decreased from 2.5 to 2.3, 2.1 and 1.5 in 2013-14 and from 2.6 to 2.4, 2.1 and 1.5 in 2014-15 at RSC 0 to 3, 6.5 and 10me/L levels of irrigation water. As compared to control, mean LAI of wheat cultivars decreased by 7.6, 19.2 and 42.3 % in 2013-14 and 8.0, 16.6 and 40.0 % in 2014-15 at RSC 3, 6.5 and 10me/L levels of sodicity. The perusal of data shows that LAI of different wheat cultivars was statistically at par at all levels of sodic water irrigation in 2013-14, however in next year of experimental study, non-significant effects of sodic water irrigation on LAI of six wheat cultivars were observed .Further exploration of data depicts that non-significant interaction between different levels of irrigation water sodicity and wheat cultivars for LAI was reported in 2013-14 as well as 2014-15.

Table 4.59 Sodic irrigation water effects on leaf area index (LAI) of wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	2.6	2.5	2.3	2.1	3.1	2.4	**2.5**
RSC 3	2.5	2.3	2.2	1.9	3.0	2.2	**2.3**
RSC 6.5	2.4	2.2	1.9	1.8	2.8	2.0	**2.1**
RSC 10	1.4	2.1	1.3	1.4	1.4	1.3	**1.5**
Mean	**2.2**	**2.3**	**1.9**	**1.8**	**2.6**	**1.9**	
LSD (5%)	**RSC = 0.3 Cultivar= 0.2 Interaction = NS**						
2014-15							
RSC 0	2.4	2.6	2.4	2.5	3.0	2.8	**2.6**
RSC 3	2.2	2.4	2.3	2.0	2.9	2.6	**2.4**
RSC 6.5	1.9	2.2	2.1	1.8	2.4	2.1	**2.1**
RSC 10	1.7	1.8	1.4	1.6	1.5	1.3	**1.5**
Mean	**2.1**	**2.3**	**2.0**	**1.9**	**2.5**	**2.2**	
LSD (5%)	**RSC = 0.4 Cultivar= NS Interaction = NS**						

4.2.4.4 Mineral composition (Na, K, P and Ca) of wheat cultivars at tillering stage

Plant samples of wheat cultivars namely KRL210, PBW621, HD 2967, PBW658, PBW 590 and Berbet were taken at tillering stage for analysis of sodium (Na), potassium (K), phosphorous (P) and calcium (Ca) and results related to these elements were discussed under following headings;

4.2.4.4.1 Plant sodium content of wheat cultivars as affected of sodic irrigation water

Plant sodium (Na) content of different wheat cultivarsas affected by different levels of sodic irrigation water were determined at tillering stage during first and second year of experimental study (Table 4.60). The data revealed that as sodicity of irrigation water increases, there is significant increase in plant Na content in 2013-14 and 2014-15. It is evident from data that average plant Na content increased from 0.077 in control to 0.107, 0.141 and 0.171% at RSC 3, 6.5 and 10 me/L levels of sodic irrigation water in 2013-14 and from 0.078 (control) to 0.106, 0.144 and 0.169% at corresponding RSC levels in 2014-15. Saqib *et al* (2006) also reported similar results under saline sodic soils EC=15dS/m and SAR

=35) as compared to control. They observed increase in leaf Na^+ concentration from 30mol/$m^3$to 200 mol/m^3 in three wheat cultivars (Aqaab, MH-97 and Inqlab). The average plant Na content in normal irrigation treatment tends to remain constant over time with an average of 0.075% as there are no effects of sodic irrigation water.

Table 4.60 Plant sodium content (%) of wheat cultivars as affected of sodic irrigation water

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.048	0.077	0.086	0.083	0.085	0.082	**0.077**
RSC 3	0.065	0.087	0.104	0.134	0.145	0.103	**0.107**
RSC 6.5	0.083	0.128	0.130	0.183	0.172	0.152	**0.141**
RSC 10	0.136	0.137	0.175	0.192	0.191	0.195	**0.171**
Mean	**0.083**	**0.107**	**0.124**	**0.150**	**0.150**	**0.133**	
LSD (5%)	**RSC = 0.01 Cultivar = 0.02 Interaction = NS**						
2014-15							
RSC 0	0.052	0.063	0.076	0.089	0.085	0..073	**0.078**
RSC 3	0.067	0.072	0.098	0.145	0.153	0.101	**0.106**
RSC 6.5	0.086	0.114	0.145	0.186	0.187	0.143	**0.144**
RSC 10	0.124	0.129	0.183	0.194	0.197	0.187	**0.169**
Mean	**0.082**	**0.095**	**0.126**	**0.153**	**0.156**	**0.126**	
LSD (5%)	**RSC = 0.005 Cultivar = 0.01 Interaction = 0.02**						

Further exploration of data depicted that average plant Na content among different wheat cultivars ranged from 0.083 to 0.150% and from 0.082 to 0.156% in 2013-14 as well as 2014-15. It was observed that maximum plant Na content was observed in cultivar PBW658 and minimum was retained by KRL210 during first as well as second year of research study. The interaction between RSC levels of irrigation water and wheat cultivars for plant Na content was observed to be non-significant in 2013-14, whereas it was found to be significant in 2014-15, where plant Na content was statistically at par RSC 3 and 6.5 me/L levels of sodic irrigation water for cultivars HD2967 and PBW590.

4.2.4.4.2 Sodic irrigation water effects on plant potassium content of wheat cultivars at tillering stage

The data regarding sodic water irrigation effects on plant potassium (K) content along with statistical analysis in 2013-14 and 2014-15 at tillering stage was displayed in Table 4.61. It was observed that plant K content significantly decreased with increasing levels of sodic water irrigation during first and second year of research study. The average plant K content decreased by 8.3, 22.5 and 37.5 % and 9.2, 23.5 and 37.8% at RSC 3, 6.5 and 10 me/L levels of sodicity as compared to control in 2013-14 and 2014-15, respectively. In general increasing soil ESP decrease K availably to plants.

Table 4.61 Sodic irrigation water effects on plant potassium content (%) of wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.117	0.108	0.121	0.133	0.139	0.120	**0.120**
RSC 3	0.095	0.096	0.116	0.127	0.122	0.102	**0.110**
RSC 6.5	0.087	0.072	0.098	0.095	0.113	0.093	**0.093**
RSC 10	0.069	0.062	0.077	0.075	0.086	0.080	**0.075**
Mean	**0.092**	**0.086**	**0.103**	**0.105**	**0.113**	**0.098**	
LSD (5%)	**RSC = 0.014 Cultivar = 0.012 Interaction = NS**						
2014-15							
RSC 0	0.104	0.112	0.123	0.128	0.135	0.124	**0.119**
RSC 3	0.091	0.099	0.118	0.120	0.119	0.104	**0.108**
RSC 6.5	0.083	0.080	0.094	0.092	0.104	0.095	**0.091**
RSC 10	0.070	0.065	0.072	0.073	0.083	0.082	**0.074**
Mean	**0.087**	**0.089**	**0.102**	**0.103**	**0.108**	**0.101**	
LSD (5%)	**RSC = 0.011 Cultivar = 0.007 Interaction = NS**						

Among different wheat cultivars, maximum plant K was accumulated by PBW658 (0.113% and 0.108%), whereas minimum was retained in KRL210 (0.092% and 0.087%) in 2013-14 as well as 2014-15 . It is evident from data that plant K content of different wheat cultivars ranged from 0.062 to 0.139 % in 2013-14 and varied from 0.065 to 0.135% in 2014-15 at different levels of sodicity. Furthermore, non-significant interaction results were observed for plant K between RSC levels and wheat cultivars at tillering stage during first and second year of experimental study.

4.2.4.4.3 Plant Na/ K ratio as affected by sodicity of irrigation water

Plant Na/K ratio of different wheat cultivars as affected by different RSC levels in 2013-14 and 2014-15 is presented in Table 4.62. It is evident from data that plant Na/K ratio significantly increased with increasing levels of sodic irrigation water. The average plant Na/K ratio increased from 0.63 in RSC 0 to 0.96, 1.52 and 2.28 at RSC 3, 6.5 and 10 me/L levels of sodicity in 2013-14. Corresponding increase in 2014-15 was from 0.60 (RSC 0) to

0.96, 1.55 and 2.27 at respective RSC levels. Out of six wheat cultivars, the maximum and minimum plant Na/K ratio was observed in cultivar PBW 590 and KRL 210 for both years. Interaction effects for plant Na/K ratio were significant in 2013-14 and 2014-15.

Table 4.62 Sodic irrigation water effects on plant Na/K ratio of wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.41	0.71	0.71	0.62	0.61	0.68	**0.63**
RSC 3	0.68	0.91	0.90	1.06	1.19	1.01	**0.96**
RSC 6.5	0.95	1.78	1.33	1.93	1.52	1.63	**1.52**
RSC 10	1.97	2.21	2.27	2.56	2.22	2.44	**2.28**
Mean	**1.00**	**1.40**	**1.30**	**1.54**	**1.39**	**1.44**	
LSD (5%)	**RSC = 0.004 Cultivar = 0.003 Interaction = 0.007**						
2014-15							
RSC 0	0.50	0.56	0.62	0.70	0.63	0.59	**0.60**
RSC 3	0.74	0.73	0.83	1.21	1.29	0.97	**0.96**
RSC 6.5	1.04	1.43	1.54	2.02	1.80	1.51	**1.55**
RSC 10	1.77	1.98	2.54	2.66	2.37	2.28	**2.27**
Mean	**1.01**	**1.17**	**1.38**	**1.65**	**1.52**	**1.34**	
LSD (5%)	**RSC = 0.007 Cultivar = 0.007 Interaction = 0.014**						

4.2.4.4.4 Effect of sodic irrigation water on plant phosphorous content of wheat cultivars at tillering stage

The influence of increasing RSC levels of irrigation water on plantphosphorous (P) content of different wheat cultivar was measured at tillering stage in 2013-14 and 2014-15 and discussed in Table 4.63. It was clear from data that plant P content of wheat cultivars decreased significantly with increasing levels of RSC in irrigation water.In 2013-14, mean plant P content was 0.26% in control, while it was 0.20, 0.16 and 0.12% at RSC 3, 6.5 and 10me/L levels of sodicity. The corresponding values in 2014-15 were 0.25, 0.21, 0.18 and 0.13% at respective RSC levels. As phosphorus fixation is problem in sodic soils (NaOH-P), therefore uptake of phosphorus by plants also decrease.

Table 4.63 Effect of sodic irrigation water on plant phosphorous content (%) of wheat cultivars at tillering stage

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.30	0.23	0.22	0.34	0.22	0.20	**0.26**
RSC 3	0.26	0.20	0.17	0.26	0.19	0.16	**0.20**
RSC 6.5	0.21	0.15	0.13	0.18	0.17	0.13	**0.16**
RSC 10	0.15	0.11	0.10	0.14	0.13	0.11	**0.12**
Mean	**0.23**	**0.18**	**0.16**	**0.23**	**0.18**	**0.15**	
LSD (5%)	**RSC = 0.01 Cultivar = 0.02 Interaction = NS**						
2014-15							
RSC 0	0.29	0.19	0.26	0.29	0.25	0.22	**0.25**
RSC 3	0.23	0.17	0.23	0.26	0.22	0.17	**0.21**
RSC 6.5	0.21	0.13	0.19	0.20	0.19	0.13	**0.18**
RSC 10	0.17	0.11	0.14	0.13	0.15	0.11	**0.13**
Mean	**0.23**	**0.15**	**0.21**	**0.22**	**0.20**	**0.16**	
LSD (5%)	**RSC = 0.01 Cultivar = 0.02 Interaction = NS**						

Further exploration of data depicts that average plant P content was statstically at par for different wheat cultivars in 2013-14 and 2014-15 with maximum plant P content was recorded in cultivar KRL210 followed by PBW590 for two years of research study and minimum in cultivars Barbet and PBW621 in 2013-14 and 2014-15. It was observed that interaction between different wheat cultivars and sodicity levels was reported to be non-significant for plant P at tillering stage during first as well as second year of experimental study.

4.2.4.4.5 Plant calcium content of different wheat cultivars as affected by sodic irrigation water at tillering stage

The data pertaining to plant calcium (Ca) content of different wheat cultivars as affected by increasing RSC levels of irrigation water at tillering stage was presented inTable 4.64. It was observed that plant Ca content of different wheat cultivars follows similar trend as that of plant P content i.e. decreasing with increasing sodicity of irrigation water during first as well as second year of research study. The data revealed that plant Ca content was 0.024% in control which decreased to 0.020, 0.018 and 0.010% at RSC 3, 6.5 and 10me/L levels of sodicity in 2013-14. Likewise in 2014-15, corresponding values were 0.023, 0.020, 0.016 and 0.012% at respective RSC levels. Plant Ca uptake decrease in sodic soils due to high Na^+ concentration in soil solution.

Table 4.64 Plant calcium content (%) of different wheat cultivars at tillering stage

Treatment	KRL210	PBW621	HD2967	PBW590	PBW658	Berbet	Mean
2013-14							
RSC 0	0.018	0.026	0.032	0.023	0.027	0.022	**0.024**
RSC 3	0.014	0.018	0.022	0.021	0.024	0.020	**0.020**
RSC 6.5	0.012	0.016	0.020	0.017	0.023	0.020	**0.018**
RSC 10	0.010	0.012	0.011	0.008	0.012	0.010	**0.010**
Mean	**0.013**	**0.018**	**0.021**	**0.017**	**0.021**	**0.018**	
LSD (5%)	**RSC = 0.003 Cultivar = 0.003 Interaction = NS**						
2014-15							
RSC 0	0.019	0.024	0.030	0.022	0.026	0.021	**0.023**
RSC 3	0.017	0.020	0.024	0.017	0.024	0.018	**0.020**
RSC 6.5	0.013	0.017	0.019	0.014	0.020	0.013	**0.016**
RSC 10	0.011	0.014	0.013	0.009	0.017	0.011	**0.012**
Mean	**0.015**	**0.019**	**0.021**	**0.015**	**0.022**	**0.016**	
LSD (5%)	**RSC = 0.001 Cultivar = 0.002 Interaction = NS**						

When results pertaining to six wheat cultivars were considered, it was observed that maximum plant Ca content was obtained by cultivars HD2967 and PBW658 and minimum was retained by KRL210 and PBW590 in 2013-14 and 2014-15. For different wheat cultivars, plant Ca content was statistically at par during first as well as second year of experimental study. The interaction between sodicity levels and wheat cultivars for plant Ca was found to be non-significant in 2013-14 and 2014-15.

4.2.4.5 Yield and yield attributes, mineral composition and quality parameters of wheat cultivars as affected by sodic irrigation water at maturity

4.2.4.5.1 Plant height of different wheat cultivars as affected by sodic irrigation water at maturity

Effects of different levels of sodic water irrigation on plant height of six wheat cultivars along with statistically analysis in 2013-14 as well 2014-15 were presented in Table 4.65. It has been observed that plant height of different wheat cultivars was significantly decreased with increased sodicity levels expect at RSC 3me/L in 2013-14. The mean plant height tends to remain constant over time with an average of 85.0 cm as there are no effects of sodic water irrigation. It is evident from data that maximum reduction in average plant height occurs at sodicity level of 10 me/L in 2013-14 and 2014-15, which decreased by 15.2 % and 13.9 % over control. The mean plant height of different wheat cultivars decreased from 85.4 cm in control to 83.7, 81.5 and 72.4cm in 2013-14 and from 84.6 cm to 81.8, 80.1 and 72.8 cm in 2014-15 at RSC 3, 6.5 and 10 me/L levels of sodic irrigation water.

Table 4.65 Plant height (cm) of different wheat cultivars as affected by sodic irrigation water at maturity

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	83.6	87.4	87.0	77.7	87.2	89.4	**85.4**
RSC 3	81.8	86.8	86.5	76.0	85.1	85.9	**83.7**
RSC 6.5	81.4	85.5	81.6	74.7	80.6	85.5	**81.5**
RSC 10	70.3	73.5	78.6	66.1	73.1	73.0	**72.4**
Mean	**79.3**	**83.3**	**83.5**	**73.7**	**81.5**	**83.5**	
LSD (5%)	**RSC= 4.5**	**Cultivar = 3.8**		**Interaction = NS**			
2014-15							
RSC 0	82.6	86.6	86.0	75.7	88.3	88.1	**84.6**
RSC 3	81.1	84.2	85.6	73.0	83.4	83.9	**81.8**
RSC 6.5	79.2	83.5	84.2	72.3	78.6	82.2	**80.1**
RSC 10	72.3	71.5	78.8	68.1	74.6	72.2	**72.8**
Mean	**78.8**	**81.5**	**83.6**	**72.3**	**81.2**	**81.6**	
LSD (5%)	**RSC= 1.4**	**Cultivar = 1.4**		**Interaction =2.9**			

When results pertaining to six wheat cultivars were considered, it was observed that plant height was statistically at par for all cultivars in 2013-14 as well as 2014-15. The average plant height of six wheat cultivars ranged from 73.7 cm to 83.5 cm in 2013-14 and varied from 72.3 to 83.6 cm in 2014-15. It is evident from data that non-significant interaction between sodicity levels and wheat cultivars were observed for plant height in 2013-14, however in next year of research study , this interaction was reported to be significant , where plant height was statistically at par at RSC 3 and 6.5 me/L levels of sodic irrigation water for cultivars PBW621 and HD2967, respectively.

4.2.4.5.2 Effect of sodic irrigation water on number of spikes/m^2 of different wheat cultivars

The data pertaining to number of spikes/m^{2}of different wheat cultivars was recorded in 2013-14 as well as 2014-15 and presented in Table 4.66. The data revealed that increasing sodicity of irrigation water significantly decreased number of spikes/m^{2}of wheat cultivars during first and second year of research study. The mean number of spikes/m^{2}of wheat cultivars decreased by 5.0, 13.1 and 23.3 % in 2013-14 and 4.8, 13.4 and 22.1 % in 2014-15 at RSC 3, 6.5 and 10 me/L levels of sodic irrigation water as compared to control. These results are in accordance with Choudhary *et al* (2007), they reported that number of spikes /m^2 of wheat cultivars (PBW 343) decreased by 9.4, 17.9 and 45.3 % under RSC 3, 6.5 and 10me/L levels as compared to canal water. It was observed that number of spikes/m^{2}of different wheat cultivars ranged from 268 to 373 in 2013-14 and from 270 to 366 cm in 2014-15 at different levels of sodic water irrigation.

Table 4.66 Effect of sodic irrigation water on number of spikes/ m^{2}of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	357	373	368	341	362	359	**360**
RSC 3	336	355	351	328	348	334	**342**
RSC 6.5	293	328	322	307	320	310	**313**
RSC 10	268	284	272	270	288	273	**276**
Mean	**314**	**335**	**328**	**312**	**330**	**319**	
LSD (5%)	**RSC = 3.2**	**Cultivar = 3.6**		**Interaction = 7.3**			
2014-15							
RSC 0	350	366	359	348	357	358	**356**
RSC 3	332	350	348	335	341	328	**339**
RSC 6.5	298	317	319	306	312	298	**308**
RSC 10	270	281	280	272	285	271	**277**
Mean	**312**	**329**	**327**	**315**	**324**	**314**	
LSD (5%)	**RSC = 6.9**	**Cultivar = 4.1**		**Interaction = NS**			

Out of different wheat cultivars maximum average number of spikes/m^{2}was observed in PBW621 during first and second year of research study, whereas minimum was reported in PBW590 in 2013-14 and KRL210 in 2014-15, respectively. The interaction effects between RSC levels and wheat cultivars for number of spikes/m^{2}were reported to be non-significant in 2014-15 , however this interaction was found to be significant in 2013-14, where number of spikes/m^2 were statistically at par at RSC 3 and 6.5 me/L levels of sodic irrigation water for cultivars HD2967 and PBW 590 , respectively.

4.2.4.5.3 Spike length of different wheat cultivars as affected by sodic water irrigation

It is evident from data that spike lengthof different wheat cultivars were significantly decreased with increasing sodicity of irrigation water (Table 4.67). The average spike lengthof wheat cultivars decreased from 9.6 cm in control to 9.3, 8.8 and 8.1 at RSC 3, 6.5 and 10 me/L levels of sodicity in 2013-14. Conversely, in 2014-15 corresponding values decreased from 9.6 cm (control) to 9.3, 8.7 and 8.1 cm at respective levels of sodic water irrigation. Almost similar results were reported by Saqib *et al* (2006). They reported that average spike length of three wheat cultivars deceased from 11.2 cm to 7.5 cm in saline soil compared to normal soil (EC=15dS/m and SAR 30). Furthermore, the data revealed that maximum reduction in average spike lengthoccurs at highest level of sodicity (RSC = 10 me/L) which decreased by 15.6% over control in 2013-14 as well as 2014-15. The average spike lengthamong wheat cultivars ranged from 7.3 to 11.1 cm in 2013-14 and varied from 7.6 to 11.1 cm in 2014-15 at different levels of sodic water irrigation.

Table 4.67 Spike length (cm) of different wheat cultivars as affected by sodic water irrigation

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	8.8	9.3	10.0	9.6	8.6	11.1	**9.6**
RSC 3	8.6	9.2	9.6	9.0	8.4	10.6	**9.3**
RSC 6.5	7.6	9.0	9.5	8.8	8.2	9.9	**8.8**
RSC 10	7.3	8.3	8.4	8.3	7.5	8.9	**8.1**
Mean	**8.1**	**8.9**	**9.4**	**8.9**	**8.2**	**10.2**	
LSD (5%)	**RSC= 0.3**		**Cultivar = 0.2**		**Interaction = NS**		
2014-15							
RSC 0	9.1	9.6	10.2	9.1	8.5	11.1	**9.6**
RSC 3	8.9	9.4	9.4	9.2	8.3	10.8	**9.3**
RSC 6.5	8.1	9.1	9.2	8.4	8.0	9.5	**8.7**
RSC 10	7.7	8.6	8.3	8.1	7.6	8.5	**8.1**
Mean	**8.4**	**9.2**	**9.3**	**8.7**	**8.1**	**9.9**	
LSD (5%)	**RSC= 0.3**		**Cultivar = 0.3**		**Interaction = 0.6**		

It is evident from data that maximum average spike length was observed in cultivar Berbet during first as well as second year of research study, whereas minimum was reported in cultivars KRL210 in 2013-14 and PBW658 in 2014-15, respectively. The perusal of data shows that non-significant interaction was observed for spike lengthbetween sodicity levels and wheat cultivars in 2013-14, however it was reported to be significant in 2014-15, where spike length was statistically at par at RSC 3 and 6.5 me/L levels of irrigation water sodicity for cultivars HD2967 and PBW590.

4.2.4.5.4 Effect of sodic water irrigation water on grain weight/spike of wheat cultivars

The results pertaining to grain weight/spike of wheat cultivars at different levels of sodicity along with statistical analysis during first and second year of research study were displayed in Table 4.68. It is evident from data that grain weight/spike significantly decreased as sodicity of irrigation water increases in 2013-14 and 2014-15. The mean grain weight/

spike decreased by 10.0, 25.0% and 40.0 % and 14.3, 23.8 and 38.1 % at RSC 3, 6.5 and 10 me/L levels of sodicity as compared to control with maximum reduction occurs at highest level of sodicity in 2013-14 as well 2014-15.

Table 4.68 Effect of sodic irrigation water on grain weight per spike (g) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	1.8	2.3	2.1	1.7	2.3	1.9	**2.0**
RSC 3	1.7	2.2	2.0	1.5	1.7	1.8	**1.8**
RSC 6.5	1.6	1.8	1.9	1.2	1.4	1.2	**1.5**
RSC 10	1.3	1.5	1.4	1.1	1.1	1.0	**1.2**
Mean	**1.6**	**2.0**	**1.9**	**1.4**	**1.6**	**1.5**	
LSD (5%)	**RSC = 0.2 Cultivar = 0.2 Interaction = NS**						
2014-15							
RSC 0	1.7	2.6	2.2	2.0	2.1	1.8	**2.1**
RSC 3	1.5	2.4	2.0	1.7	1.9	1.5	**1.8**
RSC 6.5	1.4	2.1	1.8	1.5	1.6	1.3	**1.6**
RSC 10	1.2	1.9	1.3	1.2	1.1	1.1	**1.3**
Mean	**1.5**	**2.2**	**1.8**	**1.6**	**1.7**	**1.4**	
LSD (5%)	**RSC = 0.1 Cultivar = 0.2 Interaction = NS**						

The data revealed that for different wheat cultivars mean grain weight/ spike varied from 1.4 to 2.0 g and ranged from 1.4 to 2.2 g for first and second year of experimental study at different levels of sodic water irrigation. The mean grain weight/spike among different wheat cultivar was statistically at par in 2013-14 as well as 2014-15.When results related to interaction were considered, it was found that non-significant interaction was observed for grain weight/spike between sodic water irrigation levels and six wheat cultivars during first as well as second year of research study.

4.2.4.5.5 Thousand grain weight of wheat cultivars as influenced by sodic water irrigation

Sodic water irrigation effects on thousand grain weight (TGW) of six wheat cultivars were observed in 2013-14 and 2014-15 as presented in Table 4.69.The data shows that TGW decreased significantly at all levels of sodicity during first as well as second year of research study. It has been observed that TGW decreased from 43.2g in control to 41.4, 39.9 and 38.0 g and from 44.1 g (control) to 41.5, 39.3 and 37.2g in 2013-14 and 2014-15 at RSC 3, 6.5 and 10me/L levels of sodicity, respectively. These results were found to be in line with Murtaza *et al* (2009). The reported that average TGW of six wheat cultivars decrease significantly from 28.2g to 15.5 g as EC/SAR ratio increased.(from 0.9:1.5 to 12:48).

Table 4.69 Thousand grain weight (g) of wheat cultivars as influenced by sodicity of irrigation water

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	40.2	46.3	45.6	40.0	46.2	41.0	**43.2**
RSC 3	40.0	43.9	43.3	38.2	42.8	40.3	**41.4**
RSC 6.5	39.7	41.7	42.5	37.9	39.1	38.9	**39.9**
RSC 10	38.9	39.0	39.1	36.0	38.3	37.1	**38.0**
Mean	**39.7**	**42.7**	**42.6**	**38.0**	**41.6**	**39.3**	
LSD (5%)	**RSC = 1.6**		**Cultivar = 2.4**		**Interaction = NS**		
2014-15							
RSC 0	41.8	45.2	45.0	42.7	47.2	42.8	**44.1**
RSC 3	39.4	41.0	43.6	40.6	43.7	40.7	**41.5**
RSC 6.5	38.5	38.8	41.4	38.4	40.3	38.1	**39.3**
RSC 10	37.9	37.0	38.3	36.4	37.3	36.1	**37.2**
Mean	**39.4**	**40.5**	**42.1**	**39.5**	**42.1**	**39.4**	
LSD (5%)	**RSC = 1.7**		**Cultivar = 1.8**		**Interaction = NS**		

The TGW among different wheat cultivars ranged from 36.0 to 46.3 g in 2013-14 and varied from 36.1 to 47.2 g in 2014-15 at different levels of sodicity. It is evident from data that maximum TGW was observed in cultivar PBW621 in 2013-14 and cultivars HD2967 and PBW658 in 2014-15. Conversely, minimum TGW was observed for cultivar PBW 590 in 2013-14 and for KRL210 and Berbet in 2014-15. The perusal of data shows that non-significant interaction was observed for TGW between RSC levels and wheat cultivars in 2013-14 as well as 2014-15.

4.2.4.5.6 Effects of sodic water irrigation on biomass of wheat cultivars

Irrigation with different levels of sodic water resulted in significant decrease in biomass of wheat cultivars in 2013-14 and 2014-15 as presented in Table 4.70. It was observed that with increase in sodicity from RSC 0 to 3, 6.5 and 10me/L levels , mean biomass decreased from 13.09 to 12.57,11.66 and 10.65 t/ha in 2013-14 and from 13.15 t/ha to 12.66,11.77 and 10.61 t/ha in 2014-15. The parentage relative decrease in biomass of wheat cultivars at increasing levels of sodicity was observed to be 96.2, 89.3 and 81.7 % in first year and 96.2, 89.3 and 80.3 % in second year of experimental study as compared to control.

Table 4.70 Effect of sodic irrigation water on biomass (t/ha) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	13.03	14.23	13.70	10.80	14.03	12.80	**13.09**
RSC 3	12.86	14.06	13.13	10.16	12.80	12.40	**12.57**
RSC 6.5	12.26	13.13	12.56	9.13	11.73	11.13	**11.66**
RSC 10	10.90	12.26	11.70	8.83	10.56	9.56	**10.65**
Mean	**12.29**	**13.42**	**12.76**	**9.73**	**12.28**	**11.47**	
LSD (5%)	**RSC = 0.10**		**Cultivar = 0.11**		**Interaction = 0.23**		
2014-15							
RSC 0	13.46	14.00	13.90	10.56	14.73	12.26	**13.15**
RSC 3	12.46	14.50	13.40	10.50	12.70	12.40	**12.66**
RSC 6.5	12.50	13.20	12.40	9.50	11.33	11.70	**11.77**
RSC 10	10.56	12.00	11.70	9.06	10.90	9.36	**10.61**
Mean	**12.25**	**13.42**	**12.85**	**9.90**	**12.44**	**11.43**	
LSD (5%)	**RSC = 0.07**		**Cultivar = 0.18**		**Interaction = 0.36**		

When results pertaining to biomass among wheat cultivars were considered, it was observed that maximum average biomass was recorded for cultivar PBW 621 and minimum in cultivar PBW590 in 2013-14 as well as 2014-15. Significant interaction effects were found between sodicity levels and wheat cultivars for biomass in 2013-14 and 2014-15. It was observed that biomass was statistically at par RSC 3 and 6.5 me/L levels of sodicity for cultivars PBW621 and HD 2967 in 2013-14 as well as 2014-15, respectively.

4.2.4.5.7 Effect of sodic irrigation water on grain yield of wheat cultivars

The data pertaining to effect of sodic water irrigation on grain yield of different wheat cultivars in 2013-14 as well as 2014-15 was presented in Table 4.71. It was evident from data that grain yield of wheat cultivars significantly decreased at all levels of sodicity for first year as well as second year of research study. Decline in crop yield as a result of sodic water could be ascribed to deteriorating effect of high pH on other soil properties (Choudhary *et al* 2004), permeability properties and aeration problem due to higher ESP levels (Josan *et al* 1998) and Ca-deficient in soil solution (Minhas and Gupta 1992) due to high RSC of irrigation water. It was observed that grain yield of wheat cultivars decreased from 5.53 t/ha in control to 5.30,4.90 and 4.41 t/ha at RSC 3, 6.5 and 10me/L levels of sodicity in 2013-14, whereas it decreased from 5.43 t/ha (control) to 5.21,4.84 and 4.40 t/ha in 2014-15 at respective levels of sodic water irrigation. The maximum reduction in grain yield occurs at highest level of sodicity, which decreased by 20.2 and 18.9% as compared to control in 2013-14 and 2014-15. The data shows that percentage relative decrease in grain yield at increasing levels of sodicity was 96.4, 89.1and 80.0 % in 2013-14 and 95.9, 89.1 and 81.0% in 2014-15 over control.

Among different wheat cultivars maximum grain yield was recorded in cultivars PBW621 (5.62 and 5.55 t/ha) followed by HD2967 (5.46 and 5.38t/ha) in 2013-14 and 2014-15. Contrary to this, minimum grain yield was observed for cultivar PBW590 (4.28 and 4.15t/ha) during first as well as second year of research study. The perusal of data shows that grain yield of different wheat cultivars ranged from 3.77 to 6.0 t/ha in 2013-14 and varied from 3.74 to 5.87 t/ha in 2014-15 at different levels of sodic irrigation water. Choudharay *et al* (2012) also reported similar results in three year duration study at RSC 0, 3, 6.5 and 10me/L levels of sodic irrigation water. They compared performance of three whet cultivars namely PBW 343, PBW 502 and PBW 550. Out of these three cultivars maximum average grain yield was reported by PBW 343 (4.86t/ha) followed by PBW 502 (4.74t/ha) and PBW 550 (4.01t/ha) at these RSC levels. They further concluded that cultivars PBW 343 should be preferred over remaining two to obtain acceptable yield levels without any loss in grain quality in sols irrigation with water containing RSC > 5me/L). Similarly in present research study cultivars PBW 621 should be preferred over all five wheat cultivars to grow under high RSC irrigation water. The interaction effect of sodicity levels and wheat cultivars were found to be non-significant in 2014-15, whereas in 2013-14, it was reported to be significant.

Table 4.71 Effect of sodic irrigation water on grain yield (t/ha) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	5.26	6.00	5.82	4.84	5.93	5.37	**5.53**
RSC 3	5.20	5.90	5.63	4.48	5.34	5.27	**5.30**
RSC 6.5	5.13	5.40	5.56	3.94	4.85	4.49	**4.90**
RSC 10	4.53	5.20	4.90	3.83	4.23	3.77	**4.41**
Mean	**5.03**	**5.62**	**5.46**	**4.28**	**5.09**	**4.72**	
LSD (5%)	**RSC = 0.15 Cultivar = 0.14 Interaction = 0.27**						
2014-15							
RSC 0	5.33	5.87	5.79	4.76	5.72	5.22	**5.45**
RSC 3	5.24	5.81	5.65	4.24	5.11	5.12	**5.21**
RSC 6.5	5.15	5.33	5.37	3.87	4.94	4.37	**4.84**
RSC 10	4.63	5.18	4.73	3.74	4.34	3.81	**4.40**
Mean	**5.09**	**5.55**	**5.38**	**4.15**	**5.03**	**4.63**	
LSD (5%)	**RSC = 0.22 Cultivar = 0.26 Interaction = NS**						
Pooled data							
RSC 0	5.30	5.94	5.81	4.80	5.83	5.30	**5.49**
RSC 3	5.22	5.86	5.64	4.36	5.23	5.20	**5.26**
RSC 6.5	5.14	5.37	5.47	3.91	4.90	4.43	**4.87**
RSC 10	4.58	5.19	4.82	3.79	4.29	3.79	**4.41**
Mean	**5.06**	**5.59**	**5.43**	**4.21**	**5.06**	**4.68**	
LSD (5%)	**RSC = 0.13 , Cultivar = 0.14 , Interaction = 0.28,**						

4.2.4.5.8 Influence of sodic water irrigation on straw yield of wheat cultivars

Effects of different levels of sodic water irrigation on straw yield of wheat cultivars were recorded in 2013-14 and 2014-15 and were discussed in Table 4.72. It was observed that average straw yield in control was 7.56 t/ha while it was 7.25, 6.75 and 6.23 t/ha at RSC levels of 3, 6.5 and 10me/L of sodicity in 2013-14 and corresponding values in 2014-15 were 7.72,7.45,6.92 and 6.21 t/ha at respective levels of sodic water irrigation. The percentage relative decrease in straw yield with increasing RSC levels was 94.7, 89.5 and 82.9 % and 97.4, 89.6 and 80.5 % over control during first and second year of experimental study.

Among different wheat cultivars maximum average straw yield was retained by cultivar PBW621 followed by HD2967 in 2013-14 and 2014-15, whereas minimum was observed in cultivar PBW 590 in respective years. It is evident from data that interaction between two factors (RSC levels and wheat cultivars) was significant for first and second year of research study. The perusal of data shows that straw yield was statistically at par at RSC 6.5 and 10 me/L levels of sodicity for cultivars PBW621 and HD 2967 in 2013-14 and at RSC 3 and 6.5me/L levels for same cultivars in 2014-15.

Table 4.72Influence of sodic irrigation water on straw yield (t/ha) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	7.77	8.23	7.84	5.94	8.09	7.43	**7.56**
RSC 3	7.66	8.16	7.50	5.70	7.43	7.13	**7.25**
RSC 6.5	7.07	7.73	7.03	5.17	6.87	6.63	**6.75**
RSC 10	6.46	7.03	6.80	5.01	6.37	5.80	**6.23**
Mean	**7.24**	**7.79**	**7.30**	**5.45**	**7.19**	**6.75**	
LSD (5%)	**RSC = 0.15 Cultivar = 0.16 Interaction = 0.33**						
2014-15							
RSC 0	8.12	8.14	8.07	5.83	9.03	7.11	**7.72**
RSC 3	7.22	8.66	7.76	6.28	7.58	7.19	**7.45**
RSC 6.5	7.31	7.89	7.04	5.65	6.37	7.31	**6.92**
RSC 10	5.92	6.82	7.00	5.32	6.63	5.55	**6.21**
Mean	**7.14**	**7.88**	**7.47**	**5.77**	**7.41**	**6.79**	
LSD (5%)	**RSC = 0.19 Cultivar = 0.32 Interaction = 0.65**						

4.2.4.5.9 Sodic irrigation water influence on harvest index of wheat cultivars

The data related to harvest index as influenced by the different levels of sodicity in 2013-14 and 2014-15 was presented in Table 4.73.The non- significant relationship of harvest index with sodicity levels and different wheat cultivars was observed for first and second year of experimental study. The average harvest index ranged from 0.41 to 0.42 at different sodicity levels in 2013-14 and 2014-15. It was observed that interaction effects of RSC levels and wheat cultivars for harvest index were also found to be non- significant in 2013-14 as well 2014-15.

Table 4.73 Sodic irrigation water influence on harvest indexof wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.40	0.42	0.42	0.44	0.42	0.41	**0.42**
RSC 3	0.40	0.41	0.42	0.44	0.41	0.42	**0.42**
RSC 6.5	0.42	0.41	0.44	0.43	0.41	0.40	**0.42**
RSC 10	0.41	0.42	0.41	0.43	0.40	0.39	**0.41**
Mean	**0.41**	**0.41**	**0.42**	**0.43**	**0.41**	**0.41**	
LSD (5%)	**RSC = NS Cultivar = 0.01 Interaction = NS**						
2014-15							
RSC 0	0.39	0.41	0.41	0.45	0.39	0.42	**0.41**
RSC 3	0.42	0.40	0.42	0.40	0.40	0.42	**0.41**
RSC 6.5	0.41	0.40	0.43	0.41	0.43	0.37	**0.41**
RSC 10	0.44	0.43	0.40	0.41	0.39	0.40	**0.41**
Mean	**0.41**	**0.41**	**0.41**	**0.41**	**0.40**	**0.40**	
LSD (5%)	**RSC = NS Cultivar = NS Interaction = NS**						

4.2.4.6 Mineral composition of wheat cultivars at maturity

Grain and straw sample of different wheat cultivars were analyzed for sodium (Na), potassium (K) , phosphorous (P) and calcium (Ca) as affected by different levels of salinity using wet digestion method in 2013-14 and 2014-15 and were discussed under following headings.

4.2.4.6.1 Effect of sodic water irrigation on grain sodium content of wheat cultivars

Irrigation with different levels of sodic water significantly increases grain sodium (Na) content in six wheat cultivars over two years(Table 4.74). It is evident that average grain Na content increased from 0.037% in control (RSC 0) to 0.052, 0.072, and 0.090 % at RSC 3, 6.5 and 10 me/L levels of sodic irrigation water.The grain Na content among wheat cultivars ranged from 0.025 to 0.095 % in at different levels of sodicity. The maximum and minimum average grain Na content was reported in cultivar PBW 590 (0.073%) and KRL 210 (0.053%) acroos two years. Non-significant interaction between sodicity levels and wheat cultivars was observed for grain Na content.

4.2.4.6.2 Grain potassium content of different wheat cultivars as affected by sodic irrigation water

The data pertaining to effect of sodic water irrigation on grain potassium (K) content was presented in Table 4.74. The data revealed that grain K content significantly decreased with increasing levels of sodic water irrigation across two years. The mean grain K content decreased by 14.6, 28.0 and 44.0 % atRSC 3, 6.5 and 10me/L levels as compared to control**.**

When results pertaining to grain K content among different wheat cultivars were considered, it was found that maximum accumulation of average K was observed in grains of cultivars Berbet and KRL210 (0.064%)and minimum in grains of cultivar HD2967 (0.049%)over two years. The interaction effects for grain K content were non-significant.

4.2.4.6.3 Na/K ratio in grains of different wheat cultivars under sodic water irrigation

The data regarding to grain Na/K ratio as affected by different levels of sodic water irrigation was presented in Table 4.74**.**The grain Na/K ratio significantly increased from 0.50 in RSC 0 (control) to 0.82, 1.37, and 2.43 at RSC 3, 6.5 and 10me/L levels of sodicity across two years. Out of six wheat cultivars maximum grain Na/K ratio was observed in cultivar PBW621 (1.42) while minimum in KRL 210 (0.97). Interaction effects for grain Na/K ratio were non-significant over two years.

Table 4.74 Effect of sodic irrigation water on grain sodium and potassium content (%) and Na/K ratio of wheat cultivars across two years

Grain Na (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.031	0.032	0.025	0.047	0.044	0.045	**0.037**
RSC 3	0.038	0.048	0.037	0.065	0.062	0.059	**0.052**
RSC 6.5	0.055	0.060	0.073	0.085	0.076	0.083	**0.072**
RSC 10	0.090	0.088	0.082	0.098	0.088	0.095	**0.090**
Mean	**0.053**	**0.057**	**0.054**	**0.073**	**0.067**	**0.070**	
LSD (5%)	**RSC = 0.006 ,Cultivar = 0.005 , Interaction = 0.010**						
Grain K (%)							
RSC 0	0.078	0.075	0.065	0.074	0.080	0.080	**0.075**
RSC 3	0.069	0.059	0.057	0.066	0.064	0.069	**0.064**
RSC 6.5	0.060	0.049	0.045	0.054	0.055	0.060	**0.054**
RSC 10	0.048	0.036	0.032	0.045	0.045	0.044	**0.042**
Mean	**0.064**	**0.055**	**0.049**	**0.060**	**0.061**	**0.064**	
LSD (5%)	**RSC = 0.006 ,Cultivar = 0.005 , Interaction = NS**						
Grain Na/K ratio							
RSC 0	0.42	0.41	0.37	0.67	0.55	0.56	**0.50**
RSC 3	0.55	0.90	0.70	0.98	0.95	0.83	**0.82**
RSC 6.5	0.94	1.30	1.65	1.57	1.38	1.38	**1.37**
RSC 10	1.99	3.06	2.91	2.33	2.07	2.22	**2.43**
Mean	**0.97**	**1.42**	**1.41**	**1.39**	**1.23**	**1.24**	
LSD (5%)	**RSC = 0.28 ,Cultivar = 0.14 , Interaction = 0.28**						

4.2.4.6.4 Influence of sodic irrigation water on grain phosphorous content of different wheat cultivars

The data presented in Table 4.75 revealed that grain phosphorous (P) content significantly decreased with increasing sodicity of irrigation water from 0.22 % in control to 0.18, 0.15 and 0.11 % at RSC 3, 6.5 and 10me/L levels of sodic irrigation water.

The average grain P content of different wheat cultivars varied from 0.13 to 0.20 % across two years. Non-significant interaction between RSC levels and wheat cultivars was observed for grain P content.

4.2.4.6.5 Sodic irrigation water effects on grain calcium content of wheat cultivars

It was observed that the graincalcium (Ca) content follows the same trend as that of grain P at different levels of sodicity i.e. decreasing with increasing sodicity of irrigation water (Table 4.75).The mean grain Ca content,decreased by 22.2 and 44.4 at RSC 6.5 and 10me/L overcontrol.

It was observed that grain Ca content among different wheat cultivars was on paracroos two years. It was observed that interaction effects for grain Ca were non-significant.

Table 4.75 Influence of sodic irrigation water on grain phosphorous and calcium content (%) of different wheat cultivars over two years

Grain P (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.24	0.24	0.20	0.26	0.18	0.18	**0.22**
RSC 3	0.22	0.21	0.17	0.22	0.16	0.15	**0.18**
RSC 6.5	0.17	0.17	0.14	0.18	0.12	0.12	**0.15**
RSC 10	0.13	0.14	0.09	0.14	0.09	0.09	**0.11**
Mean	**0.19**	**0.19**	**0.15**	**0.20**	**0.13**	**0.13**	
LSD (5%)	**RSC = 0.01 ,Cultivar = 0.02 , Interaction = NS**						
Grain Ca (%)							
RSC 0	0.010	0.009	0.011	0.010	0.009	0.011	**0.009**
RSC 3	0.009	0.008	0.009	0.008	0.008	0.010	**0.009**
RSC 6.5	0.008	0.007	0.007	0.007	0.006	0.009	**0.007**
RSC 10	0.006	0.005	0.006	0.005	0.004	0.006	**0.005**
Mean	**0.009**	**0.007**	**0.008**	**0.007**	**0.007**	**0.009**	
LSD (5%)	**RSC = 0.0004 ,Cultivar = 0.0006 , Interaction = NS**						

4.2.4.6.6 Effect of sodic irrigation water on straw sodium content wheat cultivars

The data presented in Table 4.76 revealed thatincreasing RSC levels of irrigation water significantly increased straw Na content expect at RSC 3me/L of irrigation water across two years. The average straw Na content increased from 0.060 in control to 0.077, 0.102 and 0.135 % at RSC 3, 6.5 and 10me/L levels of irrigation water in 2013-14 and from 0.058 to 0.078, 0.105 and 0.132 % at respective RSC levels in 2014-15. Among different wheat cultivars average straw Na content ranged from 0.071 to 0.109 % in two years. The interaction between two factors (RSC levels and wheat cultivars) for straw Na content was significant.

Table 4.76 Effect of sodic irrigation water on straw sodium and potassium content (%) and Na/K ratio of wheat cultivars over two years

Straw Na (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.034	0.044	0.057	0.087	0.076	0.062	**0.060**
RSC 3	0.057	0.064	0.070	0.100	0.095	0.081	**0.077**
RSC 6.5	0.074	0.095	0.087	0.114	0.115	0.128	**0.102**
RSC 10	0.119	0.116	0.141	0.132	0.146	0.154	**0.135**
Mean	**0.071**	**0.080**	**0.088**	**0.109**	**0.108**	**0.106**	
LSD (5%)	**RSC = 0.011 ,Cultivar = 0.006 , Interaction = 0.013**						
Straw K (%)							
RSC 0	0.100	0.104	0.104	0.097	0.112	0.115	**0.105**
RSC 3	0.081	0.095	0.094	0.085	0.091	0.094	**0.090**
RSC 6.5	0.064	0.074	0.083	0.078	0.086	0.081	**0.078**
RSC 10	0.052	0.059	0.055	0.066	0.068	0.064	**0.060**
Mean	**0.074**	**0.083**	**0.069**	**0.081**	**0.089**	**0.088**	
LSD (5%)	**RSC = 0.004 ,Cultivar = 0.005 Interaction = 0.010**						
Straw Na/K ratio							
RSC 0	0.35	0.42	0.55	0.93	0.68	0.52	**0.58**
RSC 3	0.72	0.65	0.74	1.17	1.08	0.86	**0.87**
RSC 6.5	1.17	1.42	1.07	1.53	1.35	1.67	**1.37**
RSC 10	2.54	2.03	2.68	2.03	2.16	2.46	**2.31**
Mean	**1.19**	**1.13**	**1.26**	**1.41**	**1.32**	**1.38**	
LSD (5%)	**RSC = 0.24 ,Cultivar = 0.12 , Interaction = 0.26**						

4.2.4.6.7Straw potassium content of different wheat cultivars as affected by sodic irrigation water

It was observed that the straw potassium (K) content significantly decreased by 14.2, 25.7 and 42.8 % as compared to control (Table 4.76). The data shows that mean straw K content among different wheat cultivars was onpar for cultivars PBW 658 and Berbet over two years. Interaction effects for straw K content were significant across two years.

4.2.4.6.8 Straw Na/K ratio of different wheat cultivars under sodic water irrigation

The data pertaining to straw Na/K ratio for six wheat cultivars as affected by sodic water irrigation was presented in Table 4.75. The data revealed that straw Na/K ratio increased from 0.58 to 0.87, 1.37, and 2.31 asRSC of irrigation water increases from 0 to 3, 6.5 and 10me/L levels, respectively.

When results related to straw Na/K ratio for different wheat cultivars were considered it was observed that maximum and minimum straw Na/K ratio was observed in cultivar PBW 590 and PBW 621over two years. Interaction between RSC levels and wheat cultivars for straw Na/K ratio was significant across two years.

4.2.4.6.9 Sodic irrigation water effects on straw phosphorus content of wheat cultivars

It is evident from data that straw P content of six wheat cultivars significantly decreased with increasing RSC levels of irrigation water (Table 4.77).

Table 4.77 Sodic irrigation water effects on straw phosphorous and calcium content (%) of wheat cultivars over two years

Straw P (%)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	0.023	0.019	0.020	0.019	0.034	0.042	**0.026**
RSC 3	0.019	0.015	0.017	0.017	0.029	0.032	**0.021**
RSC 6.5	0.014	0.012	0.013	0.014	0.024	0.025	**0.017**
RSC 10	0.010	0.010	0.010	0.011	0.017	0.019	**0.013**
Mean	**0.016**	**0.014**	**0.015**	**0.015**	**0.026**	**0.030**	
LSD (5%)	**RSC = 0.002,Cultivar = 0.002, Interaction = 0.004**						
Straw Ca (%)							
RSC 0	0.013	0.013	0.012	0.014	0.012	0.012	**0.013**
RSC 3	0.012	0.011	0.010	0.011	0.012	0.010	**0.011**
RSC 6.5	0.010	0.009	0.008	0.010	0.010	0.008	**0.009**
RSC 10	0.009	0.007	0.008	0.009	0.007	0.007	**0.007**
Mean	**0.011**	**0.009**	**0.010**	**0.011**	**0.010**	**0.009**	
LSD (5%)	**RSC = 0.004 ,Cultivar = 0.008 , Interaction = NS**						

The average straw P content was 0.026 % in control (RSC 0) which decreased to 0.021, 0.017 and 0.013 % at RSC 3, 6.5 and 10me/L, levels of sodicity, respectively. The straw P content among different wheat cultivars ranged from 0.014 to 0.030 % over two years. The maximum average straw P content was reported in cultivars Berbet and and minimum in cultivar PBW 621. The perusal of data shows that interaction between RSC levels and wheat cultivars was significant for straw P content across two years.

4.2.4.6.10 Effect of sodic water irrigation on straw calcium content of wheat cultivars

The data regarding straw calcium (Ca) content of different wheat cultivars as affected by increasing RSC levels of irrigation water is presented in Table 4.77. It was observed that straw Ca content of wheat cultivars follows similar trend as that of straw P content. The data revealed that straw Ca content deceased by 15.3, 30.7 and 46.2 % at RSC 3, 6.5 and 10me/L levels of sodic irrigation water as compared to control across two years. When results pertaining to six wheat cultivars were considered it was observed that straw Ca content was on par for six cultivars. The interaction between sodicity level and wheat cultivars for straw Ca content was non-significant.

4.2.4.7Quality parameters

The effect of different RSC levels of sodic water irrigation on two quality parameters i.e. protein content (%) and test weight (kg/hl) were determined on grains of different wheat cultivars in 2013-14 as well as 2014-15 and results were discussed under following headings:

4.2.4.7.1 Influences of sodic irrigation water on protein content of wheat cultivars

Thedata presented in Table 4.78 revealed that protein content of different wheat cultivars decrease significantly with increasing sodicity in 2014-15, whereas in 2013-14 sodic irrigation water treatments have no effect on protein content of different wheat cultivars. Choudhary *et al* (2012) also reported that grain protein content was not significantly affected by high RSC irrigation water.

The average protein content decreased from 11.7 to 11.1 % for first year and from 12.0 to 11.2 % for second year of research study, as sodicity increases from 0 to 10 me/L levels, respectively. It is evident from data that mean protein content was statistically at par for all cultivars in 2013-14, however in 2014-15 it was found to be non-significant. Further exploration of data depicted that non-significant results were obtained for protein content between RSC levels and wheat cultivars during first as well as second year of experimental study.

Table 4.78 Influence of sodic irrigation water on protein content (%) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	11.9	11.5	11.4	11.7	12.3	11.4	**11.7**
RSC 3	11.8	11.4	11.3	11.5	12.0	11.2	**11.5**
RSC 6.5	11.6	11.3	11.2	11.3	11.7	11.0	**11.3**
RSC 10	11.4	11.1	11.0	11.0	11.3	10.9	**11.1**
Mean	**11.6**	**11.3**	**11.2**	**11.4**	**11.8**	**11.2**	
LSD (5%)	**RSC = NS**		**Cultivar = 0.34**		**Interaction = NS**		
2014-15							
RSC 0	12.3	12.2	11.6	11.9	12.3	11.7	**12.0**
RSC 3	12.0	11.0	11.4	11.6	12.0	11.5	**11.5**
RSC 6.5	11.7	11.7	11.2	11.2	11.6	11.3	**11.4**
RSC 10	11.5	11.6	11.0	11.0	11.3	11.0	**11.2**
Mean	**11.8**	**11.6**	**11.3**	**11.4**	**11.8**	**11.3**	
LSD (5%)	**RSC = 0.43**		**Cultivar = NS**		**Interaction = NS**		

4.2.4.7.2 Effect of sodic water irrigation on test weight of wheat cultivars

The data pertaining to test weight of different cultivars as affected by irrigation water sodicity along with statistically analysis in 2013-14 and 2014-15 was presented in Table 4.79. The data revealed that test weight of different wheat cultivars decreased significantly at RSC levels of 6.5 and 10 me/L in 2013-14 as well as in 2014-15. The average test weight decreased from 76.2 to 74.3 kg/hl in 2013-14 and from 74.5 to 73.0 kg/hl in 2014-15 as RSC levels increased from 0 to 10me/L.

Among different wheat cultivars average test weight varied from 73.7 to 76.2 kg/hl and ranged from 72.6 to 75.0 kg/hl during first and second year of research study. It was observed that non-significant interaction effects were reported for test weight between sodicity levels and wheat cultivars in 2013-14 as well as 2014-15.

Table 4.79 Effect of sodic irrigation water on test weight (kg/hl) of wheat cultivars

<table>
<tr><th colspan="8">2013-14</th></tr>
<tr><th>Treatment</th><th>KRL210</th><th>PBW621</th><th>HD2967</th><th>PBW590</th><th>PBW658</th><th>Berbet</th><th>Mean</th></tr>
<tr><td>RSC 0</td><td>76.6</td><td>76.5</td><td>76.3</td><td>76.8</td><td>74.6</td><td>76.3</td><td>76.2</td></tr>
<tr><td>RSC 3</td><td>76.3</td><td>76.0</td><td>75.5</td><td>76.1</td><td>74.0</td><td>75.8</td><td>75.6</td></tr>
<tr><td>RSC 6.5</td><td>76.0</td><td>75.1</td><td>75.3</td><td>75.5</td><td>73.5</td><td>75.0</td><td>75.1</td></tr>
<tr><td>RSC 10</td><td>75.8</td><td>74.0</td><td>74.6</td><td>73.6</td><td>73.0</td><td>74.6</td><td>74.3</td></tr>
<tr><td>Mean</td><td>76.2</td><td>75.4</td><td>75.5</td><td>75.5</td><td>73.7</td><td>75.4</td><td></td></tr>
<tr><td>LSD (5%)</td><td colspan="7">RSC = 0.9 Cultivar = 0.8 Interaction = NS</td></tr>
<tr><th colspan="8">2014-15</th></tr>
<tr><td>RSC 0</td><td>75.8</td><td>73.6</td><td>74.0</td><td>75.8</td><td>73.5</td><td>74.3</td><td>74.5</td></tr>
<tr><td>RSC 3</td><td>75.1</td><td>72.6</td><td>73.5</td><td>75.0</td><td>73.3</td><td>73.8</td><td>73.9</td></tr>
<tr><td>RSC 6.5</td><td>74.6</td><td>72.3</td><td>73.3</td><td>74.8</td><td>72.5</td><td>73.5</td><td>73.5</td></tr>
<tr><td>RSC 10</td><td>74.5</td><td>71.8</td><td>73.1</td><td>74.2</td><td>71.3</td><td>73.3</td><td>73.0</td></tr>
<tr><td>Mean</td><td>75.0</td><td>72.6</td><td>73.4</td><td>74.9</td><td>72.6</td><td>73.7</td><td></td></tr>
<tr><td>LSD (5%)</td><td colspan="7">RSC = 0.8 Cultivar = 0.9 Interaction = NS</td></tr>
</table>

Experiment 3: Saline and sodic irrigation effects on carbon and nitrogen mineralization.

4.3 Carbon and nitrogen mineralization

Soil samples irrigated with different levels of saline and sodic water were harvested after 14, 42 and 84 days of incubation period and were analyzed for carbon (Cumulative respiration (CR), microbial biomass carbon (MBC) and nitrogen mineralization (NH_4^+-N and NO_3-N). The results pertaining to these soil properties were discussed under the following headings.

4.3.1 Effect of saline and sodic irrigation water cumulative respiration after 14, 42 and 84 days

The data presented in Table 4.80 revealed that significant reduction in CR occurs as salinity and sodicity of irrigation water increases, however with the addition of carbon @ 1 % there was significant improvement in CR over saline and sodic irrigation treatments. As salinity of irrigation water increase, CR decreased significantly at 14, 42 and 84 days of incubation study and maximum reduction occur at highest level of salinity i.e. 12 dS/m. CR decreased by 23.3 & 43.0%, 38.5 & 56.9 % and 22.4 & 52.0 % after 14, 42 and 84 days at EC 6 and 12dS/m over non-saline soil. These results were in agreement with findings of Shah and Shah (2011). Mavi *et al* (2012) also observed decrease in CR by 43 to 59 % as EC values increase from 0.4 to 4 dS/m after 64 days of incubation study. Further exploration of data depicted that compared to saline soils, addition of C @ 1% significantly increased CR in all the treatments. Elmajdoub and Marschner (2013) also reported that CR increased with addition of carbon compared to unamended soil.

Table 4.80 Saline and sodic irrigation water effects on cumulative respiration (mg CO_2-C/g Soil) throughout incubation period

Treatment	Incubation period		
	14 days	**42 days**	**84 days**
E_0C_0	0.30^d	0.65^d	0.98d
E_0C_1	0.98^a	2.51^a	4.93^a
E_6C_0	0.23^e	0.40^e	0.78^e
E_6C_1	0.83^b	1.60^b	3.30^b
$E_{12}C_0$	0.17^f	0.28^f	0.47^f
$E_{12}C_1$	0.56^c	1.20^c	2.70^c
R_0C_0	0.42^d	0.76^d	1.87^d
R_0C_1	1.10a	2.86^a	5.10^a
$R_{6.5}C_0$	0.28^f	0.50^f	0.99^f
$R_{6.5}C_1$	0.86^c	1.84^c	3.56^c
$R_{10}C_0$	0.35^e	0.61^e	1.38^e
$R_{10}C_1$	0.93^b	2.14^b	4.71^b

The perusal of data shows that sodic water significantly affects CR at 14, 42 and 84 days of incubation period. The CR decreased significantly up to 6.5 me/L levels of sodic water due to toxicity Na and again increases at RSC 10me/L, due to solubilization of soil organic matter which provided additional substrate for decomposition by microbes. These results were reported by several workers (Nelson *et al* 1996, Jandl and Sollins 1997 and Mavi *et al* 2012). Further, compared to sodic soil, addition of carbon @ 1% significantly increased CR after 14, 42 and 84 days of incubation period.

4.3.2 Effect of saline and sodic irrigation water on microbial biomass carbon throughout incubation period

It was observed that MBC follows similar trend as that of CR (Table 4.81). In saline water irrigated soil, MBC significantly deceased a salinity increases from 0 to 12 dS/m levels. It is evident from data that addition of carbon @ 1 % significantly increased MBC as compared to saline soil. The MBC increased by 42.6, 38.9 and 47.6 % at 1% C addition over saline soil after 14 days of incubation period at EC 0, 6 and 12 dS/m levels. Corresponding values after 42 and 84 days were 44.9, 48.4, 39.8% and 32.3, 18.7 and 19.6 % as compared to saline soils. Similar findings were reported by Elmajdoub and Marschner (2013)on addition

Table 4.81 Saline and sodic irrigation water effects on microbial biomass carbon (mg/kg) after 14, 42 and 84 days of incubation period

Treatment	Incubation period		
	14 days	42 days	84 days
E_0C_0	73.6^c	225.9^d	545.4^b
E_0C_1	128.3^a	410.5^a	721.9^a
E_6C_0	55.7^e	170.5^e	415.2^e
E_6C_1	91.2^b	330.7^b	510.5^c
$E_{12}C_0$	32.7^f	142.3^f	370.7^f
$E_{12}C_1$	62.5^d	236.4^c	461.5^d
R_0C_0	82.1^d	242.9^d	556.4^d
R_0C_1	140.5^a	419.2^a	735.7^a
$R_{6.5}C_0$	65.2^f	180.7^f	431.6^f
$R_{6.5}C_1$	105.4^c	342.8^c	630.5^c
$R_{10}C_0$	71.3^e	210.5^e	515.3^e
$R_{10}C_1$	129.6^b	378.3^b	678.2^b

of carbon @ 1% MBC increased from 82.1 to 140.5mg /kg, 65.2 to 105.4 mg/kg, and 71.3 to 129.6 mg/kg after 14 days of incubation as compared to sodic soils at RSC levels of 0, 6.5 and 10me/L. Likewise after 42 and 84 days of incubation study it increased from 242.9 to 419.2mg/kg ,180.7 to 342.8 mg/kg , 210.5 to 378.3 mg/kg and from 556.4 to 735.7 mg/kg, 431.6 to 630.5 mf/kg and 575.3 to 678.2 mg/kg at respective RSC level of irrigation water.

4.3.3 Saline and sodic irrigation water effects on nitrogen mineralization ($NH4^+$ -N and NO_3 -N) throughout incubation study

Table 4.82 Effect of saline and sodic irrigation water on $NH4^+$ -N (mg/kg)after 14, 42 and 84 days of incubation period

Treatment	Incubation period		
	14 days	**42 days**	**84 days**
E_0C_0	51.4^c	42.3^c	84.5^c
E_0C_1	65.7^a	58.4^a	110.2^a
E_6C_0	40.5^d	36.5^d	68.7^d
E_6C_1	57.1^b	49.8^b	90.1^b
$E_{12}C_0$	28.7^f	21.5^f	45.4^f
$E_{12}C_1$	34.2^e	29.7^e	60.6^e
R_0C_0	71.2^c	68.7^b	101.5^c
R_0C_1	85.3^a	79.6^a	125.4^a
$R_{6.5}C_0$	45.4^f	31.2^f	70.2^f
$R_{6.5}C_1$	54.1^e	41.3^e	90.8^d
$R_{10}C_0$	62.4^d	50.5^d	80.7^e
$R_{10}C_1$	79.1^b	59.2^c	113.2^b

4.3.3.1 Saline and sodic irrigation water effects on nitrogen mineralization $NH4^+$ -N throughout incubation study

The data related to effect of saline and sodic irrigation water on NH_4^+-N at different days of incubation period was presented in Table 4.82. It is evident from data that $NH4^+$-N significantly decreased from 14 days to 42 days of incubation again increases up to 84 days of incubation both in both in amended and unamended soils. This decrease in NH_4^+-N is due to osmotic effects on microbes whereas increase up to 84 days occurs as ammonifer bacteria are more tolerant to salinity than nitrifers (Pathak and Rao 1998). However, with the addition of carbon @ 1% NH_4^+-N increased from 51.4 to 65.7 mg/kg, 40.5 to 57.1 and 28.7 to 34.2 mg/kg over saline soils at EC 0, 6 and 12 dS/m levels of irrigation water. The corresponding values after 42 and 84 days of incubation increased from 42.3 to 58.4, 36.5 to 49.8 and 21.5 to 29.7 mg/kg and 84.5 to 110.2, 58.7 to 90.1 and 45.4 to 60.6 mg/kg , respectively.

Similarly in sodic water treated soil significantly increased in NH_4^+-N was observed with the addition of carbon at the rate of 1% after 14 to 42 and 84 day of incubation. In sodic irrigated soil ammonium N showing decreasing trend from 14 days to 42 days and again increases up to 84 days of incubation. Similar trend was also observed in carbon amended soils.

Table 4.83 Effect of saline and sodic irrigation water on NO_3 -N (mg/kg)after 14, 42 and 84 days of incubation period

Treatment	**Incubation period**		
	14 days	**42 days**	**84 days**
E_0C_0	74.5^b	60.3^b	45.4^b
E_0C_1	85.4^a	72.2^a	58.7^a
E_6C_0	55.7^d	46.1^d	30.2^d
E_6C_1	65.2^c	54.6^c	39.5^c
$E_{12}C_0$	36.4^f	27.5^f	16.6^f
$E_{12}C_1$	48.3^e	38.1^e	24.3^e
R_0C_0	85.5^c	92.3^d	71.1^d
R_0C_1	98.1^a	126.3^a	103.2^a
$R_{6.5}C_0$	50.1^f	73.2^f	46.5^f
$R_{6.5}C_1$	60.3^e	85.6^e	59.6^e
$R_{10}C_0$	70.2^d	104.5^c	81.2^c
$R_{10}C_1$	90.5^b	115.6^b	90.4^b

4.3.3.2 Saline and sodic irrigation water on effects of NO_3 –N throughout incubation period

The data presented in Table 4.83shows that NO_3-N have decreasing trend from 14 days to 42 and 84 days of incubation in carbon amended as well as saline irrigated soils. However, with increasing sodicity of irrigation water, NO_3-N shows increasing trend from 14 days to 42 days and again decreases up to 84 days of incubation. Similar trend was also observed with the addition of carbon at the rate of 1% at respective days of incubation in sodic soils. It was observed that with increasing level of salinity there was significant reduction in NO_3 at 14, 42 and 84 days of incubation at EC 0, 6 and 12 dS/m levels. However, in carbon amended soils significant increase was observed at respective EC levels after 14, 42 and 84 days of incubation. In case of sodic irrigated and carbon amended soils, with increase in RSC levels of irrigation water there was significant increase in NO_3-N from 14 to 42 days of incubation and again decreasing trend was observed at the end of incubation study.

CHAPTER V

SUMMARY

As tolerance of wheat crop to salinity and sodicity varies among differentgenotypes, evaluation of new high-yielding wheat cultivars for tolerance tosalinity and sodicity is very important from time to time. These tolerant cultivars will be able to efficiently utilize poor quality irrigation water without significant reduction in grain yield. Keeping this in view, present research study was conducted on Research Farm, Department of Soil Science, PAU, Ludhiana, to observe saline and sodic irrigation effects on performance of six wheat cultivars and soil health

5.1 Saline irrigation effects on performance of wheat cultivars and soil health

Results of field experiment under saline irrigation water revealed that increase in salinity of irrigation water significantly decreased SOC, available N,P,K,S and DTPA-Zn, soluble ions (K, Ca+Mg, HCO_3^- and SO_4^{-2}) and increased soil pH, EC, soluble Na and Cl^-, SAR and ESP in 2013-14 and 2014-15. The results showed that physical properties were not adversely affected by different levels of salinity of irrigation water for 0-15 cm soil depth in both years except thedispersion ratio of soil.Microbial properties such as MBC, MBN, DHA and CWEC significantly decreased with increasing salinity of irrigation water. Compared to EC 0 (control), DHA, MBC and CWOC decreased by about 50 % and MBN by 70% at the highest level of irrigation water (EC 12 dS m^{-1}).Soil biological properties were more affected at high salinity levels (EC 9 and 12 dSm^{-1})compared to low salinity levels.

Salinity of irrigation water adversaly affected plant and yield parameters, which resulted inlower grain yieldsof different wheat cultivars (osmotic effects and specific ion toxicity of Na and Cl). The data revealed that plant parameters (plant height, no of tillers m^{-2} and LAI) significantly decreased with increasing levels of irrigation water salinity. Plant analysis at tillering stage shows that increasing salinity levels resulted in progressive increase in plant Na content of different wheat cultivars which decreased plant K, Pand Ca content in both years. Plant Na^+/K^+ ratio increased with increase in salinity for different wheat cultivars in both years. Similar trend was also observed for grain and straw analysis in 2013-14 and 2014-15. Yield parameters of different wheatcultivars (spike length, TGW, grain weight $spike^{-1}$ and number of $spikesm^{-2}$) were more affected at higher salinity levels compared to low levels in both years. Data across two years revealed that up to EC 9 dS m^{-1}cultivars PBW 658 and HD 2967 performed better on the basis of absolute yields. However, based on relative yield cultivar KRL 210 (salt tolerant) was on par with these two cultivars. At EC 12 dSm^{-1}, PBW 658 producedsignificantly higher grain yield (4.23 tha^{-1}) than cultivar HD 2967 (4.11 tha^{-1}) and PBW621 (3.99 tha^{-1}), therefore should be preferred on water having salinity more than 9 dS m^{-1}.

5.2 Sodic irrigation effects on performance of wheat cultivars and soil health

Long term use of sodic water adversly affected chemical, physical and biological soil health, which caused reduction in grain yields of different wheat cultivars. The results revealed that increasing RSC levels of irrigation water significantly decreased SOC, available N, P, K, S and DTPA-Zn and soluble ions (K, Ca+Mg, Cl^- and SO_4^{-2}) and increased soil pH, EC, soluble Na and HCO_3^-, SAR and ESP. Physical properties such as bulk density and dispersion ratio increased with increasing sodicity, while decreasing trend was observed for hydraulic properties (infiltrationrate, saturated hydraulic conductivity and water holding capacity) and Mean weight diameter. This can be attributed to deteriorating effect of high soilpHand permeability and aeration problems due to higher ESP levels on soil properties.

Plant height, number of tillersm^{-2} and LAI significantly decreased with increasing sodicity of irrigation water. Plant, grain and straw analysis at tillering stage and maturity shows that increasing alkalinity levels resulted in increased Na content and Na^+/K^+ratio of different wheat cultivars and decreased K, Pand Ca content in both years. Yield parameters such as spike length, TGW, grain weight spike^{-1} and number of spikes m^{-2} were more adverselyaffected at higher sodicity levels (RSC 6.5 and 10 me L^{-1}) in 2013-14 and 2014-15. The grain yield decreased significantly with increasing alkalinity of irrigation water, but cultivars exhibited differential response to RSC levels in both years. Data in two years revealed that up to RSC 6.5 me L^{-1} cultivars PBW 621 and HD 2967 performed better on the basis of absolute yields but based on relative yield cultivar KRL 210 cultivar(developed by CSSRI, Karnal, India) was on par with these cultivars. At highest RSC of 10me L^{-1}, cultivarPBW 621, however, produced high yields (87-88% relative yields). Therefore cultivar PBW621 should be preferred on soils irrigated with waters containing RSC higher than 6.5me L^{-1}.

5.3 Saline and sodic irrigation effects on carbon and nitrogen mineralization

Carbon mineralization was measured through cumulative respiration (CR) and MBC and N mineralization through NH_4^+-N and NO_3^--N for 12 weeks of incubation study. The results revealed that CR, MBC decreased significantly as salinity and sodicity of irrigation water increased. However, with addition of carbon @ 1% significantimprovement in CR and MBC was observed throughout incubation study (microbes use carbon as energy source). Mineralization of N (measured through NH_4^+-N and NO_3^--N) was low in saline and sodic enviornment, showed increase upon addition of carbon.

In conclusions, differential contribution of yield parameters (number of spikesm^{-2}, spike length, TGW and grain weight spike^{-1}) towards grain yield was observed for different wheat cultivars. Such differences can be exploited by the plant breeders to induce higher salinity and sodicity tolerance in newly developed wheat germplasms. Research efforts need to be continued in future as well to evaluate new high-yielding wheat cultivars released from time to time for their performance under saline and sodic irrigation waters. It will help to identify high yielding and most suitable wheat cultivars for saline and sodic environments. Further integrated research work should be done in physiology, plant breeding and soil science disciplinesto increase salt tolerance of newly released wheat genotypes.

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LIST OF SUBMITTED/ACCEPTED/PUBLISHED RESEARCH ARTICLES

Sr. No	Publication	Name of the journal	NAAS rating	Status
1	Effect of irrigation water alkalinity on performance of some wheat cultivars in a semi-arid region of Northwest India	Agricultural water management	8.33	Submitted
2	Performance of some wheat cultivars under saline irrigation water in field conditions	Communication in Soil Science and Plant Analysis	6.42	Submitted
3	Irrigation induced salinization effects on soil biological properties	Journal of the Indian Society of Soil Science	4.95	Submitted

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Title: EFFECT OF IRRIGATION WATER ALKALINITY ON PERFORMANCE OF SOME WHEAT CULTIVARS IN A SEMI-ARID REGION OF NORTHWEST INDIA

Article Type: Research Paper

Keywords: Alkalinity, RSC, Cultivar, Grain yield

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Abstract: The objective of this field investigation was to study the response of six wheat cultivars (KRL 210, PBW 621, HD2967, PBW 590, PBW 550 and Berbet) to four levels of residual sodium carbonate (RSC) in irrigation water: 0, 3, 6.5 and 10me L-1.Increase in RSC significantly increased soil pH, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) and adversely affected soil physical properties. Yield parameters were adversely affected by different RSC levels. The grain yield decreased significantly with increasing alkalinity of irrigation water, but cultivars exhibited differential response to RSC levels in both years. Data in two years revealed that up to RSC 6.5 meL-1 cultivars PBW 621 and HD 2967 performed better on the basis of absolute yields but based on relative yield KRL 210 cultivar was on par with these cultivars. At highest RSC of 10 me L-1, PBW 621 however produced high yields(87-88% relative yields).Therefore cultivar PBW621 should be preferred on soils irrigated with waters containing RSC higher than 6.5 me L-1in North western India.

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To

Editorial office

Agriculture Water Management

Respected Sir,

I wish to submit research article entitled "**Effect of irrigation water alkalinity on performance of some wheat cultivars in a semi-arid region of northwest India"** by Pawitar Singh, O P Choudhary and Pritpal Singh in journal Agricultural Water Management. I hope you will find my paper suitable for publication in your reputed journal.

Thanking You

Yours Sincerely

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Highlights

- Increasing RSC of irrigation water significantly increased soil pH, SAR and ESP in 2013-14 and 2014-15 years
- Irrigation with alkali water significantly increased soil bulk density and dispersion ratio, while all other physical properties (MWD, SHC, IR and WHC) decreased with increasing RSC levels
- For water having RSC up to 6.5 me L^{-1} commercial cultivars PBW 621 and HD 2967 performed better; at par with salt tolerant (KRL210) cultivar developed by CSSRI, Karnal, India. However at RSC 10 me L^{-1}, cultivar PBW 621 produced high yield.
- Differential contribution of yield parameters (number of spikes m^{-2}, spike length, thousand grain weight and grain weight spike $^{-1}$) towards grain yield was observed for different wheat cultivars. Such differences can be exploited by the plant breeders to induce higher sodicity tolerance in newly developed wheat germplasms.

EFFECT OF IRRIGATION WATERALKALINITY ON PERFORMANCE OF SOME WHEAT CULTIVARS IN A SEMI-ARID REGION OF NORTHWEST INDIA

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Abstract

The objective of this field investigation was to study the response of six wheat cultivars (KRL 210, PBW 621, HD2967, PBW 590, PBW 550 and Berbet) to four levels of residual sodium carbonate (RSC) in irrigation water: 0, 3, 6.5 and 10me L^{-1}.Increase in RSC significantly increased soil pH, sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) and adversely affected soil physical properties. Yield parameters were adversely affected by different RSC levels. The grain yield decreased significantly with increasing alkalinity of irrigation water, but cultivars exhibited differential response to RSC levels in both years. Data in two years revealed that up to RSC 6.5 meL^{-1} cultivars PBW 621 and HD 2967 performed better on the basis of absolute yields but based on relative yield KRL 210 cultivar was on par with these cultivars. At highest RSC of 10 me L^{-1}, PBW 621 however produced high yields(87-88% relative yields).Therefore cultivar PBW621 should be preferred on soils irrigated with waters containing RSC higher than 6.5 me L^{-1}in North western India.

KEYWORDS: Alkalinity, RSC, Cultivar, Grain yield

1. INTRODUCTION

Sodic soils generally exit in semi arid regions (annual rainfall 500-700 mm) and occupies 434 m ha area globally (FAO-AGL, 2000). Irrigation water quality plays an important role in context of sodicity buildup that could adversely impact agricultural crop productivity and soil health (Pitman and Lauchli, 2002; Choudhary et al., 2011). Good quality water resources are becoming increasingly scarce for use in agriculture and are allocated with priority to domestic and industrial users. Consequently, marginal quality water is used for irrigation with little or no consideration of their long term impact on soils, especially in the arid and semi arid regions. Large part of the Australia, the Indian sub-continent, China, countries in the Middle East, parts in North and South America, Europe and substantial parts of North Africa lacks sufficient supplies of good quality water (Seckler et al., 1998). It is estimated that about 10 m ha of irrigated land in the world suffer from secondary salinization and sodification (Szaboles, 1994). In India, this problem is particular acute in Northwestern parts, where majority of ground waters contain high concentrations of bicarbonates and variable soluble salt concentration (Minhas and Gupta, 1992; Minhas and Bajwa, 2001). In Punjab, out of 42 percent poor quality ground water, 25 percent are saline, 69 percent are alkali and 6percent are saline-alkali in nature (PRSC, 2010). These poor quality ground waters are concentrated in drier Southwestern regions of Punjab. Continuous and indiscriminate use of alkali water however, poses a series threat to soil health and crop productivity mainly through increased pH, sodium saturation of soil and associated deterioration of soil physical properties (Gupta and Abrol, 2000; Choudhary et al., 2004).Wheat is a moderately salt

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tolerant crop(Mass and Hoffman, 1977). It is the most common field crop grown on 6m ha of Indo-Gangetic plans (Chhuneja et al., 2005). Effect of alkali irrigation water on wheat crop and its cultivars were reported by several workers (Choudhary et al., 1996; Josan et al., 1998; Rajpar et al., 2004; Murtaza et al., 2009; Choudhary et al., 2012). Because tolerance to salinity and alkalinity various among different wheat genotypes (Tester and Davenport, 2003; Munns, 2005; Munns and Tester, 2008). It is very important to evaluate new high yielding cultivars released from time to time for their performance under alkali irrigation water. Therefore, present field investigations were carried out to study the effect of alkali waters (with varying level of RSC) on soil properties and wheat yield.

2. MATERIALS AND METHODS

This experiment was conducted for two years (2013–14 to 2014–15) at the experimental farm of Punjab Agricultural University, Ludhiana, India, using six wheat cultivars viz. KRL 210, PBW 621, HD2967, PBW 590, PBW 658 and Berbet and four levels of RSC in irrigation water (0, 3, 6.5, and 10 me L^{-1}). The plot size was 2.5 m × 2.0 m with a buffer band of 0.5 m. Two sets (set 1 and set 2) of these cultivars were made consisting of three cultivars in each set. Ten lines (3 for each cultivars and the border line) were sown in each plot for set 1 and set 2. The row to row spacing of wheat crop was maintained at 0.2 m. The experiment was laid out in a split plot design with three replications. The normal sandy loam soil classified as Typic Ustochrepthad pH = 7.9; electrical conductivity (EC) (1:2 soil: water) = 0.20 dSm^{-1};organic C = 0.28% ; calcium carbonate <1 %; clay content = 7.2%; and exchangeable sodium percentage (ESP) = 4.2 in 0–30 cm soil layer. Good quality canal water (CW), used as control treatment, had EC = 0.40 dS m^{-1},RSC = 0, and sodium adsorption ratio (SAR) = 1.2. Three levels of sodicwater (RSC of 3 me L^{-1} [EC 0.60 dS m^{-1} and SAR 3.8], 6.5 me L^{-1}[EC 0.90 dSm^{-1} and SAR 7.3] and 10 me L^{-1}[EC 1.40 dSm^{-1} and SAR11.0] were used in the study. These alkali waters were created by dissolving requisite amounts of $NaHCO_3$ (0.25, 0.55 and 0.84 g of $NaHCO_3$ per liter in CW, respectively). Such waters are typical of the alkali groundwater found in the southwestern region of Punjab, where wheat is the most common winter crop. The experimental field plots had been receiving respective alkali irrigation water for 18 years before start of this experiment. A basal dose of 150 kg N (urea), 26 kg P (diammonium phosphate), 50 kg K (muriate of potash), and 10 kg Zn/ha (zinc sulfate) was uniformly applied to all the plots. Wheat cultivars were sown on 11th November in 2013 and harvested on 17th April, 2014 in first year whereas in second these cultivars were sown on 5th November, 2014 and harvested on 27th April, 2015.The soil in the 0–30 cm layer in each plot was properly mixed and leveled to minimize the variation within the plot. All the plots were then brought to field capacity by giving a pre-sowing irrigation (with respective water treatments assigned to various plots). At each irrigation, 60 mm water, equivalent to evaporation from the U.S. class A pan after making adjustment for the rainfall received, was applied. During each growing season, wheat crop received 5 irrigations in first year and 4 irrigations in second year given at 4 to 5 weeks intervals. The desired volume of the treatment waters was supplied to the respective plots through a rubber hose (5 cm diameter).

2.1 Measurements

Soil samples were taken in the third week of April each year from 0–15, 15–30, 30–60, 60-90 and 90-120 cm soil layers with an auger that was 4-cm in diameter. The soil samples were air-dried and ground to pass through a 2-mm sieve. Soil pH and EC of these samples were determined in 1:2 soil:water ratio. Soluble cations and exchangeable sodium percentage were determined using the methods outlined in the *USDAHandbook 60* (Richards, 1954). Soil physical properties such as bulk density, mean weight diameter, saturated hydraulic conductivity, infiltration rate, dispersion ratio and water holding capacity were measured methods described by several workers (Blake and Hartge, 1986; Kemper and Rosenau, 1986; Klute and Dirkson ,1986; Bouwer 1986; Richards , 1954)

2.2 Statistical Analysis

Data was analyzed using analysis of variance (ANOVA) with CPCS1 software and regression analysis was done using MINITAB 15 software.

3 RESULTS AND DISCUSSION

3.1 SOIL CHEMICAL PROPERTIES

3.1.1 Soil pH

Soil pH significantly increased by increase in RSC of irrigation water in both years (Table 1). The mean soil pH (0–120 cm soil)was 7.55 under CW irrigation, which progressively increased to 7.62,8.39, and 9.06 under 3, 6.5, and 10 meL^{-1} RSC treatments, respectively in the first year and correspondingly increased from 7.42 to 7.95, 8.37 and 9.03in the second year at respective RSC levels. In the 15–30 cm soil layer under RSC6.5 and RSC10 treatments, significantly higher soil pH was observed in the second year compared with first year.

Table 1Effect of alkali irrigation water on soil pH

2013-14						
Treatments/ Soil depth	**0-15 cm**	**15-30 cm**	**30-60 cm**	**60-90 cm**	**90-120 cm**	**Mean**
RSC 0	7.35	7.44	7.56	7.61	7.80	**7.55**
RSC 3	7.80	7.75	7.58	7.51	7.44	**7.62**
RSC 6.5	8.59	8.54	8.40	8.27	8.13	**8.39**
RSC 10	9.47	9.38	9.15	8.72	8.61	**9.06**
Mean	**8.30**	**8.28**	**8.17**	**8.03**	**7.99**	
LSD (5%)	**RSC= 0.38 Depth= 0.16 RSC x Depth = 0.32**					
2014-15						
RSC 0	7.50	7.79	7.40	7.25	7.14	**7.42**
RSC 3	7.88	8.40	8.20	7.82	7.48	**7.95**
RSC 6.5	8.46	8.60	8.37	8.24	8.19	**8.37**
RSC 10	9.40	9.45	9.20	8.63	8.48	**9.03**
Mean	**8.31**	**8.56**	**8.29**	**7.98**	**7.82**	
LSD (5%)	**RSC= 0.03 Depth= 0.02 RSC x Depth = 0.05**					

It can be attributed to progressive increase in the alkalinity in this layer across time, causing higher soil pH in second year. At RSC 10 level, soil pH remained higher than 8.5 in both years, except at 90-120cm layers where it remained closer to threshold value of 8.5. Compared with surface layers, soil pH progressively decreased to lower values at increasing soil depths (30-120 cm) at all RSC levels in both years. It occurred because of restricted downward movement of water and salt into the lower layers because of higher soil dispersion (Josan et al., 1998). Similar results were also reported by Choudhary et al. (2012).

Although there was a significant increase in soil EC at RSC6.5 and RSC10 treatments over RSC0 and RSC3 (data not presented) but EC even in these two treatments remained less than1 dSm^{-1}to adversely affect the yield of wheat cultivars as threshold level of salinity for wheat being quite high (ECe =6 dSm^{-1}) (Ayers and Westcot , 1985)

3.1.2 Sodium adsorption ratio (SAR)

Sodium adsorption ratio progressively increased with increasing levels of RSC in irrigation water in 2013-14 and 2014-15. The SAR increased from 2.5 to 20 in 2013-14 and from 2.4 to 17 in 2014-15 as irrigation water alkalinity increased from RSC 0 to RSC 10 me L^{-1}. In 2013-14, at RSC 0 and 3 progressive increase in SAR was observed up to 50 cm soil depth and then sharply decreased to 80 cm and again increased at lower soil layers in first year (at all RSC levels). However in second year higher SAR was observed up to 0-30cm at all RSC levels than surface layers, which decrease linearly thereafter up to 120 cm soil depth .Similar results were also reported by Choudhary et al. (2007).

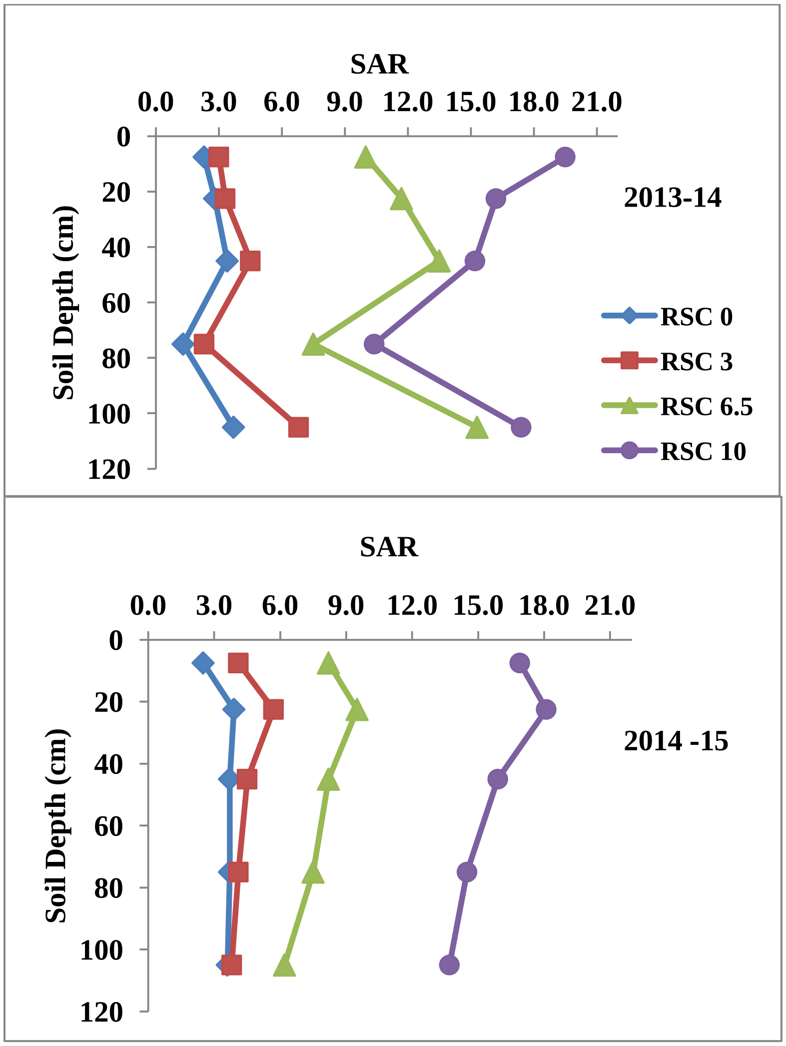

Figure 1 SAR of soil as affected by alkali irrigation water

3.1.3 Exchangeable sodium percentage (ESP)

Soil depth distribution of ESP in the soil profile was similar to that observed in case of SAR. The values of ESP were higher in magnitude than SAR at al RSC levels and all depths (Figure 2). Higher ESP values were recorded in the surface layers (0-30 cm) than in lower soil layers under irrigation with RSC6.5 and RSC10 waters. This can be attributed to a progressive decrease in permeability of soil with increase in RSC of irrigation water. Higher soil pH and ESP were caused by increased soil dispersion and accumulation of Na carbonate and bicarbonate in the surface layers because of evapo-concentration of the alkali water (Josan et al., 1998; Grattan and Oster, 2003; Oster, 2004; Choudhary et al., 2006). These results are in agreement with Choudhary et al. (2007).

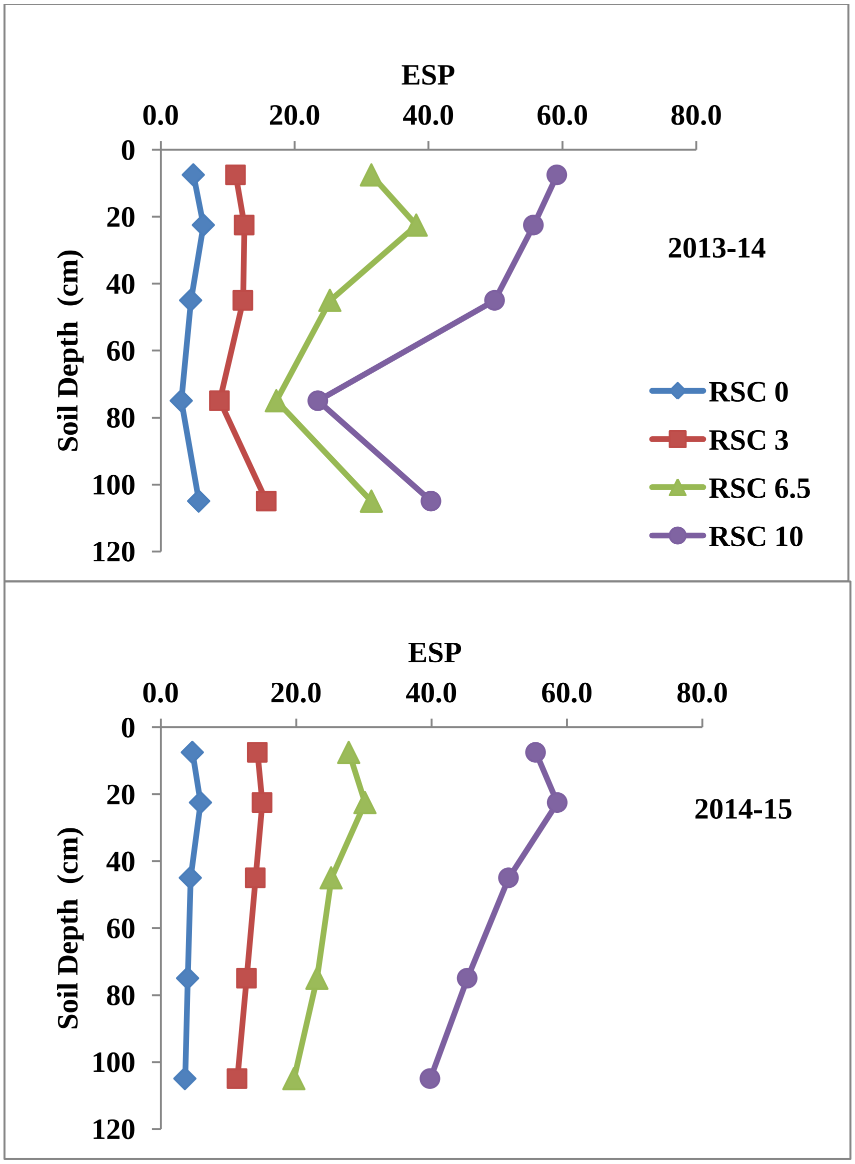

Figure 2 Effect of alkali irrigation water on soil ESP

3.2 SOIL PHYSICAL PROPERTIES

Soil physical properties which include bulk density, mean weight diameter (MWD), saturated hydraulic conductivity (SHC), infiltration rate (IR), dispersion ratio (DR) and water holding capacity (WHC) were adversely affected by alkali irrigation water. Irrigation with alkali water significantly increased soil bulk density and dispersion ratio, while all other physical properties (MWD, SHC, IR and WHC) decreased with increasing RSC levels. Increasing RSC levels of irrigation water progressively increased bulk density of soil from 1.49 Mg m^{-3} in RSC 0 to 1.55, 1.61 and 1.66 at RSC 3, RSC 6.5 and RSC10 meL^{-1} treatments and dispersion ratio from 0.356 in control to 0.458, 0.560 and 0.621 at respective RSC levels. At the end of the experiment (2013–2015), the minimum SHC and IR (0.12 and 1.1 cm hr^{-1}) was measured in the plots irrigated with RSC 10, which decreased by 55.5 and 57.6 % compared with plots irrigated with CW (0.27 and 2.6 cm hr^{-1}) (Table 2).

Table 2Effect of alkali irrigation water on physical properties of soil at end of experiment

Treatment	**Bulk density (Mg m^{-3})**	**Mean weight diameter (mm)**	**Saturated hydraulic conductivity (cm hr^{-1})**	**Infiltration rate (cm hr^{-1})**	**Dispersion ratio**	**Water holding capacity (%)**
RSC 0	1.49	0.89	0.27	2.6	0.356	39.2
RSC 3	1.55	0.84	0.24	2.3	0.458	36.1
RSC 6.5	1.61	0.79	0.18	1.7	0.560	32.4
RSC 10	1.66	0.73	0.12	1.1	0.621	28.5
LSD (5%)	**0.02**	**0.01**	**0.07**	**0.3**	**0.021**	**5.8**

Increasing ESP and clay migration and its accumulation in the soil pores under higher RSC water (RSC 6.5 and RSC10 meL^{-1}) appeared to be the cause of decline in SHC and IR (Josan et al., 1998; Ayers and Westcot, 1985; Nayak et al., 2004). When irrigated with RSC 10 alkali water MWD decreased from 0.89 to 0.73 mm and WHC from 39.2 to 28.5 % compared with CW irrigation. El-tarif and Gharaibeh (2007) also found that mean weight diameter decrease with increase in soil exchangeable sodium percentage. High level of Na also leads to structural changes which negatively affect water and air movement, and ultimately water holding capacity of soil.

3.3 GRAIN YIELD

In 2013–14, cultivars KRL 210, PBW 621 and HD2967 performed better with respect to yield at RSC 6.5 me L^{-1}, but at higher RSC (10 me L^{-1}), PBW 621, showed higher tolerance to residual alkalinity compared with other cultivars (Table 3). Although relative decrease in grain yield of PBW 621 and KRL 210 was almost same at RSC 10 me L^{-1} but PBW 621 produced higher absolute grain yield than KRL 210. Absolute grain yield of PBW 590 was less compared to Berbet when irrigated with CW and waters having RSC of 3 and 6.5 me L^{-1}. When irrigated with the highest RSC water (10 me L^{-1}), performance of both cultivars was on par. However relative decrease in grain yield was more in Berbet than PBW 590 at respective RSC level. Compared with CW irrigation, the maximum relative decrease in grain yield at each RSC level was observed in cultivar PBW 658, whereas minimum reduction was observed in KRL 210 (salt tolerant).

Table 3Effect of alkali irrigation water on grain yield (t/ha) of wheat cultivars

2013-14							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	5.26	6.00	5.82	4.84	5.93	5.37	**5.53**
RSC 3	5.20	5.90	5.63	4.48	5.34	5.27	**5.30**
RSC 6.5	5.13	5.40	5.56	3.94	4.85	4.49	**4.90**
RSC 10	4.53	5.20	4.90	3.83	4.23	3.77	**4.41**
Mean	**5.03**	**5.62**	**5.46**	**4.28**	**5.09**	**4.72**	
LSD (5%)	**RSC = 0.15 Cultivar = 0.14 RSC x Cultivar = 0.27**						
2014-15							
RSC 0	5.33	5.87	5.79	4.76	5.72	5.22	**5.45**
RSC 3	5.24	5.81	5.65	4.24	5.11	5.12	**5.21**
RSC 6.5	5.15	5.33	5.37	3.87	4.94	4.37	**4.84**
RSC 10	4.63	5.18	4.73	3.74	4.34	3.81	**4.40**
Mean	**5.09**	**5.55**	**5.38**	**4.15**	**5.03**	**4.63**	
LSD (5%)	**RSC = 0.22 Cultivar = 0.26 RSC x Cultivar = NS**						
Pooled data							
RSC 0	5.30	5.94	5.81	4.80	5.83	5.30	**5.49**
RSC 3	5.22	5.86	5.64	4.36	5.23	5.20	**5.26**
RSC 6.5	5.14	5.37	5.47	3.91	4.90	4.43	**4.87**
RSC 10	4.58	5.19	4.82	3.79	4.29	3.79	**4.41**
Mean	**5.06**	**5.59**	**5.43**	**4.21**	**5.06**	**4.68**	
LSD (5%)	**RSC = 0.13 , Cultivar = 0.14 , RSC x Cultivar = 0.28,**						

. Nevertheless, in absolute terms, high yielding cultivars PBW 621 and HD 2967 produced higher grain yield than established salt tolerant cultivar KRL 210 at all levels of RSC. In 2014–15, the trend in grain yield of different cultivars was similar. However interaction between RSC levels and cultivars was non-significant in 2014-15.

The decreased grain yield of wheat cultivars irrigated with high RSC waters may be ascribed to the Ca-deficit in the soil solution (Minhas and Bajwa, 2001) caused by high RSC in irrigation water and hence, lower Ca in plants relative to Na (Choudhary et al., 1996; Suhadya et al., 1992). The adverse effect of high pH on other soil properties (Seckler et al., 1998; Choudhary et al., 2001) and poor aeration because of high ESP levels (Josan et al., 1998) also could account for grain yield reduction.

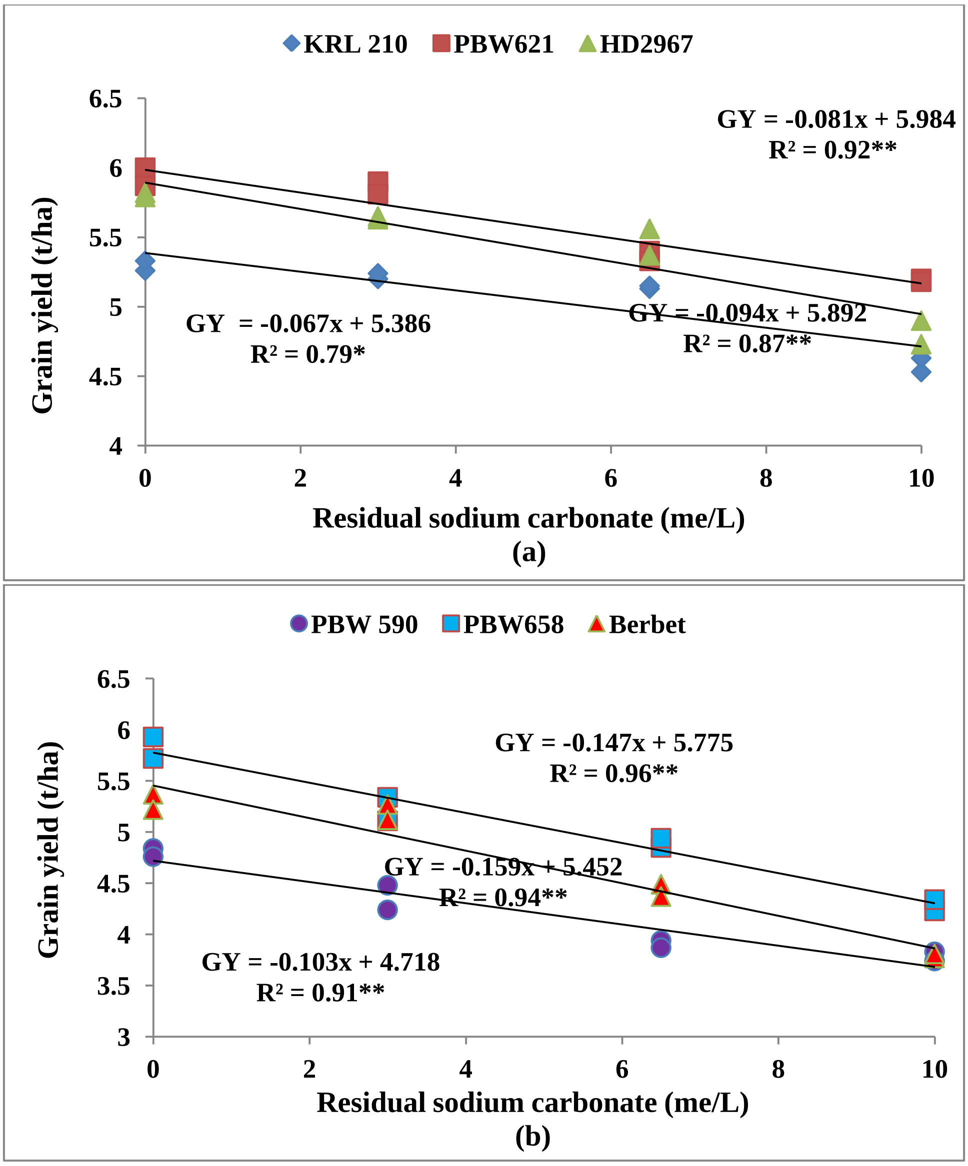

Figure 3 Grain yield of different wheat cultivars as affected by RSC of irrigation water in two years (2013-2015) (a) high yielding cultivars or cultivars with less decline in grain yield (b) low yielding cultivars or cultivars with more decline in grain yield

The above results clearly suggests that, at medium RSC level (up to 6.5 me L $^{-1}$), performance of PBW 621 and HD 2967 in absolute grain yield was similar and higher than other cultivars but salt tolerant cultivar KRL 210 produced more than 97 % relative yield (yield relative to CW) compared to 95% for cultivar HD2967 and 90% for PBW 621. At RSC 10 me L $^{-1}$, cultivar PBW 621 produced significantly higher grain yield (5.2 t ha^{-1}) than cultivar HD 2967 (4.90 t ha^{-1}) and KRL 210 (5.03t ha^{-1}) . On the basis of relative yield, these cultivars were similar (84-87%) in their performance at this RSC level.

Data in Figure 1(a) illustrates that cultivar PBW 621 produced higher yield compared with other two cultivars at each level of RSC. Between HD 2967 and KRL210, although HD 2967 produced higher yield than later but have high rate of decline per unit increase of RSC (90 kg per unit increase in RSC compared to 67 kg). Whereas cultivar KRL 210 produced lower grain yield at each level of RSC of irrigation water. Out of PBW 590, PBW 658 and Berbet, decrease was less in PBW 658 with per unit increase in RSC levels and produced higher grain yield (Figure 1(b)) whereas cultivar Berbet produced higher yield than PBW 590 but with high rate of decline per unit increase in RSC levels. Although decrease per unit increase in cultivar PBW 590 was lower (103 kg per unit RSC) than other two cultivars (147 kg for PBW 658 and 159 kg for Berbet) , it produced lower yields at all levels of RSC. Nevertheless, it comes close to cultivar Berbet at higher RSC levels (6.5 and 10 me L^{-1}).

Based on the correlation of grain yield with their yield parameters (TGW, grain weight $spike^{-1}$ and no. of spikes m^{-2}) of different wheat cultivars following regression equations were computed to identify the most important yield parameter influencing grain yield of each cultivar.Grain weight $spike^{-1}$ was most important contribution factor for KRL210 (R^2= 71.1) and PBW 658 (R^2= 89.8) towards grain yield.The predictability (R^2) further improved to 78.8 % in cultivar KRL 210 and 93.5 % in case of cultivar PBW 658 when number of spikes m^{-2} were included in the regression. For PBW 621 and PBW 590 cultivars, spike length was the important yield parameter and grain yield prediction further improved on adding number of spikes $m^{-2}$for both cultivars. For cultivars Berbet and HD 2967 number of spikes m^{-2} were most important contributing factor for grain yield and predictability improved on addition of spike length for HD 2967 and GWS for Berbet (Table 4).These results suggest that contribution of different yield parameters to grain yield was different in each cultivar. Such information can be helpful for plant breeders and biotechnologists for finalizing their breeding programmes to bring improvement in tolerance of different wheat germplasm, so that the improved cultivars are able to perform better in a sodic / alkali environment.

Table 4 Relationship of grain yields of wheat cultivars with their yield parameters

Cultivars	**R^2**
KRL 210	
(1) GY = 3.471 + 1.02 GWS	**71.1^{**}**
(2) GY = 2.923 + 0.63 GWS+ 0.004 SPIKES	**78.8^{**}**
PBW 621	
(1) GY = -0.8524 + 0.71 SL	**74.2^{**}**
(2) GY = 0.5653 + 0.39 SL + 0.005 SPIKES	**78.3^{**}**
HD 2967	
(1) GY = 1.713 + 0.011 SPIKES	**94.0^{**}**
(2) GY = 1.297 + 0.009 SPIKES + 0.12 SL	**94.3^{**}**
PBW 590	
(1) GY = -2.463 + 0.76 SL	**72.8^{**}**
(2) GY = -1.842 + 0.51 SL + 0.005 SPIKES	**74.7^{**}**
PBW 658	
(1) GY = 2.920 + 1.32 GWS	**89.8^{**}**
(2) GY = 1.027 + 0.83 GWS + 0.008 SPIKES	**93.5^{**}**
Berbet	
(1) GY = -1.074 + 0.018 SPIKES	**87.3^{**}**
(2) GY = - 0.661 + 0.016 SPIKES + 0.27 GWS	**87.5^{**}**

Abbreviations: GY= grain yield, GWS= grain weight $spike^{-1}$, TGW = thousand grain weight, SPIKES= number of spikes m^{-2}, SL = spike length)

3.4 YIELD PARAMETERS

3.4.1 No. of spikes m^{-2}

Number of spikes $m^{-2}$of the wheat cultivars were adversely affected by increase in RSC of irrigation water. Compared to CW (RSC 0), mean number of spikes m^{-2} decreased by 4.7, 13.1 and 22.9% at RSC 3, 6.5 and 10 me L^{-1} treatments, respectively (Table 5). Choudhary et al. (2007) also reported decrease in number of spikes m^{-2} of PBW 343 cultivar by 9.4, 17.9 and 45.3 % under RSC 3, 6.5 and 10 me L^{-1} levels as compared to CW. Number of spikes $m^{-2}$for cultivars PBW621 and HD2967 decreased by almost same magnitude(15, 40 and 88) at each level with increasing RSC levels from 0 to 10 me L^{-1}.When irrigated with CW cultivars PBW 658 and Berbet had same number of spikes m^{-2} but more decrease was observed in cultivar Berbet than the former as RSC of irrigation water increased from 3 to10 me L^{-1}. Maximum decrease in spike number at each RSC level was observed in cultivar Berbet. On the other hand cultivar PBW658 produced maximum number of spikes m^{-2}among all cultivars at RSC 10 me L^{-1}.

3.4.2 Spike length (cm)

Mean spike length of wheat cultivars decreased from 9.6 in CW to 9.3, 8.8 and 8.1 cm at RSC 3, 6.5and 10 me L^{-1} levels of alkaline irrigation water (Table 5). The maximum decrease in spike length of KRL 210 was observed in RSC 3 treatment and for Berbet at RSC 10 me L^{-1} compared to control. Spike length of cultivars PBW 621 and PBW 658 almost decrease by same magnitude at each level of increasing alkalinity. Compared to CW treatment, average spike length decreased by 3.1, 8.3 and 15.6% at RSC 3, 6.5 and 10 me L^{-1}. Out of six wheat cultivars, maximum mean spike length was observed in Berbet whereas minimum was reported in PBW658.

3.4.3 Thousand grain weight (TGW)

The data present in Table 5 revealed that TGW decreased significantly with increasing RSC levels in both years. Mean TGW decreased from 43.7 g in canal water treatment (RSC 0) to 41.5, 39.6 and 37.6 at RSC 3, 6.5 and 10 me L^{-1} levels. Murtaza et al. (2009) observed that average TGW of six wheat cultivars decrease significantly from 28.2 to 15.5 g as EC/SAR ratio increased from 0.9:1.5 to 12:48. There was a wide range of TGW (36.2 to 46.7 g) among different wheat cultivars at different RSC levels. Maximum average TGW was observed in cultivar HD2967 and the minimum in cultivar PBW 590. At each level of RSC, decrease in TGW was more in cultivar PBW 658 and less in KRL 210 (same trend as that of grain yield for respective cultivars). Although PBW 621 and HD 2967 have similar TGW in CW treatment but with increasing RSC levels of irrigation water at each level decrease in TGW of cultivar PBW 621 was more than HD 2967.

3.4.4 Grain weight Spike $^{-1}$(GWS)

The average grain weight spike $^{-1}$ significantly decreased by 10.0, 20.0 and 35.0 % at RSC 3, RSC 6.5 and RSC 10 me L^{-1} compared to RSC 0 across two years. Grain weight spike $^{-1}$ for cultivars KRL210 and PBW 621 at RSC 3 me L^{-1} was decrease by same magnitude (0.2 unit) but at RSC 10 me L^{-1} decrease in grain weight spike $^{-1}$ was more in PBW 621 (0.8 unit) than KRL 210 (0.5 unit). PBW 590 and Berbet have same grain weight spike $^{-1}$ when irrigated with CW but at higher RSC (6.5 and 10 me L^{-1}) PBW 590 produced higher grain weight spike $^{-1}$ than Berbet. The maximum decrease in grain weight spike $^{-1}$ at each RSC level was observed in cultivar PBW 658 across years. Grain weight spike $^{-1}$ for HD 2967 and PBW 658 decrease by similar magnitude at RSC10 me L^{-1} .

Table 5 Number of spikes m^{-2} and spike length of different wheat cultivars as affected by alkalinity of irrigation water pooled over two years

No. of spikes m^{-2}							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	354	370	364	345	360	359	**358**
RSC 3	334	353	350	332	345	331	**341**
RSC 6.5	296	323	321	307	316	304	**311**
RSC 10	269	283	276	271	287	272	**276**
Mean	**313**	**332**	**327**	**313**	**327**	**316**	
LSD (5%)	**RSC = 3.4 , Cultivar = 2.6 , RSC x Cultivar = 5.4,**						
Spike length (cm)							
RSC 0	9.0	9.5	10.1	9.4	8.6	11.1	**9.6**
RSC 3	8.8	9.3	9.5	9.1	8.4	10.7	**9.3**
RSC 6.5	7.9	9.1	9.4	8.6	8.1	9.7	**8.8**
RSC 10	7.5	8.5	8.4	8.2	7.6	8.7	**8.1**
Mean	**8.3**	**9.1**	**9.3**	**8.8**	**8.1**	**10.1**	
LSD (5%)	**RSC = 0.20 , Cultivar = 0.21 , RSC x Cultivar = 0.42**						

Table 6 Effect of alkali irrigation water on thousand grain weight and grain weight $spike^{-1}$across two years

Thousand grain weight (g)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
RSC 0	41.0	45.8	45.3	41.4	46.7	41.9	**43.7**
RSC 3	39.7	42.5	43.5	39.4	43.3	40.5	**41.5**
RSC 6.5	39.1	40.3	42.0	38.2	39.7	38.5	**39.6**
RSC 10	38.4	38.0	38.7	36.2	37.8	36.6	**37.6**
Mean	**39.6**	**41.6**	**42.4**	**38.8**	**41.9**	**39.4**	
LSD (5%)	**RSC = 1.0 , Cultivar = 1.4 , RSC x Cultivar = NS**						
Grain weight $spike^{-1}$ (g)							
RSC 0	1.8	2.5	2.2	1.9	2.2	1.9	**2.0**
RSC 3	1.6	2.3	2.0	1.6	1.8	1.7	**1.8**
RSC 6.5	1.5	2.0	1.9	1.4	1.5	1.3	**1.6**
RSC 10	1.3	1.7	1.4	1.2	1.1	1.1	**1.3**
Mean	**1.5**	**2.1**	**1.8**	**1.5**	**1.7**	**1.5**	
LSD (5%)	**RSC = 0.12 , Cultivar = 0.15, RSC x Cultivar = NS**						

4. CONCLUSIONS

Increasing RSC of irrigation water significantly increased soil pH, SAR and ESP in 2013-14 and 2014-15. At RSC 10 me L^{-1} soil pH remained higher than threshold value of 8.5 (except at 90-120cm) in both years. The SAR and ESP of soil have similar trend in first and second year but values were higher in magnitude for ESP than SAR. Irrigation with alkali water significantly increased soil bulk density and dispersion ratio, while all other physical properties (MWD, SHC, IR and WHC) decreased with increasing RSC levels. For water having RSC up to 6.5 me L^{-1} commercial cultivars PBW 621 and HD 2967 performed better; at par with salt tolerant (KRL210) cultivar developed by CSSRI, Karnal, India. However at RSC 10 me L^{-1}, cultivar PBW 621 produced high yield. Differential contribution of yield parameters (number of spikes m^{-2}, spike length, thousand grain weight and grain weight spike $^{-1}$) towards grain yield was observed for different wheat cultivars. Such differences can be exploited by the plant breeders to induce higher sodicity tolerance in newly developed wheat germplasms.

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PERFORMANCE OF SOME WHEAT CULTIVARS UNDER SALINE IRRIGATION WATER IN FIELD CONDITIONS

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PERFORMANCE OF SOME WHEAT CULTIVARS UNDER SALINE IRRIGATION WATER IN FIELD CONDITIONS

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Abstract

Most of crop salt tolerance studies are often conducted in glasshouse (hydroponics and pots) under controlled conditions and are limited under field conditions. Therefore, the present investigations were carried out to evaluate performance of six wheat cultivars for their salt tolerance on the experimental farm of the Punjab Agricultural University, Ludhiana, India irrigated with five levels of saline water (EC 0 EC 3, EC 6, EC 9 and EC 12 dS m^{-1}). Increasing salinity of irrigation water significantly increased soil pH, EC and SAR (without much difference in two years). Plant Na^+/K^+ ratio also increased with increase in salinity. Yield parameters of different cultivars (spike length, TGW, GWS and number of spikes m^{-2}) were affected more at higher salinity levels compared to low levels across two years. Data across two years revealed that up to EC 9 dSm^{-1} cultivars PBW 658 and HD 2967 were performed better on the basis of absolute yields but based on relative yield cultivar KRL 210 (salt tolerant) was on par with these cultivars and PBW 621 produced higher yield. At EC 12 dSm^{-1}, PBW 658 produce significantly higher grain yield (4.23 t ha^{-1}) than cultivar HD 2967 (4.11 t ha^{-1}) and PBW621 (3.99 t ha^{-1}), therefore should be preferred on water having salinity more than 9 dS m^{-1}.

KEYWORDS: Salinity levels, EC, cultivars, tolerance

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INTRODUCTION

Salinity is a major constraint to crop production in the arid and semiarid areas of the world, where low precipitation, high surface evaporation, irrigation with saline water, rising water tables and poor irrigation practices increase level of soluble salts (Hollington, 1998). Saline soils occupied 397 m ha area globally (FAO-AGL, 2000). Soil salinity problems can occur naturally (primary salinization) or as result of human activities (secondary salinization) (Minhas and Sharma, 2003). Secondary salinization is the gradual buildup of salt in previously salt free top soil as result of saline water irrigation. It is estimated that 20% of irrigated area is affected by secondary salinization (Hendawy et al., 2005). Soil salinity causes many adverse effects on plant growth by creating osmotic stress, ion toxicity and nutritional imbalance or a combination of these factors (Ashraf, 2004). All these factors adversely affect the plant growth, physiological and biochemical metabolism (Ashraf and Sarwar, 2002; Munns, 2002). Salts can suppress plant growth by specific and non-specific effects. Plant growth reduction due to non-specific salt effect is related to the osmotic potential of soil solution (Mass and Hoffman, 1977), on the other hand, high salt concentration cause ion toxicity stress by accumulating in cells of transpiring leaves (Munns and Termet, 1986). Salt accumulation in the soil can also negatively affect plant growth by reducing nutrient availability in the soil and decreasing uptake of essential nutrients and thereby causing nutritional imbalance in plants (Pessarakli, 1991; Grattan and Grieve, 1999)

Plant differs genetically in their response to salt tress. Salt tolerance of crops may vary with their growth stage (Maas and Grieve, 1994). In general, cereal plants are more sensitive to salinity during vegetative and early reproductive stages, and less sensitive during flowering and grain filling stage (Mass and Poss, 1989), however a difference in the salt tolerance among genotypes may also occur at different growth stages. Wheat is a moderately salt tolerant crop with threshold value of 6 dS m^{-1} above which significant yield reduction occur (Mass and Hoffman, 1977). As tolerance of crops to salinity and sodicity varies among different genotypes (Tester and Davenport, 2003; Munns, 2005; Munns and Tester, 2008), evaluation of new cultivars for their tolerance was warranted but most of salt tolerance studies are often carried out in hydroponics and pot experiments in glass house under controlled conditions (Khan et al., 2006, Hendaway et al., 2005, Asgari et al 2012., , Hussain et al., 2014) and are limited under field conditions (Houshmand et al., 2005, Ahmad et al., 2005). Therefore, the present field experiment was conducted on saline water irrigated soil to evaluate performance of wheat cultivars for their salt tolerance. Plant Na/K ratio of different wheat cultivars was also determined by wet digestion method (Page et al., 1982) at tillering stage for their salt tolerance.

MATERIAL AND METHODS

The experiment was conducted on the experimental farm of the Punjab Agricultural University, Ludhiana, India, (30° 56´ N, 75° 52´E 247 m above msl) for two years (2013-15) using six wheat cultivars (KRL210, PBW621, HD2967, PBW590, PBW658 and Berbet) and five levels of saline water (EC 0, EC 3, EC 6, EC 9 and EC 12 dS m^{-1}). The normal non-saline sandy loam soil classified as Typic Ustochrept had pH = 7.3; electrical conductivity (EC) (1:2 soil: water) = 0.30 dS m^{-1}; organic C = 2.9 g kg^{-1} and exchangeable sodium percentage (ESP) = 4.2 in 0–30 cm soil layer. Good quality water (EC 0), used as control had EC = 0.50 dS m^{-1}. Four levels of saline water EC 3, EC 6, EC 9 and EC 12 dS m^{-1} used in the study were created by dissolving requisite amounts of NaCl (1.77, 3.50, 5.31 and 7.08 g of NaCl per liter) in good quality water. The experimental field plots had been receiving respective saline irrigation water for 16 years before start of this experiment.

The experiment was laid out in split plot design with three replications and 20 cm row to row spacing was maintained between wheat cultivars. A basal dose of 165 kg N (urea), 30 kg P and (diammonium phosphate), 30 kg K (murate of potash) and 10 kg ha^{-1} (zinc sulphate) was uniformly applied to all plots. Wheat cultivars were sown on 17th November in 2013 and harvested on 25th April, 2014 in first year whereas in second these cultivars were sown on 1st November, 2014 and harvested on 20th April, 2015.Soil samples were taken in the third week of April each year from 0–15, 15–30, 30–60, 60-90 and 90-120 cm soil layers with an auger that was 4-cm in diameter. The soil samples were air-dried and ground to pass through a 2-mm sieve. Soil pH and EC of these samples were determined in 1:2 soil: water ratio and SAR was determined using methods given by Richards (1954). Yield parameters (spike length, thousand grain weight (TGW), grain weight per spike (GWS) and number of spikes m^{-2}) and grain yield of different wheat cultivars were recorded at maturity.

Statistical analysis:

Analysis of variance (ANOVA) was carried out using CPCS1 software and regression analysis was done using MINITAB 15 software.

RESULTS AND DISCUSSION

Soil chemical properties

pH

Soil pH significantly increased with increasing water salinity and soil depth in both years. The magnitude of increase was higher in plots receiving 9 and 12 dS m^{-1} levels of saline irrigation water compared with plots receiving lower and moderate salinity levels (3 and 6 dS m^{-1}). In 2013-14, mean soil pH increased from 7.34 in EC 0 to 7.81, 8.03, 8.11 and 8.23 at EC 3, 6, 9 and 12 dS m^{-1} salinity levels . Several workers reported similar results under saline water irrigation (Tedeschi et al., 2006; Ragab et al., 2008). With increasing depth from 0 to 120 cm pH narrowly increased from 7.80 to 7.95, respectively. Regardless of treatment, soil pH was higher at lower soil depths than surface soil layers which may be due to movement of salts to lower layers. These results were supported by Ghuman et al., (2010), who reported higher pH values at 15-30 cm compared to 0-15 cm soil depth. Fard et al.,

(2007) also reported more pH values for 15-30 cm over 0-15 cm soil depth. Similar trend was observed for soil pH in 2014-15.

Electrical conductivity (EC)

Soil EC increased with increase in irrigation water salinity similar to soil pH (Table 2) . However with increasing soil depth opposite trend to that observed for soil pH. Soil EC increased from 0.39 in control to 0.79, 1.58, 2.20 and 2.30 dS m^{-1} in 2013-14 and from 0.46 in EC 0 to 0.75, 1.62, 2.16 and 2.27 dS m^{-1} in 2014-15 at EC 3, 6, 9 and 12 dS m-1 salinity levels (not much significant difference in two years).

Table 1 Effect of saline irrigation water on soil pH in two years

2013-14						
Treatments /Depths	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	7.23	7.27	7.35	7.33	7.51	**7.34**
EC 3	7.65	7.80	7.99	7.78	7.85	**7.81**
EC 6	7.99	8.13	8.13	7.94	7.97	**8.03**
EC 9	8.03	8.15	8.20	8.03	8.15	**8.11**
EC 12	8.13	8.21	8.33	8.19	8.28	**8.23**
Mean	**7.80**	**7.91**	**8.00**	**7.85**	**7.95**	
LSD (5%)	**EC = 0.07 Depth = 0.05 EC x Depth = 0.10**					
2014-15						
EC 0	7.20	7.29	7.38	7.41	7.46	**7.34**
EC 3	7.34	7.48	7.59	7.69	7.75	**7.57**
EC 6	7.80	7.88	7.97	8.08	8.15	**7.97**
EC 9	8.07	8.18	8.23	8.26	8.31	**8.21**
EC 12	8.20	8.27	8.31	8.35	8.43	**8.31**
Mean	**7.72**	**7.82**	**7.89**	**7.96**	**8.02**	
LSD (5%)	**EC = 0.006 Depth = 0.02 EC x Depth = 0.04**					

Increase in soil salinity occurs due to cumulative salt build up due to irrigation with different levels of saline water. Mostafa et al., (2012) reported that increasing Na^+ concentration in irrigation water significantly increased soil salinity. Soil EC gradually decreased with increasing soil depth from 0 to 120 cm in both years. These results are in agreement with Fard et al., (2007) and Ghuman et al., (2008). Interaction effects were significant for soil EC in both years. At EC 3, soil salinity decreased from 1.61 to 1.02 as soil depth increased from 60-90 to 90-120 cm in 2013-14, however in next year (2014-15), this decrease at respective depths was less (from 1.52 to 1.36).

Table 2 Saline irrigation water effect on soil EC (dS m^{-1}) in 2013-14 and 2014-15

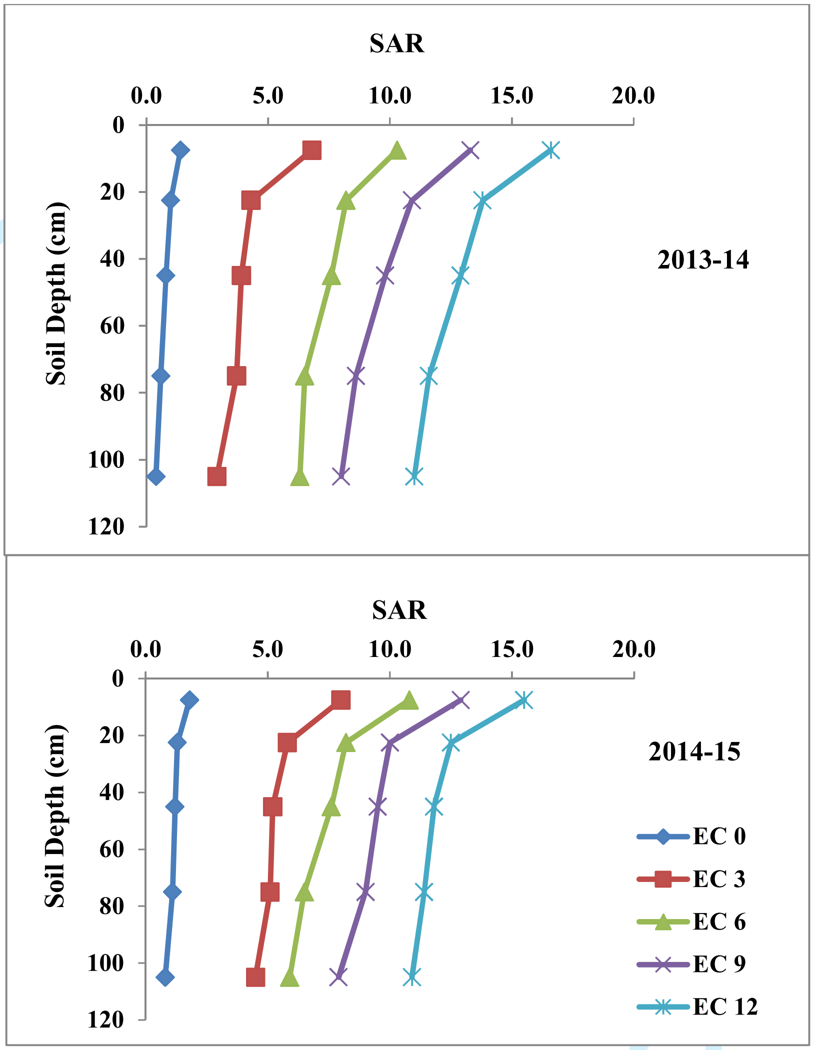
2013-14						
Treatments /Depths	**0-15**	**15-30**	**30-60**	**60-90**	**90-120**	**Mean**
EC 0	0.56	0.43	0.37	0.33	0.27	**0.39**
EC 3	0.89	0.85	0.77	0.74	0.70	**0.79**
EC 6	1.91	1.74	1.64	1.61	1.02	**1.58**
EC 9	2.32	2.27	2.21	2.15	2.09	**2.20**
EC 12	2.45	2.37	2.30	2.23	2.16	**2.30**
Mean	**1.62**	**1.53**	**1.45**	**1.41**	**1.24**	
LSD (5%)	**EC = 0.04 Depth = 0.02 EC x Depth = 0.05**					
2014-15						
EC 0	0.61	0.54	0.45	0.37	0.31	**0.46**
EC 3	0.91	0.83	0.72	0.68	0.57	**0.75**
EC 6	1.88	1.76	1.60	1.52	1.36	**1.62**
EC 9	2.32	2.20	2.16	2.10	2.05	**2.16**
EC 12	2.41	2.34	2.27	2.20	2.13	**2.27**
Mean	**1.62**	**1.53**	**1.44**	**1.37**	**1.28**	
LSD (5%)	**EC = 0.02 Depth = 0.01 EC x Depth = 0.05**					

Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) is an indicator of amount of sodium relative to Ca + Mg and is considered an index of Na hazard. Data in Fig. 1 showed that SAR increased significantly with increasing salinity levels in 2013-14 and 2014-15. In general SAR values in the surface layer (0-15cm) ranged from 15-20 at EC 9 and 12 dSm^{-1}, whereas values were around 10 at EC 6 dSm^{-1} in both years. In 2014-15 SAR value at EC 12 dSm^{-1} decreased to around 15 compared with 2013-14 , where it remained close to 20.

SAR of the soil progressively increased due to addition of Na through saline irrigation water, which resulted in significant increase in Na in proportion to Ca+Mg resulting in substantial increase in SAR in both years. Fig. 1 also depicted that with increasing soil depth SAR values decreased in all treatments. This decrease was sharp at 15-30 cm soil depth, whereas at lower soil layers decrease in SAR values were gradual in both years. Fard et al., (2007) reported that increasing irrigation water salinity resulted in increase SAR of soil and effects were more in surface as compare to sub surface soil layers.

Figure 1 Sodium adsorption ratio (SAR) as affected by salinity of irrigation water in two years



Yield parameters and grain yield

Plant Na^+/K^+ ratio:

Plant Na^+/K^+ ratio at tillering significantly increased from 0.53 to 1.81 with increasing water salinity. Among the cultivars, however, plant Na/K ratio was statistically at par across two years (Table 3). Average plant Na^+/K^+ among different cultivars ranged from 1.03 in KRL 210 and PBW 590 to 1.12 in HD 2967.

Table 3 Effect of saline irrigation water on plant Na/ K ratio and spike length of different cultivars pooled over two years

Plant Na^+/K^+ ratio							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	0.44	0.49	0.65	0.54	0.55	0.51	**0.53**
EC 3	0.61	0.63	0.80	0.68	0.74	0.69	**0.69**
EC 6	0.91	0.98	1.06	0.96	0.96	1.00	**0.98**
EC 9	1.37	1.36	1.29	1.22	1.33	1.34	**1.32**
EC 12	1.83	1.91	1.79	1.73	1.82	1.82	**1.81**
Mean	**1.03**	**1.07**	**1.12**	**1.03**	**1.08**	**1.07**	
LSD (5%)	**EC = 0.16 ,Cultivar = NS , EC x Cultivar = NS**						
Spike length (cm)							
EC 0	8.6	9.2	9.5	9.8	9.5	10.3	**9.5**
EC 3	8.3	8.7	9.2	9.5	9.4	9.9	**9.1**
EC 6	7.9	8.1	8.7	9.2	9.0	9.7	**8.7**
EC 9	7.5	7.5	8.1	8.7	8.4	9.4	**8.2**
EC 12	7.0	7.1	7.6	7.9	7.6	8.9	**7.6**
Mean	**7.8**	**8.1**	**8.6**	**9.0**	**8.8**	**9.6**	
LSD (5%)	**EC = 0.22 , Cultivar = 0.32 , EC x Cultivar = NS**						

These results suggests that plant Na^+/K^+ ratio in the present study does not reflect the salt tolerance of different wheat cultivars under field conditions. Genetic constitution seems to play more important role in their tolerance to salinity

Spike length (cm)

Mean spike length significantly decreased from 9.5 in control to 9.1, 8.7, 8.2 and 7.6 cm at EC 3, 6 9 and 12 dS m^{-1} salinity levels. In a pot experiment, Kumar et al., (2012) also reported decrease in average spike length from 10.8 to 7.1 cm for eight wheat cultivars as salinity increased from 0 to 12 dS m^{-1}. Similarly Ahmad et al., (2005) observed that mean spike length of six wheat cultivars decreased from 9.8 to 8.4 cm in saline soil (ECe = 12dS m^{-}

^{1}) compared to normal soil (ECe = 1.9 dS m^{-1}). Maximum spike length was observed for cultivar Berbet (10.3 and 8.9 cm) at EC 0 and EC 12 whereas minimum was reported in KRL 210 (8.6 and 7.0 cm) at respective salinity levels. The maximum rate of decrease was observed in cultivar PBW 621 at each salinity level, whereas minimum was reported in cultivar Berbet at EC 9 and 12 dS m^{-1}. The percentage decrease in spike length of different cultivars (KRL 210, PBW621, HD 2967, PBW 590, PBW 658 and Berbet) was 18.6, 22.8, 20.0, 19.4, 20.0 and 13.6% at EC 12 dS m^{-1} over EC 0.

Thousand grain weight

Compared to EC 0, average thousand grain weight (TGW) decreased by 3.1, 6.3, 8.5 and 13.3 % at EC 3, 6 9 and 12 dS m^{-1} salinity level. Asgen et al., (2012) reported decrease in TGW of four wheat cultivars from 43.5 to 27.0 g as salinity of irrigation water increased from 3 to 16 dS m-1. Houshmand et al., (2005) reported decrease in average TGW of eight wheat cultivars from 44.5 to 21.3 g in saline soil (EC = 3.8 dS m^{-1}) as compared to normal soil (EC = 1.1 dS m^{-1}). Salinity stress at grain filling stage can cause decrease in photosynthates mobilization to grains and thereby decreasing grain weight (Sadeghipour, 2008). Among different wheat cultivars average maximum and minimum TGW was observed for cultivar Berbet (43.1 g) and PBW 621 (38.8g). PBW 590 and PBW 621 had similar TGW when irrigated with EC 0 and 3 dS m^{-1} salinity level but at EC 6 dS m^{-1} or above TGW was more for PBW 590 cultivar than later. PBW 621 and HD 2967 have similar TGW up to EC 6 dS m^{-1} but at higher salinity levels (EC 9 and 12 dS m^{-1}) TGW was more in HD 2967 compared to PBW 621. TGW for cultivars KRL 210 and HD2967 was at par for EC 0 and EC 12 dS/m across two years.

Grain weight spike $^{-1}$

The average grain weight spike $^{-1}$ significantly decreased by 13.0, 21.7, 34.7 and 43.4 % at EC 3, 6, 9 and 12 dSm^{-1} compared to EC 0 across two years. Compared to control (EC

0), the decrease grain weight spike $^{-1}$ was similar for cultivars PBW 590 and PBW 658 with increasing salinity of irrigation water . The maximum decrease at each level of increasing salinity was observed in KRL 210 (salt tolerant) and minimum in PBW 621. The maximum (1.9 g) and minimum average (1.6 g) grain weight spike $^{-1}$ was reported for cultivars HD 2967 and PBW 590 and was on par for cultivars KRL 210, PBW 658 and Berbet.

Number of spikes/ m^2

Average number of spikes m^{-2} decreased from 319 to 228 at EC 12 dS m^{-1} salinity level compared to EC 0 across two years (Table 4). Houshmand et al., (2005) reported that average number of spikes m^{-2} decreased from 507 to 430 in saline soil (EC = 3.8 dS m^{-1}) as compared to normal soil (EC = 1.1 dS m^{-1}). Similar findings were also reported by Ahmad et al., (2005). Out of different wheat cultivars maximum and minimum average spike number was reported in cultivar HD 2967 and PBW 590 across two years. At each salinity level number of spikes m^{-2} were decreased by almost same magnitude for cultivar PBW658 and Berbet. Among different wheat cultivars, PBW 590 recorded the minimum decrease in number of spikes m^{-2} at all salinity levels. Cultivar KRL 210 has the maximum number of spikes /m^2 under EC 0 treatment but it showed more decline , thus had the minimum number when irrigated with EC 12 dS m^{-1} water among all cultivars. Number of spikes m^{-2} were higher in PBW 658 up to EC 9 dS m^{-1} compared to PBW 590 but at EC 12 dS m^{-1} number of spikes m^{-2} for both cultivars were at par. Significant interaction effects were observed for number of spikes m^{-2} for salinity levels and cultivars.

Table 4 Saline irrigation water effect on TGW, grain weight spike $^{-1}$ and number of spikes m^{-2} of different cultivars across two years

Thousand grain weight (g)							
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	42.0	42.3	42.3	41.3	42.9	45.1	**42.6**
EC 3	41.0	40.4	40.8	40.4	40.9	44.8	**41.3**
EC 6	40.1	38.3	38.7	39.3	39.6	43.3	**39.9**
EC 9	38.9	37.6	38.1	38.5	38.3	42.9	**39.0**
EC 12	36.8	35.7	36.5	37.1	36.0	39.4	**36.9**
Mean	**39.7**	**38.8**	**39.3**	**39.3**	**39.5**	**43.1**	
LSD (5%)	**EC = 0.8 ,Cultivar = 1.2 , EC x Cultivar = NS**						
Grain weight spike^{-1}							
EC 0	2.6	2.1	2.4	2.2	2.4	2.3	**2.3**
EC 3	2.0	1.9	2.1	1.9	2.1	2.1	**2.0**
EC 6	1.9	1.8	2.0	1.6	1.8	1.8	**1.8**
EC 9	1.6	1.5	1.6	1.4	1.5	1.4	**1.5**
EC 12	1.3	1.3	1.5	1.2	1.5	1.3	**1.3**
Mean	**1.8**	**1.7**	**1.9**	**1.6**	**1.8**	**1.8**	
LSD (5%)	**EC = 0.14 ,Cultivar = 0.16 , EC x Cultivar = NS**						
Number of spikes/m^2							
EC 0	325	320	333	298	321	319	**319**
EC 3	290	292	304	278	293	290	**292**
EC 6	269	268	271	264	277	272	**270**
EC 9	254	251	260	246	263	251	**254**
EC 12	218	224	244	229	229	228	**228**
Mean	**271**	**271**	**282**	**263**	**276**	**272**	
LSD (5%)	**EC = 3.8 ,Cultivar = 2.8 , EC x Cultivar = 6.3**						

Grain yield

Increasing salinity of irrigation water significantly decreased mean grain yield by 3.2, 8.8, 16.0 and 22.9 percent at EC 3, 6, 9 and 12 dS m^{-1} compared to EC 0 across two years (Table 5). Phogat et al (2011) reported decrease in average grain yield of wheat crop from 5.02 to 3.16 Mg ha $^{-1}$ as irrigation water salinity increased from 0.4 to 8.4 dS m^{-1} in two years research study. Houshmand et al (2005) also reported significant effect of salinity on grain yield reduction.

Table 5 Grain yield (t/ha) of different wheat cultivars as affected by saline irrigation water (2013-15)

			2013-14				
Treatment	**KRL210**	**PBW621**	**HD2967**	**PBW590**	**PBW658**	**Berbet**	**Mean**
EC 0	5.35	5.06	5.27	4.75	5.32	5.17	**5.15**
EC 3	5.12	4.82	5.06	4.67	5.14	4.95	**4.96**
EC 6	4.90	4.74	4.96	4.29	4.82	4.65	**4.73**
EC 9	4.44	4.39	4.54	4.08	4.47	4.16	**4.35**
EC 12	3.87	3.92	4.05	3.89	4.26	3.91	**3.98**
Mean	**4.74**	**4.58**	**4.78**	**4.34**	**4.80**	**4.57**	
LSD (5%)	**EC = 0.22 ,Cultivar = 0.26 , EC x Cultivar = NS**						
			2014-15				
EC 0	5.22	5.16	5.37	4.85	5.54	5.07	**5.20**
EC 3	5.16	5.02	5.25	4.74	5.32	4.87	**5.06**
EC 6	4.80	4.64	4.93	4.34	5.01	4.59	**4.71**
EC 9	4.36	4.43	4.49	4.23	4.47	4.16	**4.35**
EC 12	3.91	4.05	4.17	3.75	4.19	3.88	**3.99**
Mean	**4.69**	**4.66**	**4.84**	**4.38**	**4.91**	**4.51**	
LSD (5%)	**EC = 0.14 ,Cultivar = 0.09 , EC x Cultivar = NS**						
			Pooled data				
EC 0	5.29	5.11	5.32	4.80	5.43	5.12	**5.18**
EC 3	5.14	4.92	5.16	4.71	5.23	4.91	**5.01**
EC 6	4.85	4.69	4.95	4.32	4.92	4.62	**4.72**
EC 9	4.40	4.41	4.52	4.16	4.47	4.16	**4.35**
EC 12	3.89	3.99	4.11	3.82	4.23	3.90	**3.99**
Mean	**4.71**	**4.62**	**4.81**	**4.36**	**4.85**	**4.54**	
LSD (5%)	**EC = 0.12 ,Cultivar = 0.14 , EC x Cultivar = NS**						

The decrease in grain yield can be attributed to low germination and reduction in number of spikes and spikelets (Mass et al 1996; Singh and Chatrath 2001). Among different wheat cultivars maximum mean grain yield was recorded in cultivar PBW 658 (4.85 t ha^{-1}) followed by HD 2967(4.81 t ha^{-1}), whereas the minimum grain yield was observed for PBW 590 (4.36 t ha^{-1}) across two years. Cultivars PBW 621 and Berbet have similar grain yield up to EC 6 dS m^{-1} salinity level but at higher salinity (EC 9 and EC 12 dS m^{-1}), PBW 621 had more grain yield than later. When irrigated with EC 0 and EC 3 dS m^{-1} cultivars KRL 210 and HD 2967 have similar yields but above EC 6 dS m^{-1} HD 2967 outperformed KRL 210. Out of PBW 590 and Berbet salt tolerance was more for Berbet up to EC 6 dS m^{-1}, but at EC 9 dS m^{-1} grain yield of both cultivars was at par. Compared to EC 0, maximum percentage decrease in grain yield was observed for cultivar KRL 210 (26.4%) (salt tolerant) and minimum in PBW 590 (20.4%) at EC 12 dS m^{-1} across two years.

These results suggests that across two years, at EC 9 dSm^{-1}, performance of PBW 658 and HD 2967 in absolute grain yield was similar and higher than other cultivars but cultivar PBW621 produced 86 % relative yield compared to 84% for cultivar HD2967 and 82% (yield relative to good quality water (EC 0) for PBW 658. Based on relative yield, salt tolerant cultivar released by CSSRI, Karnal (KRL 210) (83%) was on par with these cultivars. At EC 12 dSm^{-1} , cultivar PBW 658 produced higher grain yield (4.23 t ha^{-1}) followed by cultivar HD 2967 (4.11 t ha^{-1}) and PBW621 (3.99 t ha^{-1}). However salt tolerant KRL 210 (3.89 t ha^{-1}) and Berbet (3.90t ha^{-1}) yielded slightly lower.

Regression equations were computed to identify the most important yield parameter affecting grain yield of each cultivar. Based on the correlation of grain yield with their yield parameters (spike length, TGW, GWS and number of spikes m^{-2}), six cultivars can be divided into two groups. In the first group (PBW 621, HD 2967 and PBW 658), spike length was the most important yield attribute influencing yield as this parameter explained about 80%

variation in grain yield in these cultivars. In the other group (KRL 210, PBW 590 and Berbet), number of spike m^{-2} was the most important yield parameter impacting grain yield (>80% grain yield). For cultivars KRL 210 and PBW 590, predictability of grain yield further improved 94.6 and 91.0% from 89.5 and 87.1%, respectively when spike length was included along with number of spikes as other variable. For other four cultivars, however, inclusion of other yield parameter along with the principal yield parameter did not improve the predictability further substantially (up to 2% only) (Table 6). These results suggest that contribution of single yield parameter (spike length for PBW 621, HD 2967 and PBW 658 and number of spike m^{-2} for KRL 210, PBW 590 and Berbet) to grain yield was similar in two groups of wheat cultivars. Such information can be helpful for plant breeders and biotechnologists to identify most important yield parameter to bring improvement on tolerance of different wheat cultivars which are able to perform better in saline soils.

Table 6 Relationship of grain yields of wheat cultivars with yield parameters

Cultivars	**R^2**
KRL 210 **(1) GY =1.001 + 0.014 SPIKES** **(2) GY = -0.515 + 0.008 SPIKES + 0.39 SL**	 **89.5**** **94.6****
PBW 621 **(1) GY = 0.8402 + 0.47 SL** **(2) GY = 0.9350 + 0.32 SL + 0.004 SPIKES**	 **83.3**** **85.3****
HD 2967 **(1) GY = 0.0831 + 0.55 SL** **(2) GY = 0.2637 + 0.39 SL + 0.004 SPIKES**	 **78.4**** **79.9****
PBW 590 **(1) GY = 0.5392 + 0.015 SPIKES** **(2) GY = 0.0771 + 0.009 SPIKES + 0.18 SL**	 **87.1**** **91.0****
PBW 658 **(1) GY = -0.3357 + 0.59 SL** **(2) GY = -0.2206 + 0.43 SL + 0.0046 SPIKES**	 **84.8**** **86.8****
Berbet **(1) GY = 0.7581 + 0.013 SPIKES** **(2) GY = - 0.1951 + 0.0120 SPIKES + 0.034 TGW**	 **83.7**** **85.0****

(Abbreviations used: GY = grain yield, SL = spike length, TGW = thousand grain weight, GWS = grain weight spike^{-1} SPIKES = number of spikes $m^{-2)}$

CONCLUSIONS

Increasing salinity of irrigation water significantly increased soil pH, EC and SAR in 2013-14 and 2014-15 years. Magnitude of increase was higher for these soil parameters receiving saline irrigation of 9 and 12 dS m^{-1}water compared with plots receiving lower salinity waters .With increasing soil depth, however, opposite trend was observed. There was not much difference observed for SAR values in both years. Plant Na^{+}/K^{+} ratio was statistically at par for different cultivars across two years. Yield parameters were adversely affected by increasing salinity of irrigation water. For cultivars PBW 621, HD 2967 and PBW 658, spike length was the most important yield attribute influencing yield (explained about 80% variation in grain yield) in these cultivars. However for KRL 210 (salt tolerant), PBW 590 and Berbet, number of spike m^{-2} was the most important yield parameter impacting grain yield (>80% grain yield). At EC 9dS m^{-1}, cultivar HD 2976 was more tolerant to salinity can be grown without much significant reduction in yield than other cultivars but at higher salinity levels PBW 658 should be a preferred choice. Research efforts need to be continued to evaluate performance of new released high-yielding wheat cultivars under saline irrigation waters to identify the most important yield parameters of suitable wheat cultivars influencing their grain yield in saline soils.

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IRRIGATION INDUCED SALINIZATION EFFECTS ON SOIL BIOLOGICAL PROPERTIES

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Abstract

Secondary soil salinilization is a big problem in irrigated agriculture. We studied the effects of irrigation-induced salinity on soil biological properties under cotton-wheat rotation on experimental farm, Punjab Agricultural University, Ludhiana, India. Fresh soil samples were collected at 0-15 cm and 15-30 cm soil depth from experimental site irrigated with five levels of saline water having EC 0, EC 3 EC 6, EC 9 and EC 12 dS m^{-1} at the end of two year experiment. These soil samples were analyzed for soil chemical properties (pH, electrical conductivity, SAR), soluble ions (Na^+, $K^{+,}$ Ca^{+2}+Mg^{+2} and Cl^-) , soil fertility (organic C , available N and P) and biological properties (microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), dehydrogenase enzyme activity (DHA) and cold water extractable carbon (CWOC)). Increasing salinity of irrigation water significantly increased soil pH, EC, SAR, soluble Na^+ and Cl^- content and decreased organic C, N and P content at two soil depths. Compared to EC 0, DHA, MBC and CWOC decreased by about 50 % and MBN by 70% at highest salinity level (EC 12 dS m^{-1}). Although values for soil biological properties were more at 0-15 cm than 15-30 cm but percentage decrease at EC 12 dS m^{-1} was almost same for two soil depths. We concluded that at higher salinity levels (EC 9 and 12 dS m^{-1}), soil chemical and biological properties were more affected compared to low salinity levels.

Keywords: Salinity, MBC, MBN, Soil depth

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INTRODUCTION

Soil salinity is a part of natural ecosystems under arid and semi-arid conditions and an increasing problem in agricultural soil throughout world (Keren 2000; Qadir et al 2000) Primary salinization is a natural phenomenon involving accumulation of salts through natural processes due to salt content accumulating due to weathering of rocks and minerals particularly salt rich parent materials. Secondary salinity developed due to irrigation is widely responsible for reducing soil and water quality, limiting crop growth, and leading to the abandonment of agricultural lands (Shirokova et al. 2000; Egamberdieva et al. 2007). Indiscriminate flood irrigation with poor drainage facilities, overexploitation of groundwater, recycling of drainage outflows for irrigation and mono-cropping of high water consumptive crops are the major factors accelerating secondary soil salinization in Mediterranean regions and in Central Asia (Qushimov et al. 2007). While the effects of soil salinity on other soil properties and plant growth are well known (Garcia and Hernandez 1996; Nelson et al. 1997; Kaur et al. 1998; Nelson and Oades 1998), information related to irrigation-induced secondary salinity effects on soil biological properties are limited and inadequate (Rietz and Haynes 2003; Tripathi et al. 2006).

Soil microbial communities and their activity are greatly influenced by salinity because microbial processes in soils control ecological function and soil fertility (Rietz and Haynes, 2003). Soil microflora plays an important role in maintaining / enhancing soil quality by regulating organic matter decomposition, nutrient availability and enhancing macro-aggregate formation.. The microbial biomass carbon (MBC) is an important component of soil organic matter and comprises 1-3% of total organic carbon (Nieder et al. 2008). It has a rapid turnover rate and is also considered to be a reservoir of labile nutrients. The microbial biomass and water-extractable pools of soil organic carbon are considered sensitive indices that characterize changes in biological conditions caused by soil management practices.

Microbial biomass is also a potential source of enzymes in soil. Among the different enzymes in soils, dehydrogenase, β-glucosidase, urease and phosphatases are important in the transformation of different plant nutrients. Dehydrogenase activity reflects the total oxidative activity of the microbial biomass (Nannipieri et al., 1990) and being involved in central aspect of metabolism. Thus, microbial parameters are sensitive indicators of changes of soil quality in response to management practices or environmental stress (Islam and Weil 2000; Rietz and Haynes 2003; Wang et al. 2008)

Earlier Egamberdieva et al. (2010) evaluate the effect of irrigation-induced salinity on soil microbial biomass and soil chemical properties under mono-cropping cotton system for 0-30 cm soil, but they have not studied soil biological properties such as microbial biomass nitrogen, dehydrogenase enzyme activity and cold water extractable carbon. Therefore, we studied these biological properties including microbial biomass carbon, at two soil depths (0-15 cm and 15-30 cm) under long-term cotton- wheat rotation with five levels of irrigation water salinity.

MATERIAL AND METHODS

Soil sampling

Fresh soil samples were collected from ongoing long term experiment (18 years) at two soil depths 0-15 and 15-30 cm irrigated with five salinity levels under cotton-wheat rotation at research farm of Department of Soil Science, Punjab Agricultural University, Ludhiana, India (30° 56´ N, 75° 52´E 247 m above msl) in April, 2015, after two years of experiment study . The normal non-saline sandy loam soil classified as Typic Ustochrept had pH = 7.3 ; electrical conductivity (EC) (1:2 soil: water) = 0.30 dS m-1; organic C = 2.9 g/kg and exchangeable sodium percentage (ESP) = 4.2 in 0–30 cm soil layer. Good quality canal water (CW), used as control treatment, had EC = 0.50 dS m^{-1}. Four levels of saline water EC

3, EC 6, EC 9 and EC 12 dS m-1 used in the study were created by dissolving requisite amounts of NaCl (1.77, 3.50, 5.31 and 7.08 g of NaCl per liter in CW, respectively).

Soil analysis

Moist soil samples were gently sieved through a 2-mm mesh and analyzed for soil biological properties. Another portion of the field-moist soil was air dried at room temperature, ground and analyzed for chemical properties. The MBC was determined by the chloroform fumigation-extraction method (Vance et al. 1987). The microbial biomass carbon was calculated as follows: microbial biomass carbon (mg Ckg/ soil) = $(C_f - C_{uf}) K_{ec}^{-1}$ where, Cf is the 0.5 M K_2SO_4 extractable organic C in chloroform fumigated soil, Cuf is the 0. 5 M K_2SO_4 extractable organic C in unfumigated soil, and Kec is the conversion factor. Microbial Biomass Nitrogen is calculated as Microbial biomass N = EN / kEN, Where EN = (total N extracted from fumigated soils) _ (total N extracted from non-fumigated soils) and kEN = 0.54 (Brookes *et al* 1985 and Joergensen and Mueller 1996). Total N in the extracts was measured using the Kjeldahl method (Bremner and Mulvaney 1982 and Brookes *et al* 1985). Cold water-extractable organic carbon was determined by shaking 10 g of soil with 50 mL of distilled water for 30 min and then centrifuging for 10 min at 5 000 rpmi (Ghosh, 2003). The organic carbon in the supernatant was measured by the dichromate digestion method (Walkley and Black, 1934). Dehydrogenase enzyme activity was assayed by the method given by Casida et al. (1964). Soil samples were incubated with 2,3,5-triphenyl tetrazolium chloride at 37 °C for 24 h and the production of triphenyl formazan (TPF) was measured.

Organic carbon, available nitrogen and phosphorous was determined by (Walkley and Black, 1934, Alkaline- Permanganate Method (Subbiah and Asija 1965) and 0.05M $NaHCO_3$ at pH 8.5 by Olsen *et al* 1954) respectively. Soluble ions were determined using method described by Richards (1954). Soil texture was determined according to International pipette method (ISSS 1929) and soil pH and electrical conductivity in a 1:2 (w/v) soil-aqueous suspension were measured using potentio-metric method and salt bridge method as described by Richards (1954)

STATISTICAL ANALYSIS

Significant variations in selected chemical and biological properties due to the effect of variable salinity levels were evaluated by the analysis of variance (ANOVA) using CPCS1 software

RESULTS AND DISCUSSION

Soil chemical properties

Increasing irrigation water salinity (ECiw) levels increased soil pH and EC at 0-15 and 15-30 cm soil depths (Table 1). Soil EC significantly and progressively increased from 0.61 in CW to 0.91, 1.88, 2.32 and 2.41 dS m^{-1} at 0-15 cm and from 0.54 in CW treatment to 0.83, 1.76, 2.20 and 2.35 dS m-1 at ECiw 3, 6, 9 and 12 dS m^{-1} salinity levels, respectively. Organic carbon, N and P significantly decreased at two soil depths with increasing salinity of irrigation water. This reduction in OC content may be due to less and more stressed microbial biomass in highly saline soils (Rietz and Haynes 2003). Average OC content decreased from 3.9 to 1.7 g kg^{-1} at 0-15 cm and 3.4 to 1.5 g kg^{-1} for 15-30 cm soil depth as salinity levels increased from EC 0 (CW) to EC 12 dS m-1 . Yuan *et al* (2007) reported decrease in soil OC content from 10.7 to 3.07 g kg^{-1} as soil salinity increased from 0.3 to 23.1 mS m^{-1}. Compared to CW (EC 0) treatment Available N decreased by 50% at highest level of salinity (EC 12 dS m^{-1}) at both the soil depths. The presence of salts in soil affects N availability through inhibition of microbial N mineralization and immobilization processes and also by increasing soil pH (Grattan and Grieve 1999). Available P content decreased from 45.6 kg ha^{-1} in EC 0 treatment to 40.9, 36.7, 29.1 and 22.8 kg ha^{-1} for 0-15 cm and from 37.8 (CW) to 32.4, 28.7, 24.2 and 20.7 at 15-30 cm soil depth at EC 3, 6, 9 and 12 dS m^{-1} respectively. Awad *et al* (1990) reported that with increasing NaCl salinity from 10 to

100mM in the solution culture, P activity decreased as a result of increased ionic strength and competition caused due to high Cl^- ions. Mashali *et al* (2009) reported decrease in available P with increasing salinity of irrigation water which they attributed to increased soil calcium (Ca) and precipitated as Ca-phosphate compounds. These results were supported by Aslam *et al* (1996).

Table 1 Secondary salinity effects on soil pH, EC, SAR, organic C and Available N and P content (0–15 and 15-30 cm soil depth)

Treatments	**Soil depths**					
	0-15 cm					
	pH	**EC**	**SAR**	**OC**	**N**	**P**
EC 0	7.20	0.61	1.8	3.9	146.2	45.6
EC 3	7.34	0.91	8.0	3.2	133.2	40.9
EC 6	7.80	1.88	10.8	2.7	121.5	36.7
EC 9	8.07	2.32	12.9	2.2	99.4	29.1
EC 12	8.20	2.41	15.5	1.7	83.6	22.8
LSD (*p*= 0.05)	**0.05**	**0.04**	**2.8**	**0.44**	**1.12**	**4.8**
15-30 cm						
EC 0	7.29	0.54	1.3	3.36	135.8	37.8
EC 3	7.48	0.83	5.8	2.90	127.4	32.4
EC 6	7.88	1.76	8.2	2.30	113.2	28.7
EC 9	8.18	2.20	10.0	2.00	91.3	24.2
EC 12	8.27	2.35	12.5	1.50	80.5	20.7
LSD (*p*= 0.05)	**0.05**	**0.02**	**2.0**	**0.48**	**2.60**	**5.1**

EC (dSm^{-1}), OC ($g\ kg^{-1}$) and N and P were measured in kg ha^{-1}units

The concentration of soluble Na^+, K^+ and Cl^- were significantly influenced by irrigation water salinity whereas non significant results were observed for $Ca+Mg^{+2}$ at two soil depths (Table 2). Soluble Na^+ content significantly increased with increasing salinity whereas soluble K^+ content decreased significantly with increasing salinity of irrigation water because saline waters dominated with NaCl suppressed potassium solubility**.** El-Boraie (1997) reported that soluble K^+ decreased with increasing salinity levels. Sodium adsorption ratio (SAR) significantly increased from 1.8 to 15.5 at 0-15 cm and from 1.3 to 12.5 for 15-30 cm at EC 12 dS m^{-1} compared to CW treatment. Mahdy (2011) reported that SAR increased from 5.29 to 8.27 with increasing salinity of irrigation water from 0.5 to 8.70 dS m^{-1} . Fard *et al* (2007) also reported that increasing irrigation water salinity resulted in increased SAR and effects were more in surface as compared to sub surface soil layer. Soluble Cl^- content increased from 0.5 in EC 0 to 2.5, 4.0, 5.1 and 6.2 me L^{-1} at 0-15 cm and 0.4 in CW treatment to 1.9, 3.5, 4.7 and 6.0 me L^{-1} at EC 3, 6, 9 and 12 dS m^{-1}, respectively. Soluble Cl^- content increased due to addition of NaCl through saline irrigation water. Similar results were also reported by Mahdy (2011).

Table 2 Secondary salinity effect on soluble ions (0–15 and 15-30 cm soil depth)

Treatments	**Soil depths**			
	0-15 cm			
	Na	**Ca+Mg**	**K**	**Cl**
EC 0	0.9	0.49	6.3	0.5
EC 3	3.9	0.47	5.3	2.5
EC 6	5.0	0.43	4.9	4.0
EC 9	5.7	0.39	3.4	5.1
EC 12	6.3	0.33	3.0	6.2
LSD (*p*= 0.05)	**0.14**	**NS**	**0.59**	**0.65**
	15-30 cm			
EC 0	0.6	0.44	5.7	0.4
EC 3	2.6	0.41	5.1	1.9
EC 6	3.6	0.38	3.5	3.5
EC 9	4.1	0.34	2.8	4.7
EC 12	4.8	0.29	2.2	6.0
LSD (*p*= 0.05)	**0.14**	**NS**	**0.20**	**0.65**

Soil biological properties

Soil biological properties were adversely affected by salinity of irrigation water (Table 3). DHA significantly decreased by 2 times at 0-15 cm and 3 times for 15-30 cm soil depth at EC 12 dS m^{-1} salinity level compared with respective (CW) treatments. This decrease in DHA may be due lower microbial biomass present in highly saline soils (Garcia *et al* 1994). Batra and Manna (1997) observed that DHA decreased significantly from 48.8 to 21.5 µg TPF hr g^{-1} soil as salinity of soil saturation extract increased from 28 to 40.8 dS m^{-1} in 0-15 cm soil layer.

Table 3 Secondary salinity effect on DHA, MBC, MBN and CWEC (0–15 and 15-30 cm soil depth)

Treatments	**Soil depths**			
	0-15 cm			
	DHA	**MBC**	**MBN**	**CWEC**
EC 0	33.2	236.4	94.4	66.0
EC 3	29.8	187.5	78.5	61.8
EC 6	25.1	166.8	55.6	50.4
EC 9	21.3	127.3	29.3	43.7
EC 12	15.0	111.5	22.2	35.9
LSD (*p* = 0.05)	**3.3**	**3.7**	**3.3**	**6.9**
15-30 cm				
EC 0	26.2	225.2	80.4	51.3
EC 3	23.5	173.8	59.5	48.7
EC 6	19.3	138.5	42.3	39.2
EC 9	13.5	110.6	24.8	32.5
EC 12	9.9	87.7	18.6	27.1
LSD (*p* = 0.05)	**4.5**	**2.5**	**2.6**	**5.8**

Tripathi *et al* (2007) observed that DHA activity decreased by 17.6 & 26.1 %, 41.5 & 44.4 % and 55.8 & 74.4 % during monsoon, winter and summer season at ECe 6.9 dS m^{-1} over control. They reported that more decrease in DHA in summer season due to lesser microbial biomass due to soil desiccation and increased salinity. Compared to CW treatment (EC 0), mean MBC decreased by 20.6, 29.4, 46.2 and 52.8 % at 0-15 cm and 22.8, 38.4 50.8 and 61.0 % for 15.-30 cm soil depth at EC 3, 6, 9 and 12 dS m^{-1} salinity levels, respectively. Decrease in MBC caused due to toxic effects of Na and Cl on soil microflora (Pankhurst *et al* 2001 and Ndour *et al* 2008) as well as due to osmotic effects (Rietz and Haynes 2003).

Microbial biomass N showed the same trend as that of MBC with increasing salinity of irrigation water. It decreased from 94.4 to 22.2 mg kg $^{-1}$ and from 80.4 to 18.6 mg kg $^{-1}$ at 0-15 cm and 15-30 cm as salinity levels increased from EC 0 to EC12 dS m^{-1} in 2013-14. Shah and Shah (2011) reported decrease in MBN from 113.8 (EC of soil < 4dS m^{-1}) to 24.8 mg kg $^{-1}$ (EC of soil > 12 dS m^{-1}) in saline soils. Yuan *et al* (2007) also reported decrease in MBN from 32.8 to 17.4 mg kg $^{-1}$ as soil salinity increased from 0.32 to 5.2 mS/m. Compared to EC 0 treatment, CWOC decreased by about 50% at EC 12 dS m^{-1} in both soil depths. Since organic matter and microbial activity are typically related to each other (Tables 1 and 3), a significant decrease in organic carbon probably intensifies the adverse effects of salinity on soil microbial biomass (Muhhamad et al. 2006). All three soil chemical properties (pH, EC and SAR) are highly and significantly correlated with biological properties (Table 4); the effect of soil pH and EC were pronounced and was similar to the effect of soil OC on all biological parameters. It suggests that pH or EC should be considered as indicator of changes in biological soil health in soil salinized due to irrigation with saline waters.

Table 4 Correlation between soil chemical and biological properties for 0-30 cm soil depth

	PH	EC	SAR	OC
DHA	-0.94	-0.92	-0.9091	0.95
MBC	-0.97	-0.96	-0.9786	0.98
MBN	-0.99	-0.98	-0.9593	0.98
CWOC	-0.97	-0.96	-0.9095	0.95

DHA (µg TPF hr g^{-1} soil), MBC, MBN and CWOC were measured in mg kg^{-1} units

In conclusions, although values for soil biological properties were more at 0-15 cm than 15-30 cm but percentage decrease at EC 12 dS/m was almost same for two soil depths. At higher salinity levels (EC 9 and 12 dS/m), soil chemical and biological properties were more affected compared to low salinity levels (below 6 dS/m).

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University and year of award : Punjab Agricultural University, Ludhiana (2012)
OCPA : 7.93/10.00
Title of Master's Thesis : Enrichment of Rice Grains with Iron through Ferti- fortification

Ph.D. (Soil Science)
University and year of award : Punjab Agricultural University, Ludhiana (2016)
OCPA : 7.96/10.00
Title of Ph.D. Thesis : Saline and Sodic Irrigation effects on Performance of Wheat Cultivars and Soil Health

Awards/Distinctions/Fellowships :

- Merit scholarship, Post-matric scholarship during M.Sc.
- Rajiv Gandhi National Fellowship during Ph.D