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Identification of geochemical processes controlling groundwater fluoride using graphical and multivariate statistical approach

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ABSTRACT

A geochemical assessment of groundwater fluoride was carried out by using a hydro-chemical approach with graphical and multivariate statistical method for identifying the occurrence of various geo-chemical processes that are responsible for high fluoride in the groundwater in the Unnao district, Uttar Pradesh. The results indicated that different natural hydro-geochemical processes such as simple dilution, natural weathering of rocks minerals especially carbonates bearing minerals, silicate weathering and various ion exchange processes are the key factors that govern the water chemistry of high fluoride contamination in groundwater. During both pre-monsoon and post- monsoon period, the ground water was found to be alkaline in nature which was a prominent factor for mobilizing fluoride from fluorite mineral. The cations dominance followed the order: $Na^{+}>Mg^{2+}>Ca^{2+}>K^{+}$ while anions dominance was $HCO_3^{-}>Cl^{-}>CO_3^{2-}>SO_4^{2-}$ Majority of the sampled water was of Na-HCO_3 type in both the seasons. During pre-monsoon, 36.36% of the sampled water was found to exceed the desirable limit prescribed by Bureau of Indian Standard, whereas, it was only 22.72% in the post monsoon period. Fluoride had a significant positive correlation with CO_3^{2-}, HCO_3^{-} and sodium adsorption ratio (SAR).

Key words: fluoride, geochemical processes, multivariate statistical approach, sodium adsorption ratio, groundwater, hydrochemistry, dental fluorosis

Introduction

Groundwater is the major source of fresh water widely used for domestic, industrial and agricultural purposes and is a replenishable resource. Therefore, the assessment on groundwater quality of any area is essential for managing and sustaining the resource for various uses. The chemical parameters of groundwater play a significant role in classifying and assessing water quality. The intensive use of groundwater and increased human activities, urbanization and industrialization are posing threat to the groundwater quality (Mor *et al.*, 2006). The quality of groundwater depends on the chemical composition of recharge water, the interaction between water and soil, soil–gas interaction, the types of rock with which it comes into contact in the unsaturated zone, the residence time of groundwater in the subsurface environment and the reactions that take place within the aquifer (Hem, 1989; Appelo and Postma, 2005). Therefore, the groundwater quality variation is a function of physical and chemical patterns in an area influenced by geological and anthropogenic activities (Subramani *et al.,* 2005). The quality gets altered when it moves along its flow path from recharge to discharge areas through the processes like: evaporation, transpiration, selective uptake by vegetation, oxidation/reduction, cation exchange, dissociation of minerals, precipitation of secondary minerals, mixing of waters, leaching of fertilizers, manure and biological process (Appelo and Postma, 1997). It has been estimated that one third of the world's population use groundwater for drinking (UNEP, 1999). There are various chemical pollutants both natural and anthropogenic in nature are contaminating the groundwater resources. Of the various point and non-point pollutants in ground water, fluoride is one of great concern as it has far reaching impact on human health both in short-term and long-term basis. Deficiency or excess of fluoride in the environment is closely associated with human health. The problem of high concentration of fluoride in groundwater sources has now become one of the most important toxicological and geo-environmental issues in not only in India but across the globe. The health effects of fluoride intake through drinking water are reviewed by Kaminsky *et al.* (1990) and WHO (1997).

More than 200 millions people from all over the world suffer from dental fluorosis caused mainly by an excess of fluoride in drinking water (Chandrajith *et al.*, 2007). Fluorosis is endemic in 20 out of 32 constituent states of India (Choubisa *et al.*, 2001). The preventive measures are only possible when the cause of occurrence and the affected areas delineated systematically. Moreover, it is also necessary to identify the geochemical reactions in the aquifer in order to assess the distribution of major ion chemistry of the region (Raju *et al.,* 2011; Reddy and Kumar, 2010). The knowledge of hydrochemistry is essential to determine the origin of chemical composition of groundwater (Zaporozec, 1972). Studying the seasonal and temporal variation of various ions in groundwater helps to identify the major processes controlling the composition of groundwater in a particular area (Rouxel *et al.*, 2011).

Role of various factors in groundwater can be understood better by applying multivariate analysis on the chemical parameters. Statistical methods of analysing hydrochemical data can be a useful tool in identifying the likely factors that cause the variations in hydrochemical composition. The objective of the present work is to discuss seasonal variations in major ion chemistry of groundwater and the factor responsible for the occurrence of fluoride using graphical as well as multivariate statistical approach.

Material and methods

Study area

The study area lies at 26°32′52″ and 27°0′49″ N latitude and 80°24'27″ and 80°50'33″ E longitude (Fig.1) in the Central Indo-Gangetic plains of Unnao district, Uttar Pradesh which is a part of Ganga-Gomti drainage basin. The area has in general a flat topography and consists of Quaternary sediments, differentiated into older alluvium and newer alluvium. This contains polycyclic sequence of yellowish-*khaki* oxidized silt clay with *Kankar* layers and subordinate micaceous sand horizon. The newer alluvium of Holocene age occupies low land and is divisible into terrace alluvium and channel alluvium (GSI, 2001). The surface water i.e. streams, *tals* and canal (Sarda canal system) and ground water sustain domestic and irrigational needs of the area. Majority of the population are engaged in agriculture. The climate of the district is characterized by a hot dry summer and pleasant winter. The period from mid June to September represents the rainy season with an annual average rainfall is 850 mm.

Sampling and analysis

The water samples were collected randomly at a random intersection of 5 km x 5 km of a square grid from shallow borewells used for drinking in the study area. The nearest village from the grid points was selected where the village does not fall exactly on the grid points. The water samples were collected from the villages chosen as our grid points both during pre-monsoon and post-monsoon period. These samples were collected in 500 ml poly-propylene bottles and transported to the laboratory for the analysis of fluoride along with the other water quality parameters. pH and electrical conductivity (EC) were determined potentio-metrically by pH electrode and conductivity electrode with the help of ORION ion analyzer (5 star series). The various water quality parameters such as carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{2-}), Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+),

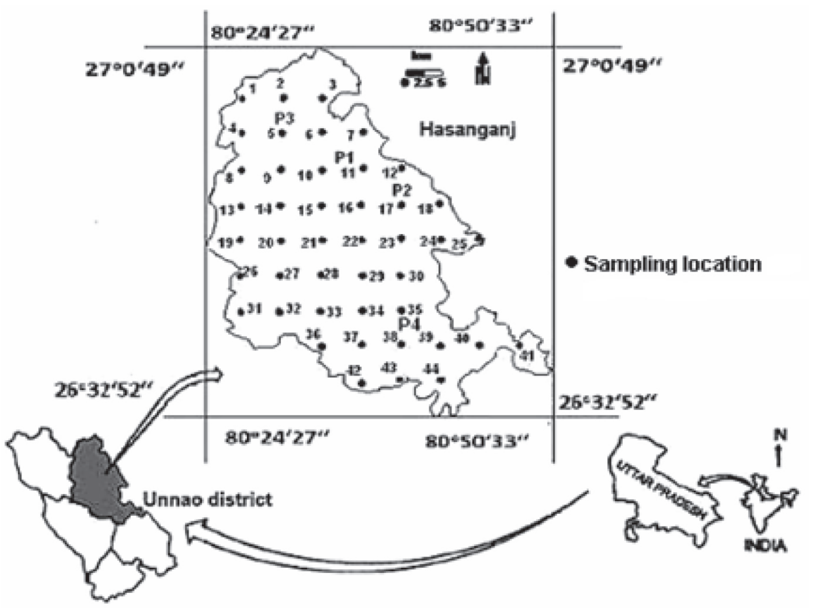


Fig. 1. Location map of study site

were determined by adopting standard method (APHA, 2005). Sodium adsorption ratio (SAR) was determined by following generic equation

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$

The F^- in water samples were determined by fluoride ion selective electrode (FISE) using ORION ion analyzer (5 star series). To 25 ml of the water sample, 25 ml of the total ion strength adjuster buffer (TISAB) (4 g CDTA + 58 g NaCl and 57 ml glacial CH_3COOH in 1 litre of distilled water adjusted to pH 5-5.5 by 6N NaOH) was added in a plastic 100 ml beaker and the F^- concentration was measured by dipping FISE in the solution mixture.

Factor analysis

The obtained hydro-chemical data was subjected to multivariate analytical technique. . The factor analysis was applied to data matrix in order to reduce the data to an easily interpretable form with the help of linear combination of a large numbers of variables. Before applying factor analysis, the data were standardized according to the criteria presented by Davis (2002). Initial factors were extracted and subjected to mathematical rotation. Varimax rotation procedure is used to maximize the difference between the variables, facilitating easy interpretation of the data. The study of factor scores reveals the extent of influence of each factor on the overall water chemistry at all locations of sampling stations. Extreme negative scores reflect areas essentially unaffected by that particular factor and positive scores reflect areas most affected. Near-zero scores indicate areas affected to an average degree.

Results and discussion

Descriptive statistics

The classical statistics parameters such as minimum, maximum, mean, standard deviations for shallow borewells during pre-monsoon and post-monsoon season of the study area are summarized in Table 1. It was found that the pH value of shallow borewells during pre-monsoon season ranged from 7.36 to 8.69 with a mean of 8.10 i.e. the water was alkaline in nature. In the post monsoon season too, the water was alkaline and the pH ranged from 7.41 to 8.67 with a mean of 8.24. The electrical conductivity (EC) ranged from 0.46 to 3.64 dS m^{-1} in the pre-monsoon and 0.38 to 3.62 dS m^{-1} in the post monsoon period with a mean of 1.08 dS m^{-1} (SD= 0.67) and 1.16 dS m^{-1} (SD= 0.73). During both pre-monsoon and post-monsoon seasons, Na^+ followed by Mg^{2+}, Ca^{2+} and K^+ were the dominant cations and HCO_3^- followed by Cl^-, CO_3^{2-} and SO_4^{2-} were dominant anions.

The fluoride concentration ranged from 0.28 to 4.92 mg l^{-1} in the pre-monsoon with a mean of 1.02 mg l^{-1} while in the post monsoon it ranged from 0.16 to 4.18 mg l^{-1} with a mean of 0.83 mg l^{-1}. During pre-monsoon period 36.36% of the sampled water was contaminated with fluoride exceeding the desirable limit of 1.0 mg l^{-1}, as prescribed by Bureau of Indian Standards (BIS, 1991) whereas in the post-monsoon it was 22.72%. Generally, recharge water dilutes the chemical concentrations during post-monsoon seasons and tend to increase towards pre-

Table 1. Classical statistics of water quality parameters of pre and post-monsoon shallow borewells of Hasanganj

	pH	EC dS m^{-1}	F^- mg l^{-1}	CO_3 me l^{-1}	HCO_3^- me l^{-1}	Cl^- me l^{-1}	SO_4^{2-} me l^{-1}	Ca^{2+} me l^{-1}	Mg^{2+} me l^{-1}	Na^+ me l^{-1}	K^+ me l^{-1}	SAR
Pre-monsoon Season												
Mean	8.10	1.08	1.02	2.16	4.16	3.45	1.28	2.25	3.98	4.38	0.49	2.47
Median	8.17	0.90	0.74	1.90	4.10	2.10	0.33	2.10	3.40	3.55	0.24	1.86
SD	0.38	0.67	0.83	1.31	1.47	4.80	1.78	1.33	2.28	3.61	0.97	1.70
Minimum	7.36	0.46	0.28	0.60	2.00	0.70	0.10	0.60	1.30	1.10	0.11	0.66
Maximum	8.69	3.64	4.92	7.80	8.40	27.00	7.00	6.20	12.60	17.00	4.50	8.57
Lower Quartile	7.85	0.69	0.49	1.35	2.95	1.20	0.19	1.20	2.90	1.80	0.15	1.17
Upper Quartile	8.43	1.13	1.18	2.60	5.00	3.30	2.05	2.85	3.85	5.40	0.32	3.19
Post-monsoon Season												
Mean	8.24	1.16	0.83	2.26	4.11	3.50	1.90	1.38	4.17	5.31	0.93	3.14
Median	8.34	0.96	0.58	1.90	3.70	2.20	0.76	1.00	3.55	4.10	0.24	2.56
SD	0.32	0.73	0.72	1.71	1.91	4.08	2.89	1.10	2.22	4.36	1.72	2.23
Minimum	7.41	0.38	0.16	0.00	1.40	0.40	0.11	0.30	1.60	0.60	0.10	0.35
Maximum	8.67	3.62	4.18	9.60	10.30	17.50	15.80	4.60	12.90	18.70	7.00	10.29
Lower Quartile	8.01	0.65	0.39	1.30	2.70	0.90	0.21	0.60	2.90	2.10	0.16	1.39
Upper Quartile	8.50	1.41	0.94	2.70	5.20	4.30	2.20	1.70	4.70	6.45	0.48	3.93

monsoon periods because of the effect of evaporation (Subba Rao *et al.*, 2002).

Quality of chemical data

The analytical precision for the measurement of ions was determined by calculating the Ionic Charge Balance Error (ICBE) which is defined as:

$$Re\,action\,Error = \frac{\sum Cations - \sum Anions}{\sum (\,Cations + \; Anions\,)} \times 100$$

The accuracy of chemical data can be checked by computation of ionic charge balance error as explained above (Lloyd and Heathcote, 1985; Mandel and Shiftan, 1981). Ó cations: sum of meq l"1 concentrations of cations Ó anions: sum of meq l"1 concentrations of anions. If the reaction error of chemical data set is greater than 5% then qualities of analysis is questionable. In the present study, ICBE was found to be 0.412 and 0.826 during pre-monsoon and post-monsoon season, respectively.

Chemical characterization of ground water (Graphical method)

There are several graphical methods (Zaporozac, 1972; Guler *et al.*, 2002) that are used for visualization and classification of hydrogeo-chemical data. The most widely accepted of these is the Piper trilinear diagram (Piper, 1944). The Piper diagram is used to infer hydrogeo-chemical facie. This diagram has three parts; a cation triangle, an anion triangle and a central diamond shaped field. In the Piper diagram the major ions are plotted in the two base triangle as cation and anion milliequivalent percentages. Total cations and total anions are each considered as 100%. The respective cations and anions locations for an analysis are projected into the diamond field, which represents the total ion relationship. The diagram has been widely used to study the similarities and differences in the composition of waters and to classify them into certain chemical type (Ahmed *et al.*, 2003; Srivastava and Ramanathan, 2008; Sadashivaiah *et al.*, 2008). In this study, an attempt was made to characterize the hydro-geochemical data by knowing the hydro-chemical facies of water generally known as water type, using Piper diagram and it was found that in pre-monsoon season and post-monsoon season, cation dominance followed $Na^{+}>Mg^{2+}$ in cation facies and $HCO_3^{-}>Cl^{-}$ in anion hydrochemical facies in majority of the samples. Thus, the water type was classified as Na-HCO_3 type in both the seasons (Fig. 2). This was further confirmed by plotting Durov diagram (Fig. 3), indicated the same water classification i.e. $NaHCO_3$ type. The Durov diagram (Durov, 1948) is an alternative to the Piper diagram which plots the major ions as the percentage of milli-equivalents in two base triangles. The main purpose of the Durov diagram is to show clustering of data points to indicate samples that have similar compositions.

Hydro-geochemical evaluation

The geochemical variations in the ionic composition of groundwater can be studied by simply plotting a scatter diagram on X-Y coordinate (Guler *et al.*, 2002). Thus, the hydro-geochemical data were subjected to conventional graphical plots to identify the prevailing mechanism and hydro-geochemical processes. The details of the identified process are:

i) Ion exchange process

Cation exchange reactions are the important geochemical reactions which controls the distribution and occurrence of ions in groundwater. When the dissolution

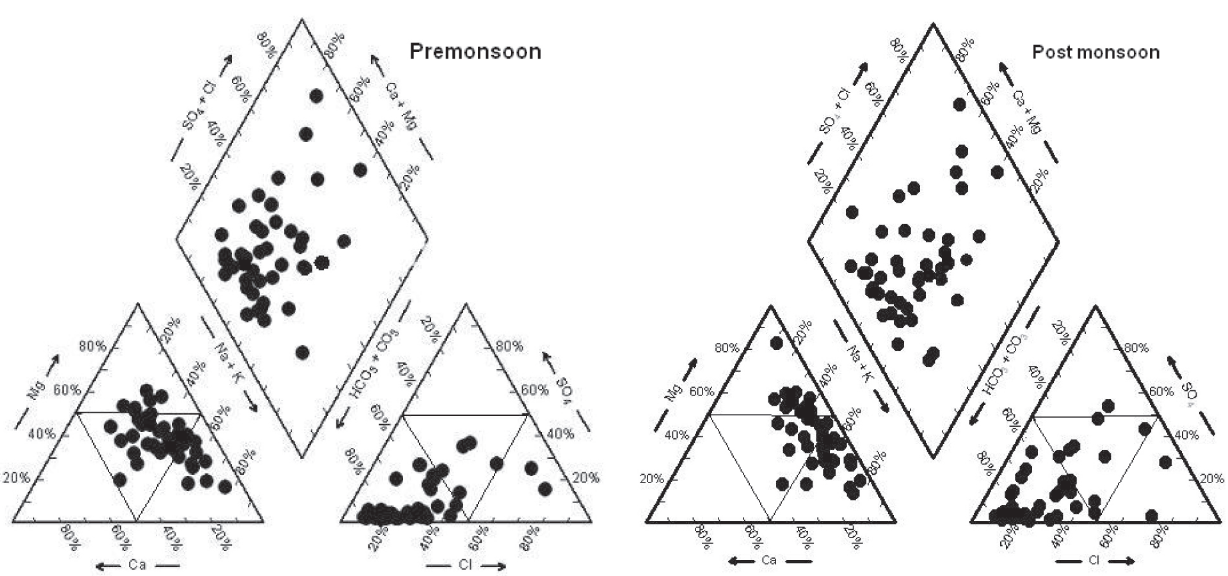
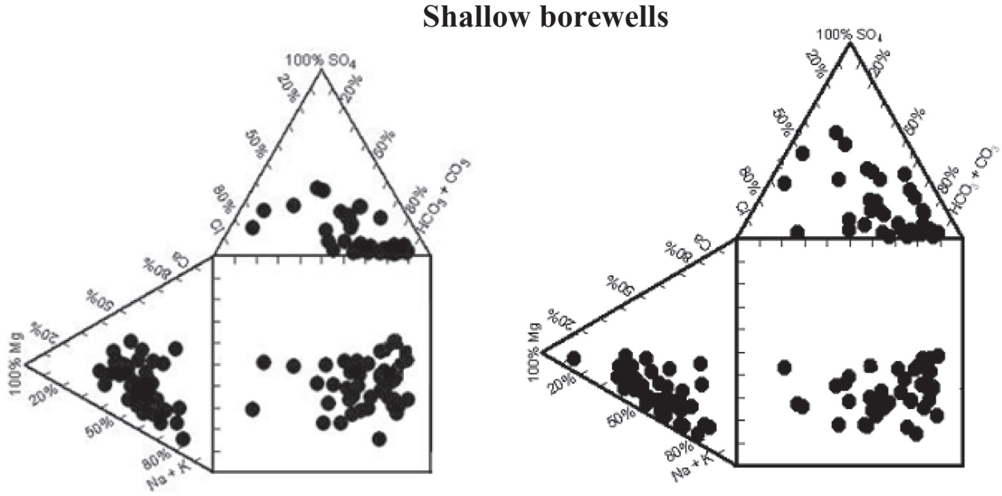


Fig. 2. Piper diagram of shallow borewells during pre-monsoon and post-monsoon season

Shallow borewells



Pre-monsoon **Post-monsoon**

Fig. 3. Durov diagram for water quality parameters of shallow borewells during pre and post monsoon seasons

of calcite, dolomite and gypsum are the dominant reaction processes, the plot of Ca^{2+}+Mg^{2+} Vs SO_4^{2-}+HCO_3^- will be close to 1:1 equiline. The ion exchange processes tend to shift the points to right due to an excess of SO_4^{2-}+HCO_3^- (Cerling *et al.*, 1989) while reverse ion exchange dominates if the points shift to the left due to excess of Ca^{2+}+Mg^{2+} over SO_4^{2-}+HCO_3^-. In the present study, most of the groundwater samples during pre-monsoon season were found to be below 1:1 equiline, explains the predominance of reverse ion exchange process while in the post monsoon season, it is almost evenly distributed on the both side of the equiline (Fig. 4a) signifies both ion exchange and reverse ion exchange processes which might be due to the possible dissolution and leaching of the ions due to recharge of groundwater from irrigation and rainfall during post monsoon season (Datta *et al.*, 1996).

Cation exchange process can also be identified using a relationship between the Na^+ and Cl^- ions. Ion exchange and industrial and/or agricultural contamination are likely responsible for increase in sodium in a gneissic terrain (Guo and Wang, 2004). High concentration of Na^+ with respect to Cl^- or depletion of Na^+ with respect to Cl^- is the evidence of cation exchange reactions (Salama, 1993; Rajmohan and Elango, 2004). In the normal ion exchange reaction, Ca^{2+} is retained in the aquifer material and Na^+ is released to water. The excess Na^+ generated by ion exchange reaction is not balanced by Cl^- but by alkalinity or SO_4^{2-}. Similarly, in the reverse ion exchange, Na^+ is retained by aquifer materials and Ca^{2+} is released to water where excess Cl^- over Na^+ is balanced by Ca^{2+} and Mg^{2+}. Hence, excess Na^+ over Cl^- or excess Cl^- over Na^+–is a good indication for ion exchange reactions. In the present study the dominance of Na^+ over chloride is shown in Fig. 4b. The plot indicates that most of the pre-monsoon samples lie above the equiline showing higher Na^+ while in the post monsoon period, slight increase of Cl^- ion occur which may be due to water level rise, triggered more dissolution of salts from soil. The higher Na^+ in groundwater is attributed to silicate weathering (Stallard and Edmund, 1983; Singh and Hasnain, 1999).

ii) Carbonate/silicate weathering process

During pre-monsoon period, the scatter diagram of Ca^{2+}+Mg^{2+} Vs SO^{2-}+HCO_3^- shows most of the points placed below 1:1 equiline, indicates predominance of silicate weathering while in post monsoon season, carbonate and silicate weathering are almost equal. The earlier researchers (Rajmohan and Elango, 2004; Kumar *et al.*, 2006) also suggested equal intensity of carbonate and silicate weathering processes when points are placed along the equiline. The carbonic acid (H_2CO_3) formed by the reaction between atmospheric carbon dioxide and water reacts with the calcium carbonate of the soil extract to form bicarbonates (HCO_3^-) and calcium ion (Ca^{2+}):

Calcite dissolution

$$CO_2+H_2O \rightarrow H_2CO_3$$

$$CaCO_3 + H_2CO_3 \rightarrow Ca^{2+} + 2HCO_3^-$$

(Carbonate weathering)

Silicate weathering

$$2NaAl\ Si_3O_8 + 2H_2CO_3 + 9H_2O \rightarrow$$

(Albite) (Silicate weathering)

$$Al_2Si_2O_5(OH)_4 + 2Na + 4H_4SiO_4 + 2HCO_3^-$$

Kaolinite

Carbonate weathering by carbonic acid water saturated with CO_2 is an intensive process and can easily dissolve the carbonate minerals available in its flow path which increases calcium, magnesium, and bicarbonate ion contents in the ground water (Elango *et al.* 2003).

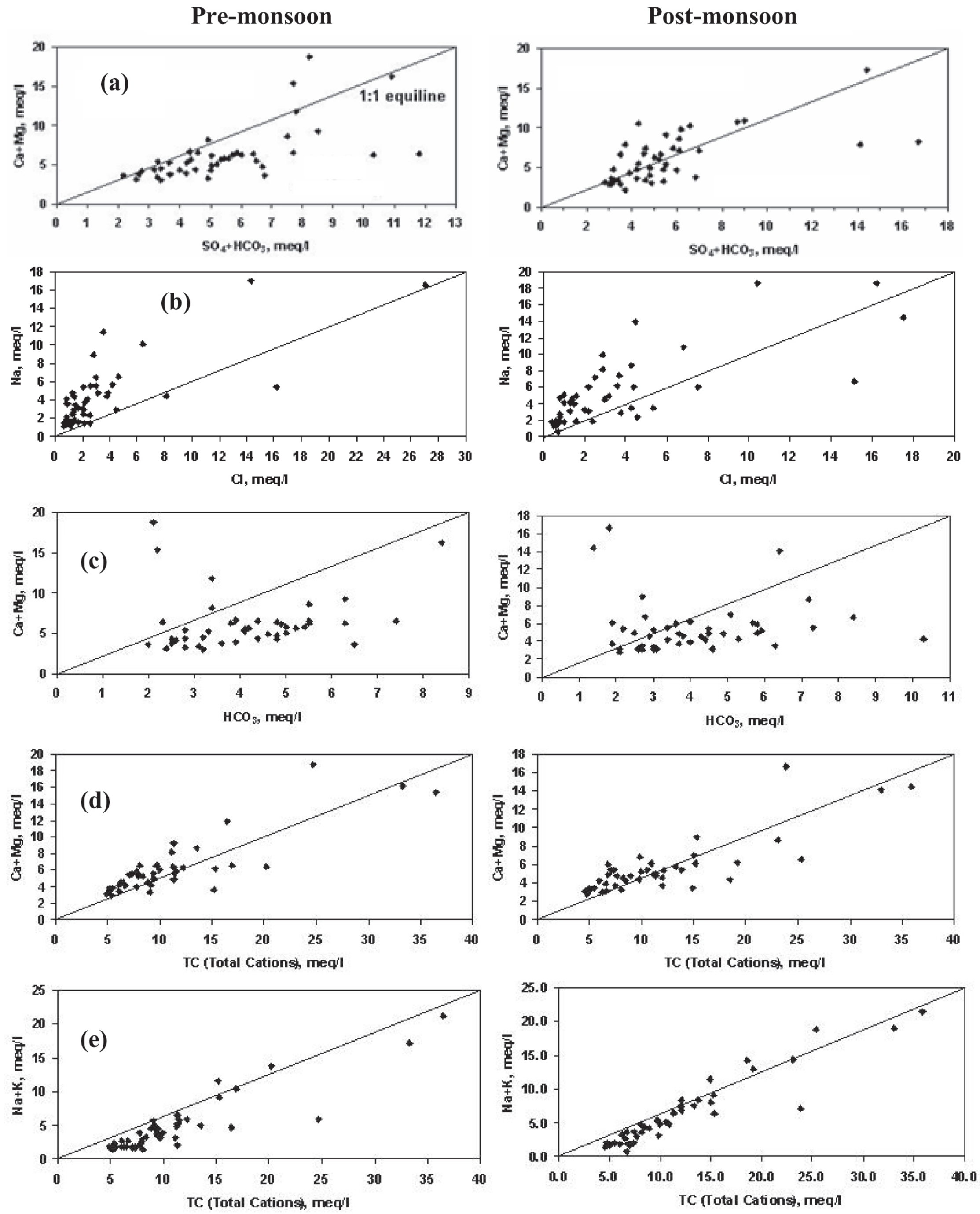


Fig. 4. Plots demonstrating geochemical classification of groundwater

A plot of $Ca^{2+}+Mg^{2+}$ versus HCO^{-}_3 (Figure 4C) shows that most of the water samples lies below the 1:1 equiline during both pre and post monsoon seasons. This reflects an excess of HCO^{-}_3 relative to $Ca^{2+}+Mg^{2+}$. The excess of bicarbonate over $Ca^{2+}+Mg^{2+}$ for samples requires that part of the alkalinity should be balanced by alkalis (Na^+ + K^+). This bicarbonate excess may arise from incongruent weathering of carbonate rocks (i.e. hydrolysis of carbonate rocks). The $Ca^{2+}+Mg^{2+}/HCO_3^-$ ratio marks the upper limit of bicarbonate input from weathering of carbonate rock (Stallard and Edmond, 1983).

A plot of (Ca^{2+} + Mg^{2+}) versus TC (total cation) for most of the samples from both seasons shows that all the points plot above the equiline (Fig. 4d). The average ratio of (Ca^{2+} + Mg^{2+})/ TC were 0.56 and 0.47 for pre and post monsoon seasons, respectively. The plot of Na^+ + K^+ against TC (Figure 4e) for most of the samples showed points below the equiline during both seasons. The average ratios of (Na^+ + K^+)/TC are 0.44 and 0.53 during pre and post monsoon seasons, respectively. Calcium and magnesium are the dominant cations during pre-monsoon which may be due to evaporation and Ca^{2+} and Mg^{2+}

Table 2. Correlation matrix of the water quality parameters of shallow borewells of Hasanganj during pre and post-monsoon season

	pH	EC	F^-	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	SAR
Pre-monsoon Season												
pH	1											
EC	-0.02	1.00										
F	*0.61	0.04	1.00									
CO_3	*0.48	*0.42	*0.45	1.00								
HCO_3	*0.42	*0.31	*0.41	*0.76	1.00							
Cl	-0.21	*0.92	-0.11	0.15	-0.04	1.00						
SO_4	-0.21	*0.71	-0.19	-0.17	-0.08	*0.69	1.00					
Ca	-0.20	*0.75	-0.23	0.14	0.20	*0.72	*0.59	1.00				
Mg	-0.19	*0.83	-0.25	0.20	0.10	*0.83	*0.63	*0.74	1.00			
Na	0.16	0.89	0.29	*0.58	*0.44	*0.75	*0.56	*0.44	*0.57	1.00		
K	-0.02	*0.58	0.12	0.10	0.08	*0.58	*0.48	*0.39	0.23	*0.52	1.00	
SAR	*0.35	*0.65	*0.58	*0.56	*0.47	*0.46	*0.40	0.13	0.24	*0.90	*0.41	1.00
Post-monsoon Season												
pH	1											
EC	-0.21	1.00										
F	*0.58	0.00	1.00									
CO_3	0.21	*0.53	*0.34	1.00								
HCO_3	*0.30	*0.36	*0.47	*0.71	1.00							
Cl	-0.29	*0.93	-0.15	*0.36	0.09	1.00						
SO_4	*-0.43	*0.67	-0.28	-0.17	-0.26	*0.66	1.00					
Ca	-0.22	*0.77	-0.14	*0.45	0.23	*0.74	*0.47	1.00				
Mg	-0.26	*0.73	-0.25	0.11	-0.12	*0.83	*0.68	*0.56	1.00			
Na	-0.06	*0.88	0.17	*0.67	*0.60	*0.75	*0.39	*0.60	*0.43	1.00		
K	-0.22	*0.53	0.00	0.11	0.04	*0.43	*0.61	*0.33	*0.32	0.22	1.00	
SAR	0.09	*0.68	*0.37	*0.62	*0.71	*0.50	0.20	*0.36	0.14	*0.93	0.10	1.00

*Marked correlations are significant at $p<0.05$

precipitation (Ekwere *et al.*, 2012). The degree of dominance however decreases during post-monsoon seasons. However, the ratio of $Na^+ + K^+$ to TC increased which indicates an increasing contribution of alkalis with increase in dissolved solids (Singh *et al.*, 2005).

Correlation analysis

The correlation matrix of the water quality parameters of shallow borewells during pre and post-monsoon season (Table 2) showed positive and negative correlations among various elements. It was found that during pre-monsoon, fluoride (F^-) showed a significant positive correlation with pH (r=+0.61), carbonate (CO_3^{2-}, r=+0.45), bicarbonate, (HCO_3^-, r=+0.41), Sodium adsorption ratio (SAR, r=+0.58) whereas calcium and magnesium did not show significant correlation with fluoride concentration. In the post monsoon too, a positive and significant correlation between F^- with pH (r=+0.58), HCO_3^- (r=+0.47), SAR (r=+0.37) was found.

The positive correlation of pH with F^- suggests that the pH is important in determining factor for F^- in ground water (Gupta et al., 2006). The process of weathering of rock releases fluoride in soil and ground water, the alkaline water can mobilize fluoride from fluorite with precipitation of calcium carbonate because the solubility of CaF_2 increases with an increase in $NaHCO_3$ rather than with other salts (Handa 1975; Saxena and Ahmed, 2001). An alkaline pH is more favorable for fluoride dissolution activity and can be represented as:

$$CaF_2 + 2NaHCO_3 = CaCO_3 + 2Na^+ + 2F^- + H_2O + CO_2$$

The positive correlation of F^- with HCO^-_3 in shallow aquifers was found to be in agreement with the earlier researcher (Muralidharan et al., 2002). Handa (1975) had explained the positive correlationship between F^- and HCO^-_3 by considering the mass law equation relating to calcite and fluorite when both are in contact with water.

$$CaCO_{3\,(s)} + H^+ + 2F^- = CaF_{2\,(s)} + HCO_3^-$$

$$K_{cal-fluor} = \frac{a_{HCO_3^-}}{a_{H^+}(a_{F^-})^2}$$

Where $K_{cal\text{-}fluor}$ = is a constant. The relationship shows that if the pH of the ground water remains reasonably

Table 3. Eigen values and factor loadings –pre-monsoon and post-monsoon of shallow borewells:Extraction method-Principal component analysis. Rotation method: varimax with Kaiser normalization

Variables	Rotated component matrix					
	Pre-monsson			Post-monsoon		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
pH	-0.204	0.562	0.467	-0.279	0.062	0.683
EC (dS m^{-1})	0.958	0.074	0.272	0.726	0.679	-0.100
F (mg l^{-1})	-0.108	0.801	0.307	-0.072	0.212	0.858
CO_3^{2-} (me l^{-1})	0.162	0.295	0.871	-0.023	0.842	0.216
HCO_3^- (me l^{-1})	0.090	0.198	0.832	-0.157	0.765	0.442
Cl^- (me l^{-1})	0.953	-0.037	-0.011	0.735	0.532	-0.275
SO_4^{2+} (me l^{-1})	0.833	0.010	-0.255	0.886	-0.001	-0.270
Ca^{2+} (me l^{-1})	0.769	-0.418	0.175	0.519	0.564	-0.252
Mg^{2+} (me l^{-1})	0.816	-0.348	0.248	0.729	0.222	-0.336
Na^+ (me l^{-1})	0.793	0.418	0.366	0.369	0.895	-0.002
K^+ (me l^{-1})	0.653	0.360	-0.261	0.805	-0.049	0.189
SAR	0.532	0.718	0.337	0.162	0.860	0.205
Eigenvalues	5.485	3.355	1.187	5.428	3.547	1.192
Variance (%)	42.190	25.810	9.132	41.750	27.281	9.171
Cumulative Variance (%)	42.190	68.000	77.132	41.750	69.032	78.203

constant, any increase or decrease in bicarbonate concentration/activity will be accompanied by a corresponding increase or decrease in the concentration /activity of fluoride ions. Since the water type during both pre-monsoon and post-monsoon period was classified as $NaHCO_3$-type, therefore such water accelerates the dissolution of CaF_2 and thereby releases fluoride into groundwater and allows calcite precipitation out of Ca^{2+} and CO_3^{2-} according to equation

$$CaF_2 + Na_2CO_3 = CaCO_3 + 2F^- + 2Na^+$$

and

$$CaF_2 + 2NaHCO_{3\,(aq)} = CaCO_3 + 2Na^+ + 2F^- + H_2O + CO_{2(aq)}$$

High F^- concentration in waters is usually associated with high alkalinity (Handa, 1975). The high correlation between Ca^{2+} and Mg^{2+} (r=0.74) in pre-monsoon and moderate correlation in post-monsoon indicated a possible ion-exchange process in the ground water system. The negative correlation between F^- and Ca^{2+} or Mg^{2+} indicated that the high fluoride ground water generally associated with low Ca^{2+} or Mg^{2+} content. The low concentration of Ca^{2+} and Mg^{2+} corresponding to high fluoride in water has earlier been reported (Maina and Gaciri, 1984; Teotia and Teotia, 1988).

Principal component analysis

The principal component analysis (PCA) which aims to load most of the total variance into one factor was used in the present study and the factors were extracted through the principal extraction method (Mahlknecht *et al.*, 2004). In order to limit the number of factors to be extracted, only factors with the eigen values greater than 1 were taken into consideration (Kaiser normalization). Contribution of a factor is said to be significant when the corresponding eigen value is greater than unity (Briz Kishore and Murali, 1992). The first three factors each of pre-monsoon and post-monsoon accounted for 77.1% and 78.2 % of the variance during pre-monsoon and post-monsoon, respectively showing eigen values > 1 were extracted from the principal factor matrix after varimax rotation (Table 3). Factor 1 of the principal component factor matrix of ground water during pre-monsoon was characterized by strong loadings of EC, Cl^-, SO^{2-}_4, Mg^{2+}, Ca^{2+}, K^+ and SAR accounted for 42.19% of variance whereas during post monsoon, it was 41.75% of total variance with high loadings on, SO^{2-}_4, K^+, Cl^-, Mg^{2+}, and EC. The percentage abundance of the above variables indicated that their sources of origin may be expected from the dissolution of rock minerals. The strong loadings of Na^+ and K^+ indicated natural weathering of rocks minerals and various ion exchange processes in the ground water system (Drever, 1997). Factor 2 (fluoride factor) accounted 25.81% of the total variance in the data in pre-monsoon season with high loadings on F^-, SAR and pH which indicated that ground water chemistry is controlled by the pH variations in the aquifer system. pH is positively correlated with F^-, indicating that an increase in pH increases dissolution of F^- ion. In post-monsoon period, factor 2 accounted 27.28% of the total variance with high loadings on Na^+, SAR, CO^{2-}_3, HCO^-_3, EC and Ca^{2+} indicating dissolution and weathering of carbonates. Factor 3 (carbonate factor) in the pre-monsoon had a high loadings on CO^{2-}_3 and HCO^-_3 accounted for 9.13% of the total variance whereas in post monsoon, the factor

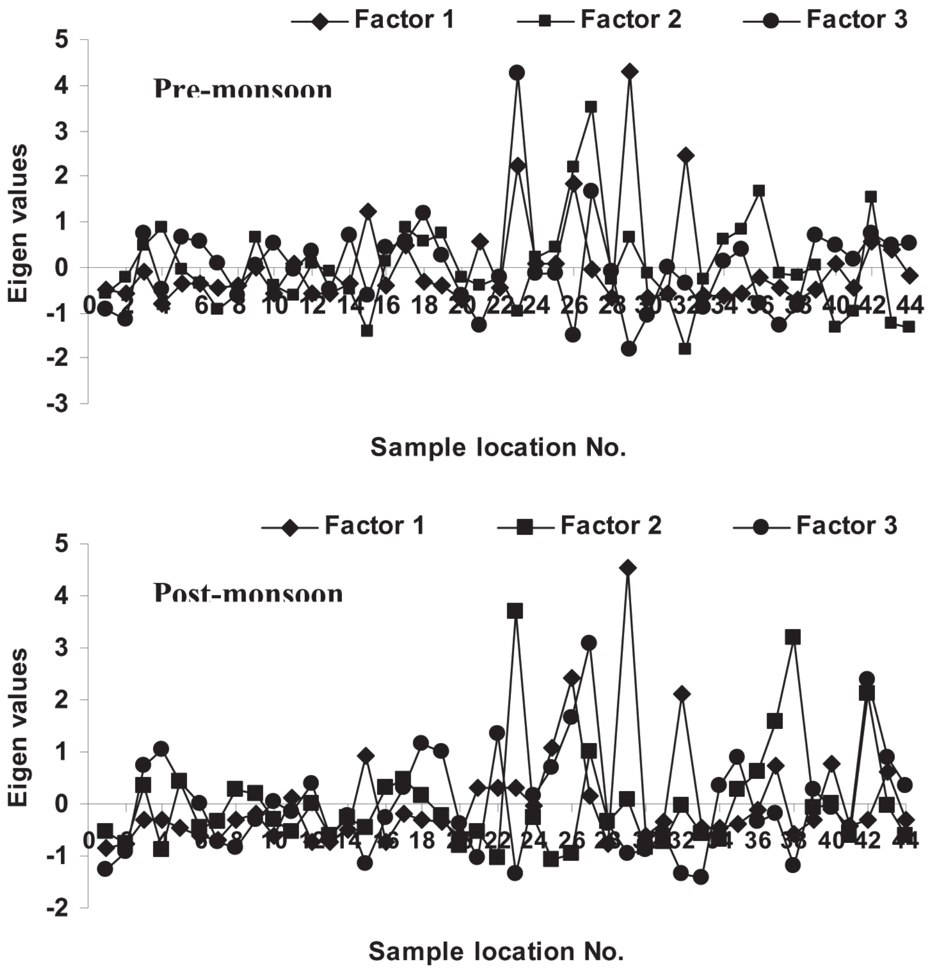


Fig. 5. Factor score plot during pre and post monsoon season

accounted 9.17% of the total variance with high loadings on F^-.

The score plot (Fig. 5) indicated the locations which are most affected by factors. Sample location 15, 23, 26, 29 and 32 were most affected by factor 1 in pre-monsoon season whereas in the post-monsoon period, location No. 15, 25, 26, 29 and 32 were influence by this factor. Factor 2 in which pH and F were dominant in pre-monsoon at locations 4, 17, 19, 26, 27, 35, 36 and 42. In the post-monsoon, however, the locations 23, 27, 37, 38 and 42 were affected by factor 2. In pre-monsoon, factor 3 was significant at locations 3, 18, 23, 27 and 42 whereas in post monsoon period, the factor was dominant at locations 4, 18, 19, 22, 26, 27, 35, 42 and 43.

Conclusion

The results of the present study indicated that the factor analysis and water chemistry is an effective approach for studying geochemistry of F^- in the ground water of the study area. The water types of majority of the samples in shallow borewells in both pre-monsoon and post-monsoon seasons were found to be Na-HCO_3 type, which helps in increasing the solubility of CaF_2 and thereby releases F^--into the ground water. The correlation studies indicated that F^- of water is significantly positively correlated with pH and HCO_3^- whereas negatively correlated with Ca^{2+} in both the sources of water. The factor analysis of the data set revealed the two factors that govern the water chemistry of the ground water are (1) Natural weathering of rock minerals specially carbonate bearing minerals, silicate weathering and various ion-exchange processes in the ground water system. (2) Alkalinity of the ground water i.e. the ground water chemistry is mainly controlled by pH variation in the aquifer. An increase of pH increases dissolution of F^- ion.

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Trend analysis of reference evapo-transpiration and governing meteorological parameters in an arid saline region of Haryana

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ABSTRACT

Long-term changes in reference evapo-traspiration (ET_o) can have profound implications on water balance, salinity development and agricultural production in any region. Temporal trends of ET_o values, estimated by Penmen Monteith approach utilizing historical weather data, were investigated for an arid region (Hisar) of Haryana. Thirty years (1981-2010) meteorological data of Hisar was statistically analyzed for estimating the trends in ET_o and governing climate parameters. Statistical significance trends in annual and seasonal (monsoon, post monsoon, winter, summer) ET_o, maximum and minimum temperature, bright sunshine hours (BSS), morning and afternoon relative humidity and wind speed was evaluated using nonparametric Mann-Kendall (MK) tests at the 10% significant level. In order to identify the dominant weather variables influencing ET_0, backward stepwise regression method was adopted. During the last 30 years, ET_o has been found to decrease significantly at annual and seasonal time scales at Hisar. Of the governing weather parameters, temperature (both maximum and minimum) showed no clear trend at annual or seasonal scales, while significant decreasing trends have been observed in BSS hours and wind speed on annual and all seasons except during monsoon. The contribution of the temperature on ET_o seems to be offset by steady reduction in wind speed and BSS hours, also reflected by strong correlation of BSS and wind speed with ET_0 evaluated through regression analysis at almost all the time scales. The nature and magnitude of trends of ET_o and other weather parameters can be purposefully utilized to derive rational climate change scenarios and evaluate their impact through controlled crop physiological and modelling studies on soil, water, salinity and crop production in arid regions of Haryana.

Key words: reference evapo-transpiration, trend analysis, Mann-Kendall test

Introduction

Anthropogenic emissions of greenhouse gases caused most of the warming during the latter half of the century. The atmospheric concentrations of the greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have all increased since 1750 due to human activity. In 2011 the concentrations of these gases were reported as 391ppm, 1803 ppb, and 324 ppb, exceeding the pre-industrial levels by about 40%, 150%, and 20%, respectively (IPCC, 2013). Almost all processes in the biosphere are influenced in some way by climate change phenomena, but environment and water resources are of the most serious concern. Spatio-temporal changes in evapotraspiration and its governing meteorological parameters are good indicators for the occurrence and impact of climate change on surface eco-hydrological system. This type of inquiry is fundamental to understand the link between ecosystem dynamics and the water cycle, particularly in arid and semi-arid environments, where water is limited in terms of scarcity but also for its intermittency and unpredictable presence (Liu *et al.*, 2010). Long-term changes in evaporation and potential evapotraspiration can have profound implications for hydrologic processes, salinity development as well as for agricultural crop performance (Chattopadhyay and Hulme, 1997).

The general expectation is that global warming will lead to an increase in evaporation (E) or reference evapotraspiration (ET_o), a key component of the hydrologic cycle. However, there are reports (Bandoyopadhyay *et al.*, 2009; Dinpashoh *et al.*, 2011) that despite an increase in air temperature, E and/or ET_o decreased in some regions across the globe. This shows that in addition to air temperature, interactive impact of changes in climatic parameters like wind speed, relative humidity, radiation, etc. could be responsible for the observed decreases in E and/or ET_o, offsetting the influence of increasing temperature. Donohue *et al.* (2010) reported that, even though changes in temperature produced the largest change (increase or decrease) in evapotraspiration, other variables such as relative humidity, wind speed and bright sunshine hours played a major role in governing evapotraspiration.

The arid climate of Hisar (Haryana) is related to its continental location on the outer margins of the south-west (SW) monsoon region. The climate of Hisar district can be classified as tropical, arid and hot being mainly dry with very hot summer and cold winter except during monsoon season when moist air of oceanic origin penetrates into the area. Dust storms, hot desiccating winds (*loo*) and chilly winds are quite common. Temperature ranges from 1 to 48°C. The hot weather season starts from mid March and continues up to the onset of monsoon in July, with April, May and June being the driest months.

The effects of climatic change and variability have been investigated by many researchers throughout the world. Gao *et al*. (2006) found decreasing trends in ET_o in China and for most river basins, except for a slightly increasing trend in the Songhua River basin. Chen *et al*. (2006) reported decreasing trends in average seasonal and annual ET_o over entire Tibetan Plateau. Wang *et al*. (2007) detected decreasing trends in E_{pan} and ET_o during summer months over the upper and middle-lower Yangtze River basin. Despite a general rise in annual mean temperature during recent decades over the Yangtze River basin, both E_{pan} and ET_o indicated decreasing trend. Similarly Zhang *et al*. (2007) found decreases in E_{pan} and ET_o at 47% and 38% of the respective stations over the Tibetan plateau. Jhajharia *et al*. (2009) observed that reference evapotraspiration decreased significantly at annual and seasonal time scales for 6 sites in NE India and even NE India as a whole. Singh and Bala (2012) reported ET_o to having a decreasing trend for January, February, March and June and an increasing trend during July, august and September and without any trend during remaining months for Gurgaon, Hisar and Ambala district during 1998-2008. Narjary and Kamra (2013) reported significant negative trend in number of rainy days, but absence of significant trends in annual and seasonal rainfall and evapotranspiration for semi- arid Karnal district of Haryana. Bandyopadhyay *et al*. (2009) also found decreasing trend in ET_o and E_{pan} all over India and attributed these to respective significant increase and decrease in relative humidity and wind speed throughout the country.

The objective of this study was to investigate the temporal trends ET_o time series over a arid region of Haryana (Hisar), using the non parametric Mann-Kendall (MK) trend test and to identify the most dominant meteorological variables affecting such changes. The study will help in understanding the trends related to crop water requirement.

Materials and methods

In order to study the changing trend of evapotraspiration and it's contributing weather parameters, 30 years (1981-2010) meteorological data was collected from Agromet observatory, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar representing saline arid zones of Haryana.

Estimation of Evapotranspiration

The most reliable and universally accepted method to estimate reference evapotraspiration (ET_o) under various types of climate is the Penman-Monteith (PM) FAO-56 method. The modified Penman- Monteith equation for estimating ET_o is a physically based model that incorporates explicitly both physiological and aerodynamic parameters. By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m and having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman-Monteith method was developed. The most recommended form of the PM method in computing ET_o is given as (Allen *et al*., 1998)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where, ET_o reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [MJ m^{-2} day^{-1}], G soil heat flux density [MJ m^{-2} day^{-1}], T mean daily air temperature at 2 m height [°C], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], e_s - e_a saturation vapour pressure deficit [kPa], D slope vapour pressure curve [kPa °C^{-1}], g psychrometric constant [kPa °C^{-1}].

Data analysis of weather variables influencing ET_o

Multilinear prediction models based on the weather parameters as independent variables and ET_o as dependent variable were fitted by backward step multiple regression (Chattopadhayay and Hulme, 1997). Based on correlation coefficients between ET_o and different weather variables, 't' test analysis was employed to select the most significant parameters, while the most significant weather parameters were selected through stepwise regression methods. Statistical analysis was done using Excel and SPSS packages (Version 16.0).

Trend Analysis

The Mann-Kendall (MK) test is a non-parametric method for identifying trends in time series data. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend.

The data values are evaluated as an ordered time series. Each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic, τ (tou), is assumed to be 0 (i.e. no trend). If a data value at a later time is higher than a data value of an earlier time, τ is incremented by 1. On the other hand, if the data value at a later time is lower than a data value sampled earlier, τ is decremented by 1. The net result of all such increments and decrements yields the final value of τ.

Let x_1, $x_{2...}$ x_n represent n data points where x_j represents the data point at time j. Then the Mann-Kendall statistic (τ) is given by

$$\tau = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} sign\ (x_j - x_k)$$

$$Sign(x_j - x_k) = 1\ if\ x_j - x_k > 0$$

$$= 0\ if\ x_j - x_k = 0$$

$$= -1\ if\ x_j - x_k < 0$$

A high positive value of τ is an indicator of an increasing trend, and a low negative value indicates a decreasing trend. The p-value for the Mann-Kendall test indicates whether there are any statistically significant trends or not. If the computed value of p> $p_á$, the null hypothesis (H_0) is rejected at á level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 90% confidence level.

Sen's slope estimator provides an estimate of the magnitude of the detected trend and is calculated as

$$T_i = \frac{x_i - x_k}{j-k} for\ i = 1,2, \dots, N \quad \dots(1)$$

Where x_i and x_j are data values at time j and k (j>k) respectively. The median of (â) N values of T_i is the Sen's slope estimator

$$\beta = T_{\frac{N+1}{2}} \text{ if N is odd}$$

$$\beta = \frac{1}{2}(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}) \text{ if N is even}$$

Positive value of â indicates an increasing trend while negative value indicates a decreasing trend in the time series.

Results and discussion

The monthly data were used to compute seasonal and annual time series of climatic data. Four seasons of the study area were defined viz. winter (December-February), summer (March-May), monsoon (June-September) and post-monsoon (October-November) on the pattern of Jhajharia *et al.* (2009).

Estimation of ET and its sensitivity to meteorological variables

The annual average ET_o of Hisar, calculated using the PM method, varied from about 3.14 mm/day to 4.87 mm/day. In the summer months ET_0 reached its peak value 4.5 to 7 mm/day. In the winter months ET_0 ranged between 1.67 to 2.36 mm/day. In order to identify the dominant variables associated with ET_0, stepwise regression method was adopted. Several researchers, namely, Chattopadhayay and Hulme (1997), Thomas (2000), and Dinpashoh *et al.* (2011) also used a similar procedure to look for the most important variable responsible for ET_o changes under different types of climatic conditions of India, China and Iran, respectively. In the present study, the stepwise regression analysis was performed between ET_0 as the dependent variable and the meteorological parameters, i.e., bright sunshine hrs (BSS), wind speed (WS), morning and afternoon relative humidity (RH_m, RH_e) and maximum and minimum temperature (T_{max}, T_{min}), as independent variables on annual and seasonal time scales by using SPSS. From the backward stepwise regression analysis of average annual data indicated bright sunshine hours, wind speed and maximum temperature having most significant influence on ET_o with coefficient of determination of 0.68 In the monsoon and winter season, BSS, wind speed and daily maximum temperature was found to be the most dominating weather variable affecting ET_o with respective coefficients of determination of 0.83 and 0.84. After BSS and wind speed, morning relative humidity was the third most important weather variable governing ET_o during summer and post monsoon season, with coefficients of determination 0.8 and 0.76 respectively (Table 1). Of all parameters affecting ET_0, minimum temperature was found to be insignificant during all seasons.

Chattopadhayay and Hulme (1997) reported that although most parts of India (except Gujarat and few parts on west coast) have witnessed temperature increases, both pan evaporation (E_{pan}) and ET_o have witnessed decreasing trends over a majority of sites in India. They also found that the relative humidity was strongly associated with changes in E_{pan}. The increasing trends in RH have counter balanced the effect of rising temperature on E_{pan} by hampering the evaporative process. Bandyopadhyay et al. (2009) also found decreasing trends in ET_o over various sites in India and attributed there to notable decrease in wind speed and significant increase in air relative humidity. Sunshine duration was also found to be the most influencing variable responsible for the observed changes in E_{pan} in winter, pre-monsoon and monsoon seasons in north east India (Jhajharia *et al.*, 2009).

Table 1. Backward multiple regression analysis for estimating the influence of weather parameters on ET_o

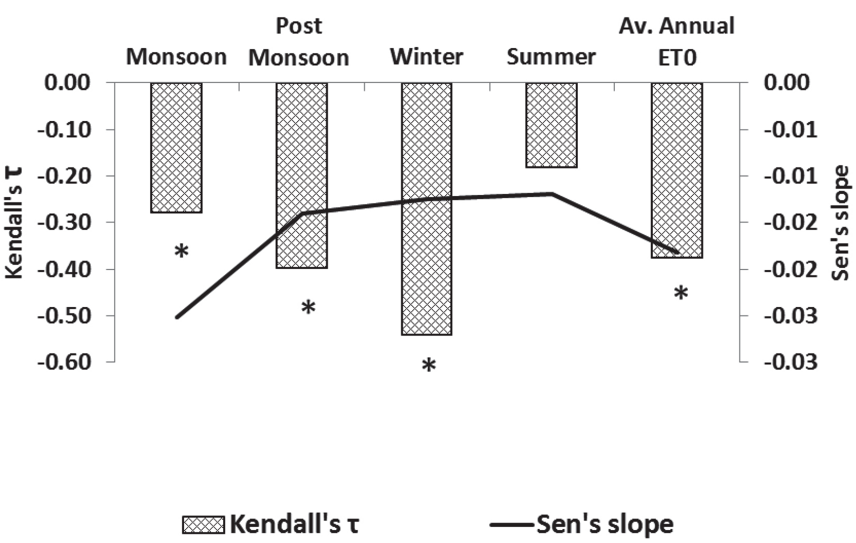
ET_o	Regression Equation	R^2	P
Annual	$- 4.64 + 0.21\ BSS + 1.01\ WS + 0.19$	0.68	0.000001
Monsoon (June – September)	$- 10.7 + 0.24\ BSS + 1.02\ WS + 0.35\ T_{max}$	0.83	0.0000000003
Post-monsoon(October- November)	$3.43+ 0.08\ BSS + 0.73WS + 0.01RH_e + 0.02\ RH_m$	0.76	0.0000001
Summer (March- May)	$-0.82 +0.24\ BSS + 1.43WS+ 0.11\ T_{max} -0.02\ RH_m$	0.81	0.00000001
Winter (December – February)	$-1.01 + 0.11\ BSS + 0.45\ WS + 0.19\ T_{max}$	0.84	0.0000000001

Trend analysis of ET_o and governing meteorological variables

Trends in ET_o and governing meteorological variables over Hisar were analyzed on monthly, seasonal and annual time scales. The results relating to seasonal and annual trends are presented in this paper. Statistically significant decreasing trends in annual, monsoon (June-September), post-monsoon (October-November) and winter (December-February), ET_o were observed at 10 % level of significance, while non significant decreasing trend were observed during summer (March-May). From the Sen's slope analysis (Fig. 1), the corresponding reduction in annual, monsoon, post monsoon and winter ET_o were estimated at 0.02, 0.03, 0.01 and 0.01 mm/day respectively. There were no perceivable trends in annual and seasonal maximum and minimum temperature reflected by non- significant nature as well as small values of τ (Fig. 2a and 2b). Trends in morning relative humidity (RH_m) and afternoon relative humidity (RH_e), derived through the MK test, at seasonal and annual time scales are presented in Fig. 2 c and Fig. 2d respectively. Statistically significant increasing trend in RH_m were observed in post-monsoon and winter season months. Similarly increasing trends in RH_e were observed in monsoon, post-monsoon, winter seasons months. From the Sen's slope analysis, it was revealed that RH_m increased @ 0.12 and 0.14% during post-monsoon and winter seasons while RH_e increased by 0.24, 0.21 and 0.38 % during monsoon, post-monsoon and winter season, respectively (Fig. 2c and Fig. 2d).

Similarly significant decreasing trends in daily BSS hours and wind speed were observed at annual and all seasonal scales, except for BSS during monsoon (Fig. 2e and Fig. 2f). The decrease in daily BSS hours occurred @ 0.06, 0.055, 0.02 and 0.04 hours per day respectively during post monsoon, winter, summer season and annually. Wind speed witnessed significant decreasing trends @ 0.02 m/s/day during monsoon and between 0.01- 0.02 m/s/day during other seasons and annually. The significant parameters governing trends of ET_o at Hisar are summarized in Table 2.

It can be seen that wind speed and bright sunshine hours have negative trends, significant at annual scale and during all seasons except of BSS during monsoon. It means that wind speed and bright sunshine hours are decreasing over time in Hisar with related affects on ET_o. Cloud cover during monsoon offsets the BSS hours resulting in non- significant negative trends. Both RH_m and RH_e have significant rising (positive) trends at all time scales, more particularly of RH_e, except during summer, while T_{max} and T_{min} have non- significant trends of similar



*Significant trend

Fig. 1. Mann-Kendall trend test for ET_o (1981-2010)

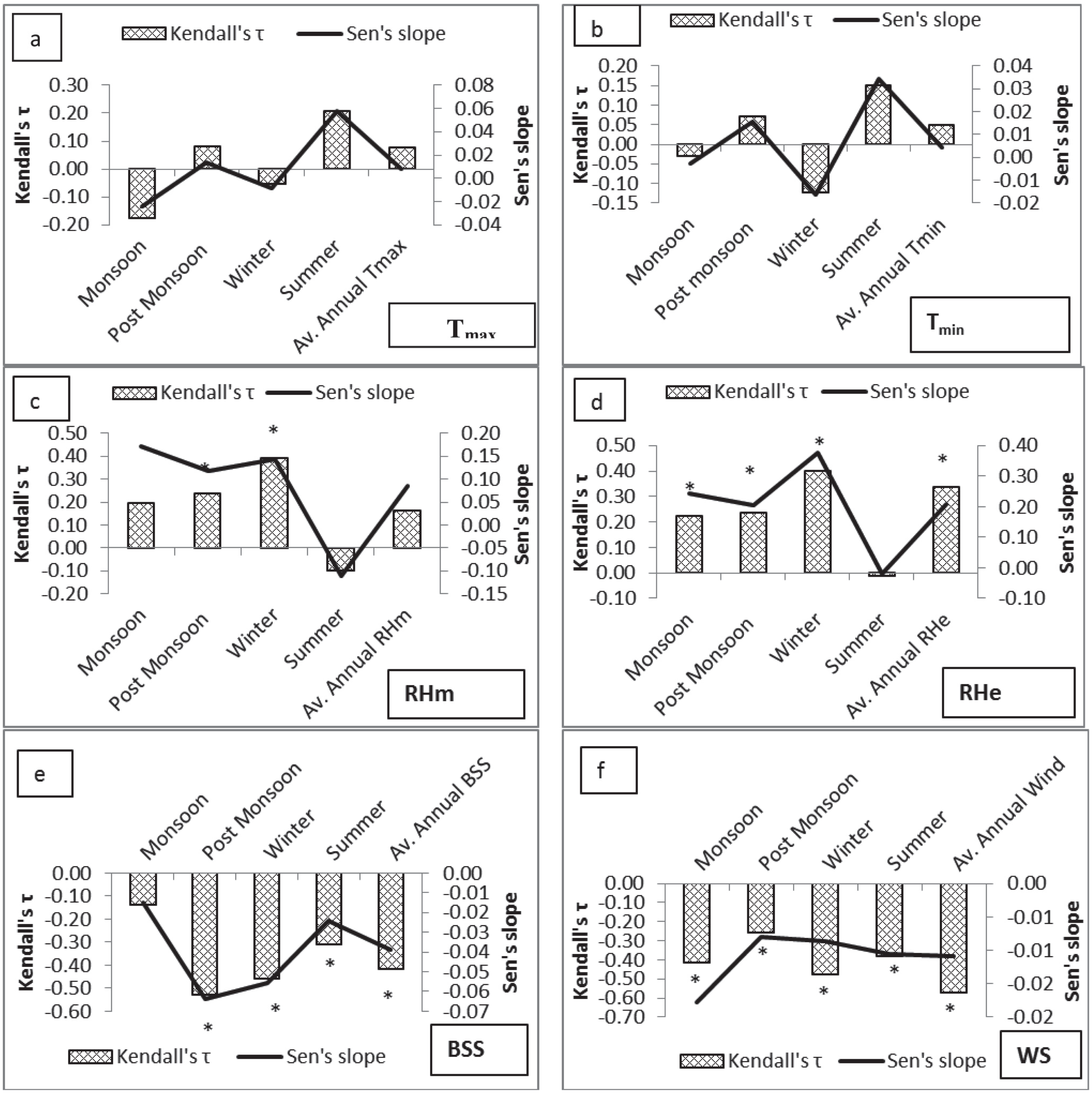


Fig. 2. Results of Mann Kendall trend test for T_{max} (a), T_{min} (b), RH_m (c), RH_e (d), BSS (e) and WS (f) for Hisar (**indicates significant trend*)

nature, rising during annual, post monsoon and summer and falling during monsoon and winter seasons. Since ET_o is linked to these weather parameters in complex intrinsic ways, such trends may be useful in creating reliable weather scenarios in modeling studies on evaluating the impact of climate change on soil, water and crop production in arid regions of Haryana and also for undertaking controlled crop physiological studies.

The results also point out that except in summer season, a significant decrease in ET_o was mainly due to the occurrence of decreased bright sunshine hours and significant decrease in wind speed. Although air temperature did not change so much but change in BSS and wind speed neutralized the effect of temperature on ET_o, but might have actually caused ET_o to decline further in seasonal and annual time scale. The findings of this study are also supported by the observed decreases in ET_o over the Yangtze River basin in China (Xu *et al*., 2006) essentially due to significant changes in net radiation and wind speed. Goyal (2004) reported that temperature followed by radiation, wind speed and vapor pressure affected ET_o significantly in an arid region in Rajasthan of India. Thomas (2000) reported sunshine duration, wind speed, relative humidity and maximum temperature to

Table 2. Significance of trends of weather parameters affecting ET_o at Hisar at different time scales

Time scale	Significant (S)/ Non- significant (NS) trends of weather parameters					
	T_{max}	T_{min}	RH_m	RH_e	BSS	WS
Annual	Positive (NS)	Positive (NS)	Positive (NS)	Positive (S)	Negative (S)	Negative (S)
Monsoon (June – September)	Negative (NS)	Negative (NS)	Positive (NS)	Positive (S)	Negative (NS)	Negative (S)
Post-monsoon (October- November)	Positive (NS)	Positive (NS)	Positive (S)	Positive (S)	Negative (S)	Negative (S)
Summer (March- May)	Positive (NS)	Positive (NS)	Negative (NS)	Negative (NS)	Negative (S)	Negative (S)
Winter (December – February)	Negative (NS)	Negative (NS)	Positive (S)	Positive (S)	Negative (S)	Negative (S)

be the main parameters affecting ET_o in the South China. Donohue *et al*. (2010) also find that the overall contribution from increases in temperature is almost entirely cancelled out by the decreases in wind speed alone over Australia.

Bright sunshine hours provide the major energy input to any evaporative process, and are an excellent estimator of evapo-transpiration. Over India, a significant continued reduction in incoming radiation was observed under all sky conditions (Padma Kumari and Goswami, 2010; Ramanathan *et al*., 2005) where aerosols and clouds together contributed to decrease in incoming radiation. Decrease in surface solar radiation may lead to decrease in evaporation and slowdown the onset of monsoon rains (Wild *et al*., 2005; Ramanathan *et al*., 2005). It is widely perceived that in all the major cities of India, aerosol concentrations have been increasing, resulting in decreased BSS hours (Ramachandran *et al*., 2006). Bandyopadhyay *et al.* (2009) related the steady wind speed decreases witnessed over India to the obstruction of wind flow offered by the ever-increasing construction works, while Vautard *et al*. (2010) and McVicar and Roderick (2010) attribute these to increases in terrestrial surface roughness at global level.

Summary and Conclusions

The nature and estimates of trends in ET_o and governing meteorological parameters of Hisar district in Haryana were investigated through the Mann-Kendall and Sen's nonparametric tests, respectively. Thirty year (1981-2010) climate data was utilized for estimation of reference ET using Penmen – Monteith method and were utilised further along with important weather parameters for trend analysis. Statistically significant decreasing trends of ET_o were observed at annual scale as well as during winter, monsoon and post-monsoon seasons. Temperature (both maximum and minimum) at Hisar has remained practically trend-less both at annual and all seasonal scales, while significant decreasing trends have been observed in BSS hours and wind speed on annual and seasonal scales except during monsoon. The contribution of the temperature, if any, on ET_o seems to be offset by steady reduction in wind speed and BSS hours. This observation is also confirmed by the strong and high sensitivity of BSS and wind speed with ET_o derived through backward stepwise regression at almost all time scales. The results of this study can be usefully utilized to create rational climate change scenarios for conducting controlled cop physiological and modelling studies on the impact of envisaged climate change on soil, water, salinity and crop production in arid regions of Haryana.

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Salt tolerance efficiency of phosphatases producing bacteria and their efficiency in hydrolyzing organic and inorganic phosphorus compounds isolated from arid soils of Rajasthan

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ABSTRACT

The bacterium isolated from arid soils was identified as *Bacillus coagulans* through its morphological and biochemical test. It was capable of growing very well in Thorton's broth containing up to 6% NaCl. At higher concentration up to 10%, the growth was moderate to sparse. The bacterium was able to grow at temperature up to 65^{0}C and pH up to 11. The average alkaline phosphatase activity was 1.4 times higher than acid phosphatase activity. Average phytase activity was 5 times higher than acid phosphatase and 3.6 times higher than alkaline phosphatase. In general, di-calcium phosphate (DCP) was solubilized more efficiently than tri-calcium phosphate (TCP) within 48 h. The 72 h incubation was found optimum for solubilization of glycerophosphate and phytate by *Bacillus coagulans* and hydrolysis of glycerophosphate (mono phosphates), in general was 62% higher than phytate (hexaphosphates). The results clearly showed that the bacterium have enough potential to exploit native organic and inorganic phosphorus to plant nutrition.

Key words: *Bacillus coagulans,* salt tolerance efficiency, acid soils, phosphatases, phytase, organic P hydrolysis, inorganic P hydrolysis

Introduction

Salinity of soil and irrigation water is one of the major factors limiting agricultural production throughout the world (Epstein *et al.*, 1980). In India about 6.73 million ha of land is affected by salinity and sodicity, highest fraction of which is distributed in arid and semi-arid regions. In Rajasthan salt affected soils occupy about 1 million ha, out of which nearly 70% area is in arid region (Mehta *et al.*, 1970). Soil phosphorus exist in bound or dissolved inorganic or organic form. The concentration of soluble P in soil is usually 1 ppm or less. Therefore the application of phosphatic fertilizers is essential for enhanced crop yield. A large proportion of P that is applied to soil as fertilizer rapidly becomes unavailable to plants, accumulating in inorganic P fractions that are fixed by chemical adsorption and precipitation and organic P fractions that are immobilized in soil organic matter (Sanyal and De Datta, 1991). Consequently, fertilized soils contain a significant amount of total P, of which 50-80% may exist in organic form (McLaughlin *et al.*, 1990). Inositol pents- and hexaphosphates (phytates) and their derivatives account for a major component of the soil organic P (Anderson, 1980). The importance of soil organic P as a source of plant available P depends on its rate of solubilization and the rate of inorganic P release. Several types of phosphatases, such as phytases, are able to increase the rate of the dephosphorylation (hydrolysis) of organic P. Phosphatases in the rhizosphere may arise from plant roots (Hayes *et al.*, 1999; Hubel and Beck, 1993) or from soil microorganisms (Tarafdar, 1995; Richardson and Hadodas, 1997). Microbial acid phosphatase was found to be more efficient in hydrolysis of organic P compounds then plant sources (Tarafdar *et al.*, 2001). Yadav and Tarafdar (2003) isolated efficient phytase and phosphatase producing fungi which was capable to hydrolyze organic P compounds. Moreover, little literature is available regarding the efficient phosphatase and phytase producing bacteria of arid soils in general and of Rajasthan in particular. In view of this, an attempt was made to isolate salt tolerance, both phosphatase and phytase producing bacteria from arid soils of Rajasthan, India and tested their efficiency to hydrolyze different organic and inorganic P compounds.

Materials and methods

The soil samples were collected from Jodhpur district of Rajasthan, which comes under arid zone of India. The characteristics of soil in survey area, vegetation/crops and rainfall are given in Table 1. The mean maximum temperature of the surveyed area varied from 38 to 46^{0}C and minimum temperature varied from 9 to 11^{0}C. Following the standard methods (Jackson, 1967) the soil

Table 1. Physico-chemical and biological characteristics of the soils, vegetation and rainfall in the survey area

Soil parameters	Characteristics
Soil texture	Loamy sand to clay loam
pH (1:2)	7.5-8.7
EC (1:2)	0.21-0.34
Organic matter	0.35 -0.61%
Available N(kg/ha)	120-290
Available K(kg/ha)	225-950
Total P(kg/ha)	565-1265
Organic P(kg/ha)	402-887
Mineral P(kg/ha)	152-638
Phytin P(kg/ha)	196-447
Available P(kg/ha)	6-10
Bacteria (x 10^4)	68-114
Fungi (x 10^4)	15-38
Actinomycetes (x 10^4)	29-73
Acid Phosphatase (µ mol PNP produced $min^{-1}g^{-1}$ soil)	0.05-0.08
Alkaline Phosphatase (µ mol PNP produced $min^{-1}g^{-1}$ soil)	0.12-0.16
Phytase (µ mol Pi released $min^{-1}g^{-1}$ soil)	1.32-1.67
Rainfall (mm)	150-600
Crops	Pearl millet, Cluster bean, Moong bean, Moth bean, Mustard, Chickpea, Chilli, Cumin

pH (1:2), EC (1:2), organic carbon, particle size distribution and available P (Olsen's) were estimated. Twenty phosphatases (acid and alkaline) and phytase-producing bacteria were isolated by using dilution plate technique on Asparagine mannitol agar medium (Subba Rao, 1977), purified and got identified from Institute of Microbial Technology, Chandigarh, India. Among these, highest phosphatases and phytase producing bacteria was identified as *Bacillus coagulans* and used for further study.

Acid and alkaline phosphatase was assayed by adopting the standard method of Tabatabai and Bremnar (1969) using acetate buffer (pH 5.4) and sodium tetra borate-NaOH buffer (pH 9.4), respectively. The enzyme substrate (4-nitrophenyle phosphate) mixture was incubated at 35°C for 1h. The phytase activity was assayed by measuring the amount of inorganic phosphate (Pi) released by hydrolysis of sodium phytate (1mM) in 100M sodium acetate buffer (pH 4.5) and incubated at 37°C for 1h. The reaction was terminated by the addition of 0.5mL 10% trichloro-acetic acid (CCl_3COOH). Proteins precipated by TCA were removed by centrifugation at 10,000 g for 10 min and the supernatant was analyzed for liberated Pi (Ames, 1966). For estimation of salt tolerance efficiency of bacteria 1 mL of 24 h old broth culture was used to inoculate 100 mL of modified Thorton's broth containing varying concentrations of sodium chloride. The culture flask was incubated at 35°C with constant shaking (200 rpm). At 24 h intervals, the bacterial culture was diluted 1:10 into fresh sodium chloride – supplemented Thorton's broth and growth of the bacterium in NaCl supplements (Thorton's broth was determined by measuring the change in absorbance at 600nm, which is a measure of cell number).

To test the efficiency of bacteria towards the hydrolysis of different organic and inorganic P compounds, 1mg mL^{-1} compound (organic or inorganic) was added separately to each flask containing 100 mL bacterial broth in triplicate, when the microbes showed maximum phosphatases activity (21 days after bacterial inoculation). The culture flask was incubated at 35°C for different time intervals. At the end of different incubation period (24, 48, 72 and 96 hours); cultures were filtered through Whatman filter No. 42 and the release of P was estimated colorimetrically as described by Jackson (1967). The mineral contents and total and organic P were estimated as described by Seeling and Jungk (1996). The phytin P was estimated by extraction of phytate with 15% CCl_3-COOH (trichloro-acetic acid) as described by Mega (1982). The data were statistically analyzed as per the procedure outlined by Gomez and Gomez (1984).

Results and discussion

The culture got identified from the Indian Institute of Microbial Technology, Chandigargh. The colony morphology test (Table 2) revealed that the bacterium was gram positive, rod shaped, long in size and single. It produced endospores which were round showing 'T' type position. The bacterium showed negative response for sporangia production but positive to fluorescence. The bacterium was able to grow at temperature ranging from 15 to 37°C. Growth at 42°C was greatly reduced and further increase in temperature proved lethal. The optimum pH was 7.5, but it was able to grow at pH range of 6.8- 11. The bacterium was negative to indole test, ethyl red test and Vogues Proskaur test. It failed to utilize citrate, hydrolase casein, starch and urea and produced nitrite and H_2S. The bacterium was positive to catalase and cytochrome oxidase tests and negative to oxidation – fermentation test and gelatin test. There was no acid production by the bacterium from a wide range of carbohydrates namely adonitol, arabinose, cellobiose, dulcitol, galactose, inositol, inulin, lactose, maltose, mannitol, mannose, melibose, raffinose, rhamnose, salicin, sorbitol, sucrose, trehalose, xylose. However, it was able to produce acid from dextrose and fructose. Rod shape, spore formation, Gram positive and catalase production relegated the bacterium to genus *Bacillus* (Bisen and Verma, 1996). Motility, production of acid from glucose and negative response for citrate utilization, nitrate reduction and casein hydrolysis characteristics were suggestive of *Bacillus coagulans* (Yadav and Yadav, 2003).

Table 2. Physico-chemical and biochemical characteristics of the identified bacteria.

Morpho-physiological		Biochemical			
Configuration	Round	Growth on Mac Conkey agar		Acid production from Carbohydrates	
Margin	Wavy	Indole	-	Adonitol	-
Elevations	Convex	Methyl red	-	Arabinose	+
Surface	Round	Voges Proskauer	+	Cellobiose	+
Density	Opaque	Citrate utilization	+	Dextrose	+
Pigments	-	Casein hydrolysis	+	Dulcitol	-
Cell shape	Rods	Starch hydrolysis	+	Fructose	+
Size	Long	Gelatin hydrolysis	+	Galactose	-
Arrangement	Single	Urea hydrolysis	-	Inositol	-
Gram's reaction	+	Nitrate reduction	+	Inulin	-
Endospore	+	H_2S production	-	Lactose	-
Position	Central	Cytochrome Oxidase	+	Maltose	+
Shape	Oval	Catalase	+	Mannitol	+
Sporangia bulging	+	Oxidation/ fermentation	-	Mannose	+
Motility	+			Melibiose	-
Fluorescence(UV)	-			Raffinose	-
Growth at temperatures				Rhamnose	-
4 °C	-			Salicin	+
10 °C	W			Sorbitol	+
15 to 65 °C	+			Sucrose	+
Growth at pH				Trehalose	W
5.0 to 11	+			Xlose	-
Growth at NaCl (%)					
2.5 to 8.5	+				
10.0	W				
Growth under anaerobic condition	+				

Table 3. Growth of *Bacillus coagulans* in different concentrations of NaCl at different time intervals.

Growth period	OD* at 600nm at different concentration of sodium chloride (%)					
(h)	0.0	2.0	4.0	6.0	8.0	10.0
2	1.34	0.84	0.67	0.53	0.37	0.24
4	3.69	2.94	1.24	0.96	0.62	0.43
6	7.36	5.68	3.54	3.25	1.94	1.48
8	9.67	6.24	4.98	3.82	2.73	1.66
16	8.42	7.35	6.67	5.34	3.68	1.92
24	8.15	6.95	6.42	4.92	4.83	2.34
LSD (p=0.05)	1.06	0.52	0.54	0.39	0.22	0.18

*The values are mean of three replications; NaCl 2.0% = 0.34M, 4.0%= 0.69M, 6.0%= 1.03M, 8.0%= 1.37M and 10.0%=1.7M

The data presented in Table 3 suggested that bacterium was highly salt tolerent. The bacterium culture attained highest growth at zero level of NaCl in Thorton's broth in 8h, while at 2.0 to 6.0 % NaCl attained in 16h and at 8.0 to 10.0% NaCl attained maximum growth in 24h. Earlier, Neumyvakin *et al.* (1990) have reported that salt tolerant mutants of *E. coli* were able to grow in a medium containing 3.5% NaCl while Parent *E. coli* could not. Similarly, Yadav and Yadav (2003) reported that *Bacillus coagulans* was capable to grow very well in Luria Beretain broth containing up to 6% NaCl and at higher concentration up to 10%, the growth was moderate to sparse.

The data (Table 4) showed significant increase in phosphatases (acid and alkaline) and phytase released by the bacterium *Bacillus coagulans*. The maximum phosphatases were observed at 21 days, while maximum phytase activity was reported at 28 days of incubation. The average alkaline phosphatase activity was 1.4 times higher than acid phosphatase secretion. The average phytase activity was 5 times higher than acid phosphatase

Table 4. Phosphatases and phytase produced by *Bacillus coagulans* at different time intervals.

Incubation period (days)	Acid Phosphatase (µ mol PNP produced min^{-1} mL^{-1})	Alkaline Phosphatase (µ mol PNP produced min^{-1} mL^{-1})	Phytase (µ mol Pi released min^{-1} mL^{-1})
7	2.07	3.51	6.47
14	3.20	4.49	15.18
21	4.35	5.68	17.96
28	2.20	3.04	21.23
LSD (p=0.05)	1.10	0.95	2.40

Table 5. Efficiency of *Bacillus coagulans* to hydrolyze different inorganic P compound.

Incubation period (h)	K_2HPO_4* Available P**	Dicalcium phosphate* Available P**	Tricalcium phosphate* Available P**
24	618.64	310.71	182.45
48	878.46	489.15	307.24
72	399.27	182.24	100.26
96	338.41	163.73	86.57
LSD (p=0.05)	158.54	117.27	113.25

*mg mL^{-1}; ** µg mL^{-1}

and 3.6 times higher than alkaline phosphatase. The decline in phosphatases activity after 21 days might be due to the onset of stationary phase in bacterium culture.

The phosphate solubilization increased with the progress of incubation period of *Bacillus coagulans* (Table 5). The 48 h incubation was optimum for solubilization of di- potassium hydrogen phosphate, di- and tri-calcium phosphate by the bacterium.

In general, DCP was solubilized more efficiently than TCP, however di- potassium hydrogen phosphate was highly solubilized by *Bacillus coagulans*. The decrease in soluble phosphorus at later incubation may be either due to decreased solubilizing efficiency and increased P absorption.

Efficiency of *Bacillus coagulans* to hydrolyse organic P compounds (Table 6) revealed that hydrolysis of glycerophosphate (mono phosphates), in general was 62% higher than phytate (hexaphosphates). The 72 h incubation was found optimum for solubilization of glycerophosphate and phytate by *Bacillus coagulans*. The higher solubility of glycerophosphate as compared to phytate may be due to the fact that phosphatases released by bacterium was more efficient to hydrolyze glycerophosphate as compared to phytate. Tarafdar *et al.* (2003) also reported that the phosphatase released from *Trichoderma harzanium* was most efficient in hydrolyzing phytaye (hexaphosphate) whereas phosphatases released from *Aspergillus rugulosa* was found to be most efficient in hydrolyzing glycerophosphate (mono phosphates).

Table 6. Efficiency of *Bacillus coagulans* to hydrolyze different organic P compound

Incubation period (h)	Glycerophosphate* Available P**	Phytin* Available P**
24	167.52	79.64
48	288.84	147.65
72	305.53	255.73
96	74.84	33.42
LSD (p=0.05)	15.14	88.46

*mg mL^{-1}; ** µg mL^{-1}

Despite the quantitative importance of organic P compounds (such as phytin) in the soil, our knowledge on the extent and mechanisms of their use by plants is still limited (Tarafdar and Claassen, 1988). Several types of phosphatases, such as phytases, are able to increase the rate of dephosphorylation (hydrolysis) of organic P compounds. It is generally believed that the hydrolysis of P from organic molecules is an indispensable step during its utilization by plant roots. Therefore, the organisms isolated in the present investigation influenced P nutrition of plants particularly in salt-affected soils.

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Effect of sewage irrigation on soil properties and yields of rice and wheat grown in reclaimed alkali soil

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ABSTRACT

A field experiment was conducted for two years to evaluate the effect of sewage water irrigation on soil properties and yields of rice and wheat in reclaimed alkali soil at the experimental farm of Central Soil Salinity Research Institute, Karnal. The treatments consisted of: T_1- application of good quality water alone; T_2- good quality water with 100% recommended dose of nitrogen (N) and phosphorus (P); T_3-raw sewage water; T_4-raw sewage water with 75% recommended dose of N and P and T_5-disinfected sewage water. Results showed significant increase in plant height, number of effective tillers, grain yield of both rice and wheat with sewage water alone (T_3) as compared to good quality water (T_1). The yields improved further when sewage water was used along with 75 % recommended dose of N and P (T_4) and were at par with treatment T_2 (good quality water with 100% recommended dose of N and P). There was higher concentration of nitrogen, phosphorus and potassium in grain and straw of rice and wheat in treatments T_2, T_3 and T_5 in comparison to treatment T_1. The concentration of micronutrients (Fe, Mn, Zn) and heavy metals (Cu, Pb, Cr, Cd, Ni) in crops did not differ significantly among different treatments. There was increased biological activity with respect to total number of bacteria and dehydrogenase activity in soil in plots irrigated with sewage water (T_3 and T_4) in comparison to good quality water (T_1 and T_2) and disinfected sewage water (T_5). The grains of both rice and wheat were free from pathogens (*E.coil*) in all the treatments. However, the population of *E.coli* (10^3 to 10^5 /g. dry soil*)* was more in soils of sewage irrigated plots (T_3, T_4) in comparison to good quality water (T_1 and T_2) and disinfected sewage (T_5) water irrigation (10^2 /g dry soil). Substantial increase in organic carbon, nitrate, total nitrogen and available phosphorus was observed in treatments T_2, T_3 and T_4 as compared to T_1 and initial values. Available K decreased in all the treatments in comparison to initial value in soil.

Key words**:** sewage, rice-wheat cropping system, soil properties, *E.coli*

Introduction

Due to rapid urbanization and industrialization, large quantities of wastewater are produced. With the current emphasis on environmental health and water pollution issues, there is an increasing awareness of the need to dispose of this wastewater safely and beneficially. Use of wastewater in agriculture could be an important consideration when its disposal is being planned in arid and semi arid regions (Pescod, 1992). Land application of wastewater is being given preference and weightage over the conventional wastewater treatment and stream disposal, since the former provides scope for exploiting the reuse potential of these waters for productive purposes. Land applied water also undergoes natural physico-chemical and biological changes in the soil matrix which is not only a highly effective low cost alternative but also an ecological balanced and environmental compatible system of wastewater management (Shende et.al. 1988). High contents of nutrients especially nitrogen and phosphorus in sewage has been reported to benefit the crop nutrition (Baddesha *et al.*, 1986; Baddesha *et al.*,1997; Prasad, 1996) but systematic information on this aspect under field conditions is lacking.

Wastewater contains many pathogenic microorganisms, which form a source of contamination of soil and crops. Although the soil-plant system does not provide favourable conditions for the growth and multiplication of these host-specific organisms, and this may actually add to the difficulty of their survival in the soil and plant ecosystem, the risk of contamination can still not be overruled. The present study was, therefore, planned to see the impact of sewage and good quality water irrigation on rice-wheat cropping system and on chemical and biological properties of soil in reclaimed alkali soil.

Materials and Methods

Experimental details

A field experiment was conducted on a reclaimed alkali soil in a fixed layout using rice-wheat-cropping

Table 1. Special features of various packages of practices followed

Feature	Rice	Wheat
Variety	Jaya	PBW 343
Date of sowing/	7.7.2000	11.11.2000
Transplanting	15.7.2001	20.11.2001
Spacing (cm)	15x15	20
Fertilizer (Kg/ha)		
N	150	150
P_2O_5	60	60
$ZnSo_4.7H_2O$	20	0
No. of irrigation	26	5
Date of harvesting	5.10.2000	15.4.2001
	30.10.2001	18.4.2002

system during 2000-2002. The experiment was laid out in randomized block design with four replications. Plot size was 4m×5m. The treatments consisted of: T_1-application of good quality water alone; T_2- good quality water with 100% recommended dose of nitrogen (N) and phosphorus (P); T_3-raw sewage; T_4-raw sewage with 75% recommended dose of N and P and T_5-disinfected sewage. Disinfection of sewage was done with bleaching powder @ of 15-mg chlorine/liter of sewage at the time of irrigation in plot itself.

Package of agronomic practices

Package of agronomic practices followed is given in table 1. One-third dose of nitrogen and full dose of phosphorus were given before transplanting of rice and sowing of wheat in both the years. The remaining two third of the nitrogen was top-dressed in two equal splits when the crops were 3 and 6 weeks old. The sources of nitrogen and phosphorus were urea and single super phosphate. Zinc was applied through zinc sulfate in rice uniformly in plots of all the treatments.

Rice was grown in wet season of 2000 to 2002. Thirty day old seedlings were transplanted during second week of June and the crop was harvested at maturity during October. Winter wheat was sown during November in 2000-2001 to 2003-2004 and harvested at maturity during April. Crops were irrigated with good quality and sewage water as per treatments as and when required (upto 25 DAT). The chemical composition of these waters is presented in table 2. Submerged conditions (5 cm standing water above soil surface) were maintained during early and reproductive (80-110 DAT) growth period of the rice crop. Weeds were removed from the plots manually.

Biometrics and yield observations

Growth and yield attributes of rice and wheat were recorded regularly. For recording plant height (PH) and length of panicle (rice only), 5 mature plants in each plot were selected randomly leaving two border rows at each side. The number of productive tillers per hill and per meter row length were recorded in each plot for rice and wheat respectively. Plants were harvested at ground level and dried in the sun for a week before threshing. After harvest of crops at maturity, grain yields were recorded for both the crops . Grain yield of rice was computed on 14% moisture content, whereas in wheat yields of grain were recorded on an air-dry basis.

Table 2. Comparison of good quality and sewage water used for irrigation

Parameter	Good water	Sewage water
pH	7.94	7.93
EC_2 (dS/m)	0.49	0.98
BOD (mg/l)	ND[a]	198
COD (mg/l)	ND	249
NH_4 –N (mg/l)	ND	12.9
NO_3-N (mg/l)	ND	2.43
CO_3 (me/l)	0.17	1.10
HCO_3 (me/l)	4.29	7.89
P (mg/l)	0.03	4.06
K (me/l)	0.09	0.29
Na (me/l)	0.90	2.38
Ca (me/l)	1.89	2.19
Mg (me/l)	2.96	3.20
Zn (mg/l)	0.12	0.24
Fe (mg/l)	0.08	0.94
Mn (mg/l)	0.00	0.03
Pb (mg/l)	0.11	0.16
Cd (mg/l)	ND	0.01
Cr (mg/l)	ND	ND
E.coli (MPN/100ml)	ND	10^{10}

a-not detected

Analytical studies

Soil samples were collected before start of experiment and after the harvest of last rice crop, ground to pass through a 2-mm sieve and analyzed for pH, electrical conductivity (EC_2), organic carbon (Walkley and Black, 1934), available P (Olsen *et al.*, 1954), available K (1N NH_4Ac, pH 7.0 extractable), and DTPA-extractable Zn, Fe, Mn, (Lindsay and Norvell, 1978). For plant chemical analysis, five mature plants from each plot were taken, washed with deionized water, dried at 67 °C. The plants were threshed; grain and straw were ground separately in a stainless steel wiley mill. The dried ground plant samples were digested in a $HClO_4$-HNO_3 mixture (1:3) and analyzed for potassium using flame-photometry, Zn, Mn, Fe and other heavy metals by atomic absorption spectrophotometery and nitrogen by Kjeldhal digestion method (Jackson, 1967). Phosphorus was determined by the Vanadomolybdo phosphoric yellow colour method. Estimation of pathogenic bacteria and total bacteria in soil was done using standard methods (APHA, 1998). Dehyrogenase activity in soil was estimated by method described by Casida *et al*. (1964). Analysis of good quality and sewage water used for irrigation was done with respect to nutrients and indicator pathogenic bacteria (*Escherichia coli*) before start of experiment following standard methods (APHA, 1998, Table 2). Indicator pathogenic bacteria (*E.coli)* were determined on grains of both rice and wheat using standard methods (APHA, 1998). The yield, yield attributing data and data on concentration of nutrients in grains and straw of rice and wheat were subjected to analysis of variance and the treatment means were tested for significance.

Results and Discussion

Crop growth and yield attributes

Results indicated significant increase in grain yield of both rice and wheat with sewage water alone (T_3) as compared to good quality water (T_1). The yields improved further when sewage water was used along with 75 % recommended dose of N and P (T_4) and were at par with treatment T_2 (good quality water with 100% recommended dose of N and P). Similarly, there was significant increase in plant height, number of effective tillers in wheat and length of panicle (rice only) in rice and wheat with treatments T_2, T_3 and T_5 in comparison to treatment T_1 (Table 3). Increase in yield of rice and wheat and yield attributes was mainly due to application of nitrogenous and phosphatic fertilizers (T_2, T_4) and presence of N and P in sewage water (T_3, T_4, T_5) in sufficient amount. Similar results were obtained by sewage irrigation in wheat and rice (Shinde *et al.*,1988) and in wheat with sewage sludge (Prasad, 1996). Better yields and related growth parameters of rice and wheat were reported in alkali soil due to application of N and P (Swarup and Singh, 1989).

Nutrient concentration in plant

Irrigation with good quality water with 100% recommended dose of N and P (T_2) and sewage water alone (T_3) and sewage water with 75% recommended dose of N and P (T_4) resulted in significantly higher concentration of N, P and K in grain and straw of rice in comparison to plants irrigated with good quality water alone (Tables 4 and 5). It seems plausible that sufficient amount of N, P, K present in sewage (Table 2) and possible recycling of these nutrients through left over bio-mass of roots contributed significantly towards enhanced concentration in plants. The results were in agreement with earlier findings with sewage and sewage sludge application in rice, wheat, vegetables and trees (Baddesha

Table 3. Effect of sewage and good quality water irrigation on grain yield and yield attributes of rice and wheat

Treats.	Grain yield (t/ha)				Yield components									
	Rice		Wheat		Plant height (cm)				Effective tillers				Panicle length (cm)	
					Rice		Wheat		Rice (No/hill)		Wheat (No/m.r.l.)		Rice	
	2000	2001	2000-01	2001-02	2000	2001	2000-01	2001-02	2000	2001	2000-01	2001-02	2000	2001
T_1	2.6	2.4	2.7	2.5	81	85	76	80	8.7	9.2	86	100	23.4	21.6
T_2	4.1	3.8	4.8	5.2	105	103	104	101	12.0	11.8	132	137	25.3	24.7
T_3	4.1	4.2	4.2	4.9	107	109	92	98	11.2	12.4	109	128	26.5	23.2
T_4	4.2	4.5	5.2	5.5	107	112	103	106	12.0	13.1	127	154	27.2	25.1
T_5	3.4	4.1	4.2	4.4	106	108	89	98	11.2	12.2	102	119	26.2	24.2
CD (5%)	0.4	0.3	0.9	0.5	14	15	5	9	1.7	1.9	9	28	1.9	0.8

Table 4. Effect of sewage and good quality irrigation water on nutrient concentration of rice

Treatment	Nutrient concentration											
	Grain						Straw					
	N	P	K	Fe	Zn	Mn	N	P	K	Fe	Zn	Mn
	%			mg kg^{-1}			%			mg kg^{-1}		
T_1	1.19	0.23	0.34	48	15	14	0.54	0.03	2.55	173	38	75
T_2	1.57	0.30	0.39	53	17	16	0.82	0.07	2.80	194	42	81
T_3	1.42	0.26	0.38	48	17	17	0.68	0.06	2.77	184	46	89
T_4	1.45	0.28	0.38	49	18	18	0.64	0.10	3.05	174	47	96
T_5	1.29	0.28	0.37	49	18	16	0.60	0.06	2.95	191	45	85
LSD(p=0.05)	0.08	0.03	0.02	NS	NS	NS	0.02	0.01	0.20	NS	NS	NS

Table 5. Effect of sewage and good quality irrigation water on nutrient composition of wheat

Treatment	Nutrient concentration											
	Grain						Straw					
	N	P	K	Fe	Zn	Mn	N	P	K	Fe	Zn	Mn
	%			mg kg^{-1}			%			mg kg^{-1}		
T_1	1.60	0.23	0.30	69	27	19	0.29	0.03	1.5	129	20	16
T_2	1.90	0.33	0.36	86	29	25	0.46	0.07	1.8	174	22	20
T_3	1.68	0.31	0.36	88	31	24	0.36	0.07	1.9	154	23	17
T_4	1.84	0.32	0.33	77	30	25	0.42	0.06	2.0	154	21	21
T_5	1.72	0.30	0.32	80	30	23	0.37	0.06	1.9	151	22	18
LSD(p=0.05)	0.09	0.02	0.02	NS	NS	NS	0.01	0.01	0.2	NS	NS	NS

Table 6. Effect of sewage and good quality irrigation water on chemical properties of soil after harvest of 2nd crop of wheat

Treatment		pH	EC_2 (dS m^{-1})	O.C (%)	NH_4-N	NO_3-N	Total-N (%)	Available K	Available P
					mg kg^{-1}			kg ha^{-1}	
T_1	0-15	7.8	0.12	0.56	5.6	12.1	0.06	201	9.3
	15-30	7.7	0.11	0.40	4.2	7.0	0.05	185	5.8
	30-60	7.7	0.11	0.23	2.8	1.4	0.04	199	3.4
T_2	0-15	7.7	0.20	0.71	11.2	16.8	0.08	204	16.4
	15-30	7.7	0.14	0.39	8.4	11.2	0.06	185	12.9
	30-60	7.7	0.15	0.24	7.7	7.0	0.05	172	10.2
T_3	0-15	7.9	0.19	0.68	9.8	16.8	0.08	190	12.2
	15-30	7.9	0.15	0.42	7.0	9.8	0.06	179	8.2
	30-60	7.9	0.14	0.21	5.6	8.4	0.04	173	7.1
T_4	0-15	7.8	0.20	0.65	9.8	12.6	0.08	193	16.6
	15-30	7.8	0.17	0.43	7.7	8.4	0.06	180	9.5
	30-60	7.8	0.15	0.28	5.6	7.0	0.05	176	7.9
T_5	0-15	7.8	0.23	0.65	8.4	11.5	0.08	185	11.5
	15-30	7.8	0.20	0.40	5.6	9.4	0.06	169	9.4
	30-60	7.8	0.19	0.25	4.9	5.8	0.04	153	6.8
Intial	0-15	7.7	0.18	0.58	16.6	5.6	0.07	235	10.3
	15-30	7.8	0.13	0.38	9.1	7.0	0.05	201	7.1
	30-60	7.8	0.12	0.22	3.4	4.9	0.04	209	6.5

et al.,1996; Prasad, 1996; Shinde *et al.*,1988). There was no significant effect of treatments on the uptake of micronutrients such as Fe, Zn and Mn in grain and straw of both the crops. Similarly, non-significant and negligible concentration of heavy metals such as, Pb, Cu, Ni, Cr, Cd was recorded in grain and straw of both the crops. It seems that concentrations of micronutrients and metals in sewage and good quality water of CSSRI campus (Table 2) did not pose a serious problem at present. Similar observations have been made by Dutta *et al*. (2000) in different crops on irrigation with sewage.

Soil chemical and biological properties

There was substantial increase in soil organic carbon, EC_2, ammonical, nitrate and total nitrogen; and available phosphorus in good quality water with recommended dose on N and P (T_2); sewage water alone (T_3) and sewage with 75 % recommended dose of N and P (T_4) after the harvest of crops in comparison to initial value (Table 6). Similar observations were made earlier (Shende *et al*. 1988; Baddesha *et al*. 1997; Mitra and Gupta, 1999) in soils irrigated with sewage water. This was due to presence of higher concentration of N, P, soluble salts in sewage, application of nitrogen and phosphatic fertilizers and recycling of nutrients and release of soluble salts by left over bio-mass of roots in treatment T_2, T_3 and T_4. However, there was decrease in available soil K in all the treatments. This was mainly due to non-application of K to both rice and wheat and the results were in agreement with the observations of Singh and Sharma (2001).

Regarding biological properties there was higher population of indicator pathogenic bacteria *E.coli* ($4.5x10^3$ to 10^5/g dry of soil) in plots of wheat irrigated with sewage (T_3, T_4) in comparison to good quality water (T_1, T_2; $1.2x10^2$/g dry soil) and disinfected sewage (T_5, $5x10^2$/g dry soil) irrigation. Similarly, the population of bacteria, dehydrogenase, urease and phosphatase activity was more in soil of sewage irrigated plots in comparison to good

Table 7. Effect of sewage water on biological properties of soil (0-30 cm) after harvest of last crop of wheat

Treatment	Bacteria (No/g dry soil)	*E.coli* (MPN/g dry soil)	Dehyrogenase (TPF ug/g dry soil)
T_1	$2.6x10^8$	$1.2x10^2$	76
T_2	$4.7x10^9$	$1.2x10^2$	178
T_3	$4.0x10^9$	$4.5x10^5$	236
T_4	$5.0x10^{12}$	$4.5x10^3$	148
T_5	$5.0x10^8$	$5.0x10^2$	164

quality water and disinfected sewage-irrigated plots (Table7). Higher biological activity in terms of enzymes and microbes on irrigation with sewage was reported earlier (Shende et.al., 1988; Giusquiani et.al.,1994). Presence of an indicator pathogenic bacteria *E.coli* in both sewage and tube well irrigated soils of crops was observed by Cadillon and Tremea (1988). Higher microbial and biological activity on irrigation with sewage was the result of increase in organic matter and soil fertility.

Pathogenic contamination of grains

The grains of both rice and wheat were free from pathogenic bacteria (*Ecoli*.). This was mainly due to lack of contact of upper portion (reproductive parts) of both the crops with sewage water and short survival of pathogens in such environment.

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Efficiency of *Trichoderma harzianum, Bacillus pumilus* and *Bacillus thuringensis* as biocontrol agents against *Fusarium solani* on tomato plants grown in sodic soils

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ABSTRACT

Tomato has emerged as one of the important commercial vegetable which is being attacked by several serious diseases such as root rot and wilt. It has been grown in open conditions in the river basins of major rivers in the world including like Indo-Gangetic plains. However, high soil pH (sodic nature of the soil) and increased incidence of soil borne diseases limited its cultivation in large extent and also reduced the productivity. The purpose of this study was to develop biological and eco-friendly disease control approaches using the isolates of genera *Trichoderma* and *Bacillus* obtained from sodic soils for increasing the productivity potential of these soils and also to make them sustainable productive lands. The efficiency of these strains was evaluated using an *in- vitro* assay and pot experiment with sodic soils of pH 9.1. The results showed that these treatments favoured greater proliferation of rhizosphere microflora. The dual treatment of *Trichoderma harzianum* and bacterial consortia of *Bacillus thuringensis* and *Bacillus pumilus* (CSR-BIO) decreased the percentage of infestation and increased the survival rate to 83.4 %. It also gave the highest plant growth height (68.0 cm) and dry weight (9.45 g / plant) in sodic soils due to their antagonistic and plant growth promoting potential.

Key words: *Trichoderma harzianum, Bacillus pumilus*, *Bacillus thuringensis*, *Fusarium solani*, antagonist potential, myceliam growth, rhizospheric bacteria, sodicity tolerance

Introduction

The various irrigation schemes resulted in complication of increasing the concentration of soluble salts along canal command areas due to rise in water table and consequent evaporation of water bringing the salts to the surface of cultivated fertile lands (Gupta and Abrol, 2000; Cicik and Cakirlar, 2002). This led to development of sodic soils which initiated the reclamation process using gypsum and pyrite (Qadir & Schubert, 2002). The growth of important crops like tomato had been restricted in these soils even after reclamation due to the lack of antagonistic microbial population that restricts the growth of important disease causing organisms (Damodaran *et al*., 2013). Tomato, considered as one of the important vegetable crop in most of the countries is sensitive to pH > 8.0 (Harold *et al*., 2007) and is constantly being attacked by many soil borne pathogens especially wilt caused by *Fusarium oxysporum* f. sp. *solani*. It accounts for 60 % of yield loss in tomato (Morsy, 2005; Srinon *et al*., 2006). It causes severe damage to the crop especially those grown in old soils (El-Fahham, 1993). Control of wilt using biological natural antagonists has been suggested as a safe alternative to chemical control methods (Poornima, 2011). The combinations of fungi and bacteria may provide protection at different times or under different conditions and occupy different or complementary niches. Such combinations may overcome inconsistencies in the performance of individual isolates (Harman *et al*., 2004). Several researchers have observed improved disease control using various biocontrol organisms such as *Trichoderma* sp. (Roberti *et al*., 1996, Lewis *et al*., 1998 and Adekunle *et al*., 2001) and *Pseudomonas* sp. (Lemanceau *et al*., 19921, Lemanceau and Alabouvette, 1993, Leeman *et al*., 1996 and Duijff *et al*., 1998). Majority of the existing biocontrol agents are restricted to pH range of 6.0 to 8.5 (Bandopadhyay *et al*., 2003) which emphasizes the need for a suitable biocontrol agent for soils of higher pH. Two bacterial isolates CSR-B-2 (*Bacillus pumilus*), CSR-B-3 (*Bacillus thuringensis*) and one fungal isolate CSR-T-1 (*Trichoderma harzianum*) was isolated from sodic soils and identified as potential growth enhancers for crops grown in sodic soils (Damodaran *et al*., 2013a). Thus in the current study these isolates (CSR-

T-1, CSR-B-2 and CSR-B-3) are evaluated for their bio-control potential against the major soil borne pathogen *Fusarium oxysporum f. sp. solani* in tomato grown in reclaimed sodic soils at Central Soil Salinity Research Institute, Regional Research Station, Lucknow under the World Bank funded NAIP project.

Materials and methods

Isolation of pathogenic fungi

Fusarium solani isolated from roots of wilted tomato plants was obtained from Department of Pathology, Indian Vegetable Research Institute, Varanasi, India. It was identified using cultural and microscopic characteristics (Light yellow, moist appearance, red with cottony and orange brown mycelium, with light brown exudates and takes 4-5 days to colonize in Potato Dextrose Agar medium) with (8-16 x 2-4 ìm microconidia's). Pathogenecity of the in tomato plant was estimated as suggested by Sneh *et al*. (1991). The isolate was cultured in PDA medium at 4^0C. Challenge inoculation in sterilized soil was carried out by growing *Fusarium solani* cultivated on the barley grain medium as described by Singleton *et al*. (1992).

Strains of microbes used

Two strains of bacteria CSR-B-2 (*Bacillus pumilus* JQ768236), CSR-B-3 (*Bacillus thuringensis* KF383226) and one strain of fungus CSR-T-1 (*Trichoderma harzianum*) identified at Plant Pathology Laboratory, Central Institute of Sub-tropical Horticulture, India were isolated from sodic rhizosphere of grasses (*Saccharum spontaneum* and *Pannisetum purpureum*) grown in sodic soils with pH 9.8.

Efficacy of antagonistic bioagents against F. solani

The three bioagents were tested for their efficacy as biocontrol agents against *F.solani*. *Trichoderma harzianum* strain and *F. solani* and were cultured on PDA medium for 7 days at $28\text{-}30^0$C. Then, a disc (0.5cm diameter) of the antagonistic fungal colony was cut and placed opposite to the colony of the pathogen. On the other hand, a streak of the bacterial strain was placed on PDA plates at 28°C for 24 h, then a mycelia disc of test fungi was placed onto PDA plates at 0.5 cm from the bacterial colony. The growth and reduction in mycelial growth of the pathogenic fungus was calculated according to Fokemma (1973).

Preparation of the inoculums and pot experiment

A loopful of bacterium and fungal mycelium was inoculated into the CSR patent protected culture media (Rai *et al*., 2011) and incubated in a rotary shaker at 150 rpm for 48 h at room temperature (28±2°C). After 48h of incubation, the CSR media broth containing 6×10^8 CFU ml^{-1} was used for treating tomato seeds @ 1 % in beakers. Seeds were air dried for 1 h and planted in plastic pots of size 15 cm diameter containing 3 kg of sterilized reclaimed sodic soil with pH 9.1 and SAR 14.52 which were infested earlier with the inoculam of *Fusarium solani* @ 5 kg / soil. Compound NPK mixture was added with irrigation water at the rate of 2 g / L into two doses. Pots were kept under greenhouse conditions till the end of experiment. Disease assessment for incidence of pre and post emergence damping – off and survival rate of seedlings were determined after 30 days of sowing as described by Phillips and Hayman (1970).

Field experiment

The field experiment was carried out at the experimental research farm of Central Soil Salinity Research Institute, Regional Research Station, Lucknow, India. The experiment was laid out in randomized block design (RBD) with plot size 3.5 x 3 m and each treatment consisted of four rows of 10 seedlings within each row. The plants were grown during two successive *rabi* seasons (September–December) of the year 2011 and 2012, where all normal agricultural practices were followed. The seeds and seedlings of tomato var. Himshona were treated with 1 % solution of the microbial inoculants grown in CSR-media (broth). The experiment involved the following treatments:

i) *F. solani* + *T. harzianum* (CSR-T-1)

ii) *F. solani* + *B. pumilus* (CSR-B-2) + *B. thuringensis* (CSR-B-3)

iii) *Fusarium solani* + CSR-BIO (CSR-T-1+CSR-B-2 +CSR-B-3)

iv) soil treated with *Fusarium solani*

During the growing period of each season, plant height (cm), fresh and dry weight (%), number of branches and plant yield were recorded.

The experiment was conducted in completely randomized block design and the data was analyzed using SAS 9.2 version.

Results and discussion

Efficacy of fungal and bacterial strains against F. solani in vitro conditions

The strains CSR-B-2, CSR-B-3 and CSR-T-1 were evaluated for antagonistic effect against *F. solani* (Table 1) on petri dishes containing PDA medium show that all the three strains succeeded in eliciting antagonistic activity against the *F. solani* pathogen. *T. harzianum* was more effective in reduction of pathogen growth by exhibiting 6.7 cm radial growth followed by *Bacillus pumilus* (3.9) and *Bacillus thurigensis* (3.6). Moreover, *T harzianum* reduced the growth percentage of *F solani* by 74.4 % and was followed by *B thurigensis* (43.3 %).

Table 1. Effect of CSR-T-1, CSR-B-2 and CSR-B-3 against the radial growth of *F.solani*

Microbial strain	Mean radial growth (cm)	Reduction %
T. harzianum (CSR-T-1)	6.7[b]	74.4[c]
B. pumilus (CSR-B-2)	3.6[a]	40.0[b]
B. thuringensis (CSR-B-3)	3.9[a]	43.3[b]
Control	9.0[c]	0.0[a]

Values are the means of three replicates. Means in the columns followed by the same subscript letter are not significantly different according to Duncan's multiple range test at p=0.05.

This reveals the ability of the strains to reduce the growth of the *F solani* which represents an important role for controlling root rot disease in tomato. Within the strains the CSR-T-1 strain exhibited higher inhibitory percentage over the growth of *F. solani* followed by CSR-B-3. This potentiality for control of the pathogen growth could be attributed to the secretion of various defense enzymes and secondary metabolites by the organisms which possess antifungal properties. Earlier findings of Montealegre *et al.*, (2005) in the *B subtilis* elicited its role in control of spore germination in *Fusarium oxysporum*. Kavino *et al.*, 2007 has also reported the role of bacterial endophytes in controlling banana bunch top virus (BBTV) disease through increased production of defense enzymes like â glucanase and chitinase. These findings are in line with those obtained by Alippi and Monaco (1994) who reported that *Bacillus subtilis* secreted antifungal metabolites like bacilli, bactracin and bacillomycin which have an inhibitory effect on fungal pathogens.

Efficiency of antagonistic biocontrol agents under green house conditions

Pot culture experiment was undertaken to assess the efficacy of the three biocontrol agents to antagonize *Fusarium solani* under green house conditions. Data revealed that soil infested with *Fusarium solani* alone significantly increased the incidence of wilting of tomato seedlings which reduced the survival percentage to 33.0 percentage when compared with soils treated with *F solani* + CSR-BIO (*Trichoderma harzianum +Bacillus pumilus + Bacillus thurigensis*) and *Trichoderma harzianum.* The treatments with CSR-Bio and *Trichoderma harzianum* has significantly decreased the damping off disease incidence (16.6 %) and exhibited 83.4 percentage survival rate (Table 2) of seedlings. Earlier workers (Zaghloul *et al.* 2007) confirmed that the combination of *Bacillus subtilis* and *Trichoderma harzianum* significantly decreased severity of the disease in comparison with the individual ones. The mechanism of *Trichoderma* and *Bacillus* action on pathogens may be attributed to its ability to attack and bind the pathogenic organism which begins to secrete extracellular protease and lipase (Cal *et al.*, 2004). Tjamose *et al.* (1998) observed that *T. harzianum* controls *Fusarium oxysporum* by competing for both rhizosphere colonization and nutrients and most of the *Trichoderma* strains produce volatile and nonvolatile toxic metabolites like harzianic acid, alamethicins, tricholin, peptaibols, 6-penthyl-alpha-pyrone, massoilactone, viridin, gliovirin, glisoprenins and heptelidic acid; which obstruct colonization by antagonized micro organisms (Vey *et al.*, 2001).

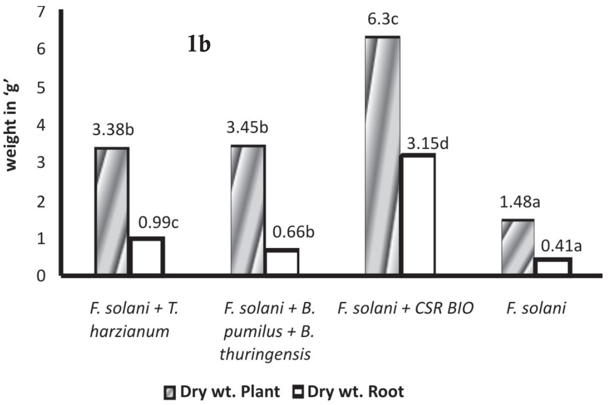
Growth parameters

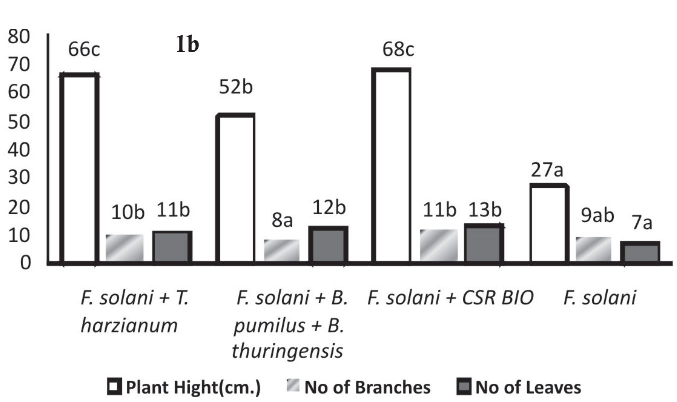
Data presented in Fig.1a and 1b revealed significantly lower values of growth parameters like plant height, number of branches, number of leaves, fresh weight and dry weight in treatments with F. *solani* when compared with the treatments involving bioagents. The plant height and dry weight of plant and dry weight of root showed significant increase in soil treated with CSR-BIO and *Trichoderma harzianum*. The synergestic mechanism of higher dry weight of plant and root was witnessed in treatment with CSR-BIO (6.3 and 3.15 g/100g, respectively) compared to treatment involving *Trichoderma harzianum* (3.38 and 0.99 g/100g). Similar results on synergistic effects were earlier observed by Niknejad *et al.* (2000) and Morsy *et al.* (2009). The growth promotion attribute of the *Bacillus pumilus* and *Bacillus thurigensis* (Damodaran *et al.,* 2014) along with bio-control attribute of the *Trichoderma harzianum* had resulted in the increased plant height and dry weight of plant and root in treatment of CSR-BIO (CSR-B-2+CSR-B-3+CSR-T-1). The

Table 2. Influence of antagonistic strains applied individually or in dual application against *F solani* and their effect on seedling survival percentage under green house conditions

Treatment	Damping off (%)		Survival plants (%)
	Pre-emergence	Postemergence	
F. solani + *T. harzianum*	16.6[a]	0.0[a] ‘	83.4[a]
F. solani + *B. pumilus* + *B. thuringensis*	25.0[b]	8.3[b]	66.6[b]
F. solani + CSR BIO (*T. harzianum* + *B. pumilus* + *B. thuringensis*)	16.6[a]	0.0[a]	83.4[a]
F. solani	44.5[c]	22.5[c]	33.0[c]

Values are the means of three replicates. Means in the columns followed by the same superscript letter are not significantly different according to Duncan's multiple range test at P=0.05.





Values are the means of three replicates. Means in the columns followed by the same alphabetical letter are not significantly different according to Duncan's multiple range test at p=0.05

Fig. 1a and 1b Effect of *F.solani* on green house tomato plant var. NS 507

treatments with growth promoting bacteria enhance the uptake of nutrients through biological processes (Hanafy-Ahmed *et al*., 1995).

Conclusions

It could be concluded that the treatment with CSR-BIO a microbial consortia of *Trichoderma harzianum*, *Bacillus pumilus* and *Bacillus thuringensis* has a significant role in control of *Fusarium* wilt of tomato comparing with other treatments and also produced higher crop growth than other treatments.

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Influence of different sources of organic matter on the improvement of quality of degraded soils

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ABSTRACT

The present investigation was carried out in the laboratory with three kinds of soil reaction (acidic, neutral and sodic) using two sources of organic resource materials (well rotten Farm Yard Manure (FYM) and Vermicompost) under saturated soil condition in a completely randomized design (CRD) replicated thrice to study the changes in different soil properties. The results show that the soil pH, organic carbon content, available nitrogen content, microbial biomass carbon and microbial biomass nitrogen contents have found to be changed to a condition which are mostly favourable for maintaining optimum soil fertility and quality with the application of vermicompost.

Key words: moisture regime, organic resources, soil fertility and soil quality

Introduction

Organic matter helps in stabilization of contaminants with humic substances including volatile organic compounds (formation of bound residue with pesticide) and this stability is also dependent upon the persistence of the soil humus complex (part of organic matter after decomposition) and maintenance or increase of the carbon pools within the soil. The new approaches to the use of organic amendments in farming have proven to be effective means of improving soil structure, enhancing soil fertility and increasing crop yields. Organic matter are excellent source of plant-available nutrients and their addition to soil could maintain high microbial populations and activities (Allen and Zink, 1999) with increased values of biomass C, basal respiration, biomass C: total organic C ratio, and metabolic quotient (qCO_2). Organic materials (plant residues) above and on the surface of the soil can provide physical 'buffering' against raindrop impact and direct insulation. Crop yields have increased with the corresponding improvements in soil quality from additions of organic matter. Significant yield increases using mulches from coffee husks (Bwamiki, *et al.*, 1998) and increases in productivity using animal manures and hay residues (Johnston *et al.*, 1989) have been reported. Vermicomposting have become much more popular in organic waste treatment recently since they eliminate some of the detrimental effects of organic wastes in the soil. Composting has been recognized as a low cost and environmentally sound process for treatment of many organic wastes (Hoitink, 1993). Bevacqua and Mellano (1993) reported that compost-treated soils had lower pH and increased levels of organic matter, primary nutrients, and soluble salts. Furthermore, composting and composts have been reported to suppress plant pathogens.

Composts have also been reported to enhance population development of beneficial nematodes such as cephaloids and rhabditids (saprophagous nematodes). Vermicomposts are products derived from the accelerated biological degradation of organic wastes by earthworms and microorganisms. Earthworms consume and fragment the organic wastes into finer particles by passing them through a grinding gizzard and derive their nourishment from microorganisms that grow upon them. The process accelerates the rates of decomposition of the organic matter, alter the physical and chemical properties of the material, leading to a humification effect in which the unstable organic matter is fully oxidized and stabilized (Albanell *et al.*, 1988; Orozco *et al.*, 1996). The end product, commonly referred to as vermicompost is greatly humified through the fragmentation of the parent organic materials by earthworms and colonization by microorganisms (Edwards and Burrows, 1988). Orlov and Biryukova (1996) reported that vermicomposts contained

Table 1. Physical, chemical and biological properties of initial soil

Properties	Acidic	Neutral	Sodic
Place of collection	Jamtara, Jharkhand	Jagulia,West Bengal	Jhunjhunu Rajasthan
Order	Oxisol	Inceptisol	Aridisol
pH	5.70	7.58	9.30
Organic Carbon (%)	0.40	0.12	0.12
Available Nitrogen (kg/ha)	82.79	59.76	62.09
Microbial Biomass Carbon (μg g^{-1})	15.28	5.68	20.85
Microbial Biomass Nitrogen (ug g^{-1})	2.50	3.00	2.00

17-36% of humic acid and 13-30% fulvic acid of the total concentration of organic matter. Vermicomposts are rich in bacteria, actinomycetes, fungi (Edwards, 1983; Tomati *et al.*, 1987; Werner and Cuevas, 1996) and cellulose-degrading bacteria (Werner and Cuevas, 1996). However, there is very little information regarding the effect of different sources of organic matter on changes in soil chemical properties in acidic, sodic and neutral soils after different intervals of their applications. Therefore, a laboratory incubation study was conducted to study the effect of different sources of organic matter on soil chemical properties which subsequently improve soil quality in sodic, acidic and neutral soils.

Materials and methods

The present investigation was carried out to study the effect of different sources of organic manures (FYM and vermicompost) on the improvement in soil fertility and quality. The chemical changes in the soil at different days of incubation, after providing the sources of organic matter were recorded in order to make a relationship between the nutrient availability and soil fertility in the soils of sodic, acidic and neutral in reaction.

The experimental soil

Three different kinds of soil were taken i.e. sodic, acidic and neutral soils. Sodic soil was taken from Jhunjhunu, Rajasthan which is derived from the order Aridisol. Acidic soil was collected from Jamtara, Jharkhand which is characterized by Oxisol. Neutral soil was collected from Nadia, West Bengal which comes under the Inceptisol order. The pre-experimental physical, chemical and biological properties of the experimental soil are appended in table 1.

Organic matter

Two types of organic matter were used i.e. farm yard manure (FYM) and Vermicompost. These organic matters were given in different doses on soil weight basis. Characteristics of different sources of organic matter are appended in the table 2.

Table 2. Salient characteristics of applied organic manures

Characteristics	FYM	Vermicompost
Moisture %	40%	60%
pH	6.52	6.37
Organic carbon	31.35	22
Total carbon (%)	47	31
Available nitrogen(kg/ha)	476.67	413.952
Total nitrogen(Kg/ha)	0.97	1.26
C:N	32.32:1	17.46:1
MBC (μg g^{-1})	240	270
MBN (μg g^{-1})	35	42

Moisture regime

Saturated moisture regime was maintained throughout the period of incubation by adding water externally at a regular interval because we mimicked the field condition of transplanted rice.

Experimental details

i. Design: Completely randomized design (CRD)
ii. Experiment: Laboratory experiment
iii. Number of replications: 3
iv . Number of treatments: 5
v. Number of soils: 3
vi. Amount of soil: 200g for each treatment of each soil
vii. Observations: 7, 14, 28, 42 (collecting the sample on the particular day of observation)

Treatments used in each soil are as follows:

T_0: Control, no application of FYM and Vermicompost
T_1: Application of FYM @ 0.5% on soil weight basis
T_2: Application of FYM @ 1% on soil weight basis
T_3: Application of Vermicompost @ 0.25% on soil weight basis
T_4: Application of Vermicompost @ 0.5% on soil weight basis

Soil analysis

The pH and EC of the soil samples was determined in 1: 2.5:: soil: water suspension by using digital pH meter (Page *et al.*,1982). The oxidizable organic carbon (OC) was determined by Walkley and Black wet oxidation method (Walkley and Black, 1934). The soil available nitrogen was determined by alkaline permanganate method (Subbiah and Asija, 1956). Microbial biomass C was determined by chloroform fumigation and extraction method (Vance *et al.,* 1987). Both fumigated and non-fumigated soils were extracted with 0.5 M K_2SO_4. The difference between C obtained from the fumigated and non-fumigated ones was taken to represent the microbial C-flush and converted to C_{mic} using the relationship: $C_{mic} = 1/0.41$ ´ C-flush and value expressed as micro gram of microbial biomass- C per gram of oven dry soil. Microbial biomass nitrogen was also estimated using the same principle of microbial biomass carbon. The filtrate extracted by K_2SO_4 of both fumigated and non-fumigated soil was digested for 1.5 hr. with addition of digestion mixture and sulphuric acid. After cooling, distillation was carried out to find the nitrogen content. The difference in nitrogen between fumigated and non-fumigated samples divided by a calibration factor (K_{EC}) 0.38 gave the measure of microbial biomass nitrogen in soil and expressed as micro gram of microbial biomass-N per gram of oven dry soil (Voroney *et al.*, 1993).

Statistical analysis

All variables like pH, EC, organic carbon, available nitrogen, Microbial biomass carbon and Microbial biomass nitrogen content were statistically analyzed following methods meant for completely randomized design (CRD). All statistical computations were done through programme SPSS (SPSS, 1999).

Results and discussion

The magnitude of pH changes varied with the source of organic matter. The pH of sodic soil gradually decreases with the progress of 42nd days of incubation irrespective of treatments. The results (Table 3) showed that the lowest mean pH value (8.93) was recorded in T_4 treatment which was closely followed by T_2 (8.96). The decrease in pH of sodic soil due to application of different

Table 3. Periodic changes in pH of different soil affected by different treatments (mean of three replications)

Treatments	Days of incubation (DOI)				Mean	Percentage increase / decrease
	7	14	28	42		
			Sodic Soil			
T_0 (control)	9.42	9.00	8.99	8.95	9.09	0
T_1 (0.5% FYM)	9.38	8.83	8.91	8.84	8.99	-1.1
T_2 (1% FYM)	9.34	8.79	8.90	8.79	8.96	-1.43
T_3 (0.25% VC)	9.4	8.95	8.95	8.78	9.02	-0.77
T_4 (0.5% VC)	9.26	8.9	8.88	8.69	8.93	-1.76
Mean	9.36	8.89	8.89	8.81		
SEm(±)	0.664	0.68	0.681	0.733		
LSD (p=0.05)	2.608	2.671	2.674	2.879		
			Acidic Soil			
T_0 (control)	5.39	5.49	5.54	5.73	5.54	0
T_1 (0.5% FYM)	5.32	5.52	5.7	5.85	5.6	1.08
T_2 (1% FYM)	5.43	5.64	5.8	5.96	5.71	3.07
T_3 (0.25% VC)	5.35	5.51	5.67	5.82	5.59	0.9
T_4 (0.5% VC)	5.5	5.8	5.95	6.19	5.86	5.78
Mean	5.4	5.59	5.73	5.91		
SEm(±)	0.686	0.798	0.675	0.667		
LSD (p=0.05)	2.695	3.132	2.65	2.619		
			Neutral Soil			
T_0 (control)	7.65	7.49	7.35	7.24	7.43	0
T_1 (0.5% FYM)	7.6	7.36	7.2	7.1	7.32	-1.48
T_2 (1% FYM)	7.54	7.2	7.1	7	7.21	-2.96
T_3 (0.25% VC)	7.63	7.3	7.22	7.15	7.33	-1.35
T_4 (0.5% VC)	7.49	7.17	7.05	6.98	7.17	-3.5
Mean	7.58	7.3	7.18	7.09		
SEm(±)	0.597	0.64	0.597	0.64		
LSD (p=0.05)	2.344	2.513	2.344	2.513		

sources of organic matter might be due to release of organic acids and sufficient amount of CO_2 resulting from the decomposition of applied organic matter (Azarmi *et al.,* 2008). In acidic soil, decomposition of organics reduced the content of iron and Mn oxides. Various organic exudates which are abundant with NH_4^+ and carbonic anhydrase temporarily reduces the pool of H^+ ions and carbonic anhydrase, catalyzes the fixation of CO_2 as $CaCO_3$ and causing the increase in pH (Haimi and Huhta, 1990). Also in respect of doses of organic matter, pH increases towards and of incubation period (Melgar and Pascual, 2010). Again in neutral soil, pH of incubation period gradually decreased towards 42nd day. With higher dose of vermicompost the decrease in pH (6.98) was recorded resulting decomposition of applied organic matter (Pawar and Patil, 2007).

The results (Table 4) revealed that the amount of organic carbon content increased significantly with the incubation irrespective of treatments. Application of vermicompost in higher dose resulted highest increase (62.5%) of organic carbon in sodic soil (Ansari, 2008). In connection with acidic soil similar parity of results were found with lower content of organic carbon in all stages of incubation. Being the presence of neutrality in soil highest content of organic carbon was found in all stages of incubation. The magnitude of such increase, however, varied with treatments. Such increase might be explained by the decomposition of applied organic matter resulting from the enhanced microbial proliferation. Application of vermicompost in higher dose resulted higher amount of organic matter present in soil, irrespective of type of soil (Mohan and Chandaragiri, 2007).

Table 4. Periodic changes in organic carbon (%) of different soil affected by different treatments (mean of three replications)

Treatments	Days of incubation (DOI)				Mean	Percentage increase / decrease
	7	14	28	42		
			Sodic Soil			
T_0 (control)	0.12	0.16	0.23	0.44	0.24	0
T_1 (0.5% FYM)	0.13	0.2	0.36	0.53	0.31	29.17
T_2 (1% FYM)	0.2	0.23	0.39	0.6	0.36	50
T_3 (0.25% VC)	0.13	0.21	0.36	0.58	0.32	33.33
T_4 (0.5% VC)	0.25	0.26	0.41	0.61	0.39	62.5
Mean	0.17	0.21	0.35	0.56		
SEm(±)	0.66	0.668	0.663	0.675		
LSD (p=0.05)	2.591	2.622	2.602	2.65		
			Acidic Soil			
T_0 (control)	0.4	0.47	0.5	0.56	0.48	0
T_1 (0.5% FYM)	0.49	0.53	0.62	0.69	0.58	20.83
T_2 (1% FYM)	0.52	0.56	0.69	0.72	0.62	29.17
T_3 (0.25% VC)	0.45	0.5	0.56	0.62	0.53	10.42
T_4 (0.5% VC)	0.61	0.69	0.75	0.82	0.72	50
Mean	0.49	0.55	0.62	0.68		
SEm(±)	0.647	0.653	0.649	0.654		
LSD (p=0.05)	2.541	2.564	2.546	2.598		
			Neutral Soil			
T_0 (control)	0.12	0.19	0.21	0.24	0.19	0
T_1 (0.5% FYM)	0.16	0.29	0.35	0.43	0.31	63.16
T_2 (1% FYM)	0.24	0.35	0.43	0.48	0.36	89.47
T_3 (0.25% VC)	0.14	0.27	0.29	0.37	0.27	42.11
T_4 (0.5% VC)	0.27	0.4	0.48	0.5	0.41	115.79
Mean	0.19	0.3	0.35	0.41		
SEm(±)	0.621	0.629	0.635	0.629		
LSD (p=0.05)	2.439	2.468	2.492	2.468		

Table 5. Periodic changes in available nitrogen (kg/ha) of different soil affected by different treatments (mean of three replications)

Treatments	Days of incubation (DOI)				Mean	Percentage increase / decrease
	7	14	28	42		
			Sodic Soil			
T_0 (control)	62.72	112.9	137.98	175.62	122.3	0
T_1 (0.5% FYM)	87.81	137.99	188.16	238.34	163.1	33.33
T_2 (1% FYM)	100.35	175.62	238.34	275.97	197.6	61.53
T_3 (0.25% VC)	75.26	125.44	163.07	200.71	141.1	15.58
T_4 (0.5% VC)	125.44	188.16	263.43	313.6	222.7	82.05
Mean	70.25	112.9	150.53	185.66		
SEm(±)	0.999	1.002	0.982	1.046		
LSD (p=0.05)	3.92	3.933	3.856	4.105		
			Acidic Soil			
T_0 (control)	82.79	110.39	124.19	144.88	115.6	0
T_1 (0.5% FYM)	124.19	151.78	193.18	227.68	174.2	50.75
T_2 (1% FYM)	144.88	172.48	206.98	248.37	193.2	67.17
T_3 (0.25% VC)	103.49	131.09	158.68	200.08	148.3	28.37
T_4 (0.5% VC)	193.18	195.18	227.67	289.77	226.5	95.96
Mean	129.71	152.18	182.14	222.16		
SEm(±)	1.012	1.015	1.11	1.076		
LSD (p=0.05)	3.973	3.984	4.356	4.225		
			Neutral Soil			
T_0 (control)	62.09	68.99	89.69	103.38	81.04	0
T_1 (0.5% FYM)	75.89	96.59	124.19	144.89	110.4	36.22
T_2 (1% FYM)	110.39	131.09	158.68	200.08	150.1	85.17
T_3 (0.25% VC)	68.99	82.79	103.49	131.09	96.59	19.19
T_4(0.5% VC)	124.19	144.89	179.38	220.78	167.3	106.45
Mean	88.31	104.87	131.09	160.04		
SEm(±)	1.013	0.971	0.999	0.982		
LSD (p=0.05)	3.978	3.81	3.922	3.855		

The amount of available N content has been found to be significantly increased in all the stages of incubation in comparison with control (Table 5). This result leads to highest 113.6% increase in the content of available nitrogen at 42^{nd} day of incubation of neutral soil which is followed by acidic (100%) and sodic soil (78.6%). The highest increase in available N is found with the application of higher dose of vermicompost (T_4) in all the stages and irrespective of soil type. Such increase in available N content might be explained by the mineralization of organic matter resulting from the greater activity of higher micro-organisms (Ambus *et al.*, 2002).

The results (Table 6) explained that the microbial biomass carbon (MBC) content in all 3 soil type, significantly increased with the progress of incubation and such increase was found to be further enhanced with the addition of different sources of organic matter at all the stages of incubation. Addition of vermicompost with higher dose leads to highest increase (281.4%) of MBC in neutral soil followed by acidic soil (247.9%) and sodic soil (226.37%), respectively. Such increase might be due to the increased microbial proliferation in soil resulting from the decomposition of applied organic matter and further highest increase in MBC content due to

Table 6. Periodic changes in microbial biomass carbon (MBC) (μg/g) of different soil affected by different treatments (mean of three replications)

Treatments	Days of incubation (DOI)				Mean	Percentage increase / decrease
	7	14	28	42		
			Sodic Soil			
T_0 (control)	21.8	49.58	73.86	100.52	61.44	0
T_1 (0.5% FYM)	64.83	142.31	189.11	204.88	150.28	144.6
T_2 (1% FYM)	73.36	150.87	210.44	234.03	167.18	172.1
T_3 (0.25% VC)	59.77	120.14	160.56	185.07	131.39	113.85
T_4 (0.5% VC)	93.36	160.07	249.24	299.42	200.52	226.37
Mean	62.63	124.59	176.64	204.78		
SEm(±)	1	0.984	1.101	1.004		
LSD (p=0.05)	3.925	3.861	4.323	3.942		
			Acidic Soil			
T_0 (control)	51.89	60.14	70.61	90.39	68.26	0
T_1 (0.5% FYM)	72.21	140.11	196.06	210.65	154.76	126.72
T_2 (1% FYM)	84.36	150.59	230.86	289.77	188.9	176.74
T_3 (0.25% VC)	69.41	130.24	180.17	200.67	145.12	112.6
T_4 (0.5% VC)	116.52	185.74	289.87	357.81	237.49	247.92
Mean	78.88	133.36	193.51	229.86		
SEm(±)	0.684	0.677	0.679	0.696		
LSD (p=0.05)	2.684	2.659	2.667	2.732		
			Neutral Soil			
T_0 (control)	60.56	80.95	100.86	120.89	90.82	0
T_1 (0.5% FYM)	100.59	186.97	265.92	320.46	218.49	187.03
T_2 (1% FYM)	120.99	220.76	316.84	389.19	261.95	250.7
T_3 (0.25% VC)	98.56	160.75	210.94	290.58	190.21	145.61
T_4 (0.5% VC)	140.08	250.43	330.57	410.62	282.93	281.44
Mean	104.16	179.97	245.03	306.35		
SEm(±)	0.663	0.678	0.681	0.669		
LSCD (p=0.05)	2.604	2.661	2.673	2.625		

vermicompost might be ascribed to the relatively higher rate of decomposition causing much greater microbial proliferation in neutral soil (Saima *et al.*, 2012).

In connection with MBC the content of MBN gradually increased with the progress of incubation irrespective of treatments, resulted highest increase at 42nd day of incubation in all soil types. Comparing the results neutral soil exhibited a relatively much higher value of MBN which might be due to the higher rate of microbial proliferation and mineralization of organic matter caused by normal pH value.

Conclusion

Result of this study showed that vermicompost applied at the rate of 0.5% performed best than the other treatments and improves the soil chemical properties such as organic carbon content, available nitrogen, MBC, MBN of acidic, neutral and sodic soils which subsequently upgrade the quality of the soil. Also, irrespective of kind of soil and organic resource material, application of organic manure improves the soil quality on long term basis and also improves the soil ecology in totality.

Table 7. Periodic changes in microbial biomass nitrogen (MBN) (µg/g) of different soil affected by different treatments (mean of three replications)

Treatments	Days of incubation (DOI)				Mean	Percentage increase / decrease
	7	14	28	42		
			Sodic Soil			
T_0 (control)	2.73	6.21	9.24	12.58	7.69	0
T_1 (0.5% FYM)	7.63	16.74	22.25	24.1	17.68	129.31
T_2 (1% FYM)	7.8	16.05	22.39	24.9	17.79	131.34
T_3 (0.25% VC)	7.47	15.02	20.07	23.13	16.42	113.52
T_4 (0.5% VC)	9.34	16.01	24.92	29.94	20.05	160.73
Mean	8.74	17.51	24.72	28.66		
LSD (p=0.05)	2.643	2.584	2.727	2.612		
SEm(±)	0.673	0.658	0.695	0.665		
			Acidic Soil			
T_0 (control)	6.49	7.52	8.83	11.3	8.53	0
T_1 (0.5% FYM)	8.41	16.31	22.82	24.52	18.02	111.25
T_2 (1% FYM)	9.07	16.19	24.82	31.16	20.31	138.1
T_3 (0.25% VC)	7.62	14.31	19.8	22.05	15.95	86.99
T_4 (0.5% VC)	9.71	15.48	24.16	29.82	19.79	132.01
Mean	10.33	17.45	25.1	29.71		
SEm(±)	0.673	0.658	0.695	0.665		
LSD (p=0.05)	2.643	2.584	2.727	2.612		
			Neutral Soil			
T_0 (control)	6.73	8.99	11.21	13.43	10.09	0
T_1 (0.5% FYM)	10.06	18.7	26.59	32.05	21.85	116.55
T_2 (1% FYM)	11	20.07	28.8	35.38	23.81	135.98
T_3 (0.25% VC)	10.37	16.92	22.2	30.59	20.02	98.41
T_4 (0.5% VC)	11.67	20.87	27.55	34.22	23.58	133.7
Mean	12.46	21.39	29.09	36.42		
SEm(±)	0.694	0.678	1.115	0.689		
LSD (p=0.05)	2.723	2.66	4.378	2.691		

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Salinity tolerance of coriander, fennel and fenugreek seed spices under semi-arid conditions of northern India

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ABSTRACT

The present study comprises of two experiments, first conducted in the field while the second in pot house. The field study was conducted on calcareous sandy loam soils of semi-arid regions irrigating crops with water of low salinity EC 4.6 dS m^{-1}, high salinity 8.7 dS m^{-1}, and alternate use of low and high salinity and observed the effect on growth, development and yield of coriander (*Coriandrum sativum* L.), fennel (*Foeniculum vulgare* Mill.) and fenugreek (*Trigonella foenum-graecum* L.). Among three modes of saline water irrigation, continuous low salinity water irrigation resulted in maximum growth and yield of all the three seed spice crops. It was followed by alternate use of irrigation where low and high salinity water irrigations were practiced. The maximum reduction in growth and yield was recorded in continuous use of high saline water irrigation. Among crops, fennel was the most tolerant followed by coriander and least tolerance was observed in fenugreek. Decrease in yield of coriander and fennel from low salinity to alternate irrigations with low and high salinity water was 6 and 27%, and 4 and 19%, respectively. In pot study, 12 promising varieties of each of coriander and fennel were evaluated for their tolerance to salinity of irrigation water ranging from 0.6 control to 3, 6, 9 and 12 dS m^{-1}. Relative yield reduction in each variety of two crops in response to salinity levels was worked out using piece-wise linear response [Salt model] fitted to yield in response to salinity. The decrease in yield ranged from 4 to 63% among different varieties of two crops. Coriander variety RCR-446 and GCR-2 were found to be most tolerant while leafy/vegetable type variety as Pant Haritma and seed type as Sadhna and Swathi were least tolerant to salinity. In case of fennel, RF-178, RF-35,GF-1 and GF-2 were most tolerant to salinity of irrigation water.

Key words: *s*eed spices, coriander, fennel, fenugreek, saline water irrigation

Introduction

India has ever been the world spice home and always renowned for the best and exclusive variety of spices produced. Though Indian spices are exported to 135 countries across all the continents of the globe but major markets are USA, Malaysia, UAE, China, Sri Lanka, Singapore, Germany, Pakistan, Japan and Saudi Arabia. Approximately 9% of the total spices produced in the country are exported. Black pepper and cardamom are the two main spices in terms of international trade however; other spices which are exported include mint products, chilli, spice oils and oleoresins, cumin, pepper, turmeric and seed spices especially coriander. Spices exports have registered an annual average growth rate of 11.1% during the last decade. Even during the global recession year of 2008-09, spices exports from India had registered an upward trend with earnings worth Rs 5300.25 crores (US$ 1168.40 million) from a total volume of 4, 70, 520 tonnes of spice products. The share of seed spices in total spice exports comes to be around 28% in terms of volume of products and 17% in terms of value (Spices Board, 2008). In total, the area under spice crops in our country is about 2.65 million hectares. Out of the total area under spices, seed spices are grown in an area of 8.51 lakh ha. Further statistics on area and production suggest that coriander, fennel and fenugreek account for 68% of total seed spice production from about 55% of the total spice growing area in our country. Though major spice producing states in the country are Kerala, Karnataka, Tamilnadu, Andhra Pradesh, Madhya Pradesh, Gujarat, Maharashtra, Orissa, Rajasthan and North Eastern States, however, Rajasthan and Gujarat are considered as the 'seed spice bowl' and together contribute more than 80% of the total seed spice production in the country (Vashishtha, 2007). The arid to semi-arid type of climatic conditions are considered as most suitable for seed spice cultivation. However, three reconciled national estimates obtained using remote sensing and GIS, indicate that out of 6.73 m ha salt affected area in our country, seed spice bowl states of Gujarat and Rajasthan occupy about 2.22 and 0.4 m ha, respectively (Singh *et al.,* 2010). In addition to huge chunk of salt affected soils, about 50% of the groundwater quality of the two states is either marginal or poor. Under above mentioned circumstances, resource poor farmers of the two states are forced to grow the economically important seed spices crops of coriander, fennel and fenugreek either on saline soils or using saline ground water for irrigation. But salinity being a major limiting factor in the crop productivity and it affects almost every aspect of the physiology and biochemistry of plants and thus in turn significantly reduces yield (Parida and Das, 2005; Munns and Tester, 2008). Cultivating salt tolerant/resistant commercial seed spices like coriander, fennel, fenugreek and cumin crops and their varieties accompanied with appropriate field management can make it possible to use saline soils/groundwater (Tatari and Abbasi Alikamar, 2004). Hence, field and pot house studies were undertaken for the assessment of salt tolerance of these crops and their varieties to minimize the yield and economic loss to the farmers and revenues.

Material and methods

This study comprised of two experiments, first set being conducted in the field under semi-arid conditions at Bir Forest Farm, Hisar while the second set was carried out in pot house at CSSRI Farm, Karnal.

Field study

A field study in split plot design for overall comparison among three crops and RBD for comparison of salinity effects on individual crops was conducted during *rabi* season of 2009-10 in calcareous (Ustic Haplocambids) sandy loam soil (EC_e 3.2 dS m^{-1}, pH 8.6) at Bir forest research farm of CSSRI, Karnal located at Hisar ($29^0 10$'N and $75^0 44$'E with altitude of 220 m above MSL) Haryana. The physical and chemical parameters of soil were determined using the procedures described by Black *et al.* (1981) and Jackson (1973). The site represents semi-arid monsoon climatic characteristics with annual average rainfall of 450 mm and most (80-85%) of which occurs during July to September. In above settings, a triplicate experiment was laid out in split plot design with three quality saline (low salinity 4.6 dS m^{-1}, high salinity 8.7 dS m^{-1}, and alternate use of low and high salinity) water irrigation in main plots to coriander (*Coriandrum sativum* L.), fennel (*Foeniculum vulgare* Mill.) and fenugreek (*Trigonella foenum graecum* L.) grown in sub-plots. The crops were sown during last week of October and recommended package of agro-practices were followed for each crop. Seven irrigations of 6 cm each were applied to coriander and fenugreek while 10 to fennel. Observations on growth *i.e.* height and number of branches development *viz*, days to flowering/seed development and maturity, and yield attributes i.e. number of umbels/pods *etc.* were recorded periodically on randomly selected and tagged five plants of each crop from every subplot. The yield of each crop realized with a given irrigation treatment was recorded from each subplot, analyzed statistically as described in Snedecor and Cochran (1982) and mean yields across all the three replications were compared at 5% level of significance.

Pot study

In pot study, 12 varieties of each of coriander (NRCSS-Acr-1, GCR-2, RCR-41, RCR446, CO-2, Hisar Sugandha, Rajendra Swathi, Sadhana, Swathi, Azad Dhania, CO4 and Pant Haritma) and fennel (GF-1, GF-2, RF-101, PF-35, RF-178, GF-11, CO-1, Hisar Swarup, Pant Madhirika, Azad Sawnt, NRCSS-AF-1 and Rajendra Sawrna) were evaluated for their salinity tolerance by subjecting them to irrigation water of salinity ranging from 0.6 (control, best quality available water) to 3, 6, 9 and 12 dS m^{-1}. The experiment was laid out in CRD with three replications of salinity treatments. Saline water of 3, 6, 9 and 12 dS m^{-1} salinity were prepared synthetically using NaCl, Na_2SO_4, $CaCl_2$. $2H_2O$ and Mg Cl_2. $6H_2O$ so that SAR does not exceed 10. Fourteen kilograms of sandy loam soil (EC_e 2.4 dS m^{-1}, pH 8.4, OC 0.35%) was filled in 18 kg capacity ceramic pots. Drainage at the bottom of pots was closed with rubber cork. Soil filled in the pots was compressed to a bulk density of 1.46 g cc^{-1} and saturated with water (4.4 liters) of treatment specific salinity. Ten seeds of each variety were sown at five equi-distance spots in moist soil of respective treatment pots which were thinned to five after 15 days of sowing. Recommended package of agro-practices for respective crops were followed for cultivation of all of the twelve varieties of both of the experimental crops. Irrigations with 750 ml of specific salinity water were given twice a week during winter up to February end but later on frequency of irrigation was alternate day. In total 26 irrigations were applied to fennel while 22 to coriander. Observations on growth, development and yield of the two crops under respective salinity treatments were recorded. Relative yield reduction in each variety of two crops in response to salinity levels was worked out using piece-wise linear response [Salt model; RY= 100- a (Irr. Water salinity- b)] fitted to yield in response to salinity (Vangenuchen, 1983). Here RY represents yield of any crop or variety realized with any given salinity level in relation to its yield with best quality water irrigation, while 'a' and 'b' represent slope of decrease in yield and threshold limit of salinity at which yield starts declining.

Results and discussion

From the 20 seed spices grown in the country, the most important are coriander, cumin, fennel and fenugreek and most of these are grown in semi-arid to arid states of Rajasthan and Gujarat either on saline soils or using saline water for irrigation because 50% of groundwater in these two states is of saline nature. Hence, the present study was taken up with a broad objective of

Table 1. Vegetative growth of coriander, fennel and fenugreek under different modes of saline water irrigation

Crop / Mode of Irrigation	Fennel			Coriander			Fenugreek*	
	Height (cm)	Primary branches (No.)	Umbels per plant	Height (cm)	Primary branches (No.)	Umbels per plant	Height (cm)	Primary branches (No.)
Low Saline	103	9	40	97	8	34	37	6
Alternate	98	8	37	94	7	31	33	6
High Saline	92	6	33	86	5	27	29	3
Mean	97.7	7.7	36.6	92.3	6.7	30.6	33	5

*Crop was damaged heavily by rabbits

identifying tolerant germplasm, and evolving saline water use strategies so as to minimize the yield loss in coriander, fennel and fenugreek. The results of the two experiments consisted of one field and another pot study are summarized and discussed in the following section.

As the salinity of irrigation water increased, there was decrease in vegetative as well as reproductive growth of fennel and coriander (Table 1). The decrease in vegetative growth i.e. height and branches was the maximum in fenugreek followed by coriander and minimum being in fennel.

However, reproductive growth *i.e* umbels and seed yield was more affected than vegetative growth.

The perusal of data from Table 2, indicate that fennel was least sensitive to saline water irrigation as the decrease in yield from continuous use of low saline (4.6 dS m^{-1}) water for irrigation to alternate irrigations of low (4.6 dS m^{-1}) and high (8.7 dS m^{-1}) salinity water and further to regular irrigations with high salinity (8.7 dS m^{-1}) water was to the extent of 4.7 and 20% in seed yield, and about 2 and 15% in total biomass production, respectively. In comparison to above extent of decrease in fennel, the seed and biomass yield of coriander decreased about 6 and 27%, and 3 and 23%, respectively indicating that coriander was comparatively more sensitive to saline environment than fennel. We could not ascertain the saline water irrigation tolerance of fenugreek because of the extensive rabbit damage in the crop. So the seed and biomass yield data of fenugreek given in Table 2 are not conclusive. The deleterious effects of high salinity irrigation water were minimized when low and high salinity water was used in alternate irrigations (Table 2) and thus adverse impacts on growth can be checked to good extent. Similar results were obtained by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008) on coriander and fennel. The harmful effects of saline water irrigation might be due to specific ions such as NaCl, $CaCl_2$ and Na_2SO_4 which inhibit the production of chlorophyll in green parts of the plants, high Na concentration also induce Ca and Mg deficiency and respiratory pathways in roots (Abel and Mackenzie, 1974; Chinnusamy *et al.*, 2005).

The genetic differences in salinity tolerance of diverse germplasm of fennel and coriander were evaluated in the pot study, where 12 promising varieties of each of the crops were subjected to five levels of irrigation water salinity ranging from 0.6 to 3, 6, 9 and 12 dSm^{-1}. Relative yield reduction in each variety of two crops in response to salinity levels was worked out using piece-wise linear response [Salt model; RY= 100- a (Irr. Water salinity- b)] fitted to yield in response to salinity (Vangenuchen, 1983). Where RY represents yield of any crop or variety realized with any given salinity level in relation to its yield with best quality water irrigation, while 'a' and 'b' represent slope of decrease in yield and threshold limit of salinity at which yield starts declining. On the basis of above piece-

Table 2. Seed and total biomass yields of coriander, fennel and fenugreek under different modes of saline water irrigation

Crop / Mode of Irrigation	Coriander (kg ha^{-1})		Fennel (kg ha^{-1})		*Fenugreek (kg ha^{-1})	
	Biomass	Seed yield	Biomass	Seed yield	Biomass	Seed yield
Low saline	1568	980	2017	1146	427	216
Alternate	1521	916	1984	1092	513	302
High saline	1209	708	1708	914	398	189
LSD (*p=0.05*)	179	102	218	183	NA	NA
	For overall comparison of three crops: seed-198; biomass-337; irrigation water salinity levels: seed- 243; biomass-376; Irrig x crop: seed- 217; biomass-351					

*Crop was damaged heavily by rabbits; NA- not analyzed for statistical comparisons

Table 3. Piece-wise linear response model constants and coefficient of determination of yields of fennel cultivars in relation to irrigation water salinity

Varieties/Parameters	a	b	r	Salinity tolerance rank
GF-1	- 0.026	4.64	**0.93	3
GF-2	- 0.029	4.39	**0.91	4
RF-101	- 0.036	3.82	**0.89	8
PF-35	- 0.023	4.67	**0.90	2
RF-178	- 0.022	4.86	**0.92	1
GF-11	- 0.039	3.74	**0.87	10
CO-1	- 0.032	3.97	**0.94	6
Hisar Swarup	- 0.041	3.79	**0.91	9
Pant Madhirika	- 0.031	4.18	**0.89	5
Azad Sawnt	- 0.034	3.86	**0.92	7
NRCSS-AF-1	- 0.041	3.70	**0.93	11
Rajendra Sawrna	- 0.040	3.68	**0.90	12

wise linear response regression model, the relative tolerance of different varieties of the fennel and coriander was worked out and presented in the Table 3. The constants of slope indicating decrease in yield in response to every unit increase in salinity of irrigation water and thresh hold limits of salinity beyond which yield of a given variety of fennel starts decline were worked out with the help of above model and presented in table 3.

From the perusal of the data on slope and constants, it can be inferred that variety RF-178, PF-35 and GF-1 were most tolerant to salinity in irrigation water whereas Rajendra Sawrna, NRCSS-AF-1 and GF-11 were most sensitive. Other varieties had tolerance limits which laid in between the two extremes i.e. the most and the least tolerant ones. These results can be understood with the case of the most tolerant variety RF-178, where it is evident that its yield started decreasing when salinity of irrigation water crossed a highest threshold (b) value of 4.86 dS m^{-1} with least decrease in yield in proportion to a unit increase in irrigation water salinity i.e. slope (a) of – 0.022. While in case of Rajendra Sawrna the most sensitive variety, the respective values of lowest ‘b’ (3.68 dS m^{-1}) and highest (- 0.40) ‘a’.

The data on the constants of threshold and slope for varieties of coriander are depicted in table 4. Among coriander varieties, the most tolerant was seed cum leafy type variety RCR-41, which had a threshold ‘b’ value of 4.57 dS m^{-1} with slope ‘a’ of – 0.021, followed by GCR-2 and CO-2, whereas Pant Haritma, Sadhna and Swathi were among the least tolerant ones. Pant Haritma, Sadhna and Swathi had the respective threshold values of 3.52, 3.49 and 3.54 dS $m^{-1,}$ and slope of – 0.051, - 0.049 and – 0.0 48, respectively.

These differences among cultivars could be due to differences in their genetic constitution which in turn affects their ability and efficiency for utilizing the environmental resources especially light, CO_2, water and nutrients. Such relation between saline water irrigation

Table 4. Linear piece-wise model response constants and coefficient of determination of yields of coriander cultivars in relation to irrigation water salinity

Varieties/Parameters	a	b	r	Salinity tolerance rank
NRCSS-Acr-1 (Veg/leafy)	- 0.045	3.64	**0.93	7
GCR-2 (Seed)	- 0.027	4.18	**0.91	2
RCR-41 (Veg/leafy)	- 0.046	3.56	**0.89	9
RCR446 (Seed/leafy)	- 0.021	4.57	**0.90	1
CO-2 (Seed)	- 0.030	4.06	**0.92	3
Hisar Sugandha (Leafy/ seed)	- 0.040	3.71	**0.87	5
Rajendra Swathi (Seed)	- 0.038	3.87	**0.92	4
Sadhana (Seed)	- 0.049	3.49	**0.91	11
Swathi (Seed)	- 0.048	3.54	**0.89	10
Azad Dhania (Veg/leafy)	- 0.044	3.61	**0.92	8
CO4 (Seed)	- 0.043	3.68	**0.93	6
Pant Haritma (Leafy)	- 0.051	3.52	**0.90	12

and diverse germplasm of fennel and coriander have been comprehensively studied and discussed by Grainfenberg *et al.* (1996) and Ahmad (1999). They also observed that long-term exposure of roots to high salt concentration make the plants suffer from drought (Bernstein, 1975), reduced water and nutrient availability, make direct toxic effect of different ions because of imbalances of mineral nutrition as a consequence of specific ions in saline water. Pascale and Beriberi (1995) observed that saline water irrigation could minimize photosynthesis due to reduction in stomata conductance and increased limitation of stomata to CO_2 uptake while Abd el-Razaek (1997) recorded changes in plant enzymatic activities under saline water irrigation.

Conclusions

From the results of present investigation, it can be inferred that fennel is more tolerant than coriander and fenugreek to saline water irrigation. The deleterious effects of high salinity water irrigation could be minimized by alternate irrigations of low and high salinity water as the yield realized with this mode was found to be almost at par with that of continuous practice of low salinity water irrigation and significantly better than continuous irrigations with high salinity water. Further, RF-178, PF-35 and GF-1 varieties of fennel and RCR-446, GCR-2 and CO-2 varieties of coriander were found to be suitable for cultivation with high salinity water irrigation.

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Productivity constraint analysis in marginal quality groundwater area under scarce canal water supply in northwest India

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ABSTRACT

A study conducted in 216 farmers fields of two minors in the Bhakra Canal system revealed wide variation in quality of groundwater and canal water availability in different reaches. Farmer's decisions were largely dependent on the quality of tubewell water to alleviate part of the canal water deficit. The analysis revealed significant yield reduction both in watercourses located in the tail of minors and fields located in the tail of watercourses. In case of wheat, the water productivity was estimated 1.95 and 1.43 kg m^{-3} in the head and tail watercourses, respectively whereas for rice, it was 0.47 and 0.37 kg m^{-3}. The productivity constraints analysis indicated the inadequate and untimely supply of canal water and marginal quality groundwater are the main causes of yield reduction of rice-wheat cropping system.

Key words: groundwater, salinity, rice-wheat system, productivity constraints

Introduction

Globally, there is a serious concern for the future water availability for man, food and management of ecosystems. With the projected increase in global population from present 6 billion to nearly 8 billion by 2025, availability of per capita fresh water is expected to decrease drastically, particularly in many developing countries. Although managing irrigation water for higher productivity under scarce condition is the need of the hour, it is a challenge to sustain the productivity in water scarce area where groundwater quality is also marginal and therefore, needs to be dealt with more reasoning. Such a situation exists in the Northwest India, where rice-wheat cropping sequence is the major food production system. In this region, protective irrigation is in practice through a rotational canal water supply system called as *warabandi*. Since the available groundwater is also marginal, its way of utilization to meet the crop demand greatly affects the land and water productivity. The ill effects of long-term use of marginal quality water on crop yield and use of effective efficiency in decision making are reported earlier (Sarwar *et al*., 2001; Hein *et al.,* 2012), but their effects under scarce canal water supply condition over the space have not been studied. Keeping this in mind, a study was conducted in a part of the Bhakra Canal System, Haryana to analyze how prevailing canal water availability in conjunction with varying quality of groundwater affects the farm level productivity in canal hierarchical system, and how farmers respond, by way of their decision-making, to deal this situation (Tyagi *et al*., 2005). The aim of this paper is to present the productivity constraint analysis on farm level crop productivity that would help to judge the scope of improving land and water productivity in the water scarce, marginal quality groundwater area.

The study area

The study was conducted in the Batta and Rohera minors of Kaithal irrigation circle (latitude $29^0$31' and $30^0$12' and longitude $76^0$10' and $76^0$43') in the Bhakra Canal system. Six watercourses, one each located at the head, middle and tail of the minors were selected (Table 1). The area fall under semi-arid region that receives an average annual rainfall of 625 mm, of that about 80% rainfall is received during the months of June to September. The average annual evaporative demand in the region is about 1600 mm.

A total 36 farmers 12 each from head, middle and tail region of the watercourse were selected from each of the watercourses. Crop cutting was done in all the selected farmers' fields to determine the crop yields during *rabi* and *kharif* seasons during 2000-02. Information related to soil and water related data and different agronomic practices adopted in the farmer's fields were collected on specifically designed questionnaire. The depth of flow, at the head of the minor was recorded on daily basis in each rotation of the canal flow. The flow rate in the minors as well as in the watercourses was measured by using a sensor

Table 1. Details of the selected watercourses

Minor	Watercourse ID	Location of watercourse	GCA* (ha)	CCA** (ha)	Design discharge of watercourse (m^3s^{-1})
	4620 R (BH)	Head	166.8	160.0	0.027
Batta	25963 L (BM)	Middle	226.4	222.0	0.037
	50820 F (BT)	Tail	253.6	244.0	0.042
	3750 R (RH)	Head	146.4	140.4	0.023
Rohera	19210 L (RM)	Middle	80.5	78.0	0.013
	44395 L (RT)	Tail	203.6	198.4	0.034

*GCA - Gross Command Area; **CCA - Cultivable Command Area

Table 2. Average EC and pH of the soil and ground water characteristics

Minor	Location of watercourse	Soils		Groundwater			
		EC_e (dS m^{-1})	pH (-)	EC (dS m^{-1})	pH (-)	SAR ($me^{1/2}$ $l^{-1/2}$)	RSC (me l^{-1})
	Head	2.2	8.7	1.4	8.2	8.3	6.0
Batta	Middle	3.7	8.4	4.2	7.8	13.3	-
	Tail	5.6	8.3	5.8	8.0	11.8	-
	Head	1.9	8.2	1.4	8.0	7.3	5.1
Rohera	Maiddle	2.1	8.3	2.4	7.7	8.0	1.2
	Tail	4.2	8.4	4.6	7.9	14.1	-

type pigmy current meter. The average discharge of the tubewells was measured to be 9.7 l s^{-1}.

Results and discussion

The productivity of crop depends on land-water related constraints such as quality of land and water, source, depth and timeliness of irrigation etc. and other constraints like crop variety, field preparation, date of sowing, fertilizer and weedicide application, date of harvesting etc. The constraints, which affect the productivity of the crops, are discussed here.

Soil and groundwater quality

In the study area, soil salinity (ECe) is observed between 0.5 to 12 dS m^{-1} (average between 1.9 to 5.6 dS m^{-1}) with an increasing salinity towards the tail of the watercourse (Table 2). The presence of excess salts in the soil increases the osmotic pressure of soil solution causing low physiological availability of water to the plant and direct toxic effects of individual ions. The SAR of soil also varies from 1.85 to 19.6 in the different reaches of the watercourses. The alkali soils lack an adequate and continuous water supply to plants due to low infiltration rates, resulting in shallow wetting zones and temporary waterlogging problems.

Groundwater is the readily available source for irrigation. The study revealed a wide variation in the groundwater quality indicating significantly higher salinity in the tail than the head and middle reaches while it was observed opposite in the case of alkalinity (Table 2). Based on water quality guidelines (Minhas and Tyagi, 1998), groundwater in 92% fields were found alkali in the head watercourse, whereas 92% fields in the tail were saline in Batta minor. In the Rohera minor, 58% fields had good quality water in the head while 84% fields had saline groundwater in the tail watercourse. The analysis indicated that the selected minors fall in the transition zone where watercourses in the head reach have either good quality or alkali water and the tail watercourses have saline water.

Canal water availability

In general, the canal water supply in the Bhakra System follows 14 days off and 7 days on for canal flow cycles during *rabi* season. However, it was observed that the supply sometimes remained closed up to 28 days and on cycle varied from 3 to 10 days. The supply timing seldom matched with the crop water demand (Ambast *et al.*, 1990). The analysis of canal water supply revealed it highly inadequate in meeting crop water requirement in both *rabi* (35 cm) and *kharif* (120 cm) seasons (Table 3). The canal supply met up to 48% of the water requirement of wheat crop during *rabi* and 46% of the water requirement of rice (after meeting about 60 cm of the water requirement from rainfall) during *kharif*. The canal supply was also inequitable as tail watercourses received up to 50% canal water as compared to head watercourses

Table 3. Canal water supply in selected watercourse in different seasons

Minor	Watercourse	Average canal water supply (cm)	
		Rabi	*Kharif*
	Head	14.8	24.1
Batta	Middle	13.9	18.9
	Tail	8.3	4.7
	Head	11.1	16.8
Rohera	Middle	10.0	14.6
	Tail	7.4	4.1

during *rabi* season. The inequity in canal supply was more during *kharif* season as only 25% water was received in the tail as compared to head watercourse in the Rohera minor, while in the Batta minor, the tail watercourse received 34% water as compared to head watercourse.

Cropping pattern

Wheat and rice were grown as the main crop in *rabi* and *kharif* seasons, respectively whereas berseem and sorghum were preferred as fodder crops (Table 4). During *rabi* season, non-availability of canal water does not affect the crop choice of the farmers due to low water requirement and high salt tolerance of wheat and was grown as main crop in all the reaches of minor. The fact that wheat can withstand salinity level up to 4 dS/m without much reduction in yield allows farmers to use both groundwater and canal water in conjunction and irrigate most of the area under their control. Rice, being an aquatic and a salt sensitive crop, requires large amount of good quality water. It was observed that the area under rice was highest in the head watercourses, due to more access to good quality canal and groundwater, and it gradually decreased towards the tail watercourses. Selection of rice variety differed according to the quality of the available groundwater. In the head watercourses, the canal water availability and good quality groundwater enabled the farmers to grow salt sensitive but high value "basmati" rice, whereas in the tail farmers grew semi-salt tolerant, coarse varieties due to less canal water availability and poor quality groundwater. Pearl millet and cotton are the low water requiring and salt tolerant crops, which occupied considerable area in the tail watercourses.

Irrigation application

Farmer's decisions were largely dependent on the quality of tubewell water to alleviate part of the canal water deficit. However, it was found that farmers throughout the minor used almost equal quantity of water, irrespective of the source to avoid deficit irrigation. Being supply oriented irrigation system; timing of the canal water supply in *warabandi* also affects its use in different reaches of the minor. It was observed that farmers in the head reaches, confident about getting canal water, utilize their each canal rotation to irrigate their main crops. If canal water was not available at the time of irrigation demand, they left part of their land un-irrigated for canal irrigation despite of relatively good quality groundwater. In the middle and tail reaches of watercourse, if canal water was not available, farmer's used their marginal quality groundwater for irrigation. Canal water received after irrigation of main crops, was used in fodder crop or was sold it to the fellow farmers. So the use of canal water decreased from head to tail reaches while opposite is in case with groundwater in both the seasons. The farmers in the tail reaches used only 30-50% canal water as compared to head reach farmers. Higher utilization of groundwater in tail reaches created salinity stress to wheat crop. To overcome salinity stress, farmers advanced irrigation application and provided one or two additional irrigations, which increased their cost of cultivation. Thus, the tail end farmers are in disadvantageous position in two ways: (i) due to saline soil and groundwater, farmers harvest lower yields than head-end farmers; (ii) their cost of cultivation is also higher due to additional watering.

Land and water productivity

The analysis indicated significant variation in the yield of both the crops at field as well as watercourse level (Table 5). The average wheat yield was about 11% less in the tail than the head watercourse in the Batta minor, whereas yield gap was 18% in the Rohera minor.

Table 4. Average area allocation (%) to various crops

Water-course	*Rabi*				*Kharif*				
	Wheat	Barseem	Sugarcane	Others	Rice	Pearl millet	Sorghum	Others	Fallow
BH	91.4	8.2	0.0	0.5	88.2	1.4	8.7	1.3	0.4
BM	78.3	6.8	12.3	2.1	29.1	15.6	12.0	16.6	26.7
BT	80.4	6.7	11.0	1.4	16.7	14.3	12.4	22.0	34.7
RH	90.7	8.2	0.2	0.5	82.2	2.0	13.2	1.6	1.1
RM	80.1	9.8	7.9	2.1	50.4	5.6	17.0	15.5	11.7
RT	90.6	8.5	0.0	0.7	26.6	37.3	16.7	6.2	9.8

Letters B and R depict Batta and Rohera minors while H, M and T depict head, middle and tail, respectively

Table 5. Yield of wheat and rice at watercourse and minor level

Watercourse	Wheat yield (t ha^{-1})			Avg WP	Rice yield (t ha^{-1})			Avg WP
	Max	Min	Avg	(kg m^{-3})	Max	Min	Avg	(kg m^{-3})
BH	5.7	3.5	4.6	1.95	6.8	3.6	4.7	0.51
BM	5.3	3.8	4.5	1.65	4.7	2.0	3.6	0.39
BT	5.0	3.0	4.1	1.51	3.5	2.0	3.0	0.25
RH	5.7	4.1	4.9	1.95	6.0	2.1	4.4	0.42
RM	5.4	3.8	4.8	1.75	5.1	2.4	3.8	0.34
RT	5.0	3.2	4.0	1.35	4.5	2.1	3.5	0.50

Depictios as in Table 4.

In case of rice, the yield gap was 36% and 20% between head and tail watercourse of Batta and Rohera minors, respectively. In both the minors, the minimum yield was about 50% and 30% of the maximum yield for wheat and rice, respectively. The water productivity analysis shows that productivity of irrigation water (canal + groundwater) decreased from head to tail of the minors in both the seasons. During *rabi* season, irrigation water was observed about 30% less productive in the tail as compared to head reaches. The groundwater productivity alone was upto 48% less productive in the tail as compared to head watercourses. Since the use of canal water decreased from head to tail reaches, it was more productive in the tail watercourses. In the *kharif* season, due to high water requirement of rice, the water productivity was quite low as compared to wheat. The productivity of irrigation water was about 50% in the tail than head watercourse of Batta minor, whereas it was more in the tail of the Rohera minor due to less water application.

Productivity constraints

Regression analysis was performed to analyze the effect of land and water related and other factors on productivity of rice-wheat system. The important factors are discussed below:

Date of sowing/transplanting**:** Date of sowing plays an important role in wheat productivity. The suitable time for wheat sowing in the region is between 1st to 15th November. It is observed that about 40% farmers sow wheat crop after 15th November causing yield reduction by 0.06 t ha^{-1} day^{-1} (Fig. 1). In case of rice, most of the farmers transplanted rice during recommended period (15th June-15th July) in the first year whereas in the second year farmers either did not transplant or transplanted rice very late due to delay in monsoon.

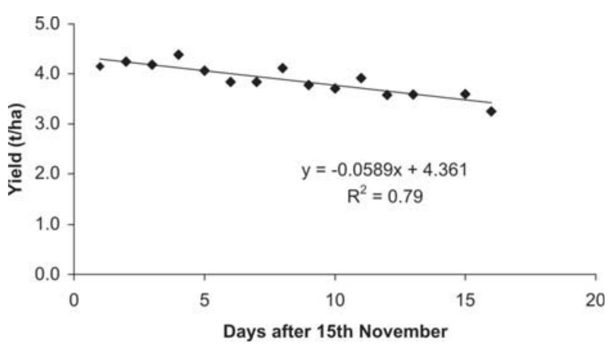

Fig. 1. Effect of delay in sowing on wheat yield

Soil salinity**:** The plot of yield of wheat and rice crops with EC and pH of the soil is shown in Fig. 2. The trend analysis indicates a decrease in yield with increase in EC of the soil for both the crops. Presence of higher amount of soluble salts in the soils by 1 dS m^{-1} resulted in yield reduction by 0.32 t ha^{-1} and 0.12 t ha^{-1} for rice and wheat, respectively.

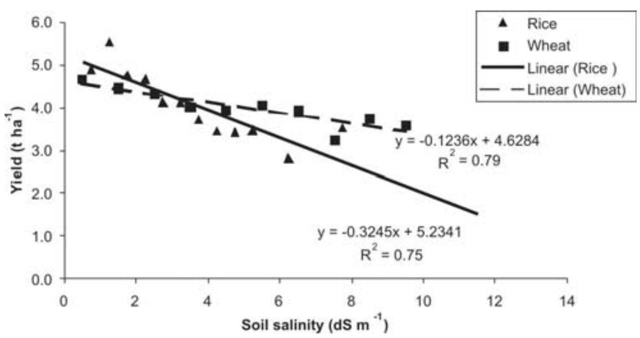

Fig. 2. Effect of soil salinity on rice-wheat yield

Quality of irrigation water: Tubewell is the readily available source of water for irrigation in the study area, but its quality deteriorates from head to tail reaches. The groundwater in head reaches of both the minors are alkali in nature, whereas in the tail reaches, groundwater is saline. The analysis indicated that groundwater salinity and alkalinity affected rice yield more severely than wheat yield. Each unit increase in salinity reduced the yield of wheat by 0.12 t ha^{-1} and rice by 0.35 t ha^{-1}. Similarly each unit increase in SAR reduced the yield of rice by 0.1 t ha^{-1} and wheat by 0.025 t ha^{-1} (Fig. 3).

Source and amount of irrigation application**:** It was found that higher use of canal water leached down the salts present in the root zone and improved the crop productivity. Thus, increase in canal water by one percent in total irrigation increased the rice and wheat yield by 0.02 and 0.007 t ha^{-1}, respectively (Fig.4). It indicated that use of just 20% canal water (25 cm in case of rice and 7

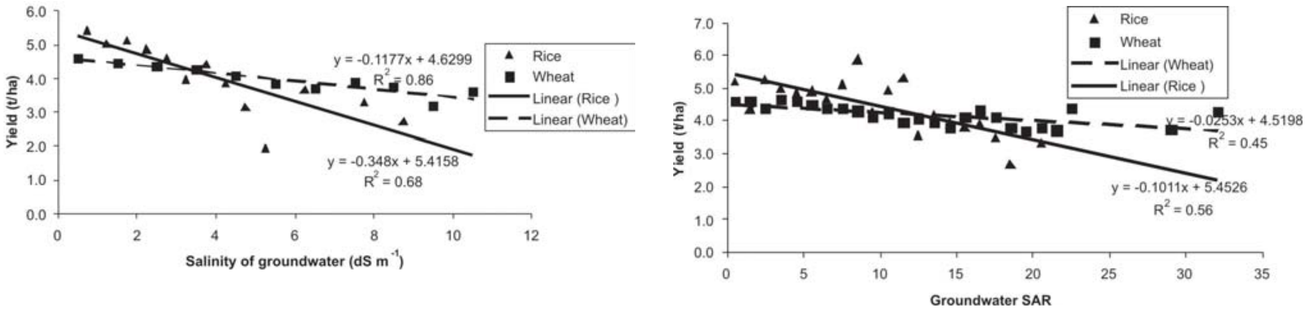

Fig. 3. Effect of groundwater (i) salinity and (ii) alkalinity on rice-wheat yield

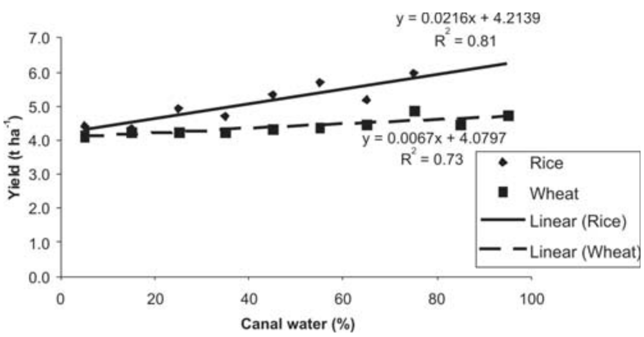

Fig. 4. Effect of canal water utilization on rice-wheat yield

cm for wheat) in irrigation could increase the productivity by 0.4 t ha^{-1} for rice and 0.14 t ha^{-1} for wheat. Fig. 5 shows that rice yield affected very severely due to deficit irrigation as compared to wheat crop. The regression equation shows that each cm of irrigation increased the rice yield by about 0.018 t ha^{-1} and 0.017 t ha^{-1} in the wheat crop.

Multiple regression analysis

The multiple regression analysis was carried out to estimate the interactive effects of various inputs on combined productivity of rice and wheat crop (Table 6). Input variables such as soil and groundwater salinity/alkalinity, sowing dates, irrigation interval, use of canal and groundwater, weedicide and fertilizer applied were included in the analysis. Soil and water salinity, percentage canal water use and seasonal water application were found to be the most significant variables in the 1st year while in place of total irrigation, groundwater application was found significant in the 2nd year. It may be due to higher groundwater application during *kharif* because of low rainfall. In both the year, groundwater salinity was found the most detrimental factor, which influenced the rice-wheat productivity. The analysis further indicated that in the 1st year each centimetre of irrigation water as well as each percent of canal water contributed 0.024 t ha^{-1} in the productivity. One unit of groundwater and soil salinity reduced the productivity by 0.15 t ha^{-1} and 0.11 t ha^{-1}, respectively. In the 2nd year, each percent of canal water contributed 0.062 t ha^{-1} in productivity while each cm of groundwater, groundwater salinity and soil salinity reduced the yield by 0.013 t ha^{-1}, 0.441 t ha^{-1}, 0.389 t ha^{-1}, respectively.

Conclusions

Constraint analysis is an important tool to understand the role of productive/detrimental factors to productivity. A detailed study to analyse the productivity constraints of rice-wheat cropping sequence in the Northwest India was carried out. The analysis indicated that the canal water supply is deficient by 70% and 80% to water requirement of wheat/rice crop in watercourses located at the head and tail of a minor, respectively. In case of wheat, salinity of tubewell water and pH of soil and in case of rice, quantity of canal water and quality of tubewell water were the main detrimental factors to the

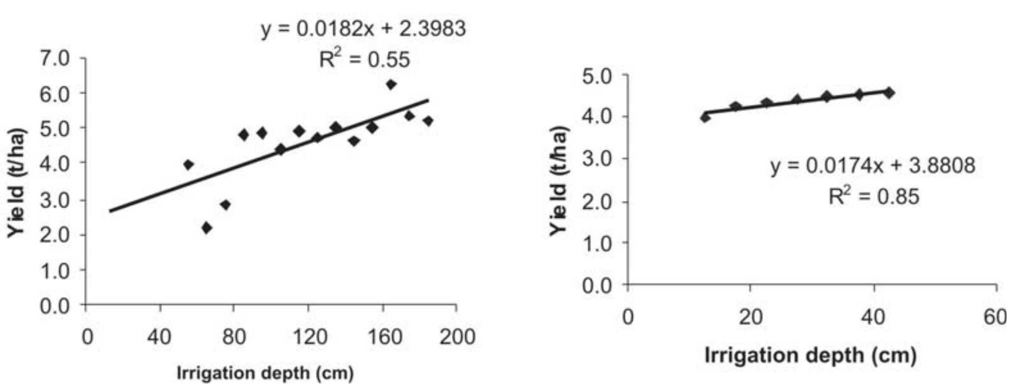

Fig. 5. Effect of total water use on rice (left)-wheat (right) yield

Table 6. Multiple regression analysis

Variable	1st Year		2nd Year	
	Coefficients	Significance (t value)	Coefficients	Significance (t value)
(Constant)	4.990	14.10	8.124	5.40
Canal water (%)	0.024	6.17	0.062	3.53
Groundwater EC (dS m^{-1})	- 0.153	- 3.20	-0.441	-2.52
Soil EC (dS m^{-1})	- 0.110	- 2.00	-0.389	-2.23
Total irrigation (cm)	0.024	11.18	—	
Groundwater (cm)	—		-0.013	-2.44
R^2	0.60		0.55	

productivity. Although non-water constraints are important, except date of sowing that affect productivity of wheat crop, other factors were found to be insensitive due to adequate supply by farmers.

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Characterization and classification of salt-affected soils of Purna valley in Vidarbha region of Maharashtra

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ABSTRACT

The present investigation was carried out in the Purna valley of vidarbha region, Maharashtra for the characterization and classification of soils. Eight profiles were studied for characterization of soils. It has been observed that, despite low level of sodicity (ESP 4.8-11.1), the soil has severe drainage problems because of low hydraulic conductivity. Similarly, high amount of smectitic clay leads to increase in bulk density which results into hard and compact soil structure. The pedons were classified as Typic Haplusterts and Vertic Haplustepts. The soils showed degradation in physical and chemical properties due to alkalinisation in subsoil. The pH was increased down the depth up to 9.5 and ESP upto 11.1. The mean weight diameter was reduced in the sub soil with concomitant increase in ESP. The soils show poor internal drainage even at the ESP values much lower than 15 ESP. The bicarbonates precipitated in subsoil layers indicate operative alkalinisation in these soils under semi-arid conditions.

Key words: soil degradation, soil classification, soil salinity, sodic soil and hydraulic conductivity

Introduction

Soils are considered as the integral part of the landscape and their characteristics are largely governed by the landforms on which they have developed (Sharma *et al*., 1999, Sawhney *et al*., 1992). Black soils (Vertisols and their intergrades) occur in many parts of the world. In India these soils occupy an area of 72.9 million hactares, 35.5 per cent of which is in the state of Maharashtra (Murthy *et al*., 1982). These soils are mainly confined to lower topographical levels and occur in most of the river valleys, one of which is Purna valley covering parts of the Amravati, Akola and Buldhana districts of Maharashtra. This valley is an oval shaped basin drained by the Purna river system. Even though the river Purna flows throughout the year, the soils along both banks have reported as being salt affected (Adyalkar, 1963). However these soils do not show any salt efflorescence on the surface (Pal, 2004). The majority of these soils occur in the lower piedmont plains or valley or in micro depressions, and are developed in the alluvium of weathered Deccan basalt (Pal and Deshpande, 1987).

The earlier work carried out in the area (Magar, 1990; Nimkar *et al*., 1992; Kadu *et al*., 1993) indicated that many soils in this valley are non-saline, the EC being less than 2 dS m^{-1} and the ESP less than 15. However, these soils have not been categorised in appropriate class because they show deterioration at ESP values much lower than 15. They are prone to waterlogging and show severe problems of drainage. It is, therefore, necessary to study the physical properties of these soils with their spatial distribution in the valley and their deterioration at different ESP in order to decide appropriate site specific management options. The cracking clay soils in the present study area are peculiar and prone to degradation problems detrimental for crop production. These soils being different from the salt affected alluvial soils found elsewhere in the country need to be studied for their detailed morphological, physical and chemical characterization. For proper agricultural planning and management of natural resources the detailed information on soils and their quality attributes is essential. Hence the present study was undertaken to characterize and classify soils of the Purna valley in eight villages on both sides of Purna River in Vidarbha region of Maharashtra.

Materials and methods

The study area comprises part of Purna valley, part of payanghat plain, an oval shaped basin of the Amravati, Akola and Buldhana districts of Maharashtra, India. The Purna valley is a faulted basin filled with sediments derived entirely from the Deccan basalt surrounding it. The total thickness of their deposit is upto 420 m (Adyalkar, 1963). The valley extends from 20° 40′ to 21°22′ N latitude and 76°15′ to 77°45′ E longitude. The study area is central portion of the valley and elevation varies from 250 m to 450 m above MSL. The study area is

Table 1. Location of sampling sites

Sr. no.	Pedon site	GPS coordinates	Elevation from MSL (m)
1.	Village- Paral Tal.Akot Dist. Akola Survey No.96	20° 57′ 04″ N 076° 57′ 36″ E	263
2.	Village-Dapura Tal.Telhara Dist. Akola. Survey No.9	20° 57′ 25″ N 076° 56′ 02″ E	263
3.	Village-Ner Tal. Telhara Dist.Akola. Survey No.86	20° 53′ 48″ N 076° 56′ 23″ E	260
4.	Village-Patsul Tal.Akot Dist. Akola Survey No.113	20° 59′ 10″ N 077° 00′ 40″ E	268
5.	Village- HingnaTamaswadi Tal.Akot Dist. Akola Survey No.28	20° 50′ 26″ N 077° 00′ 16″ E	263
6.	Village – Ugwa Tal.Akot Dist. Akola Survey No 154	20° 48′ 16″ N 077° 00′ 10″ E	274
7.	Village- Naved Tal.Bhatkuli Dist. Amravati Survey No19/1,22/1	20° 57′ 41″ N 077° 30′ 48″ E	295
8.	Village-Kholapur Tal. Bhatkuli Dist. Amravati Survey No.276.	20° 57′ 13″ N 077° 32′ 07″ E	307

characterized by hot summer and dry weather conditions except, during the south west monsoon season and thus represents a tropical subhumid dry to semi arid dry climate (Mandal and Mandal, 1998). The average annual rainfall at Amravati and Akola weather stations, which are within the study area, is 975 mm and 877 mm, respectively, with 85-90 per cent falling during the monsoon season from July to September. This is followed by a dry season from October to June. April and May are the hottest months, with mean month temperatures of 32.5 and 35.2° C, respectively. December and January are the coolest months, with mean daily temperature of about 22° C. This indicates more aridity in Akola than in Amravati. The soils of the area have Typic tropoustic soil moisture and hyperthermic temperature regime.

The salt affected area of Purna valley is mainly along both banks of the river. Overall eight representative pedons were selected based on the earlier work in the valley and traversing of the area. These sites were benchmarked by maintaining the GPS coordinates for future monitoring (Table 1). Pedon 1-6 are in Akola district and Pedon 7 and 8 are in Amravati district (Fig. 1 and Fig. 2). All the soils have almost identical agro-climatic conditions with comparable management followed by the farmers.

The soil profiles of 1.2 meter long, 1 m wide and 1.5 m deep were dug at all the selected sites. Characteristics of the pedons were studied in the field as per the methodology laid out in the soil survey manual (Soil Survey Staff, 1998). Special observations like cracking

Fig. 1. Location map of sampling sites in Purna valley of Vidarbha region

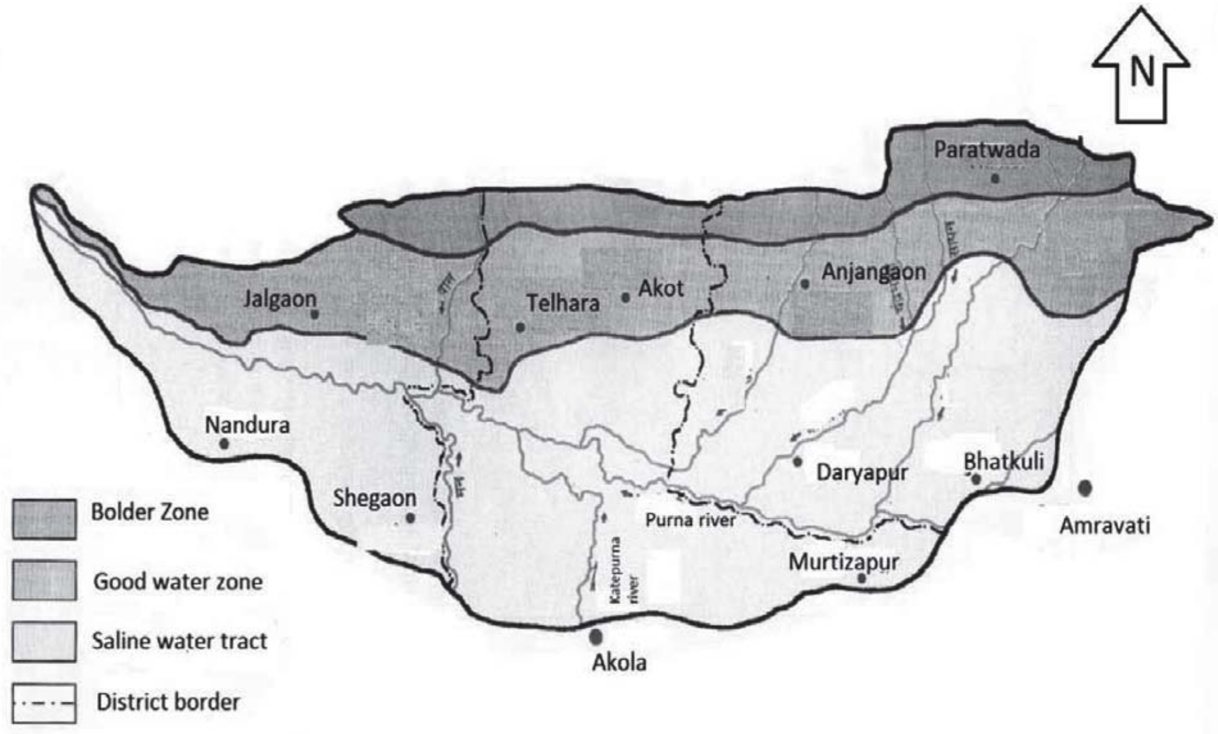

Fig. 2. Map of Purna Valley Tract in Vidarbha region of Maharashtra

depth, slickensides and other microfeatures were also recorded. Horizon wise soil samples were collected, air dried and processed as per the standard methodology.

Physical properties of the soils, such as particle size distribution were determined by the international pipette method (Klute, 1986). The bulk density was determined by clod coating method (Black and Hartge, 1986). The hydraulic conductivity was measured by constant head method described by Klute and Dirksen (1986). The coefficient of linear extensibility (COLE) was estimated by following the method of Schaffer and Signer (1976), and is defined as the ratio of difference between the moist length (Lm, length of soil clod at 33 kPa) and dry length of soil clod to its dry length (Ld, length of soil clod when dry (room temperature) (Soil Survey Staff, 1999). The volumetric shrinkage potential was estimated from measured COLE data using the relationship described by Hallberg (1977)

Chemical properties like pH and EC of the soil suspension (1:2 ratio) was determined by the methodology of Jackson (1973). For the determination of soil organic carbon (SOC), the modified Walkley and Black wet oxidation method was used (Walkley and Black, 1934; Jackson, 1973). The free calcium carbonate was determined by rapid titration method (Piper, 1966). The exchangeable cations, cation exchange capacity and saturation extract analysis of soils were determined by methods outlined by Richards (1954).

Results and discussion

Morphological properties

The soils were very deep (>140 cm), clayey in texture and dark brown to very dark greyish brown in colour. All the soils showed sub angular blocky structure in the surface horizons and very hard (dry) and friable (moist) consistence. In the subsoil, the structure consists of intersecting slickensides, forming parallel epipeds with their long axes at 30-45 degrees from the horizontal. These separate in to strong, coarse angular blocks with shiny pressure faces and firm (moist) consistence. All the pedons except pedon 6 showed slight to strong effervescence (with 10 per cent HCl) was slight to strong, however the degree of severity increases with depth. On the other hand effervescence in pedon 6 was violent, this has been mainly due to the leaching of bicarbonates during rainy season from the upper layers due to subsequent precipitation and prevailing semi- arid climatic condition (Balpande *et al.*, 1996). There were some stricking differences in the slickensides and cracking pattern in these soils. The slickensides were more developed in pedon 1 to 7 and cracks were extended upto slickensides zone in all these pedons however, the slickensides were absent in pedon 8 with cracks and pressure faces (Table 2).

Physical properties

The soils are clayey in texture and the clay content varies from 68 to 74 per cent and it increases with depth

Table 2. Morphological Characteristics of soils

Depth (cm)	Horizon	Munsell color (Moist)	Structure			Consistence			Efferve-scence	Concretion		Boun-dary	Special features
			S	G	T	D	M	W		S	Q		
Pedon -1 (Village – Paral) Typic Haplusterts													
0-18	Ap	10YR 3/2	2	M	Sbk	vh	fi	vsvp	Es	f	m	cs	Well developed
19-40	Bw	10YR 3/2	3	C	Abk	vh	fi	vsvp	Es	f	c	cs	intersecting slikensides
41-52	Bss1	10YR 2/2	3	C	Abk	vh	fi	vsvp	Ev	vf	f	cw	in third, fourth and fifth
53-72	Bss2	10YR 2/2	3	C	Abk	vh	fi	vsvp	Ev	vf	f	cw	layer. 2.5 cm wide
73-92	Bss3	10YR 2/2	3	C	Abk	vh	fr	vsvp	Ev	vf	f	cw	cracks extending upto 80
93-110	Bss4	10YR 2/2	3	C	Abk	vh	fr	vsvp	Ev	vf	f	cw	cm depth. Reduction
111-140	Bss5	10YR 2/2	3	C	Abk	vh	fr	vsvp	Ev	vf	f		mottles in sub soil.
Pedon -2 (Village – Dapura) Typic Haplusterts													
0-16	Ap	10 YR 3/3	2	M	Sbk	v	fi	vsvp	Es	f	c	cs	Well developed
17-40	Bw	10 YR 3/2	3	C	Abk	v	fi	vsvp	Es	f	m	cs	intersecting slikensides
41-68	Bss1	10 YR 3/1	3	C	Abk	v	fi	vsvp	Es	vf	f	cs	in third, fourth, fifth and
69-102	Bss2	10 YR 2/1	3	C	Abk	v	fi	vsvp	Es	vf	f	cw	sixth layer. 2 cm wide
103-134	Bss3	10 YR 2/2	3	C	Abk	v	fi	vsvp	Es	vf	f	cw	cracks extending up to
135-155	Bss4	10 YR 2/2	3	C	Abk	v	fi	vsvp	Ev	vf	f		70 cm depth. . Reduction mottles in sub soil.
Pedon -3 (Village – Ner) Typic Haplusterts													
0-16	Ap	10 YR 3/2	2	M	Sbk	vh	fi	vsvp	E	f	m	cs	Slight effervescence,
17-40	Bw	10 YR 3/2	2	M	Sbk	vh	fi	vsvp	E	f	c	cs	lime nodules in last two
41-66	Bss1	10 YR 2/2	3	C	Abk	vh	fi	vsvp	E	vf	f	cw	layers,1.5 cm wide
67-98	Bss2	10 YR 2/2	3	C	Abk	vh	fi	vsvp	E	vf	f	cw	cracks up to 80 cm
99-120	Bss3	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	vf	f	cw	depth,well developed
121-154	Bss4	10 YR 2/2	3	C	Abk	vh	fr	vsvp	Es	vf	f		intersecting slikensides.
Pedon -4 (Village – Patsul) Typic Haplusterts													
0-18	Ap	10 YR 3/2	2	M	Sbk	vh	fi	vsvp	Es	f	m	cs	Soil highly calcareous,
19-41	Bw	10 YR 3/3	2	M	Sbk	vh	fi	vsvp	Es	f	m	cs	well developed
42-68	Bss1	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	f	c	cw	slickensides in third,
69-92	Bss2	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	f	c	as	fourth layer. 2 cm wide
93-120	Bss3	10 YR 3/4	3	C	Abk	vh	fi	vsvp	Es	vf	f	as	cracks up to 92 cm
121-152	Bw	10 YR 3/4	3	C	Abk	vh	fi	vsvp	Es	f	c		depth. . Reduction mottles in sub soil.

Contd...

Pedon -5 (Village – Hingna- Tamaswadi) Typic Haplusterts													
0-16	Ap	10 YR 3/2	2	M	Sbk	vh	fi	vsvp	E	f	c	cs	Well developed
17-42	Bw	10 YR 3/3	2	M	Sbk	vh	fi	vsvp	E	f	c	cs	intersecting slikensides.
43-67	Bss1	10 YR 3/1	3	C	Abk	vh	fi	vsvp	E	f	c	cs	2 cm wide cracks upto
68-90	Bss2	10 YR 2/2	3	C	Abk	vh	fi	vsvp	E	vf	f	cw	90 cm depth. Many
91-115	Bss3	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	vf	f	cw	concretions in last two
116-130	Bss4	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	vf	f		layers.
Pedon -6 (Village – Ugwa) Typic Haplusterts													
0-16	Ap	10 YR 3/3	2	M	Sbk	v	fi	vsvp	Ev	vf	f	cs	Calcium carbonate
17-40	Bw	10 YR 3/4	3	C	Abk	v	fi	vsvp	Ev	vf	c	cs	nodules. Continuous
41-65	Bss1	10 YR 3/2	3	C	Abk	v	fi	vsvp	Ev	f	f	cs	well developed
66-90	Bss2	10 YR 3/2	3	C	Abk	v	fi	vsvp	Ev	f	f	cw	slikensides from third
91-120	Bss3	10 YR 3/2	3	C	Abk	v	fi	vsvp	Ev	f	f	cw	layer. Reduction mottles
121-150	Bss4	10 YR 2/2	3	C	Abk	v	fi	vsvp	Ev	f	f	cw	in sub soil.
151-180	Bss5	10 YR 2/2	3	C	Abk	v	fi	vsvp	Ev	f	f		
Pedon -7 (Village – Naved) Typic Haplusterts													
0-16	Ap	10 YR 3/2	2	M	Sbk	vh	fr	vsvp	E	vf	f	cs	Yellow calcareous
17-42	Bss1	10 YR 2/2	3	C	Abk	vh	fi	vsvp	E	vf	f	cw	materials with lime
43-67	Bss2	10 YR 2/2	3	C	Abk	vh	fi	vsvp	Es	vf	f	cw	nodules in last layer.
68-97	Bss3	10 YR 2/1	3	C	Abk	vh	fi	vsvp	Es	vf	c	cw	Well developed
98-121	Bss4	10 YR 2/1	3	C	Abk	vh	fi	vsvp	Es	f	f	cw	slikensides from second
122-141	Bw1	10 YR 3/4	3	C	Abk	vh	fi	vsvp	Es	f	f	cw	layer to fourth layer.
142-160	Bw2	10 YR 3/4	3	C	Abk	vh	fi	vsvp	Es	f	f		
Pedon -8 (Village – Kholapur)) Vertic Haplustepts													
0-16	Ap	10 YR 3/2	2	M	Sbk	vh	fr	vsvp	Es	vf	c	cs	Many calcium carbonate
17-45	Bw1	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	f	c	cs	nodules from second to
46-65	Bw2	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	vf	m	cs	last layer.
66-84	Bw3	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	vf	f	cw	Cracks and pressure
85-100	Bw4	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	f	f	cw	faces observed.
101-120	Bw5	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	f	f	cw	
121-150	Bw6	10 YR 3/4	2	M	Sbk	vh	fi	vsvp	Es	c	c		

in all the pedons. The very high clay content of these soils can be attributed to their formation from basaltic parent material (Pal and Deshpande, 1987). The bulk density was quite variable in different horizons and varied from 1.20 to 1.84 Mg m^{-3}. It was relatively lower in the surface horizons and increases with depth in all the soils that may be due to comparatively more organic matter in the surface horizons and higher swelling pressure and compaction caused due to smectitic clay content in the subsoil (Ahuja *et al.*, 1988). The hydraulic conductivity can be attributed to the degradation of soil by increasing sodium on the exchange complex and also due to the inherent clayey nature of these soils resulting into slow water transmission. Considerable reduction in hydraulic conductivity with depth was also observed in deep black soils of this region by Kadu *et al.* (1993).

The value of COLE ranges from 0.18 to 0.28 cm cm^{-1}, indicating high swell shrink activities in these soils due to predominance of smectitic clay (Balpande *et al.*, 1996). On the basis of categorization of COLE value, all the soils under the study fall into very high shrink swell soils (Nayak *et al.*, 2006). The volumetric shrinkage potential ranged from 64.3 to 109.71 per cent. The volumetric shrinkage potential reflects an understandable swell shrink nature of these soils. The mean weight diameter was found to be varied from 0.38 to 0.69 mm in different horizons of the soil profile and it was decreased down to the depth. The downward decrease in mean weight diameter can be attributed to subsoil sodicity in these soils (Table 3).

Chemical properties

The soils are neutral to strongly alkaline in reaction and pH value varies from 7.0 to 9.5, which increases down the depth in the soil profile (Table 4). All the soils are calcareous in nature and the value of $CaCO_3$ varies from 5.75 to 16.37 per cent in different horizons with a tendency to increase with depth. This may be due to semi-arid climatic condition, where the leaching of bicarbonates during rainy season from upper layers and subsequent precipitation triggers development of sodicity in subsoils of black soils (Balpande *et al.*, 1996). The ECe of all the pedons is much less than 4 dSm^{-1}, indicating no salinity hazards. The ECe varies from 0.42- 2.7 dS m^{-1} in different horizons which increases down the depth in all profile. The subsoil increase in ECe indicates that salinization process is also operative in these soils which results into accumulation of salts in lower horizons.These soils are impoverished of organic carbon, it ranges from 0.09 to 0.44 per cent and it decreases with depth in all the pedons.

The cation exchange capacity of the soils was high and it varies from 44.5 to 66.5 C mol (p+) kg^{-1}. It was very high due to predominance of smectitic mineralogy of these soils. The exchange complex of all the soils shows dominance of Ca^{2+} followed by Mg^{2+} and K^{+}. The Ca^{2+} and Mg^{2+} content decreased with the depth in all the soils however, exchangeable Na^{+} shows reverse trend. The exchangeable sodium percentage (ESP) ranges from 5.0 to 11.1 in different pedons and in general it increases with depth in the profile. This can be attributed to lower topographical situation of these soils formed in this valley which favours accumulation of soils and subsequent sodification under the condition of semi –arid climate coupled with slow permeability of these soils. An increase in ESP with depth is general observation for black soils in the semi- arid region of the peninsular India (Nimkar *et al.*, 1992).The saturation extract (Table 5) showed dominance of sodium ions over the calcium and magnesium and it varies from 4.2 to 14.9 me L^{-1} in different horizons while predominance of chloride and sulphate ions with HCO_3^- ions were also found. The SAR of the pedons varies from 3.35 to 12.41. The initiation of alkalinisation is operative in subsurface layers as a consequence of salt accumulation and its progress in upward direction alongwith capillary rise of soil solution during dry periods.

Soil classification

Based on morphometric, physical and chemical characteristics, the pedons were grouped into different taxa. Pedon 1-7 which are deep (>140cm) with cracks,

Table 3. Physical properties of soils

Depth (cm)	Horizon	Hydraulic conductivity (mm hr^{-1})	Bulk density (Mg m^{-3})	COLE (cm cm^{-1})	Volumetric shrinkage potential (%)	Mean weight diameter (mm)	Mechanical composition (%)		
							Sand	Silt	Clay
Pedon -1 (Village – Paral) Typic Haplusterts									
0-18	Ap	2.6	1.61	0.22	81.58	0.58	5.6	26.4	68.0
19-40	Bw	1.2	1.61	0.24	90.66	0.54	3.5	25.6	70.9
41-52	Bss1	1.1	1.63	0.21	77.15	0.50	3.8	24.4	71.8
53-72	Bss2	0.9	1.71	0.18	64.30	0.48	6.0	22.2	71.8
73-92	Bss3	0.8	1.73	0.26	100.03	0.46	6.6	20.4	73.0
93-110	Bss4	0.6	1.77	0.27	104.83	0.44	6.8	20.2	73.0
111-140	Bss5	0.5	1.74	0.25	95.31	0.40	6.0	20.0	74.0

Contd...

Depth (cm)	Horizon	Hydraulic Conductivity (mm hr^{-1})	Bulk density Mg m^{-3}	COLE (cm cm^{-1})	Volumetric Shrinkage Potential (%)	Mean weight Diameter (mm)	Mechanical composition (%)		
							Sand	Silt	Clay
Pedon -2 (Village – Dapura) Typic Haplusterts									
0-16	Ap	3.0	1.66	0.19	68.51	0.66	7.2	24.3	68.5
17-40	Bw	2.8	1.68	0.25	95.31	0.64	6.5	24.2	69.2
41-68	Bss1	2.3	1.69	0.26	100.03	0.63	6.8	23.2	70.0
69-102	Bss2	1.3	1.71	0.26	100.03	0.58	5.6	22.6	71.7
103-134	Bss3	1.0	1.74	0.27	104.83	0.54	4.6	22.4	73.0
135-155	Bss4	0.9	1.76	0.28	109.71	0.48	6.4	20.1	73.5
Pedon -3 (Village – Ner) Typic Haplusterts									
0-16	Ap	3.1	1.68	0.24	90.66	0.69	6.4	26.8	66.7
17-40	Bw	2.7	1.68	0.26	100.03	0.67	6.6	25.4	68.0
41-66	Bss1	1.7	1.72	0.26	100.03	0.64	4.8	25.2	70.0
67-98	Bss2	0.9	1.74	0.28	109.71	0.59	3.3	24.9	71.7
99-120	Bss3	0.8	1.77	0.28	109.71	0.57	4.1	24.1	71.7
121-154	Bss4	0.8	1.81	0.28	109.71	0.55	3.0	24.0	73.0
Pedon -4 (Village – Patsul) Typic Haplusterts									
0-18	Ap	2.8	1.31	0.22	81.58	0.67	6.6	25.4	68.0
19-41	Bw	2.6	1.30	0.24	90.66	0.65	6.4	25.3	68.2
42-68	Bss1	2.3	1.20	0.26	100.03	0.54	5.8	24.9	69.2
69-92	Bss2	1.3	1.21	0.27	104.83	0.52	5.8	24.2	70.0
93-120	Bss3	1.0	1.27	0.27	104.83	0.49	5.2	23.0	71.7
121-152	Bw	0.8	1.33	0.28	109.71	0.46	7.6	22.4	70.0
Pedon -5 (Village – Hingna- Tamaswadi) Typic Haplusterts									
0-16	Ap	3.4	1.35	0.21	77.15	0.66	4.2	26.5	69.2
17-42	Bw	3.0	1.33	0.22	81.58	0.62	3.7	26.3	70.0
43-67	Bss1	1.8	1.27	0.23	86.08	0.60	2.4	25.8	71.7
98-90	Bss2	1.1	1.26	0.24	90.66	0.58	2.8	25.4	71.7
91-115	Bss3	1.0	1.23	0.24	90.66	0.56	2.8	24.2	73.0
116-130	Bss4	0.8	1.20	0.26	100.03	0.54	2.5	24.0	73.5
Pedon -6 (Village – Ugwa) Typic Haplusterts									
0-16	Ap	3.0	1.68	0.21	77.15	0.59	4.2	26.5	69.2
17-40	Bw	2.7	1.69	0.26	100.03	0.54	4.6	25.4	70.0
41-65	Bss1	2.3	1.71	0.26	100.03	0.46	3.9	24.3	71.7
66-90	Bss2	2.1	1.74	0.27	104.83	0.44	2.8	24.2	73.0
91-120	Bss3	1.7	1.76	0.26	100.03	0.42	2.6	23.9	73.5
121-150	Bss4	0.9	1.80	0.27	104.83	0.39	3.0	23.5	73.5
151-180	Bss5	0.8	1.81	0.28	109.71	0.38	4.0	23.0	73.0
Pedon -7 (Village – Naved) Typic Haplusterts									
0-16	Ap	2.6	1.60	0.25	95.31	0.59	8.7	24.5	66.7
17-42	Bss1	2.6	1.67	0.26	100.03	0.58	8.5	24.3	67.2
43-67	Bss2	1.5	1.69	0.26	100.03	0.54	7.5	24.0	68.5
68-97	Bss3	1.4	1.72	0.26	100.03	0.49	6.4	23.6	70.0
98-121	Bss4	1.4	1.75	0.26	100.03	0.48	4.7	23.5	71.7
122-141	Bw1	1.0	1.82	0.28	109.71	0.46	6.8	23.2	70.0
142-160	Bw2	0.8	1.84	0.28	109.71	0.44	8.7	22.0	69.2
Pedon -8 (Village – Kholapur)) Vertic Haplustepts									
0-16	Ap	3.0	1.28	0.22	81.58	0.69	6.3	25.2	68.5
17-45	Bw1	2.6	1.21	0.23	86.08	0.68	6.4	24.3	69.2
46-65	Bw2	2.4	1.37	0.23	86.08	0.64	6.1	23.9	70.0
66-84	Bw3	2.3	1.25	0.24	90.66	0.58	6.5	23.5	70.0
85-100	Bw4	1.4	1.23	0.26	100.03	0.56	5.3	22.9	71.7
101-120	Bw5	1.0	1.25	0.27	104.83	0.46	5.6	22.6	71.7
121-150	Bw6	0.9	1.29	0.28	109.71	0.44	8.7	22.0	69.2

Table 4. Chemical Properties of soils

Depth (cm)	Horizon	pH (1:2)	EC (1:2) (dSm^{-1})	$CaCO_3$ (%)	Organic carbon (%)	Extractable bases c mol (p+)kg^{-1} Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	CEC cmol (p+)kg^{-1}	Base Saturation (%)	ESP	EMP	Ca/ Mg
Pedon -1 (Village – Paral) Typic Haplusterts															
0-18	Ap	8.0	0.11	9.4	0.44	35.2	10.2	5.1	1.1	51.6	52.2	98.8	9.7	19.5	3.5
19-40	Bw	8.8	0.13	9.4	0.13	33.7	9.4	4.5	1.1	48.7	54.6	89.2	8.2	17.2	3.6
41-52	Bss1	8.9	0.14	11.9	0.13	32.8	8.6	4.0	1.2	46.6	55.6	83.8	7.2	15.5	3.8
53-73	Bss2	9.0	0.13	10.6	0.13	32.9	8.0	3.2	0.6	44.7	56.5	79.0	5.5	14.2	4.1
73-92	Bss3	9.1	0.17	11.9	0.19	30.6	8.0	3.7	0.6	43.0	60.4	70.1	6.1	13.4	3.8
93-110	Bss4	9.0	0.22	14.4	0.19	30.1	7.7	4.0	0.6	42.4	66.1	64.2	6.0	11.6	3.9
111- 140	Bss5	8.0	0.11	9.4	0.44	30.0	7.4	3.9	0.6	41.9	66.4	63.1	5.8	11.1	4.0
Pedon -2 (Village – Dapura) Typic Haplusterts															
0-16	Ap	8.6	0.12	9.1	0.44	32.4	12.1	3.1	1.0	48.6	61.5	79.0	5.0	19.7	2.7
17-40	Bw	9.3	0.23	9.8	0.39	32.2	12.0	6.8	0.9	51.9	61.6	84.2	11.1	19.5	2.7
41-68	Bss1	9.3	0.23	12.5	0.39	31.1	10.7	6.4	0.7	48.9	62.3	78.9	10.3	17.2	2.9
69-102	Bss2	9.5	0.24	13.1	0.19	30.7	10.4	5.6	1.1	47.8	62.7	69.5	8.9	16.6	2.9
103-134	Bss3	9.1	0.44	14.4	0.19	27.9	9.7	4.3	1.0	42.9	60.0	71.5	7.1	16.2	2.9
135-155	Bss4	9.0	0.48	16.1	0.13	22.7	8.5	4.1	0.8	36.1	60.1	60.0	6.7	14.1	2.8
Pedon -3 (Village – Ner) Typic Haplusterts															
0-16	Ap	7.7	0.25	11.6	0.40	31.3	11.7	4.4	0.7	48.1	56.1	85.7	9.0	20.8	2.7
178-40	Bw	8.4	0.11	11.6	0.36	31.0	11.4	3.2	0.7	46.3	56.7	81.6	5.6	20.1	2.7
41-66	Bss1	8.5	0.10	11.0	0.32	27.2	10.6	4.7	1.1	43.6	57.7	75.6	8.0	18.4	2.6
67-98	Bss2	8.5	0.13	15.6	0.18	25.4	10.2	4.7	0.7	41.0	58.0	70.7	8.1	17.6	2.5
99-120	Bss3	8.2	0.13	15.7	0.09	25.0	9.4	4.9	0.8	40.1	58.3	68.8	8.4	16.1	2.7
121-154	Bss4	8.5	0.25	16.0	0.11	24.0	9.1	4.2	0.7	38.0	59.6	63.9	7.0	15.3	2.6
Pedon -4 (Village – Patsul) Typic Haplusterts															
0-18	Ap	7.5	0.12	9.1	0.31	32.0	11.7	3.2	1.0	47.9	57.2	83.8	5.6	20.5	2.7
19-41	Bw	7.7	0.12	10.0	0.29	35.6	11.4	4.5	1.0	52.5	64.9	80.9	6.9	17.7	3.1
42-68	Bss1	7.9	0.11	14.0	0.33	30.0	10.7	4.2	0.9	45.8	64.7	70.8	6.5	16.5	2.8
69-92	Bss2	8.2	0.11	15.2	0.28	28.9	10.3	4.3	0.8	44.2	65.7	67.3	6.5	15.7	2.8
93-120	Bss3	8.2	0.11	16.4	0.26	27.5	9.7	4.2	0.7	42.1	66.1	64.0	6.3	14.7	2.8
121-152	Bw	8.4	0.15	16.2	0.13	24.6	8.4	5.5	0.7	39.2	66.5	58.9	8.2	12.6	2.9
Pedon -5 (Village – Hingna-Tamaswadi) Typic Haplusterts															
0-16	Ap	8.0	0.17	10.4	0.44	46.4	11.1	3.3	0.9	61.7	63.0	97.9	5.2	17.6	4.2
17-42	Bw	8.6	0.12	10.8	0.42	44.3	10.7	3.4	0.7	59.0	59.0	99.2	5.6	18.1	4.1
43-67	Bss1	8.9	0.11	12.6	0.39	42.8	10.2	3.4	0.5	57.0	57.0	94.8	5.7	17.9	4.2
68-90	Bss2	8.9	0.13	13.6	0.34	39.7	9.4	4.2	0.8	54.1	54.1	87.4	6.7	17.4	4.2
91-115	Bss3	8.0	0.17	10.4	0.44	38.2	9.2	4.6	0.7	52.7	52.7	84.0	7.3	17.5	4.2
116-130	Bss4	8.6	0.12	10.8	0.42	30.3	8.7	4.4	1.1	44.5	44.5	70.1	6.9	19.5	3.5
Pedon -6 (Village – Ugwa) Typic Haplusterts															
0-16	Ap	8.2	0.13	11.1	0.24	42.4	12.6	3.1	0.9	59.0	60.4	97.6	5.1	20.9	3.4
17-40	Bw	8.7	0.13	11.4	0.38	42.2	12.1	3.2	0.6	58.1	60.9	95.4	5.1	19.9	3.5
41-65	Bss1	8.5	0.12	11.6	0.35	40.3	10.4	3.7	0.5	54.9	59.6	92.3	6.2	17.4	3.9
66-90	Bss2	8.5	0.12	11.3	0.39	40.0	10.1	3.2	1.0	54.3	65.7	82.7	4.8	15.4	4.0
91-120	Bss3	8.4	0.12	16.3	0.15	38.7	10.3	3.9	0.8	53.7	63.5	84.7	6.1	16.2	3.8
120-150	Bss4	8.2	0.13	11.1	0.24	34.5	9.8	4.3	0.7	49.3	63.7	77.5	6.7	15.4	3.5
150-180	Bss5	8.7	0.13	11.4	0.38	30.1	8.7	4.2	0.7	43.8	64.9	67.5	6.5	13.4	3.5
Pedon -7 (Village – Nawed) Typic Haplusterts															
0-16	Ap	7.9	0.11	5.8	0.29	35.3	13.5	4.3	0.7	53.7	54.3	98.8	7.8	24.9	2.6
17-42	Bss1	8.2	0.10	6.3	0.44	33.7	12.7	4.4	0.6	51.3	55.2	93.0	7.9	23.0	2.7
43-67	Bss2	8.3	0.14	6.9	0.40	32.1	12.5	4.5	0.8	49.9	56.1	89.0	8.0	22.3	2.6
68-97	Bss3	8.2	0.13	7.6	0.40	30.4	11.4	3.3	0.8	45.9	56.5	81.2	5.8	20.2	2.7

Contd...

Depth (cm)	Horizon	pH (1:2)	EC (1:2) (dSm^{-1})	$CaCO_3$ (%)	Organic carbon (%)	Extractable bases Ca^{2+}	Mg^{2+} c mol (p+)kg^{-1}	Na^+	K^+	Sum	CEC cmol (p+)kg^{-1}	Base Saturation (%)	ESP	EMP	Ca/Mg
98-121	Bss4	7.0	0.45	13.6	0.31	30.0	10.2	3.4	1.1	44.8	59.6	75.2	5.7	17.1	2.9
122-141	Bw1	7.9	0.36	13.7	0.19	28.5	9.4	3.2	0.9	42.0	61.3	68.6	5.2	15.3	3.0
142-160	Bw2	8.5	0.25	15.0	0.09	28.3	9.2	3.1	0.8	41.4	62.8	66.0	5.0	14.6	3.1
Pedon -8 (Village – Kholapur) Vertic Haplustepts															
0-16	Ap	8.5	0.11	13.4	0.44	42.3	12.6	4.0	1.1	60.0	61.0	98.0	6.5	20.7	3.4
17-45	Bw1	8.5	0.12	13.7	0.40	40.4	11.5	3.3	1.1	56.3	58.2	96.8	5.6	19.8	3.5
46-65	Bw2	8.4	0.10	15.0	0.34	40.1	10.7	3.4	1.0	55.2	58.4	94.4	5.8	18.3	3.7
66-84	Bw3	8.4	0.12	15.4	0.24	38.7	10.2	3.4	0.9	53.2	59.4	89.5	5.6	17.2	3.8
85-100	Bw4	8.5	0.13	15.4	0.20	32.4	9.7	3.3	0.9	46.3	60.8	75.6	5.3	16.0	3.3
101-120	Bw5	8.5	0.11	16.1	0.19	32.0	9.3	3.2	0.8	45.3	60.9	74.5	5.1	15.3	3.4
121-150	Bw6	8.6	0.14	16.3	0.13	30.1	8.4	3.0	0.7	42.2	60.0	70.4	5.0	14.0	3.6

Table 5. Saturation paste extract analysis data

Depth (cm)	Hori-zon	Satura-tion %	pHs	ECe (dS m^{-1})	Soluble Cations and Anions Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}	SAR	RSC
					me L^{-1} of saturation extract								
Pedon -1 (Village – Paral) Typic Haplusterts													
0-18	Ap	65.5	8.07	1.72	1.1	3.2	4.9	0.41	6.4	0.8	1.01	4.75	2.1
19-40	Bw	67.8	8.78	1.74	1.4	3.0	5.2	0.44	6.2	0.6	1.42	5.00	1.8
41-52	Bss1	69.2	8.89	1.69	1.8	3.4	5.4	0.29	6.6	0.5	1.61	4.73	1.4
53-72	Bss2	70.4	8.98	1.87	2.0	3.7	5.8	0.26	6.9	0.9	2.02	4.87	1.2
73-92	Bss3	72.4	8.98	1.99	2.2	3.9	6.0	0.24	7.2	1.4	2.42	4.87	1.2
93-110	Bss4	74.6	8.96	2.24	2.2	3.9	6.4	0.15	7.5	1.2	2.61	5.20	1.4
111-140	Bss5	74.6	8.94	2.74	2.4	3.8	6.2	0.12	7.7	1.4	2.91	5.00	1.6
Pedon -2 (Village – Dapura) Typic Haplusterts													
0-16	Ap	69.2	8.82	0.97	1.2	2.0	4.6	0.44	4.8	1.4	0.80	5.16	1.6
17-40	Bw	68.2	8.94	0.99	1.0	2.1	4.4	0.41	5.2	1.2	1.20	5.00	2.1
41-68	Bss1	66.5	8.97	1.05	0.8	2.4	4.8	0.34	5.8	1.6	1.42	5.39	2.6
69-102	Bss2	72.5	8.77	1.14	0.8	2.2	4.4	0.21	5.8	2.0	1.60	5.11	2.8
103-134	Bss3	78.9	8.99	1.94	1.2	3.0	5.2	0.23	6.2	2.2	2.54	5.09	2.0
135-155	Bss4	77.9	9.12	2.05	1.4	3.2	5.9	0.14	6.5	2.4	2.68	5.10	1.9
Pedon -3 (Village – Ner) Typic Haplusterts													
0-16	Ap	78.2	7.77	0.54	1.4	2.0	4.5	0.44	3.9	1.4	1.81	4.89	0.5
17-40	Bw	74.5	8.31	0.69	1.1	2.2	4.3	0.41	4.7	1.2	1.60	4.77	1.4
41-66	Bss1	77.2	8.42	0.74	1.0	2.4	4.2	0.24	4.9	1.2	1.40	4.56	1.5
67-98	Bss2	74.5	8.51	0.89	0.9	2.7	4.1	0.27	5.2	2.3	1.10	4.36	1.6
99-120	Bss3	76.2	8.16	0.94	0.8	2.2	5.2	0.18	5.5	2.4	0.90	6.50	2.5
121-154	Bss4	70.4	8.24	1.14	0.6	2.9	5.3	0.12	5.8	3.1	2.10	5.80	2.3
Pedon -4 (Village – Patsul) Typic Haplusterts													
0-18	Ap	68.5	7.67	0.69	1.8	2.1	4.9	0.27	5.4	2.5	2.70	5.44	1.5
19-41	Bw	72.6	7.77	0.68	1.4	2.3	4.8	0.22	5.9	2.9	2.00	5.00	2.2
42-68	Bss1	74.2	7.87	0.76	1.2	2.8	4.8	0.26	6.0	3.5	2.50	4.80	2.0
69-92	Bss2	77.5	8.21	0.81	0.9	2.8	4.2	0.29	6.5	3.4	2.20	4.37	2.8
93-120	Bss3	78.6	8.24	0.84	0.9	3.4	5.2	0.16	6.5	3.2	3.60	5.04	2.2
121-152	Bw	79.2	8.37	1.11	2.2	3.2	5.3	0.14	7.2	2.9	2.40	4.56	2.6
Pedon -5 (Village – Hingna- Tamaswadi) Typic Haplusterts													
0-16	Ap	72.4	7.97	0.71	2.8	3.4	4.9	0.24	6.2	4.9	3.40	3.95	0.3
17-42	Bw	74.5	8.54	0.62	2.4	3.6	5.7	0.27	7.4	4.8	2.50	4.67	1.4

Contd...

Depth (cm)	Hori-zon	Satura-tion %	pHs	ECe (dS m^{-1})	Soluble Cations and Anions								
					Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	SAR	RSC
					me L^{-1} of saturation extract								
43-67	Bss1	68.9	8.89	0.61	2.6	3.7	5.9	0.21	9.2	4.6	2.30	4.72	2.9
98-90	Bss2	70.4	8.82	0.42	1.9	4.0	6.4	0.19	9.7	5.8	2.10	5.28	3.8
91-115	Bss3	77.6	8.84	0.51	1.7	4.2	6.8	0.17	10.2	4.0	1.80	5.61	4.3
116-130	Bss4	78.2	8.49	0.55	1.4	4.0	6.2	0.12	9.9	4.2	1.20	5.34	4.5
Pedon -6 (Village – Ugwa) Typic Haplusterts													
0-16	Ap	72.4	8.40	0.84	2.1	4.7	5.4	0.29	7.7	4.0	2.16	4.15	1.1
17-40	Bw	77.6	8.67	0.94	2.1	4.9	5.5	0.24	7.4	4.4	1.91	4.16	0.4
41-65	Bss1	74.2	8.69	0.99	2.0	4.9	4.4	0.21	8.9	4.4	1.41	3.35	2.0
66-90	Bss2	78.2	8.63	0.97	1.8	5.0	4.9	0.19	8.4	3.7	1.41	3.76	1.6
91-120	Bss3	79.6	8.55	1.01	1.6	5.1	6.2	0.17	8.2	3.8	1.24	4.80	1.8
121-150	Bss4	74.5	8.34	1.04	1.2	4.4	6.6	0.14	9.2	2.9	1.81	5.64	3.6
151-180	Bss5	78.5	8.44	1.15	1.1	4.4	6.9	0.12	8.4	2.1	1.26	5.89	2.9
Pedon -7 (Village – Naved) Typic Haplusterts													
0-16	Ap	69.4	7.99	0.67	2.4	3.0	14.9	0.32	10.7	4.8	6.62	12.41	4.9
17-42	Bss1	68.7	8.26	0.89	3.0	4.9	6.2	0.34	10.9	4.8	6.54	4.42	3.0
43-67	Bss2	72.4	8.31	0.94	2.0	5.0	7.4	0.31	9.4	3.2	5.72	5.6.0	2.4
68-97	Bss3	74.6	8.24	1.01	2.5	5.4	12.2	0.24	8.6	3.5	5.28	8.71	0.7
98-121	Bss4	75.4	7.02	1.24	2.2	5.2	12.4	0.24	9.4	3.8	4.49	7.25	3.0
122-141	Bw1	77.4	7.44	1.44	1.9	5.8	10.2	0.14	9.9	3.8	4.94	7.39	2.2
142-160	Bw2	78.9	8.94	1.49	1.2	5.8	9.4	0.12	8.4	3.1	3.21	7.70	1.4
Pedon -8 (Village – Kholapur)) Vertic Haplustepts													
0-16	Ap	74.2	8.54	0.91	2.8	3.4	6.03	0.19	6.81	5.1	3.6	4.27	0.4
17-45	Bw1	75.8	8.59	0.91	2.0	3.2	6.05	0.21	6.91	5.6	3.22	5.81	1.7
46-65	Bw2	74.6	8.44	0.88	1.4	3.6	6.82	0.14	6.99	6.6	2.22	5.28	1.9
66-84	Bw3	78.9	8.49	1.01	1.2	5.8	7.74	0.14	7.49	6.8	2.36	5.68	0.4
85-100	Bw4	74.6	8.59	1.09	1.2	5.7	7.08	0.18	8.44	7.0	3.41	4.14	1.5
101-120	Bw5	78.4	8.48	1.08	1.1	5.4	8.63	0.16	9.21	7.4	3.49	5.16	3.1
121-150	Bw6	79.2	8.54	1.21	1.1	6.7	8.94	0.15	9.26	7.9	3.66	6.12	1.3

clay more than 30 per cent and slickensides (>25 cm thick zone) underlain by cambic horizon qualify for order Vertisol and meet the requirement for the subgroup Typic Haplustert with very fine textural class. On the other hand the soils are very deep (>140 cm), possessing cracks, quite high amount of clay (>30 per cent) but absence of slickenside zone in pedon 8 possess ochric epipedon underlain by cambic subsurface diagnostic horizon and hence, these soils have been grouped into order Inceptisols. In view of ustic moisture regime for the region, the pedon qualify for Ustept suborder. However, since the soils possess cracks with high amount of swelling clay and high COLE values showing vertic properties but absence of slickensides qualify this soils as Vertic subgroup and therefore they qualify as Vertic Haplustepts.

The reduction in mean weight diameter and hydraulic conductivity observed in the sub soil concomitant with increasing ESP justifies the cause of degradation of these soils and it also further becomes apparent that these adverse degradative process occurs in these soils at much lower ESP values than 15. This indicates that these soils need to be classified based on measurable physical properties like hydraulic conductivity and the ESP level used for categorizing sodic soils should be brought down.

Conclusions

From the present study it can be concluded that the soils developed in lower topographical conditions in the valley under semi-arid climate with high amount of swelling clay possess low hydraulic conductivity and thus are prone to degradation as sub soil sodicity resulting into deterioration of soil structure and impairment of drainage associated with the problems like increased pH in subsoil. Despite low level of sodicity, the soils showed severe drainage problems because of low hydraulic conductivity. The bicarbonates precipitated in subsoil indicated operative alkalinisation under semi-arid conditions. The subsoil sodicity also leads to downward decrease in mean weight diameter. The soils showed poor internal drainage even at the ESP values much lower than 15.

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Growth and fruit characteristics of edible cactus (*Opuntia ficus-indica*) under salt stress environment

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ABSTRACT

The advancing desertification coupled with increasing problems of salinity and drought warrants the development of appropriate technologies and identification of the crops capable of sustaining valuable food and fodder production in arid and semi-arid areas. Edible cactus (*Opuntia ficus-indica*) can provide a large range of commodities in the areas with scarce and degraded available resources. Thus, it has raised renewed interest and hope to attain potential productivity in the stressed areas. A sizeable part of India is affected by salt and drought conditions, thus, potentially suitable for cultivation of edible cactus to generate alternate source of livelihood and employment. There is a need to generate information on its critical limits of salinity tolerance and ability to mitigate the salt stress in these areas. A pot experiment was conducted at Central Soil Salinity Research Institute, Karnal during 2008-2011. Clone 1280 was grown using two quality irrigation waters in combination with three soil salinity levels. The observations on growth suggests that the plant is moderately tolerant to soil salinity and most of the growth parameters, viz., number of sprouts, plant height and number of cladodes started declining at 6 dS m^{-1} soil salinity. No significant adverse effect of saline water irrigation was found on survival of cactus at EC_{iw} 4 dSm^{-1} except reduction in the number of sprouts produced. The above ground parts of biomass production were found sensitive at EC_e 6 dSm^{-1} soil salinity, while root biomass production was more sensitive to saline water irrigation rather than soil salinity. Finally, fruit quality characteristic of promising edible cactus clones and their potential of acceptability as a palatable fruit among general public was evaluated.

Key words: edible cactus, *Opuntia ficus-indica*, clone, salinity, irrigation water, fruit characteristics

Introduction

Cactus (*Opuntia ficus-indica*) has been commercially exploited as fruit, vegetable, forage, energy, medicinal and dye yielding crop in arid and semi-arid areas of world. The countries where cactus is commonly cultivated are Mexico, Brazil, Argentina, South Africa, Israel, USA, Italy and many other Latin American countries. Cactus was identified as a potential crop for arid and semi-arid regions of world (Lahsasni *et al*., 2003). The cultivation of cactus as a commercial crop is little known in Indian sub-continent. Only the wild cactus is found growing in wastelands, as hedge around agricultural fields to protect crops from wild life and as a decorative plant in parks and home gardens. Cactus is used for several purposes but the most significant uses include: as a fruit and vegetable for human consumption (Snyman, 2004), forage for livestock and as a red dye. Several other minor uses of cactus are: control of diabetes, ethanol production, as live fence and for industrial use of its *galactomannan* mucilage and cosmetics such as shampoo, cream, and body lotions, etc. (Felker *et al*., 1997; Feugang *et al*., 2006; Singh, 2006). Owing to its high water use efficiency per unit dry matter production, because of crassulacean acid metabolism (CAM), photosynthetic pathway, the plant has ample scope of its introduction and cultivation in rain-fed and dry land areas of India, where 67 per cent of the poor rural population is settled. Cactus has special significance in drought prone area of the country where cactus plantation will help in augmenting food and fodder requirement and thus halting migration of cattle and human beings to other areas. Planting of trees and bushes like cactus on all kinds of wastelands, on field boundaries, road and railway track sides etc. in all drought prone and salt-affected areas of the country has tremendous potential to generate livelihood opportunities in resource poor conditions. The low cost of cactus establishment and production as well as its tolerance to drought make it well suited to become a viable future industry in rain-fed areas. In addition to its remarkable value as cattle and human food, it has a potential for soil and water conservation when planted on slopes in the hilly terrace in the rain-fed areas of the country.

Plenty of literature available on physiology of *Opuntia ficus-indica* and its response to the environment, points towards its increasing economic importance for fruit, fodder and industries (Nobel and Zutta, 2008; Felker *et al.*, 2005; Galizzi *et al.*, 2004; Felker and Inglese, 2003; Anderson, 2001; Inglese *et al.*, 1995). Being drought tolerant prickly pears are suited to those areas, where rainfall is scarce and unreliable, and irrigation water is limited which causes upward thrust of salts of these soils in most parts of the year. Due to the limitation of the feed resource as a result of rangeland degradation, there is more concern for cactus pear, which has ability to produce satisfactory amounts of fruits and fodder under the prevailing stress conditions (Felker and Inglese, 2003). The optimum conditions for its growth are available in summer rainfall regions having average rainfall between 300-600 mm. Hot sunny days and cool dry winter where temperature do not fall below 5^{o} C are most suitable for cactus production. Cactus thrives best on sandy and sandy loam soils. However, it does well even on heavy soils with adequate drainage. Gravelly or stony lands especially at the foot hill slopes are also suitable. Further, it thrives well on slightly alkaline soils rich in calcium and potassium. This indicates that any soil which is not suitable for other crops can be planted to cactus provided that area is not subject to prolonged waterlogging. A large part of India is, thus, suitable for its cultivation to generate alternate source of livelihood and employment. There are more than 150 districts in India which are highly drought prone; this crop has tremendous potential to augment forage production in those areas.

In arid and semi-arid regions, aridity is also associated with soil and ground water salinity. There are only few studies describing adaptations of *Opuntia* to water scarcity and its responses to salinity are not well quantified (Murillo-Amador *et al.*, 2001; Pimienta-Barrios *et al.*, 2002). Establishment of cactus pear under salt affected arid conditions is very critical for its survival, growth and development. In general, cactus pear is found growing under resource scarce conditions. So to realize the full potential of cactus pear in arid zones, there is a need to generate information on its critical limits of salinity tolerance and ability to mitigate the salt stress.

Materials and methods

A pot experiment was conducted at Central Soil Salinity Research Institute, Karnal, situated at 29^{o}42' N latitude and 76^{o}57' E longitude and an altitude of 243 meter above mean sea level. Annual rainfall was 68, 48 and 110 cm for the year 2008, 2009 and 2010, respectively. Clone 1280 (fruit) was planted in 30 kg capacity ceramic pots for studying the critical limits of soil and irrigation water salinity. The pots were uniformly filled with sandy loam soil (pH 7.8, organic matter 2.8 g kg^{-1} soil, clay 14%) having three salinity levels viz; normal (EC_e 0.6 dS m^{-1}), EC_e ~ 4 & 6 dS m^{-1}. The pots were maintained by mixing required quantity of three salts i.e. NaCl, $MgSO_4.7H_2O$ and $CaCl_2.2H_2O$ in the ratio of 30: 2: 4 on the soil weight basis giving three wetting and drying cycles and were adjusted to required salinity. Two quality irrigation waters EC_e ~ 2 & 4 dS m^{-1} salinity were applied. The experiment was laid out in split plot design with three replications. The plants were uniformly supplied with N, P and K dose (at the rate of 100, 50 and 100 kg ha^{-1}, respectively in addition to 10 t ha^{-1} FYM. The NPK were supplied through di-ammonium phosphate, urea and muriate of potash. Observations were recorded on survival at the beginning, number of new sprouts, plant height (cm) and numbers of cladodes for each plant were recorded at six months interval for three years and final plant height, number of cladodes and fresh biomass of shoot and root were recorded in 2012 after five years of planting by destructive sampling. For observing fruit characteristics, ripen fruits were harvested from four promising clones (1270, 1271, 1280 and 1287) and their length, diameter, weight, moisture (%), TSS (^{o}B) and phosphorus nitrogen (p/n %) ratio were measured. The ripe fruits of these clones were given to 527 persons in years 2008, 2009 and 2010 for taste analysis based upon taste and sweetness. Each individual varying in age from 28 to 50 years was asked to give a score on a 0 to 10 scale. The data presented are either average of three years (Fig.1) or after five years of planting (Fig. 2). Analysis of variance at 95% confidence interval was applied to each data set to assess the effects of treatments on all recorded parameters. Each variable was analysed statistically by 'two way ANOVA' using Genstat release 13 (GenStat® 13th Edition, VSN International Ltd., Lawes Agricultural Trust, Rothamsted, UK) statistical software. To determine critical differences, Fisher's protected least significant difference test was used. The method of Fisher (1949) was used in order to determine the least significant difference (*lsd*).

Results and discussion

Establishment and growth

Results of three years of experimentation showed that cactus clone 1280 had better (although not significant) survival of 84 % (average) when irrigated with water of 2 dS m^{-1} salinity as compared to 81% survival under 4 dS m^{-1} salinity irrigation water (Fig.1A). This slight reduction in survival percentage was also observed in plants grown in soil of EC_e 4 dS m^{-1} salinity (82%) and (79%) in 6 dS m^{-1} soil salinity as compared to normal (0.6 dS m^{-1}) soil (86%). Perusal of data presented in Figure1A showed reduction of survival (%) in various levels of soil and water salinity (data presented are average of three years). The average number of new sprouts emerged at six monthly interval were reduced significantly in various treatments of water quality (p= 0.002) and soil salinity (p =0.001) (Fig.1B). On an average 1.08 new sprouts were emerged in every six months in 2 dS m^{-1} salinity water irrigation treatment, that was significantly higher (*lsd* 0.21) than 4

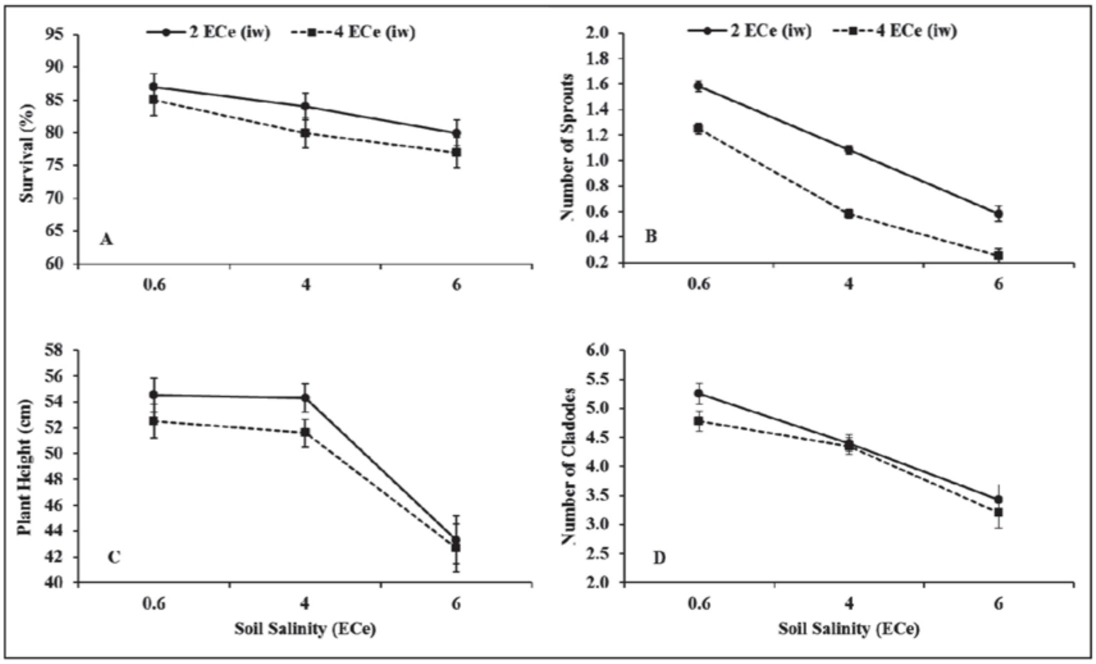

Fig. 1. Effect of soil salinity (EC_e~ 0.6, 4.0 and 6.0 dS m^{-1}) and water quality (EC_{iw}~ 2.0 and 4.0 dS m^{-1}) on (A) Survival (%), (B) Number of sprouts, at beginning and (C) Plant height, (D) Number of cladodes of *Opuntia ficus-indica*, after three years of growth under The vertical bars are standard error of means (SEm±) of respective mean values.

dS m^{-1} water quality treatments. Among different soil salinity treatments, the highest numbers of sprouts (1.42) emerged in normal soils (0.6 dS m^{-1}) and sprouts emergence was significantly (*lsd* 0.26) reduced in 4 dS m^{-1}, (0.83) and further in 6 dS m^{-1} soil salinity (0.42) (Fig.1B).

Plant height was reduced significantly (p=0.007) with increase in soil salinity (EC_e) from normal (0.6 dS m^{-1}) to 4.0 dS m^{-1} and then to 6.0 dS m^{-1} though this reduction was not significant (p=0.802) in case of saline water treatments (Fig.1C). The average plant height in 2 and 4 dS m^{-1} salinity waters were 50.7 cm and 49.9 cm, respectively (*lsd* 6.18). There was a reduction in plant height from 54.4 cm to 53.5 cm in soil salinity ECe 4 dS m^{-1} as compared to normal (0.6 dS m^{-1}) and there was a significant (*lsd* 7.57) reduction to 43 cm in 6.0 dS m^{-1} soil salinity treatment (Fig.1C).

Again, the three years average of number of cladodes produced every six months were reduced significantly (p=0.008) with the increase in soil salinity and a non-significant (p=0.549) reduction when irrigation water salinity increased from 2.0 dS m^{-1} to 4.0 dS m^{-1} (Fig.1D). The number of cladodes produced was reduced from 5.02 in normal (0.6 dS m^{-1}) to 4.38 in 4.0 dS m^{-1} and further to 3.32 in 6.0 dS m^{-1} soil salinity (*lsd* 1.03). The reduction in number of cladodes was from 4.36 to 4.11(*lsd* 0.84) in 2.0 and 4.0 dS m^{-1} salinity irrigation water (Fig.1D).

Opuntia species are reported to be tolerant to water stress but sensitive to high salinity (Nerd *et al*., 1991; Murillo-Amador *et al*., 2001). However, plant responses to salinity may differ with genotype and several authors reported the ability of the species to survive and grow in saline environments (Maas and Grattan, 1999). In the present study the survival of cactus clone did not reduce drastically up to 6.0 dS m^{-1} soil salinity and 4.0 dS m^{-1} of water salinity. The higher survival rate of prickly pear in moderate salinity proved its ability to proliferate in saline conditions. According to Nerd *et al*. (1991), salinity did not play a significant role in fruit yield and plant height. Nobel *et al.,* (1984) reported the survival of *C. validus* on temporarily highly saline soils. In present study plant height, number of sprouts, and cladodes reduced significantly in 6 dS m^{-1} of soil salinity, whereas, irrigation water salinity up to 4.0 dS m^{-1} had no adverse significant effect on these parameters except number of sprouts emerged which reduced significantly with the application of saline water after three years of growth (Fig.1). Decrease in plant height of clone 1280 might have resulted from the excessive accumulation of salts in cladodes to toxic levels. Inward ion retention through the selective ion transport across the roots, and the special possibilities of carbon budgeting as a result of CAM (Nobel *et al.,* 1984) would be the possible reasons for cactus to be a productive crop on moderately saline soils. The salt build-up in soil at 6.0 dS m^{-1} of salinity affected plant processes adversely through osmotic effects and ionic imbalances; however, those could be offset by adequate supply of nutrients.

Growth and biomass (after five years)

After five years, the plants under various treatments were differed in plant height. Plant height was reduced (although not significantly; p=0.293) with increase in water salinity from 2 to 4 dS m^{-1} and there was a significant (p=0.037) reduction when soil salinity increased (EC_e) from normal (0.6 dS m^{-1}) to 6.0 dSm^{-1}, although treatment with 4.0 dS m^{-1} soil salinity was at par with normal soil treatment (Fig. 2A). The average plant heights in 2 and 4 dS m^{-1} water were 96.8 cm and 92.9 cm, respectively (*lsd* 7.48). There was a reduction in plant height from 100.7cm in normal (0.6 dS m^{-1}) to 95.5cm in 4.0 dS m^{-1} soil salinity, however, reduction in plant height to 88.5 cm reached significant (*lsd* 9.17) levels in 6.0 dS m^{-1} soil salinity treatment (Fig. 2A).The number of cladodes produced after five years were reduced with the increase in soil salinity and also when irrigation water salinity increased from 2.0 to 4.0 dS m^{-1} (Fig. 2B), although, this reduction was statistically not significant (p=0.09 and 0.368, respectively). The number of cladodes produced was reduced from 13 in normal (0.6 dS m^{-1}) to 12.5 in 4.0 dS m^{-1} and further to 10.96 in 6.0 dS m^{-1} soil salinity (*lsd* 1.90) levels. The reduction in number of cladodes in 2.0 dS m^{-1} and 4.0 dS m^{-1} salinity water irrigation was from 12.5 to 11.81 (*lsd* 1.55) (Fig. 2B) which is statistically non significant.

Fresh above ground biomass was reduced significantly with increased soil salinity (p=0.001), but this reduction was not significant (p=0.356) for saline water irrigation treatments (Fig. 2C). The highest shoot biomass (5.05 kg) was produced with normal salinity (0.6 dS m^{-1}), significantly reduced to 4.15 kg in EC_e 4.0 dS m^{-1} and further to 3.69 kg in EC_e 6.0 dS m^{-1} soil salinity (*lsd* 0.69). The reduction in fresh shoot biomass in EC_e 4.0 dS m^{-1} salinity water irrigation was from 4.42 (in ECe 2.0 dS m^{-1}) to 4.17 kg (*lsd* 0.56) (Fig. 2C). The reduction in fresh root biomass was not significant (p=0.152) in various soil salinity treatments, but significant (p=0.032) in saline water irrigation treatments (Fig. 2D). The root biomasses produced in normal (0.6 dS m^{-1}), EC_e 4.0 and 6.0 dS m^{-1} soil salinity treatments were 0.58, 0.52 and 0.49 kg, respectively (*lsd* 0.097). There was a significant reduction (*lsd* 0.079) in root biomass (0.58 kg) at EC_{iw} 2.0 dS m^{-1} to biomass (0.49 kg) at 4.0 dS m^{-1} salinity of irrigation water.

The plant height and number of cladodes reduced significantly in 6 dS m^{-1} of salinity, whereas, irrigation water salinity up to 4.0 dS m^{-1} had no significant effect after five years of growth (Fig.2A,B). The possible reasons and processes of this discussed in earlier section (establishment and growth) also explain for the reduction in plant growth after five years. Acclimation of cell sensitivity to salinity, a key short-term strategy for ecological survival of plant and a crucial feature for deciding where cacti can be successfully cultivated, was similar for stems and roots (Nobel and Zutta, 2008). The accumulation process involves many factors (Chetti and Nobel, 1987; Thomashow, 1999). For example, the total fresh biomass accumulation was a function of number of sprouts emerged, plant height gained and number of cladodes produced as interactive response of these parameters in different salinity treatments in the study (Fig. 2C).The total biomass accumulation is related to the cladode surface area (Garcia de Cortazar and Nobel, 1992).The lower above ground biomass accumulation

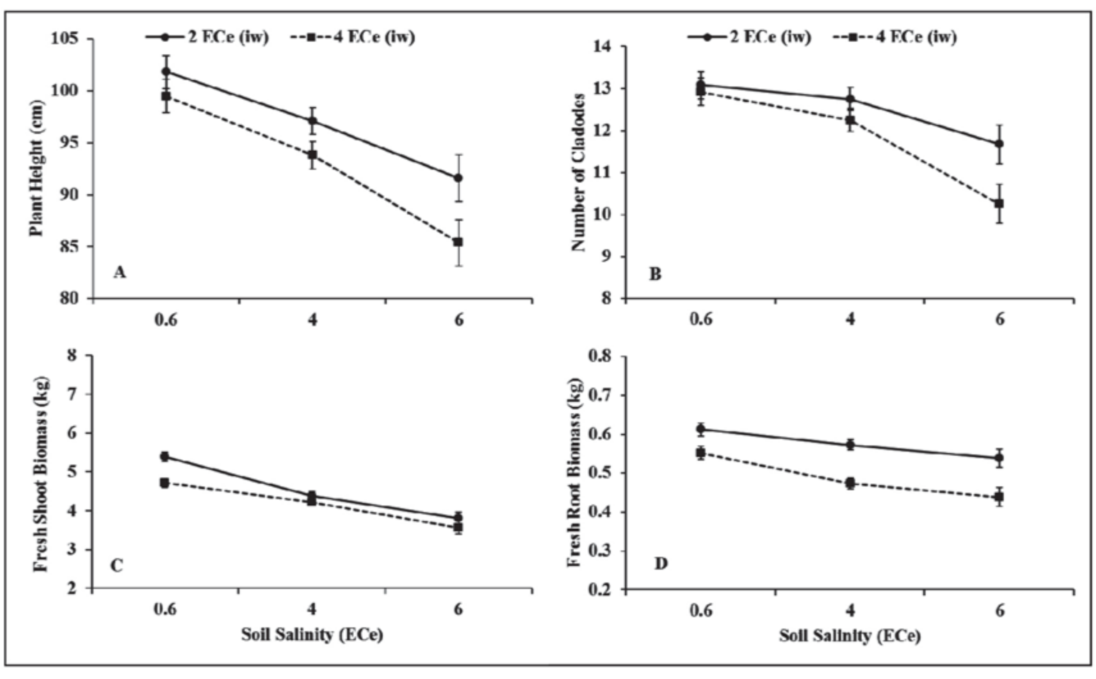

Fig. 2. Effect of soil salinity (ECe~ 0.6, 4.0 and 6.0 dS m^{-1}) and water quality (ECiw~ 2.0 and 4.0 dS m^{-1}) on (A) plant height, (B) number of cladodes, (C) fresh shoot biomass and, (D) fresh root biomass of *Opuntia ficus-indica*, after five years of growth. The vertical bars are standard error of means (SEm±) of respective mean values.

with the increase in salinity in this study could be ascribed to a strategy of *Opuntia* that favours survival rather than vegetative growth and, therefore, makes it more adaptable to adverse conditions. *Opuntia* is a drought tolerant crop, since even the smallest amount of water it absorbs is used efficiently (Snyman, 2004). It is able to do this due to its relatively shallow and horizontally spread root system and the ability, when other crops are not able to withdraw water from the soil at a very low moisture stage (Singh and Singh, 2003; Snyman, 2004). The root system differs from that of other plants as they develop xeromorphic characteristics which enable the plant to survive prolonged periods of drought (Sudzuki, 1995). This could also be the reason of higher sensitivity of roots to irrigation water salinity rather than soil salinity in contrary to the above ground parts (Fig. 2D).

Fruit characteristics

Length, diameter, weight, moisture (%), TSS (°B) and p/n (%) of fruit collected from four promising clones (1270, 1271, 1280 and 1287) were determined and presented in Table 1. It was observed that clone 1287 produced bigger fruits and, as such, higher fruit yield followed by 1271. Clone 1280 had more moisture content (91.39%) and hence more juicy than other types but lower in brix TSS (3°B) and hence low in sweetness. The lower moisture content in clones 1270, 1271 and 1287 provides tough texture to the fruits, hence better transportability. The brix TSS that is a measure of sweetness was higher in clone 1270 followed by 1271 (11°B and 10°B, respectively). The p/n ratio is also an important parameter to determine the taste of fruit and was higher in the latter two clones (Table 1.).

Fruit quality has rarely been investigated in relation to environment. The wide variability in yield most probably depends on orchard design and management, however, cultivar behavior in terms of plant fertility and productivity needs to be investigated in comparative trials, under different environmental conditions. Fruit size depends on seed number, cladode load, water availability, and ripening time (Nerd *et al.*, 1991; Inglese *et al.*, 1995). The sugar content plays a decisive role in defining fruit quality, since consumers favor sweet fruits. Sugars, mainly glucose and fructose, accumulate faster during the final weeks of flesh development and it is generally recognized that optimum total soluble solids (TSS) values at harvest should range between 13-15% (Barbera *et al.*, 1992).

Rating of cactus fruit

The ripe fruits of these clones were provided to a total of 527 persons for palatability analysis based upon their taste and sweetness. The taste evaluation group comprised doctors, scientists, advocates, students, technicians, and farmers. Individuals, varying in age from 28 to 50 years, were asked to give a score on a 0 to 10 scale. In 2008, total 115 persons rated the fruits and 18% of them gave a score of 8, or more; whereas 7% people did not like the taste and gave a score less than 5. In year 2009, total 169 persons rated the fruit and 19% rated it more than 8. Again in 2010, 16% people (243 respondents) rated the fruits above 8. The persons rated fruit less than 5 were 9 and 12% in 2009 and 2010, respectively. Majority of the people *i.e* 75% in 2008, 72% each in 2009 and 2010 rated the fruits between 5 to 8 (Table 2). Most of the people suggested improving it further for seedless character and more sweetness.

Table1. Fruit characteristics of different cactus clones planted at CSSRI, Karnal

Clone	Length (cm)	Diameter (cm)	Weight (gm/fruit)	Moisture (%)	TSS (°B)	p/n (%)
1270	6.5	3.6	54.5	84.08	11	4.31
1271	6.8	3.7	62.5	83.74	10	4.46
1280	6.8	3.2	49.0	91.39	3	3.42
1287	8.2	3.8	81.2	83.78	8	3.70
Mean	7.1	3.6	61.8	85.75	8	3.97

Table 2. Rating of cactus fruit based on sweetness and taste on a 0 to 10 scale by 527 respondents

Year (Respondents)	2008 (115)			2009 (169)			2010 (243)		
Scale	<5	5- 8	>8	<5	5-8	>8	<5	5-8	>8
Taste	3	90	22	14	117	38	13	188	42
Sweetness	4	88	23	6	122	41	17	181	45
Flavor	9	84	22	10	120	39	32	174	37
Ease in eating	13	76	26	26	131	12	34	169	40
Ease in handling	13	94	8	18	121	30	49	162	32
Per cent	7	75	18	9	72	19	12	72	16

Many species of *Opuntia* have been naturalized world-wide since the 15th century and are common in the subsistence agriculture of many communities in dry land areas. However, fruit consumption is still limited to local or ethnic markets, and cactus pear still has to go far before it becomes a major fruit crop world-wide (Inglese *et al*., 1995). Presence of thick, hard seeds in the flesh and spines on outer covering are the major constraints limiting the consumption of cactus pears.

Conclusion

Once established in salt-affected area with underlying poor quality water the edible cactus has potential to yield fodder and fruit. The plant is moderately tolerant to soil salinity and most of the growth parameters viz., number of sprouts, plant height and number of cladodes start showing sensitivity at or above EC_e 6.0 dS m^{-1} soil salinity. No significant effect of saline water irrigation found up to 4.0 dS m^{-1} (EC_{iw}) except the significant reduction in number of sprouts produced. The above ground biomass production was found sensitive to soil salinity level of 6 dS m^{-1}, while root biomass production was more sensitive to saline water irrigation rather than soil salinity. Finally, cactus can be given importance as a potential crop in dry regions as an alternative fruit crop and identifying salt tolerant clones (such as prickly pear cactus) might help in evolving suitable plant/variety for utilizing saline water for higher fruit production; fortunately these are also of medicinal value and need less measures of protection. For that fruit quality characteristic of promising edible cactus clones and their potential of acceptability as a palatable fruit among general public found very encouraging.

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