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Field-scale modeling of salt and water balance and crop yields with conjunctive use of different quality waters

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ABSTRACT

Unscientific over-irrigation and poor water management in absence of adequate drainage with quest for boosting crop production has caused tremendous disturbance in hydrologic equilibrium with recharge component far exceeding the discharge component and resulting in marked rise in water table. Extensive fertile areas in many irrigated projects have been inflicted by the twin problem of water logging and soil salinity. Therefore, it is urgent need to reclaim the areas affected with these problems and make them to productive. Although subsurface drainage systems have been very effective measures to control soil salinity and water-logging, disposal of saline drainage effluent is a major constraint. Therefore, field experiment was conducted with different combinations of drainage water (DW, EC 4.1 to 6.6 dS m^{-1}), underground water (GW, EC 21.1 dS m^{-1}) and good quality canal water (CW, EC 0.23 dS m^{-1}) for three years. Results of this study indicated that yields of sorghum and wheat were not affected significantly under CW and conjunctive use of CW and DW. Soil profile salinity (0-30 cm) under these treatments was within permissible limit (EC_e < 4 to 5 dS m^{-1}) after harvest of wheat crop and it was concluded that reuse of DW alone or in cyclic use for irrigation is the most appropriate option for increasing crop productivity and also to maintain leaching of salts in the root zone. Over the years, modelling approaches have played an increasing important role in making agricultural and environmental policies and formulating measures to reduce the water logging and soil salinity in different parts of world. In recent years, increased emphasis has been put on validation of model used for that purpose. Therefore, objectives of this study were (i) to validate the SWAP model with data related to salinity build-up, water balance and grain yield of crops irrigated with different qualities of waters obtained from field experiments, and (ii)) to analyze long-term scenarios of salinization and crop yield with the calibrated model. Model parameters related to salt balance (change of water storage ΔW, change of salt storage ΔS, soil water flux at bottom profile Q_{bot} and their salt concentration C_{bot} , amount of water of drainage water and their salt concentration D_r and C_{Dr}) and water balance (actual and potential evapo-transpiration rate, actual and potential transpiration rate, precipitation and irrigation) and yield of wheat and sorghum were calibrated and validated by comparing model predictions with field data collected for 3 years. The results indicated that the simulated values of EC, water balance components were close to the observed data. Yield of sorghum and wheat appeared to be reasonably comparably to the field data. Outputs of the decision support system include a field and target-specific irrigation scheduling with different qualities of waters together with farm- and field based salts and water balance, comprising amount of salts both accumulation and leaching components of the system were discussed. The impact of each irrigation scenario on crop performance, and salinization/desalinization processes occurring in the soil profile (0-180 cm) was evaluated through water management response indicators (WMRI). Recommendations may be updated on a monthly/seasonal basis to take the account of deviations of weather conditions from the 10- year mean. Depending on existing management and site characteristics, simulated with SWAP for 20 years suggest that it is possible to maintain salt levels within permissible limit without sacrificing crop yield.

Key words: SWAP model, sorghum, wheat, water balance, conjunctive use, waterlogging, relative transpiration

Introduction

Irrigation in conjunction with increased fertilizer use and other improved agronomic practices has played a key role in exploiting the yield potential of high yielding crop cultivars and also in minimizing the ill effects weather adversities, thereby heralding green revolution in India. Irrigated lands in many countries are being extended to augment agricultural production for meeting the increasing demand of the fast growing population. This resulted in a tremendous increase in the irrigated areas from 149 million ha in 1950 (Arnold *et al.,* 1990) to 276.71 million ha in 2002 (FAO, 2005). It has been estimated that out of 60.2 million ha damaged by waterlogging and soil salinity in the irrigated land at the global level, 39.9 million ha (about 2/3 of the affected land) occurred only in five countries, namely India, China, USA, Pakistan and formerly USSR. The problems of excess amounts of salts and high water tables are more serious in the irrigated semi-arid and arid regions and these problems have most often been attributed to large-scale introduction of irrigation into areas hitherto unirrigated faulty on-farm water management and inadequate drainage measures. In the arid and semi-arid regions, where groundwater rises within about 2 m of the soil surface, groundwater contributes substantially to evaporation from the soil surface and water uptake by the plants. Evaporation from the soil surface and water uptake leaves the soluble salts in the profile, resulting in a gradual accumulation in the root zone such that, in course of time, the soil becomes salinized. In the initial years the crop yield may be only marginally reduced, but more serious affects may occur in the subsequent years and finally lands may have to be abandoned because salts render them completely unproductive.

India's annual net groundwater draft is 135 × 109 m^3. Out of this, 32 × 109 m^3 is estimated to consist of saline and/or sodic water (Minhas and Samra, 2003), which is about one-fourth of the total volume of groundwater used in the country. The use of marginal-quality groundwater resources without appropriate soil-, crop- and irrigation-management strategies poses considerable risks, in terms of the development of salinity, sodicity, ion-specific toxicity, and nutrient imbalances in soils (Sharma and Minhas, 2005). These conditions reduce crop productivity and limit the choice of crops that can be grown. However, options are available for the use of saline and sodic groundwater through the use of improved methods of water conservation, remediation, development, and application (Rhoades, 1999; Tyagi and Sharma, 2000; Qadir and Oster, 2004). Haryana is a semi-arid state in India, which covers an area of 44212 km^2 and has an annual rainfall, which varies from 500 to 1200 mm. The underground water is 37, 16 and 47 % of good, marginal and saline, respectively. The state faces the problem of water table rise in more than 2.8 million ha out of its 3.8 million ha arable land mainly in the central and north-western part of the state. The area under the influence of water table rise is largely in brackish and saline groundwater. In addition to the salts contributed by groundwater, canal water supply of about 1.05 million ha-m adds to the existing salinity problem substantially. Increasing pressure on land resources due to growing demand for food and food products require that areas affected with this problem is to reclaim and make them to productive. In most irrigated land in the semi-arid and arid areas in the country, artificial drainage is indispensable to overcome and avoid the problems of waterlogging and soil salinity. Although subsurface drainage systems have been very effective measures to control soil salinity and waterlogging, disposal of saline drainage effluent is a major constraint particularly in areas with poor quality groundwater and without any natural outlet. The disposal of drainage effluents in Haryana is socially and politically not feasible because the water is being used for human and animal consumption. Therefore, reuse of drainage effluent for irrigation is the most appropriate option for increasing crop productivity and also to maintain leaching of salts in the root zone. There are two major approaches that can be used to improve and sustain agricultural production in a salt-prone environment: (i) modifying the environment to suit the plant, and (ii) modifying the plant to suit the environment. Both approaches have been used, either singly or in combination (Tyagi and Sharma, 2000). However, the first approach has been used more extensively because it enables the plants to respond better not only to the water used but also to the other production inputs involved. These approaches provide socially and environmentally favourable levels of agricultural production, provided that the characteristics of the water and the soil, and the intended management and uses of the crops, are taken into consideration (Tyagi and Sharma, 2000; Qadir *et al.*, 2003; Oster and Birkle, 2004)

Using drainage water for irrigation is possible by adopting improved water management with due attention for proper leaching of salts and maintaining reasonable high yield levels of the crops. Therefore, field experiments were conducted at experimental farm Mundlana for three years to analyze the changes of soil moisture and salt concentration with conjunctive use of saline drainage and underground water with fresh canal water and to investigate the effect of conjunctive use of these waters on growth, yield and water use efficiency of crops in the sequence. The information generated from these experiments is site specific. To conduct or repeat such studies at different sites, regions and under various soil, crops and agro-climatic conditions is too expensive, laborious and time consuming. One effective way to reduce the number and duration of expensive field experiments is to simulate and validate the site-specific experimental results using a numerical simulation model. Therefore, the first objective of this study was to explore the possibility of applying the Soil Water Atmosphere Plant (SWAP) model to irrigated fields in semi-arid climate in India and (ii) to simulate and validate the SWAP model using the field experiments which were conducted in India under irrigated conditions, and (iii) to analyze and compare several irrigation scheduling scenarios from a production and environmental point of view.

Materials and methods

Model description

Feddes *et al.* (1978) developed the one-dimensional model SWATR to describe transient water flow in a heterogeneous soil-root system, which is affected by groundwater. This model was further developed by Belmans *et al*. (1983), Wesseling *et al*. (1991), Van den Broek *et al.* (1994) and Van Dam *et al*. (1997) and is now referred to as SWAP. The model aims to simulate accurately water flow, solute transport, heat flow and crop growth in the air-plant-soil environment at field scale level.

The upper boundary conditions of the system are determined by the potential evapotranspiration, irrigation and precipitation. Basic, daily meteorological data are used to calculate daily potential evapotranspiration following Penman-Monteith method (Smith, 1992). If basic meteorological data are not available, potential evapotranspiration or reference evapotranspiration can be used as input. Precipitation may be provided either at a daily basis or at actual intensities. Short term rainfall data allow the calculation of runoff and preferential flow.

Crop growth is simulated by the code WOFOST 6.0 (Spitters *et al*., 1989). The processes considered include rate of phenological development, interception of global radiation, CO_2 assimilation, biomass accumulation of leaves, stems, storage organs and roots, leaf decay and root extension. The assimilation rate is affected by water and/or salinity stress in the root zone. If simulation of crop growth is not needed, the user should prescribe leaf area index, crop height and rooting depth as function of development stage. The potential evapotranspiration rate is divided into potential transpiration rate and potential evaporation rate based on the actual leaf area index or crop cover. Reduction of the potential transpiration rate depends on the soil water pressure head (Feddes *et al.*, 1978) and the salinity concentration (Maas and Hoffman, 1977), as depicted in Fig. 1. Reduction of potential evaporation rate depends on the maximum soil water flux in the top soil and is calculated by an empirical function following Black *et al*. (1969) or Boesten and Stroosnijder (1986).

SWAP employs the Richards' equation for soil water movement in the soil matrix. A physical description rather than a parametric description of water flow is important as it allows the use of soil physical data bases and the simulation of all kind of management scenarios. In order to solve the Richards' equation, the soil hydraulic functions of each soil layer should be known. The soil hydraulic functions, expressing the relations between soil moisture content, pressure head and unsaturated hydraulic conductivity, are described by the Van Genuchten-Mualem analytical model (Van Genuchten, 1980). Options for the soil water lower boundary include soil water flux, groundwater height, soil water flux as function of groundwater height, free drainage and lysimeter with free drainage.

Regarding solutes, SWAP simulates convection, diffusion and dispersion, non-linear adsorption, first order decomposition and root uptake (Boesten and van der Linden, 1991). This permits the simulation of ordinary pesticide and salt transport, including the effect of salinity on crop growth. The program is written in FORTRAN 77 and may run on 486 or higher IBM compatible PC's. A graphical user interface facilitates Windows-based input of data and analysis of simulation results. SWAP theory is in more detail described by Van Dam *et al.* (1997) and the program use is documented by Kroes *et al*. (1999).

Field Experiments

Climate

The climate of the experimental area is semi-arid and the south-eastern current of the summer monsoon brings the much-needed rains from July to September. From October to June, the weather remains dry except a few showers received from the western depressions. The average annual rainfall amounts 740 mm and about 75 %

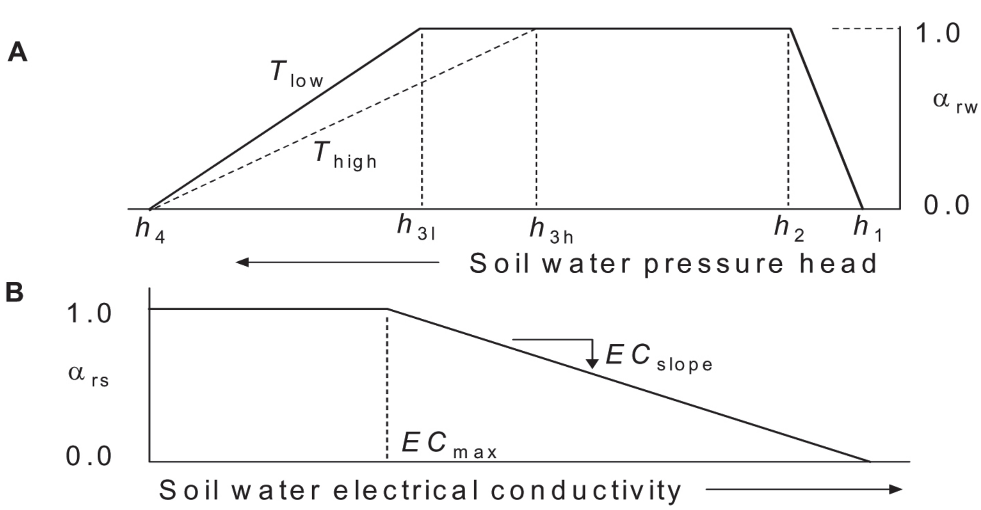

Fig. 1. (A) Reduction coefficient for root water uptake, α_{rw}, as function of soil water pressure head h and potential transpiration rate T_p (Feddes *et al.*, 1978); (B) Reduction coefficient for root water uptake, α_{rs}, as function of soil water electrical conductivity EC_{sw} (Maas and Hoffman, 1977).

Table 1. Soil texture, saturated hydraulic conductivity (K_s), saturation (q_s) and residual (q_r) soil moisture content of the experimental soil.

Soil Layers	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	K_s (cm/ d)
I	0-30	53.6	27.7	18.7	Sandy loam	0.515	0.011	48.7
II	30-75	32.6	41.8	25.6	Loam	0.432	0.010	60.0
III	75-215	21.2	51.6	27.2	Sandy clay loam	0.410	0.012	25.5

of rainfall occurs during July to September. This uneven distribution of rainfall is a major factor for irrigation demand to meet evapotranspiration of crops. The maximum air temperature is attained in the month of May and is about 41 °C. The minimum air temperature is recorded in the month of December or January reaching to 2°C. Pan-evaporation exceeds precipitation throughout the year except in the rainy months. Due to rise of water table during the rainy season, fresh rainwater does not cause an effective leaching of salts. This situation necessitates the provision of sub-surface drainage for control of water table and effective rainwater leaching.

Experimental site

The Mundlana experimental field has one drainage outlet, which serves nearly 180 km^2 area with a peak discharge capacity of 11.55 m^3/s during heavy rains; part of drain water enters the area and inundates the field to a depth of 0.1 to 1.0 m. The experimental area is flat with gentle slopes of 0.2 to 0.1 %. Even during the dry periods, the sub-surface drainage system has no natural out fall and hence a pumped outlet had to be provided.

Soil profile

Surface soils are sandy-loam in texture having about 53.6 % fine sand. The soil texture becomes gradually finer with depth (Table 1). The soil layers from 0.3 to 0.75 m are loamy in texture and below 0.75 m depth soil is sandy clay loam. The soil in the upper 2.5 m is highly compacted with bulk density value of 1.52 to 1.57 g cm^{-3} and in the lower layers the bulk density is about 1.45 g cm^{-3}.

Original soil salinity and water table

The initial soil salinity was high, with more than half of the area having EC_e > 50 dS m^{-1} in the surface layer (0-15 cm). The soil salinity gradually decreased in the rainy season at all depths and reduced to 25 and 10 dS m^{-1} in the 0-15 and 15-30 cm depths, respectively. The soil contains chiefly the chloride and suphate salts of Na, Ca and Mg. Due to predominance of sodium salt; the sodium absorption ratio of the soil solution is invariably high. Water table of Mundlana experimental farm reaches the ground surface during the monsoon season and recession to a depth of about 1.4 m in the surface during dry period. The rate of fall of water table corresponds to the average evaporation rate from January to May, in which period there was practically no recharge of groundwater. This indicates that the natural groundwater drainage of the area is negligible.

Drainage system

The system was laid out in an area of 7.93 ha in 1984. Three drains spacing of 50, 67 and 84 m were adopted with a length of 120 m on both sides of the centrally located collector drain. The average depth of laterals was kept at 1.75 m and the collector drain at 2.1 m with a longitudinal slope of 0.1 and 0.22 %, respectively. Perforated PVC pipes of 90 mm diameter for 67 and 84 m spacing and 75 mm diameter for 50 m drain spacing were used. The installation of the drainage system was done by manual labour. The rain water was used as the main component for leaching. During the first year, 403 mm rainfall occurred and the area was bunded to prevent the surface runoff. Besides rainfall, 23 cm water was applied from the canal. The ECe (dS m^{-1}) in the soil surface (0-10 cm) was reduced from 83 to 4.7, 39.4 to 4.15, 31.6 to 3.87, 20.0 to 3.76, 13.1 to 3.55 and 13.0 to 3.11 at 0-5, 5-15 and 15-30 and 30-90, 90-120 and 120-150 cm depths, respectively during first year of sub-surface drainage. The soil salinity five years after installation of the drainage system is given in Table 2.

Experimental techniques

The field experiment at Mundlana drainage area was initiated in 1990 for reuse of drainage water. Sorghum *(Sorghum bicolour)* during rainy season and wheat (*Triticum aestivum)* in winter season and experiment was conducted in the sequence from 1990 to 1993. Field trial was laid out in randomized block design with a plot size of 40 m^2 with four replications. The irrigation water treatments chosen were (i) continuous use of canal water (CW), (ii) continuous application of drainage water (DW), (iii) continuous use of ground water (GW), (iv) canal water alternation with drainage water, AD, (v) canal water alternation with underground water, AG. In each irrigation 7.5 cm of water was applied and measured with Parshall flume, and a presowing irrigation with 10 cm was given with canal water to both crops. The chemical composition of canal, ground and drainage water is given in Table 3.

Table 2. Soil characteristics before sowing of the crop after 5 years of instalation of drainage (June 1990).

Soil depth (cm)	pH	ECe (dS/m)	Na^+	$Ca^{2+}+Mg^{2+}$	$CO_3^{2-}+CO_3^-$ (m mol l^{-1})	Cl^-	SO_4^{2-}
0-15	7.2	1.91	8.3	11.1	2.71	12.5	5.23
15-30	7.2	2.15	10.1	12.1	2.91	13.1	4.76
30-45	7.3	2.21	11.4	12.7	2.75	14.8	4.71
45-60	7.3	2.25	11.8	13.1	2.85	16.2	4.43
60-90	7.2	2.41	11.9	13.2	2.55	19.6	4.34
90-120	7.2	2.68	12.2	14.1	2.54	21.8	5.02

Table 3. Chemical composition of canal, ground and drainage waters

Source of water	pH	ECe (dS/m)	Na^+	$Ca^{2+}+Mg^{2+}$	$CO_3^{2-}+CO_3^-$ (m mol l^{-1})	Cl^-	SO_4^{2-}
Canal	7.2	0.35	0.72	2.76	1.57	0.36	2.23
Ground water	8.3	21.1	271.7	113.4	11.1	162.0	169.1
DW 1990	7.9	6.4	47.5	33.2	2.82	39.2	29.46
DW 1991	7.8	5.5	37.5	25.8	2.31	34.7	28.8
DW 1992	7.8	4.3	25.9	18.4	2.17	24.2	21.12
DW 1993	7.8	4.1	22.1	12.1	2.15	22.2	20.45

DW for drainage water

Two irrigations were given to sorghum with canal and ground water according to treatment and ground water also applied in place of drainage water treatment because of low availability of drainage water during initial stage of sorghum crop. In sorghum crop, half of nitrogen (30 kg ha^{-1}) was applied at sowing and remaining half of nitrogen (30 kg ha^{-1}) as given at first irrigation. Sorghum was sown in row with 25 cm spacing. A uniform dose of 30 kg ha^{-1} P_2O_5 as single super phosphate and zinc as 10 kg ha^{-1} zinc sulphate was applied at sowing of sorghum. For wheat, one third of nitrogen (50 kg ha^{-1}) was applied at sowing and remaining two third (100 kg ha^{-1}) of nitrogen as given in two equal splits at 30 and 45 days after sowing. Wheat variety HD 2009 was sown in row with 25 cm spacing. A uniform dose of 60 kg ha^{-1} P_2O_5 as single super phosphate and zinc as 20 kg ha^{-1}zinc sulphate was applied at sowing of wheat. Grain and straw yield were recorded at air-dry basis.

Water management response indicators

The crop growth and yield is affected by availability of water and nutrients in the soil and by surrounding climatic conditions. Therefore, yield is the main indicator for evaluating the success of a certain water management practices. But solely the yield parameter fails in describing the functioning of an operational irrigation system and its long-term changes of waterlogging and soil salinazation. Evaluating of an irrigation technique should include the changes of salt and water storage in the root zone. Therefore, the efficient water management technique should compromise the following two aspects between plant and soil response indicators.

Plant system

1. Yield reduction (YD)

   $YD = Y_a / Y_p$

   in which

   Y_a = Actual yield of the particular treatment (kg ha^{-1}) and

   Y_p = Potential yield of canal irrigated treatment (kg ha^{-1}).

2. Relative transpiration (RT)

   $RT = \Sigma T_{act} / \Sigma T_{pot}$

   in which

   T_{act} = Actual transpiration rates of the particular treatment (cm) and

   T_{pot} = Potential transpiration rates of canal irrigated treatment (cm).

3. Relative evapotranspiration (RET)

   $RET = \Sigma ET_{act} / \Sigma ET_{pot}$

   in which

   ΣET_{act} = Actual Evapotranspiration rates of the particular treatment (cm) and

ΣET_{pot} = Potential Evapotranspiration rates of canal irrigated treatment (cm).

4. Transpiration efficiency (TE)

   $TE = \Sigma T_{act} / \Sigma (I\pi + P)$

   in which

   T_{act} = Actual transpiration rates (cm)

   $I\pi$ = Irrigation applied (cm) and

   P = Precipitation during the period (cm).

5. Evapotranspiration efficiency (ETE)

   $ETE = \Sigma ET_{act} / \Sigma (I\pi + P)$

   whereas ,

   ET_{act} = Actual evapotranspiration rates (cm)

   $I\pi$ = Irrigation applied (cm) and

   P = Precipitation during the period (cm).

Soil system

The soil water/salt storage changes for the entire vertical soil profile (0-205 cm in present case), Δ S and Δ W can be estimated by the following salt and water balance equations:

$\Delta W = P + I\pi + Q_{bot} - T_{act} - E_{act} - D_r$

$\Delta S = I\pi * C_{ir} + Q_{bot} * C_{bot} + D_r * C_{Dr}$

in which

Δ W = Change of water storage (cm)

Δ S = Change of salt storage (mg/cm^3)

Q_{bot} and C_{bot} = Soil water flux at bottom profile (cm) and their salt concentration (mg/cm^3)

D_r and C_{Dr} = Amount of water of drainage water (cm) and their salt concentration (mg/cm^3)

The change in moisture and salt storage for the specific soil depth (d_z) and for the specific time period (sowing to harvest) was computed as:

Moisture storage change, $\Delta W_z (cm) = (\theta_{zfin} - \theta_{zini}) * d_z$

Salt storage change, $\Delta S_z (mg/cm^3) = (S_{zfin} - S_{zini}) * d_z$

Whereas,

θ_{zfin} and Δ_{zini} are the final and initial water content in the profile (cm)

S_{zfin} and S_{zini} are the final and initial salt concentration in the profile (mg/cm^3)

Results and discussion

Grain yield

Forage yield of sorghum and grain yield of wheat deferred significantly at different modes of irrigation (Table 4). The reduction in yield of both crops with the application of GW alone or in cyclic modes associated with stunted growth and increased mortality of plants as results of a higher salt concentration in the root zone. Differences in yield of both crops due to use of drainage water alone or cyclic mode were not significant. The yield obtained of sorghum with canal water is considered to be the potential yield (100 %), the mean relative yield of sorghum with one post sowing irrigation with drainage water was reduced to 90.1, 89.7 and 98.2 %, respectively during 1990, 1991 and 1992. The yield reductions with ground water were 92.4, 87.3 and 89.5 % in respective years. Cyclic irrigation with canal and drainage water treatment, forage yield of sorghum was decreased from 100 to 94.6, 91.5 and 95.8 % in 1990, 1991 and 1992, respectively whereas yield decreased to 93.2, 90.3 and 95.0 % in respective years with alternative use of canal and ground water. Considering the yield obtained of wheat with the use of canal water throughout to be potential (100 %), the relative yield of wheat with underground water was reduced to 67.2, 56.8 and 47.4 % during 1990-91, 1991-92 and 1992-93, respectively. Similarly, yield was reduced for drainage water, to 94.9, 96.3 and 94.1 % in respective seasons. The yield reduction under cyclic mode was observed to 97.1, 94.7 and 93 % with AD and 89.1, 85.6 and 86.7 % under AG in 1990-91, 1991-92 and 1992-93, respectively. The yield reduction of wheat was greater than sorghum when crop was irrigated either with drainage water or ground water mainly due to sufficient amount of water available from

Table. 4. Sowing and harvest dates of crops and their yields.

Crops	Sowing date	Harvest date	Grain\ Forage yields (Mg ha^{-1})					
			CW	DW	GW	AD	AG	LSD (p = 0.05)
Sorghum	4-6-90	22-8-90	57.8	52.4	53.7	54.6	53.8	3.52
Wheat	8-11-90	17-4-91	4.81	4.57	3.10	4.43	4.32	0.21
Sorghum	5-6-91	18-8-91	49.9	46.2	44.2	45.7	45.1	1.84
Wheat	10-11-91	16-4-92	4.61	4.44	2.62	4.36	3.95	0.36
Sorghum	30-5-92	17-8-92	51.2	47.1	45.8	49.1	48.9	2.11
Wheat	12-11-92	19-4-93	4.74	4.48	2.25	4.71	4.10	0.29

rains for leaching of salts during growing seasons of sorghum crop.

Rhoades *et al.* (1989) have reported that substantial amounts of saline drainage water (EC = 4 dS m^{-1}) can be used with little yield reduction, whereas in India, saline waters of more than 6-7 dS m^{-1}) have been used for wheat production in light textured soils (Mondal and Sharma, 1979). A field survey of the Haryana farmers, who are using poor quality underground waters either for direct irrigation or after mixing it with canal water, showed that farmers apparently considered a yield reduction in the range 30 to 40 % as the upper limit above which irrigation with saline water is not economical attractive (Boumans *et al.*, 1988). Our results showed an average yield reduction of 10 to 14 % when the wheat crop is irrigated with underground water (EC = 21.1 dS m^{-1}) alternating with good quality canal water.

Soil salinity

The soil profile ECe at the time of sowing of sorghum (April 1990) ranged from 1.76 to 3.15 dS m^{-1}). The 455 mm rains received from June to September 1990 leached out the salts, which was accumulated during the sorghum-growing season. After the cessation of rains, soil salinity was less than 2 dS/m in all the treatments to a depth of 120 cm during the initial stage of wheat crop. Soil salinity after the harvest of wheat increased when crop was irrigated with high salinity underground water (EC = 21.1 dS m^{-1}). The ECe (dS m^{-1}) of the soil profile varied from 1.13 to 1.78, 3.45 to 4.27, 7.86 to 11.43, 3.11 to 3.81 and 3.71 to 5.17 with canal, drainage, ground water, alternative drainage and alternative ground water, respectively. Soil salinity increased (except canal water) to a depth of 120 cm but the largest increase was above a depth of 60 cm after harvest of wheat crop in 1991. Salinity of soil during second (1991-92) and also during third year (1992-93) followed the similar trends as the first year, but salt buildup below 15 cm soil profile was more when irrigations were given with ground water. Monsoon rainfall and pre-sowing irrigation of wheat during second and third years also leached most of the salts from the surface and sub-surface profiles. This downward leaching of salts reduced the salinity levels within the acceptable limits for good seed germination of both crops with underground water treatment. Leaching of soluble salts was brought about with sufficient rains during June to September in both the years and no extra water was applied for leaching of salts. Kijne (1996) reported that under monsoonal type climate in Pakistan, waters with salt concentrations as high as EC 12 dS m^{-1} could be used for growing salt-tolerant and moderately salt-tolerant crops on coarse-textured soils. But on fine-textured soils, waters with an EC of more than 2 dS m^{-1} often create salinity problems. In addition, the leaching requirements of soils increase with the salinity of the irrigation water and the sensitivity of the crop to salinity.

Model calibration and validation

The model (SWAP) calibration to the field observations is carried out for the agricultural year 1990-91 (one wheat and one sorghum crops including fallow period) using the experimental data on reuse of saline drainage and ground waters. The data required for Van Genuchten – Mualem parameters describing the water retention and unsaturated hydraulic conductivity characteristics are given in Table 5. A two-way approach is adopted to calculate the daily potential evapotranspiration. The first step is the calculation of reference evapotranspiration, using Penman-Monteith equation for wet and dry canopy with completely covering the soil and potential evaporation rate of wet, bare soil. The second step is to calculate evapotranspiration using crop coefficient that was developed by Tyagi and Sharma (1995). The reduction of water uptake by roots due to water and/or salinity stress was also considered in the model. The critical pressure head (h^3 h, Fig.1) was taken as –400 cm (wheat) and –325 cm (sorghum) for the higher evaporative demand of 5 cm d^{-1}. At low evaporative demand of 1 cm d^{-1}, the (h^3l) amounted –1500 cm for wheat and -2500 cm for sorghum. The data were kept constant for all the water quality treatments for the whole study period. At the bottom boundary, we prescribed the groundwater levels according to the measurements.

Table 5. Model input data for Van Genuchten – Mualem parameters describing the water retention and unsaturated hydraulic conductivity characteristics.

Soil layers	K_s (cm/d)	α (l/cm)	n (-)	K_{expo} (-)
I	48.7	0.0213	1.80	-0.400
II	60.0	0.0205	1.90	-1.000
III	25.5	0.182	1.952	-1.40

The soil and plant-water relationship necessary for SWAP model were calibrated for 1990-91, i.e. first year of the experiment from reuse of drainage, ground and canal waters and their alternative modes taking the first complete annual cycle of sorghum and wheat crops. The fallow period also included from last week of August to second week of November 1990. The various relevant crop characteristics for Karnal conditions refereed to calibration of the SWAP model are presented in Table 6. The maximum effective root length for the wheat and sorghum was taken as 130 and 150 cm, respectively. Estimated leaf area index of wheat exceeded 1.0 m^2m^{-2} at 7 weeks after sowing and it was reached a maximum of 4.4 m^2m^{-2} during 15 weeks after sowing and thereafter rapidly decreased due to leaf senescence. The leaf area index of sorghum up to 4th week was less than 1 m^2m^{-2} but it showed an increasing trends and peak values of 5.6 m^2m^{-2} was recorded at the time of forage harvest. The estimated crop coefficient (Kc) values of wheat measured by lysimeter experiment at Karnal by FAO radiation method during initial, crop development, reproductive and last stages, were 0.47, 1.36, 1.02 and 0.35, respectively and these values estimated by PanE methods were 0.75, 1.30, 1.16 and 0.33 in respective stages (Tyagi and Sharma, 1995). During the sorghum season, the estimated average stage wise Kc values differ markedly with FAO Kc values in the respective stage except the third stage (reproductive phase). Crop coefficient was in the range of 0.45 to 0.93 during the different stages. Study conducted at Karnal indicated that the EC_e threshold at which yield reduction starts for different stages ranged from 4.1 to 8.89 for sorghum and 3.06 to 4.73 for wheat (Minhas and Gupta, 1993). The EC_e slope for both the crops was set at 9.5 to 14.6 for sorghum and 9.3 to 13. 2 for wheat. In the present study, the initial pressure head of –145.4, -121.9, -101.12, -90.1 and –66.9 cm for 0-15, 15-30, 30-60, 60-90 and 90-120 cm, respectively were provided in each compartment, and initial solute concentrations of 3.17, 3.08, 2.76, 3.43 and 3.22 mg/ cm^3 at respective depths were defined.

The model predicted salt concentration did match closely with the field observed EC_e levels as shown in case of CW, GW, DW and cyclic mode of these waters in Fig. 2. The predicted values of soil ECe was closer to observed values when crop was irrigated with underground water than canal water (Fig.2). Probably the model simulates

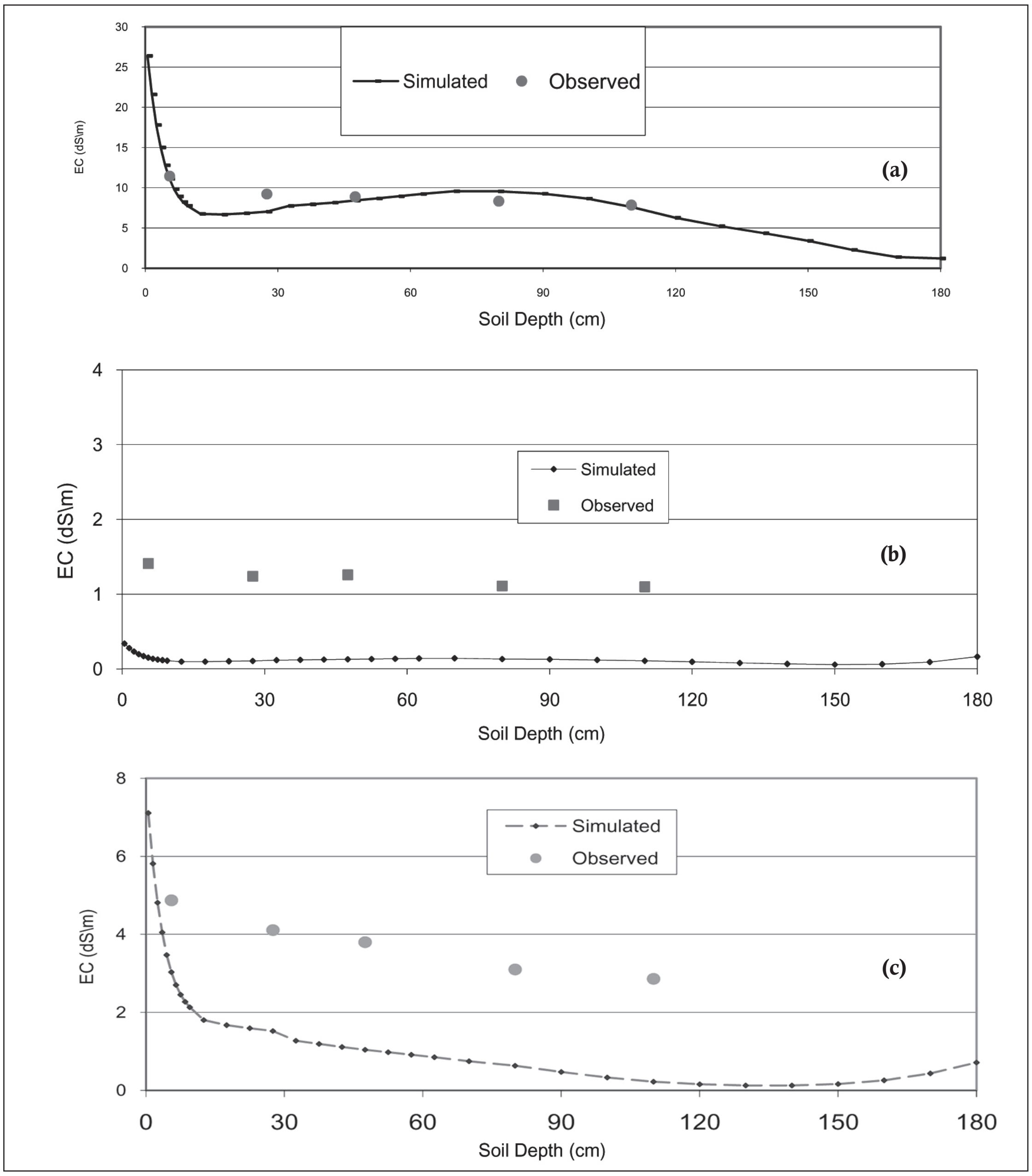

Fig. 2. SWAP simulated (lines) and measured (points) soil profile salinity (0-180 cm) under crop irrigated with (a) groundwater, (b) canal water and (c) drainage water.

Table 6. Ranges of plant characteristics of sorghum and wheat

Characteristics	Sorghum	Wheat
Duration (days)	77 - 79	155 - 158
Leaf area index (m^2/m^2)	0.05 - 5.6	0 - 4.4
Rooting depth (m)	0.5 - 1. 50	0.0 - 1.30
Yield response factor	0.9 - 1.0	0.9 - 1.0
Rooting density distribution	0.4 - 1.0	0.15 - 1.0
Crop factor	0 - 1.28	0 - 1.36
EC_e threshold (dS/m)	4.10 - 8.8	3.06 - 4.73
EC_e (EC slop) (dS/m)	9.5 - 14.6	9.3 - 13.2

more leaching of salts with uniform soil layers when EC_e is less than 2, compared to observe values. The SWAP model has been calibrated quite nicely and the simulated and measured crop yield data are in close matching. When both crops are irrigated with underground poor quality water, simulated yield reduced to 96 and 61 % for sorghum and wheat, respectively. Thus, the difference between field observed and estimated values by model was only 3.6 and 6.2 %, for respective crop.

The validation study between model prediction and field observations was done using the experimental data of 1991-93 (2nd and 3rd complete annual cycles starting from sorghum 1991 and ending of wheat 1992-93, 700 days period). The soil, water and plants parameters calibrated during the 1st year of the experiment of different qualities of waters were kept as such for validation study with SWAP model per the norms of calibration and validation procedure. The profile water salinity values, nicely validated with SWAP model, and could match very closely also during the validation period with the field observed values for ground water, drainage water and their alternative modes. The EC_e (dS m^{-1}) under canal water predicted by model is less than 1 while field observed salinity was slightly higher than 1.0. Finally, the average differences of the model predicted and field observed grain yields of both crops were very small, as shown in Fig. 3. The measured and simulated grain yield of sorghum differed only 2.7 to 4.3 t ha^{-1} (5.7 to 8.7 %) during 1991-92 and 1.3 to 3.0 t ha^{-1} (2.1 to 6.1 %) during 1992-93. Similarly, the small differences of wheat yield of 0.17 to 0.29 t ha^{-1} (3.7 to 6.4 %) during 1991-92 and 0.07 to 0.33 t ha^{-1} (1.6 to 7.0 %) in 1992-93 is further reflects the utility and power of the SWAP model and its excellent validation. Thus, the quite satisfactory agreement between the model simulation and field observation for various soil, water and crops parameters has provided the required confidence in using the successfully calibrated and validated SWAP simulation model for short term and long term (two decades or more) scenario analysis. Oster and Birkle (2004) provided information about the growth habits and reported that 70 % of yield of several forage crops were obtained when irrigated with a saline–sodic water (EC 10 dS m^{-1} and SAR 15).

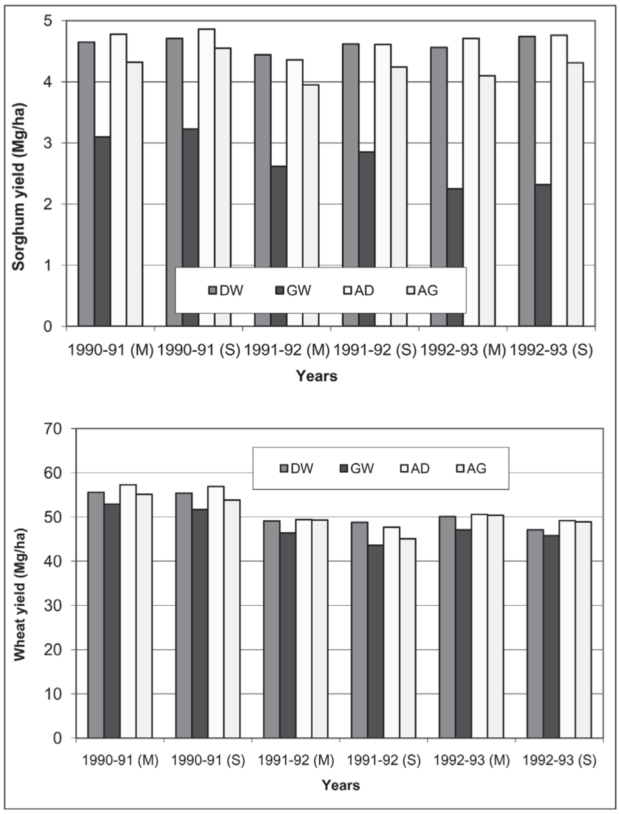

Fig. 3. SWAP simulated (S) and measured (M) yield of sorghum and wheat under different qualities of water.

Scenario study

Wherever water is scarce, ways need to be found for its best possible use. In this respect, one realm for exercising efficiency is recognized. The one form of efficiency applies to perform in accomplishing a specific goal without using more water than necessary; for example, in efficient irrigation the water is applied to crop production and to preserve the salt balance in the soil, which can minimize the nonproductive evaporation, deep percolation and other losses. On the short-term basis, the marginal impact of water management variables like quantity, quality and its application frequency is essential to achieve higher water application efficiency. Irrigation management scenario with similar results on the short term may have a different impact on soil salinity and crop production in the long term. Therefore, long-term impact of these scenario on environment degradation by SWAP model is very essential.

Short-term scenarios

The various short-term irrigation management scenarios are simulated and compared with the simulated results of a reference irrigation scenario, which is based on the results from the experiments, which were conducted during 1990-91 to 1991-92 at the Mundlana drainage area in Haryana (India) and presented in Table

7. The recommendations include a presowing irrigation with canal water (EC_{iw} = 0 .36 dS m^{-1}) to leach the salts during the initial stage of crop growth. This is essential because the evaporation during the months of May and June is about 10-12 mm/d, which causes salt accumulation in the surface layer, and also because sorghum crop is sensitive to salinity during germination stage. In the under irrigation scenario, two changes are made, first is the irrigation depth which is decreased from 60 cm to 48 cm (20 %) of the reference depth and second is a post sowing irrigation of inferior quality of ground water mixed with canal water (EC_{iw} = 10.7 dS m^{-1}) is given to sorghum and all irrigations with drainage water (EC_{iw} = 6.4 – 4.1 dS m^{-1}) are given to wheat crop. In the low irrigation frequency scenario, the number of irrigtaions are reduced, while the total amount of irrigation water is kept the same as that of under irrigation scenario.

The results of salts and water balance under different scenarios are given in Tables 8, 9 and 10. The initial salt storage in all the scenarios was set at around 142 mg / cm^3 to compare the obtained results. In case of reference scenario, the wheat crop is over-irrigated than sorghum crop, as indicated by higher salts storage changes during the wheat season (+ 24.2 and + 13.6 mg\cm^3) compared to sorghum crop (- 80.8 and - 3.4 mg/cm^3). When the rainfall is about 42.3 cm during monsoon season from June to September, some amounts of salt were accumulated in the soil profile with low irrigation frequency or under irrigation scenarios compared with reference scenario.

During the winter season (November to March), salts accumulation was higher in reference scenario compared to the under or lower irrigation frequency scenarios. It is mainly due to higher amount of drainage water (42 cm) is applied under reference scenario than the low irrigation frequency or under irrigation scenarios (33 cm). The yield reductions and transpiration of sorghum are not affected by the irrigation given under different scenarios. In the low irrigation frequency scenario, more salts are leached due to less amount of water was taken by plants compared to reference scenario and thus more water is available for leaching of salts. In the under or low irrigation scenarios, relative ET, transpiration efficiency and evapotranspiration efficiency are more than in the reference scenario. Managing salt and water balance by means of changing the irrigation interval or depth is more effective in the wheat (Nov. to April) season than in the sorghum season.

Long-term scenarios

The long-term scenario studies (1990-91 to 2010 -11) were carried out in order to predict long-term trends of soil salinity and crop yield under current practices. The long-term scenarios are based on the previous mentioned reference scenario, changing the irrigation depth, frequency and water quality. The annual complete cycle for the years 2000-2001 and 2015-2016, comprising of sorghum and wheat crops in the sequence, have been considered for analyzing and discussing the results obtained after 10 and 25 years of simulation. The farmers

Table 7. Details of management scenarios in term of quantity (cm), quality (mg/cm^3) and frequency of water application.

Scenarios	Sorghum season (June to Aug.)						Wheat season (Nov. to April)					
	Quantity (cm)		Quality (mg/cm^3)		Frequency (No.)		Quantity (cm)		Quality (mg/cm^3)		Frequency (No.)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Reference (60 cm)	10	8	0.280	0.280	1	1	10	8	0.2	5.12	1	4
Under irrigation (48 cm)	8	7	0.280	8.58	1	1	7	6.5	5.12 / 4.48	5.12/ 4.48	1	4
Low frequency (48 cm)	8	7	0.280	8.58	1	1	9	8	5.12 / 4.48	5.12/ 4.48	1	3

Table 8. Salt and water balance during sorghum seasons.

Scenarios		P (cm)	Iπ (cm)	T_{act} (cm)	E_{act} (cm)	ΔW (cm)	ΔS (mg/ cm^3)	Q_{bot} (cm)	Q_{bot}* C_{bot} (mg/cm^3)
Reference	1990-91	50.4	18.0	23.6	8.5	-13.2	-80.8	-49.5	-72.8
	1991-92	42.3	18.0	21.6	9.2	11.4	-3.4	-17.2	-2.63
Under	1990-91	50.4	15.0	23.6	8.7	-46.2	-37.9	-15.5	-92.5
irrigation	1991-92	42.3	15.0	21.6	9.2	11.8	16.5	-14.3	0.28
Low	1990-91	50.4	15.0	23.6	9.4	-13.2	-42.7	-45.2	-64.5
Frequency	1991-92	42.3	15.0	21.6	13.7	11.0	21.6	-14.3	-7.16

of the area do not have enough canal water at their disposal; therefore rainfall is the only source of good quality water for leaching the salts. Table 11 shows that the relative yields of both crops are not affected by under irrigation or low frequency irrigation scenarios. The higher values of relative ET, transpiration efficiency and ET efficiency are obtained when 20 % less water is applied, either through under irrigation or low frequency irrigation compared with reference scenario.

From 1990-1991 to 2000-2001, the salt storage in the profile increased to 19.3 mg/cm^3 (1.93 t ha^{-1}) in reference scenario compared to 29.7 and 29.1 mg/cm^3 (2.9 t ha^{-1}) in case of under irrigation and low frequency irrigation (Table 12). During the next 25 years (2015 –2016), there will be no salts buildup in the profile under reference scenario as indicated by salt storage value of -52.5 mg/cm^2 In other two scenarios (under or low frequency irrigation), the salts buildup are very less (2.9 and 1.7 mg/cm^3, respectively).

Table 9. Salt and water balance during wheat seasons.

Scenarios		P (cm)	Iπ (cm)	T_{act} (cm)	E_{act} (cm)	ΔW (cm)	ΔS (mg/ cm^3)	Q_{bot} (cm)	Q_{bot}* C_{bot} (mg/cm^3)
Reference	1990-91	11.03	42	25.1	10.6	-6.16	24.2	-39.6	-61.2
	1991-92	8.34	42	21.2	7.2	-0.54	13.6	-40.2	-50.7
Under	1990-91	11.03	33	26.1	10.6	-6.63	-8.2	-16.8	-84.4
irrigation	1991-92	8.34	33	21.2	7.3	-0.85	13.3	-14.8	-49.2
Low	1990-91	11.03	33	25.2	7.8	8.1	-7.1	-35.7	-89.5
frequency	1991-92	8.34	33	21.2	7.4	-1.23	-5.2	-35.2	-59.7

Table 10. Crop response indicators under different scenarios.

Scenarios		Relative yield		Relative ET		Transpiration efficiency		Evapotranspiration efficiency	
		Sorghum	Wheat	Sorghum	Wheat	Sorghum	Wheat	Sorghum	Wheat
Reference	1990-91	1.00	1.00	86.6	71.0	34.4	50.3	47.4	67.1
	1991-92	1.00	1.00	85.9	61.5	35.6	47.5	50.3	63.5
Under	1990-91	1.00	1.00	89.3	86.6	35.7	56.7	48.6	74.0
irrigation	1991-92	1.00	1.00	86.6	87.5	37.4	50.8	53.1	64.7
Low	1990-91	1.00	1.00	89.7	79.6	36.0	54.0	48.9	68.0
frequency	1991-92	1.00	0.99	87.2	78.6	40.7	46.5	52.7	59.0

Table 11. Plant response indicators under different long-term scenarios

Scenarios		Relative Yield		Relative ET		Transpiration Efficiency		Evapotranspiration Efficiency	
		Sorghum	Wheat	Sorghum	Wheat	Sorghum	Wheat	Sorghum	Wheat
Reference	2000-01	1.00	1.00	85.6	72.0	35.4	51.3	48.4	67.4
	2015-16	1.00	1.00	84.9	64.5	36.6	48.5	49.3	64.5
Under	2000-01	1.00	1.00	90.3	86.6	36.7	57.7	50.6	76.0
irrigation	2015-2016	1.00	1.00	87.6	88.5	38.4	53.8	54.1	66.7
Low	2000-01	1.00	0.99	89.7	78.6	37.0	55.0	49.9	69.0
frequency	2015-2016	1.00	0.99	87.2	79.6	39.7	47.5	53.7	62.0

Table 12. Salt and water balance under different long-term scenarios.

Scenarios		P (cm)	Iπ (cm)	T_{act} (cm)	E_{act} (cm)	ΔW (cm)	ΔS (mg/ cm^3)	Q_{bot} (cm)	Q_{bot}* C_{bot} (mg/cm^3)
Reference	2000-2001	65.1	60	46.4	26.5	-0.01	19.3	-49.0	-46.9
	2015-2016	60.9	60	43.5	22.8	-5.86	-52.5	-45.8	-123.0
Under	2000-2001	65.1	48	46.5	26.6	-0.2	29.7	-37.0	-43.1
iirrigation	2015-2016	60.9	48	42.3	24.9	1.5	2.9	-38.0	-71.9
Low	2000-2001	65.4	48	46.4	26.4	-0.10	29.1	-37.1	-43.8
frequency	2010-2011	60.9	48	42.1	24.6	1.5	1.7	-38.3	-71.4

Conclusions

The main term of reference of this study is to explore the possibility of applying the Soil Water Atmosphere Plant (SWAP) model to know the salts and water balance in the crop root zone under irrigated conditions in India. This model was first calibrated and subsequently validated using field observations of three years. The computed values of yields, and salt and water balance agreed quite satisfactorily with field observations. The scenarios analysis for management variables (e.g. quantity, quality and frequency of irrigation) was performed. The interval of irrigation with drainage water appeared to be a suitable management option for farmers to control their salinity and optimize their crop yield. Long-term analysis from 1990-91 to 2015-16 (25 years) was carried out for sorghum-wheat cropping sequence using drainage water of 6.1 to 4.1 dS $m^{-1}$for irrigation. Model simulations showed that good crop yield could be achieved by using the waters continuously over a period of 20 years without any deterioration of soil sustainability. To recommend suitable combinations on quality and quantity of irrigation water in other drainage areas located under various agro-climatic conditions, the simulation study with SWAP model can be extended in coming years.

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Soil fertility evaluation in alluvial soils of Western Uttar Pradesh in Gangetic Plains for sustainable crop production

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ABSTRACT

A semi-detailed soil survey of 3.91 lakh ha was carried out using Geo-coded IRS-IC, LISS-III and Survey of India toposheet on 1:50,000 scale of Meerut district, Uttar Pradesh. Eight soil pedons, each representing a series occurring on old alluvial plain, recent alluvial plain, levee plain and active flood plain were characterized and assessed for soil fertility. The soils have been mapped into 45 mapping units of 22 soil series in the district. The soils were very deep, moderately well to somewhat excessively drained and occurred on nearly level to gentle slopes. The soils of old/recent alluvial plains are coarse loamy/fine loamy Typic Haplustepts and those occurring on levee and active flood plains Typic Ustipsamments and coarse loamy over sandy Fluventic Haplustepts. The soils are neutral to very strongly alkaline (6.6 to 9.3) in reaction, low to medium in organic carbon content. The cation exchange capacity of soils ranges from low to medium (0.32 to 15.96 cmol (p^+) kg^{-1}), which varies with organic carbon and clay content. About 67.35 and 28.01 per cent area of the district is low in available nitrogen and potassium, respectively. The soils of the district are adequate in available P and micronutrients (DTPA extractable Cu, Zn, Fe & Mn) content. Available N and K had positive correlation with clay, organic carbon and CEC; whereas, available P had negative correlation with pH, EC and $CaCO_3$. However, DTPA extractable Zn and Cu had positive correlation with organic carbon, clay, and CEC. Available Fe negatively correlated with pH, EC and $CaCO_3$ and available Mn had negative correlation with pH and CaCO3 content.

Key words: geo-coded satellite data, physiography, DTPA extractable micronutrients, soil health, alluvial soils.

Introduction

India is facing a problem of increasing food production due to an ever increasing population and there is an immense pressure and over exploitation of our limited and shrinking soil resource, increasing of both macro and micro nutrient deficiencies in the Indian soils, leading to its degradation at an alarming rate, jeopardizing our food security. The long-term fertilizer experiments conducted in different agro-ecologies under intensive cropping and management systems indicated that increasing deficiencies of nutrients are site-specific and management influenced. There are increasing evidences that with the conjunctive use of inorganic fertilizers and organic manures/ residues, the deficiencies of the nutrients are mitigated and productivity enhanced. The knowledge of site-specific nutrient status is therefore, essential for sound fertilizer recommendation and mitigating nutrient deficiencies. With this in view, the present investigation was undertaken.

Materials and methods

The present study was undertaken in Meerut district of Uttar Pradesh, located between 28° 44' to 29° 18' N latitudes and 77° 8' to 78° 8' E longitudes, covering an area of 3,91,100 ha at an elevation between 205-240 meters above mean sea level (MSL). The district comprises of six tehsils viz. Baghpat, Baraut, Sardhana, Meerut, Mawana and Khekhra with 18 development blocks. It is bounded by the river Ganges in the east, the river Yamuna in the west, district Muzzaffarnagar in the north and district Ghaziabad in the south. The area is drained by the Ganga, Yamuna, Hindan rivers and their tributaries. The soils of the area are developed on the alluvium of these rivers system. The climate of the area is semiarid, subtropical and monsoonic with annual rainfall of 915 mm, of which nearly 80% is received during monsoon season. The mean maximum and minimum temperatures are 40°C and 23°C in summer and 21°C and 8°C in winter, respectively. The hydro-thermal regimes of the district are ustic and hyperthermic, respectively (Sehgal and Mandal, 1994).

A three tier approach (Sehgal *et al.*, 1987) was adopted for soil resource mapping. Eight typifying pedons, each

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Table 1. Site characteristics of different soil series in Meerut district

Soils Series	Location	Slope (%)	Drainage	Erosion	Flooding	Land Use
Icholi (P1)	28° 57' 00" N, 77° 36' 54" E	0-1	Moderately well	Nil to very slight	-	Cultivated
Masuri (P2)	29° 09' 06" N, 77° 41' 12" E	0-1	Moderately well	Nil to very slight	-	Cultivated
Parichhatgarh (P3)	28° 56' 24" N, 77° 47' 54" E	0-1	Well	Slight	-	Cultivated
Jiwana (P4)	29° 08' 16" N, 77° 20' 18" E	0-1	Well	Slight	-	Cultivated
Mawana (P5)	29° 10' 48" N, 77° 31' 36" E	0-3	Well	Slight	-	Cultivated
Hastinapur (P6)	28° 56' 42" N, 78° 02' 06" E	1-5	Excessive	Moderate	-	Thin forest / scrub
Khanpur (P7)	29° 03' 06" N, 77° 11' 36" E	0-3	Well	Slight to moderate	Occasional	Cultivated
Jagaus (P8)	29° 01' 48" N, 77° 26' 24" E	1-3	Excessive	Slight to moderate	Occasional to severe	Cultivated

representing a series occurring on old alluvial plain (*Icholi* and *Masuri*), recent alluvial plain (*Parichhatgarh, Jiwana and Mawana*), levee plain (Hastinapur) and active flood plain (Khanpur and Jagaus) were selected for the study (Table 1). Besides collecting one hundred and fifty surface (0-15 cm) soil samples, representative pedons of the identified soil series were also studied in details and horizon wise soil samples were collected for laboratory characterization using standard analytical procedures (Black, 1965; Jackson, 1973; Lindsay and Norvell, 1978). Soils were classified as per Soil Taxonomy (Soil Survey Staff, 2003). Fertility assessment for all the 45 soil mapping units delineated in the district was made following the standard critical limits.

Results and discussion

Physico-chemical characteristics

The physico-chemical characteristics of the soils (Table 2) indicated that sand and silt fractions constitute the major portion in mechanical composition. Sand content increases with depth in *Hastinapur, Khanpur* and *Jagaus* soils of active flood plain and levees, could be due to sandy parent material whereas it showed decreasing trend in the soils of old / recent alluvial plains. In general subsurface horizons of old/recent alluvial plain soils (P1 to P5) exhibit higher clay content as compared to surface one's except soils of active flood plain and levees have reverse trend (P6, P7 & P8) indicating an increased degree of weathering, soil development and clay translocation from the upper layers (Ogunwale & Ashaye, 1975; Virgo & Holmes, 1977). The *Masuri, Jiwana, Khanpur* and *Jagaus* soils are calcareous whereas *Icholi, Parichhatgarh, Mawana* and *Hastinapur* soils are non calcareous. The soils of *Parichhatgarh* and *Hastinapur* soils are neutral in reaction, whereas rest of the soils are slightly to strongly alkaline in nature (Verma *et al.,* 2012). The higher pH values of *Masuri, Jiwana, Khanpur* and *Jagaus* soils might be due to the lime rich parent material (Gawande and Tamhane, 1971)), whereas in *Mawana* soils, pH is high due to salinity (chloride and sulphates of calcium and magnesium). Nearly 43.8 % area of the district is moderately to strongly alkaline, of which around 12.63 % is saline/sodic. It was further revealed that the organic carbon content decreases gradually with increasing soil depth. The CEC of soils varies from 0.32 to 15.96 cmol (p^+) kg^{-1}. In general, CEC increased in subsurface horizons as compared to surface horizons except in the soils of active flood plain and levees which is mainly due to variation in their clay content since all these soils are low in organic carbon.

Available nutrient status

The data presented in table 3 revealed that the N content of soils were low (45.2 to 460.6 kg ha^{-1}), however only 29.77 per cent area having medium available N, indicating widespread nitrogen deficiency in these soils, thereby suggesting that high yields cannot be obtained without N application. Soils containing less than 0.5 per cent organic carbon or 280 kg ha^{-1} of alkaline permanganate oxidizable N are considered to be N deficient. Soils of the district were adequate in available P. Nearly 86.28 and 10.84 per cent area of the district had medium and high available phosphorous, respectively. Almost all the major soils are medium in available P, except *Icholi, Masuri* and *Hastinapur* which are high in available P. Phosphrous is considered to be the backbone of balanced fertilizer use because of securing N efficiency. Its availability is highly sensitive to soil pH, calcareousness, organic carbon and soil texture. The available K content varied from 33.6 to 375.2 kg ha^{-1} and its deficiency is as widespread as that of P since about 67.92 per cent area of the district had medium K, whereas 28.01 per cent area is low in available K, which might be due to the heavy removal of K by harvested crops and inadequate K application (Pasricha, 2002). The available potassium status is governed by its release dynamics besides topo-sequential occurrence of soils, slope gradient, texture, mineralogical makeup and water regime.

With intensive cultivation of high yielding varieties, deficiencies of micronutrients in the soils is increasing at

Table 2. Physico-chemical characteristics of soils

Horizon	Depth (cm)	Sand	Silt (%)	Clay	pH (1:2.5)	EC (dS m^{-1})	O.C.	$CaCO_3$ (%)	CEC [C mol (p+) kg^{-1}]
Icholi (P1): Fine loamy, mixed, hyperthermic Typic Haplustepts									
Ap	0-12	56.25	26.75	17.00	7.40	0.25	0.28	-	8.58
AB	12-30	51.25	28.75	20.00	7.20	0.19	0.23	-	8.64
Bw_1	30-52	43.25	28.00	28.75	7.35	0.16	0.19	-	11.16
Bw_2	52-82	39.29	29.46	31.25	7.50	0.14	0.17	-	15.96
Bw_3	82-108	35.50	35.50	29.00	7.35	0.14	0.13	-	13.84
Bw_4	108-132	32.44	34.25	33.31	7.35	0.12	0.11	-	15.88
Bw_5	132-154	36.00	33.00	31.00	7.40	0.11	0.08	-	15.12
Masuri (P2): Fine loamy, mixed (Calcareous), hyperthermic Typic Haplustepts									
Ap	0-18	54.50	27.00	18.50	7.89	0.67	0.81	0.27	13.76
AB	18-45	43.50	31.50	25.00	8.73	0.17	0.30	0.38	12.90
Bw_1	45-70	41.50	28.25	30.25	9.40	0.24	0.11	0.81	14.12
Bw_2	70-92	40.00	28.00	32.00	9.68	0.44	0.11	0.62	15.48
Bw_3	92-113	40.25	27.50	32.25	9.75	0.49	0.08	0.67	15.05
Bw_4	113-136	43.50	25.75	30.75	9.74	0.45	0.06	0.81	14.19
Bw_5	136-360	43.75	25.75	30.50	9.70	0.48	0.02	1.15	14.10
Parichhatgarh (P3): Fine loamy, mixed, hyperthermic Typic Haplustepts									
Ap	0-14	61.25	22.50	16.25	7.22	0.24	0.27	-	8.56
AB	14-34	55.55	26.00	18.45	7.21	0.24	0.23	-	9.10
Bw_1	34-59	41.50	32.25	26.25	7.25	0.21	0.15	-	12.42
Bw_2	59-82	35.75	30.25	34.00	7.35	0.20	0.11	-	15.28
Bw_3	82-110	33.50	32.25	34.25	7.35	0.16	0.11	-	14.62
Bw_4	110-128	36.88	29.25	33.87	7.40	0.15	0.06	-	15.30
Bw_5	128-150	37.50	35.50	27.00	7.50	0.13	0.04	-	12.50
Jiwana (P4): Fine loamy, mixed (Calcareous), hyperthermic Typic Haplustepts									
Ap	0-15	69.00	14.25	16.75	8.40	5.10	0.74	0.95	10.65
AB	15-31	65.00	17.75	17.25	8.30	1.45	0.29	0.72	10.54
Bw_1	31-57	45.63	34.25	20.12	8.40	0.90	0.23	0.72	11.12
Bw_2	57-86	45.50	33.25	21.25	8.30	0.80	0.23	0.71	11.72
Bw_3	86-118	42.32	35.93	21.75	8.40	0.80	0.22	0.67	12.10
Bw_4	118-140	45.99	28.01	26.00	8.40	0.80	0.19	0.72	14.35
Bw_5	140-158	46.01	28.24	25.75	8.50	0.65	0.15	0.81	14.25
Mawana (P5): Coarse loamy, mixed, hyperthermic Typic Haplustepts									
Ap	0-16	73.00	16.50	10.50	8.05	0.12	0.36	Nil	6.12
AB	16-42	70.25	17.00	12.75	8.31	0.08	0.19	-	6.84
Bw_1	42-75	69.75	15.00	15.25	8.33	0.07	0.19	-	7.56
Bw_2	75-105	70.50	12.50	17.00	8.43	0.07	0.15	-	8.28
Bw_3	105-130	71.50	14.25	14.25	8.45	0.07	0.10	-	7.92
Bw_4	130-155	74.00	12.50	13.50	8.50	0.06	0.09	-	6.66
Hastinapur (P6): Mixed,hyperthermic Typic Ustipsamments									
A	0-16	84.00	10.25	5.75	6.56	0.04	0.27	Nil	3.12
AC	16-40	86.50	8.50	5.00	6.66	0.03	0.21	-	2.65
C_1	40-68	86.25	8.75	5.00	6.96	0.02	0.15	-	2.56
C_2	68-95	89.50	7.00	3.50	7.00	0.02	0.13	-	1.80
C_3	95-124	88.50	8.00	3.50	7.11	0.02	0.08	-	1.74
C_4	124-155	89.50	7.75	2.75	7.20	0.02	0.04	-	1.41
Khanpur (P7): Coarse loamy over sandy, mixed (Calcareous), hyperthermic Fluventic Haplustepts									
Ap	0-17	70.75	12.00	17.25	8.28	0.43	0.38	4.22	9.32
Bw_1	17-43	69.34	14.25	16.41	8.94	0.21	0.13	4.84	8.03
Bw_2	43-76	65.50	24.25	10.25	8.94	0.21	0.13	10.12	6.02
C_1	76-103	89.99	1.76	8.25	8.96	0.18	0.06	6.96	4.82

Table 2 ***Contd..***

Hori-zon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5)	EC (dS m^{-1})	O.C. (%)	$CaCO_3$ (%)	CEC [C mol (p+) kg^{-1}]
C_2	103-132	86.28	5.97	7.75	9.00	0.15	0.09	4.99	3.78
C_3	132-155	91.75	2.50	5.75	8.97	0.16	0.06	4.12	3.44
Jagaus (P8): Mixed (Calcareous), hyperthermic Typic Ustipsamments									
Ap	0-15	79.75	14.00	6.25	8.24	0.19	0.23	1.77	3.42
AC	15-34	85.75	9.75	4.50	8.94	0.12	0.06	3.60	2.30
C_1	34-58	92.00	5.50	2.50	9.07	0.10	0.05	3.21	1.28
C_2	58-74	92.25	5.00	2.75	9.16	0.07	0.04	2.59	1.37
C_3	74-100	95.75	3.00	1.25	9.18	0.07	0.02	2.76	0.65
C_4	100-128	97.00	2.50	0.50	9.20	0.06	0.01	2.71	0.32
C_5	128-150	97.00	2.25	0.75	9.28	0.06	0.02	2.62	0.38

a faster rate, limiting crop production. Among micronutrients, zinc deficiency was found to be the most common problem for declining productivity as 60.21 per cent area of the district had adequate zinc content whereas sizeable chunk of the area had low (1.04%) and medium (35.87%) available zinc, necessitating its application through Zn containing fertilizers. Its availability is sensitive to soil pH and presence of free lime, clay and organic matter content of the soils (Sakal *et al.*, 1988; Khan *et al.,* 1997). The DTPA extractable Cu ranged from 0.30 to 2.81 mg kg^{-1}, indicating that present source of alluvium is rich in Cu bearing minerals. Almost similar content of available Cu was also reported by Singh and Tripathi (1983). The soils of the district are adequate to high in available Cu in all the soils. Available Fe content in the soils ranged from 3.44 to 53.74 mg kg^{-1} with highest content in *Icholi* soil series. The higher availability of Fe in *Icholi* soils might be due to the hydromorphic microclimate. Nearly 31.73 and 65.39 per cent soils of the district are medium and high in available iron, respectively. The soils rich in free lime, P and well to somewhat excessively drained are likely to suffer from Fe deficiency. The available manganese ranged from 3.84 mg kg^{-1} in *Hastinapur* to 57.26 mg kg^{-1} in *Icholi* soils. Such wide variation in available Mn might be due to sandy texture, low organic carbon, high pH and calcium carbonate (Randhawa and Singh, 1997). The data further revealed that the soils of the district are adequate in available Mn.

Relationship of available nutrient with soil properties

The data indicated that available nitrogen have positive correlation with clay (r = 0.88**), organic carbon (r = 0.66*) and CEC (r = 0.86**) in surface soils (Table 4). Whereas, available P had negative correlation with

Table 3. Available nutrient status of soils

Soils	Nitrogen (kg ha^{-1})	Phosphorous (kg ha^{-1})	Potash (kg ha^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})
Icholi (P1)	190.6-410.2 (330.4)*	7.50-56.00 (29.22)	95.2-369.6 (157.2)	0.37-2.27 (1.22)	0.30-2.58 (1.54)	9.50-53.74 (26.96)	14.62-57.26 (38.76)
Masuri (P2)	222.8-460.6 (356.2)	17.60-58.56 (31.17)	140.0-375.2 (197.4)	0.39-2.58 (1.43)	0.49-2.81 (1.40)	7.22-18.56 (10.21)	6.58-40.04 (20.13)
Parichhatgarh (P3)	156.2-360.4 (238.5)	8.40-37.20 (19.60)	78.4-224.0 (106.5)	0.32-1.97 (1.08)	0.36-2.22 (1.03)	3.78-24.90 (12.51)	14.84-55.70 (34.46)
Jiwana (P4)	160.4-290.2 (246.2)	15.70-26.90 (20.30)	145.6-308.0 (190.4)	0.44-1.61 (1.25)	0.54-2.64 (1.31)	3.44-15.50 (6.81)	8.67-53.32 (29.93)
Mawana (P5)	140.0-212.4 (182.4)	6.90-35.30 (16.09)	44.8-280.0 (106.9)	0.39-1.62 (1.11)	0.59-2.85 (1.20)	9.84-46.93 (30.48)	7.50-28.06 (14.59)
Hastinapur (P6)	45.2-122.6 (66.5)	8.40-43.10 (31.28)	33.6-240.8 (152.1)	0.41-0.95 (0.76)	0.34-0.55 (0.41)	6.40-31.02 (13.87)	3.84-28.94 (14.62)
Khanpur (P7)	80.4-190.2 (124.6)	8.20-31.80 (20.83)	84.0-235.2 (151.2)	0.46-1.52 (0.90)	0.46-2.13 (1.04)	6.60-23.22 (13.08)	12.20-34.58 (21.15)
Jagaus (P8)	61.6-104.4 (71.5)	12.90-33.60 (20.30)	78.4-308.0 (164.5)	0.67-1.59 (1.05)	0.32-2.56 (1.23)	5.20-20.98 (9.23)	8.36-38.24 (24.01)

* Values in parenthesis are mean values

Table 4. Correlation of soil available nutrients with soil properties

Available Nutrients	Clay	Organic Carbon	pH	EC	$CaCO_3$	CEC
Nitrogen (N)	0.88**	0.66*	0.01	0.23	-0.47	0.86**
Phosphorous (P)	0.13	0.25	-0.49	-0.20	-0.31	0.13
Potash (K)	0.23	0.62	0.34	0.50	0.17	0.37
Zinc (Zn)	0.70*	0.71*	0.37	0.36	-0.33	0.77*
Copper (Cu)	0.62	0.36	0.54	0.25	-0.01	0.59
Iron (Fe)	0.00	-0.32	-0.24	-0.44	-0.36	-0.14
Manganese (Mn)	0.48	0.00	-0.16	0.26	-0.14	0.33

*, **Values significant at 5 per cent and 1 per cent level, respectively

pH (r= -0.49), EC (r = -0.20) and $CaCO_3$ (r = -0.31). Available K had positive correlation with organic carbon (r = 0.62) in the soil. However, DTPA extractable Zn had positive correlation with organic carbon (r = 0.71*), clay (r =0.70*), and CEC (r = 0.77*) and negatively correlated with $CaCO_3$ (r = -0.33). Available copper had positive correlation with clay (r = 0.62), O.C. (r = 0.36) and CEC (r = 0.58). A significant relationship of soil organic carbon and DTPA extractable Zn and Cu in surface soils supported the findings of Follet and Lindsay (1970), Behra and Shukla (2013) and Singh *et al.* (2013). Available Fe negatively correlated with pH (r = -0.24), EC (r = -0.44) and $CaCO_3$ (r = -0.36) in soils. Whereas, available Mn had negative correlation with pH(r = -0.16), CaCO3 (r = 0.14) and positive correlation with clay (r = 0.48) and CEC (r = 0.33). Baruah *et al*. (2013) also observed similar findings for available Fe and Mn with pH, EC and $CaCO_3$ in soils of Annagramam and Kurinjipadi block of Cuddalore district, Tamilnadu.

Conclusion

It is evident from the study that N deficiency in these soils is widespread whereas P and K deficiencies are not far behind those of N as almost 86.28 per cent of the area is medium in P and 95.93 per cent is low to medium in K fertility. Among micronutrients, Zn and Fe deficiencies are found to be the limiting factor for crop production. Indications are that, Cu deficiency may emerge as a problem in the coming years. Therefore, conjunctive use of inorganic fertilizers and recycling of organic manures/ crop residues coupled with green manuring is essential in maintaining soil quality, enhancing nutrient use efficiency and realizing optimum yields of crops. Nutrient management in proper way not only sustained the productivity over a long period of time but also improved soil properties. Incorporation of residual biomass in large quantity as a result of better harvest on balanced application of nutrients is responsible for sustaining the crop productivity and soil health. External supply of nutrients in balanced form also improved the physical condition and biological activity of soil which favours nutrient transformations in soil. Thus, nutrient management is only the key to sustain the productivity and improving soil health.

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Assessment of soil degradation in Vertisols of Upper Wardha Command area, Maharashtra, India

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ABSTRACT

The soils The Upper Wardha Command area are deep to very deep, calcareous, clayey, dark brown to very dark gray in colour and have well developed slickensides in subsurface horizons and meet the specifications of the Vertisol order of Soil Taxonomy. The soils are under perennial irrigation of medium salinity and low sodium water quality. In present study the soils were found to be moderate to strongly alkaline, non-saline (ECe < 2 dS m^{-1}) with high CEC (48 to 60 cmol(p+) kg^{-1}) and base saturation (89 to 99 per cent). The ESP, EMP, Ca/Mg ratio and SAR ranged from 0.9 to 17.1 per cent, 20 to 49 per cent, 0.6 to 3.8 and 0.6 to 15.6, (mmol $L^{-1})^{½}$, respectively. Clay fraction, dominated with smectite (41 to 67 per cent) along with considerable amount of plagioclase feldspar, was the source of sodium ions. The development of sodicity in the soils attributed to the semi-arid climatic conditions that have induced the pedogenetic process of depletion of calcium ions from the soil solution in the form of calaium carbonate, thereby resulting in an increase of both the ESP and EMP with pedon depth. The natural degradation process further aggravated by the injudicious irrigation, increases the sodicity in the surface horizon. The high smectitic clay, pH, CEC, ESP and SAR were responsible for high shrink-swell potential of these soils as COLE (0.17 to 0.27) and VSP (60.2 to 100 per cent) values falls in very high shrink-swell class. The high ESP, EMP, COLE and WDC impaired the drainage (HC 0.01 to 2.4 cm hr^{-1}) which in turn waterlogged the soils. In order to optimize the production on sustainable basis improvement in natural drainage, applying suitable modification in land configuration, use of gypsum, proper selection of crops and far-spaced irrigation should be taken on priority basis.

Keywords : hydraulic properties, sodicity, water management, Vertisols, land configuration

Introduction

Black soils (Vertisols and vertic intergrades) occur widely in many parts of the world including India. They occupy an area of 72.9 million hectares in India, 35.5 per cent of which are in the state of Maharashatra. Vertisols and associated soils are generally very deep (150-200 cm), fine textured with clay content ranging from 45-68 percent with montmorillonite as the dominant clay mineral. These soils exhibit high shrink-swell potential and develop wide cracks of 4-6 cm extending up to 100 cm depth. These soils also have high water holding capacity and slow to very slow permeability and somewhat imperfect to poor drainability. These soils are calcareous in nature (2 to 12% $CaCO_3$) with calcium carbonate occurring in the form of nodules, *kankar* and powdery form. The soils are characterised by narrow workable moisture range and suffer varying degree of degradation.

These soils are mainly confined to the lower topographical levels and occur in most of the river valleys, one of which is the Wardha river valley. The Upper Wardha command is the part of Wardha valley that covers the districts of Wardha, Amravati and Yavatmal, where the canal irrigation system has been commissioned recently. The natural degradation of these soils occurred due to the aridity of the climate and poor drainage caused by subsoil sodicity which is further aggravated due to irrigation reported to become deleterious to the properties of these soils (Balpande *et al*., 1996). Establishing the cause-effect relationship is essential so that methods can be developed to restore the productivity of already degraded soils and to prevent further development of similar problems. Because of the recently commissioned irrigation in the valley, the present study is carried out to identify the relationship between irrigation and soil physical properties and to deduce plausible solution for irrigation management.

Material and methods

The study area of the Upper Wardha irrigation project lies between 21º10' to 21º18' N latitude and 78º5' to 78º15' E longitude. Fifteen pedons from Vertisols occurring in Wardha district, Maharashtra were studied and out of them data of six representative soil pedons are presented here. All the six pedons were under canal irrigation. Among six pedons, Pedon 1 and 4 to 6 were under irrigation for 10 to 12 years, whereas pedon 2 and 3 were under irrigation for the last 6 years. This comprises of the left bank canal head zone which is the first area to receive irrigation. Soils in this command area have developed from basalt and its alluvium. The average elevation of the study area varies from 320 to 400 m above MSL and the climate is semi-arid, subtropical with an annual rainfall of 979 mm. The principal agricultural crops grown in *kharif* season are cotton (*Gossypium sp*.), sorghum (*Sorghum bicolor*), tur (*Cajanas cajan*), soybean (*Glycine max*) and mung (*Phaseolus aureus*), where as in *rabi* season wheat (*Triticum sp.*) and gram (*Cicer arietinum*) are grown mainly on black soils. But in some pockets sugarcane (*Saccharum officinarum*) and orchards of mandarin (*Citrus reticulata)* are also grown under irrigation.

The site and morphological characteristics of these soils were described and horizonwise soil samples were collected (Soil Survey Division Staff, 1995). The mechanical composition of soils estimated by following the international pipette method (Piper, 1966). For estimation of saturated hydraulic conductivity, 200 g of air dry sample passed through 2 mm sieve dumped in one motion in the permeameter that was fitted with a screen and filter paper. The permeameter was then tapped 100 times to attain a uniform bulk density. After saturating the soil with distilled water, the saturated hydraulic conductivity was measured using the constant head method of Richards (1954). Water dispersible clay (WDC) estimated as per U.S.D.A., (1972), and coefficient of linear extensibility (COLE) as described by Schafer and Singer (1976).The volumetric shrinkage potential (VSP) was computed from the measured COLE data using the relationship (Hallberg, 1977) $VSP = [(COLE+1)^3 -1] x100$. The fine earth fraction was analysed for pH, exchangeable cations, cation exchange capacity (CEC) according to method outlined by Jackson (1973). The saturation extract of soils was analysed for their ECe and cations and anions by Richards (1954). X-ray examination of parallel oriented samples saturated with either Ca or K (Jackson, 1979) was done using Phillips Diffractometer with Ni-filtered radiation and a scanning speed of $2^0 2ø$ min^{-1}.

Results

Morphological properties

The depth of soils varied from 120 to 150 cm and dark brown (10 YR 4/2M) to very dark gray (10 YR 3/1M) in colour (Table 1). The surface horizons of all the pedons had subangular blocky structure and slightly hard to hard (dry) and friable (moist) consistence. However, subsurface horizons had angular blocky structure and were hard to very hard (dry) and firm to very firm (moist) consistency. These soils showed well developed intersecting slickensides (33 cm onwards) with wedge shaped aggregates that broke into angular blocks. The effervescence with dilute HCl was slight to strong in surface horizons and strong to violent in subsurface horizons. The occurrence of iron and manganese concretion in pedon 3 and 5 reflects the poor drainage condition of these soils. All these showed most of the characteristics of Vertisols which had well developed slickenside in Bss horizon in the subsoil.

Physical characteristics

All the soils are clayey and clay content ranged from 41.4 to 67.2 per cent (Table 2). The silt and sand content ranged from 24.2 to 40.1 and 0.8 to 28.9 per cent, respectively. The water dispersible clay ranged between 15.6 and 28.1 per cent which increased with depth. COLE and volumetric shrinkage potential (VSP) varied from 0.17 to 0.27 cm cm^{-1} and 60.2 to 100 percent. The saturated hydraulic conductivity (HC) ranged from 0.01 to 2.4 cm hr^{-1} and in general, it decreases with depth.

Chemical properties

The soils are calcareous (6.4 to 15.4 per cent $CaCO_3$) and moderately to strongly alkaline in reaction with pH 8.0 to 8.9 (Table 3). The organic carbon content varied from 2.8 to 7.5 g kg^{-1}. The CEC of the soils are high [48.5 to 59.6 $cmol(p^+)$ kg^{-1}] due to high clay content and predominance of smectite. Among the exchangeable cations, Ca was dominant followed by Mg, Na and K in all the pedons except in Bss horizons of pedons 4 and 6, where Mg was dominant. The exchangeable Ca decreased and exchangeable Mg increased with depth. The Ca/Mg ratio was normally between 0.6 to 3.8. All the soils had ECe less than 4 dS m^{-1} indicating no salinity hazard (Table 3). However, ESP showed a very wide variation ranging from 0.9 to 17.1 and EMP ranged from 20.2 to 49.7. The SAR of the soils solution ranged from 0.6 to 15.6 (mmol $L^{-1})^{1/2}$(Table 3). Mineralogy of clay factions of these soils indicates smectite as dominant clay mineral (41 to 67 per cent) along with Sm/K interstratified mineral. Mineralogy of soil fractions indicates the presence of smectite, followed by vermiculite, chlorite, mica, Sm/K interstratified mineral, quartz and feldspar.

Discussion

In the Upper Wardha command area farmers are taking 2 to 3 crops in a year or perennial crops like sugarcane with canal irrigation. Farmers used to irrigate the crops with flood irrigation system (uncontroled irrigation) and most of the minor canals are unlined and possess uncontrolled seepage. The problems of water logging and rise in water table were noticed in the Vertisols of the command area. Water quality of various samples of canal and well were mostly moderately saline (0.54 to 0.74 dS m^{-1}) and low in sodium having C_2S_1 rating except Wardha maneri and Jambnera well sample which were high in salinity (0.81 to 1.20 dS m^{-1}) and low in sodium (C_3S_1). Normally this water is not suitable for irrigation

Table 1. Brief Morphometric description of soils

Depth (cm)	Horizon	Boundry D	Boundry T	Munsell colour (moist)	Texture	Structure	Consistence Dry	Consistence Moist	Consistence Wet	Efferve-scence (10% dil HCl)	Concretions S	Concretions Q	Other Features
Pedon 1 : Mandala													
0-15	Ap	c	s	10YR 3/3	Clay	3 c sbk	sh	fr	sssp	Slight	f	c	Well developed
15-30	A	c	s	10YR 3/3	Clay	2 m sbk	h	fr	sp	Slight	f	c	slickensides
30-60	Bw	c	w	10YR 3/2	Clay	2 m abk	h	fi	sp	Slight	m	c	below 60 cm
60-85	Bss1	c	w	10YR 3/2	Clay	2 m abk	vh	fi	svp	Violent	m	c	depth
85-123	Bss2	-		10YR 3/1	Clay	2 m abk	vh	fi	vsvp	Violent	m	m	
Pedon 2 : Wardha-maneri													
0-15	Ap	c	s	10YR 3/3	Clay	2 m sbk	h	fr	sp	Slight	f	f	Slickensides
15-30	A	c	s	10YR 3/2	Clay	2 m sbk	h	fr	sp	Slight	f	f	below 54 cm
30-54	Bw	c	w	10YR 3/1	Clay	2 m abk	h	fr	vsp	Slight	f	c	depth
54-76	Bss1	c	w	10YR 3/2	Clay	3 m abk	vh	fi	vsvp	Slight	f	c	
76-126	Bss2	,	-	10YR 3/1	Clay	3 m abk	vh	fi	vsvp	Strong	m	m	
Pedon 3 : Jambnera													
0-18	Ap	c	s	10YR 4/2	Clay	1 m sbk	sh	fr	sssp	Slight	f	c	Slickensides
18-40	A	c	w	10YR 3/3	Clay	1 m sbk	sh	fr	sssp	Slight	f	c	below 40 cm
40-73	Bw	d	w	10YR 3/2	Clay	2 m abk	sh	fi	ssp	Strong	m	c	depth
73-120	Bss		-	10YR 3/2	Clay	2 m abk	h	fi	sp	Strong	m	m	
Pedon 4 : Talegaon													
0-13	Ap	c	s	10YR 3/3	Clay	2 m sbk	h	fi	sp	Strong	f	c	Cracks 30 to 50
13-35	A	c	s	10YR 3/3	Clay	2 m sbk	vh	fi	vsp	Violent	f	c	mm wide ; well
35-60	Bw	c	b	10YR 3/2	Clay	2 m abk	vh	fi	vsvp	Violent	m	c	developed
60-100	Bss1	c	w	10YR 3/2	Clay	2 m abk	vh	vfi	vsvp	Violent	m	m	slickensides
100-150	Bss2		-	10YR 3/3	Clay	2 m abk	vh	vfi	vsvp	Violent	m	m	and mottles below 60 cm depth; mottles with 5YR 5/6 and 5YR 4/1 colour
Pedon 5 : Parsoda													
0-11	Ap	c	s	10YR 3/3	Clay	1 m sbk	sh	fr	sp	Strong	f	c	slickensides below 33 cm depth.
11-33	Bw	g	s	10YR 3/2	Clay	2 m sbk	h	fi	svp	Strong	f	c	
33-86	Bss1	c	I	10YR 3/2	Clay	2 m abk	vh	fi	vsvp	Violent	m	m	
86-132	Bss2			10YR 3/2	Clay	2 m abk	vh	vfi	vsvp	Violent	m	m	
Pedon 6 : Sujatpur													
0-20	Ap	c	s	10YR 4/2	Clay	2 m sbk	h	fr	sssp	Slight	f	c	Pressure faces
20-37	A	c	s	10YR 3/2	Clay	2 m sbk	h	fr	sp	Strong	f	c	below 37 cm
37-60	Bw	g	w	10YR 3/2	Clay	2 m abk	h	fi	svp	Strong	f	c	depth ;
60-100	Bss1	d	w	10YR 3/1	Clay	2 m abk	vh	vfi	vsvp	Strong	m	c	slickensides
100-145	Bss2		-	10YR 3/1	Clay	2 m abk	vh	vfi	vsvp	Violent	m	m	below 60 cm depth

Note : Symbols used are according to Soil Survey Manual notations (Soil Survey Division Staff, 1995)

Table 2. Physical properties of soils

Depth	Horizon	Size class and particle diameter (mm) Sand (2.0 - 0.05)	Silt (0.05 - 0.002)	Clay (< 0.002)	Hydraulic conductivity (cm hr^{-1})	COLE	VSP	WDC
		% of less than 2 mm						
				Pedon 1 : Mandala				
0-15	Ap	7.4	38.9	53.7	1.5	0.19	68.5	15.6
15-30	A	7.1	37.1	55.8	1.1	0.2	72.8	17.2
30-60	Bw	6.9	36.1	57.0	0.6	0.23	86.1	22.1
60-85	Bss1	5.6	34.2	60.2	0.7	0.22	81.6	23.5
85-123	Bss2	4.7	33.6	61.7	0.4	0.21	77.2	22.1
				Pedon 2 : Wardha-maneri				
0-15	Ap	7.6	35.9	56.5	1.9	0.18	64.3	18.5
15-30	A	1.2	39.3	59.5	1.8	0.19	68.5	17.9
30-54	Bw	1.1	36.8	62.1	1.3	0.23	86.1	18.6
54-76	Bss1	1.1	30.4	68.5	0.8	0.22	81.6	20.2
76-126	Bss2	0.8	35	64.2	0.5	0.23	86.1	21.6
				Pedon 3 : Jambnera				
0-18	Ap	28.9	29.7	41.4	2.4	0.17	60.2	12.6
18-40	A	23.2	32.6	44.2	2.2	0.17	60.2	14.3
40-73	Bw	17.5	32.4	50.1	1.7	0.18	64.3	15.6
73-120	Bss	11.9	35.4	52.7	1.3	0.18	64.3	15.8
				Pedon 4 : Talegaon				
0-13	Ap	7.8	40.1	52.1	1.7	0.17	60.2	22
13-35	A	8.9	37.7	53.4	0.7	0.21	77.2	19.5
35-60	Bw	8.4	33.1	58.5	0.3	0.19	68.5	22.3
60-100	Bss1	11.5	28.4	60.1	0.2	0.23	86.1	24.1
100-150	Bss2	11.9	24.2	63.9	0.1	0.23	86.1	25.0
				Pedon 5 : Parsoda				
0-11	Ap	11.1	30.8	58.1	0.9	0.19	68.5	20.4
11-33	Bw	8.7	30.7	60.6	0.5	0.23	86.1	25.2
33-86	Bss1	6.8	29.4	63.8	0.4	0.23	86.1	25.6
86-132	Bss2	5.8	28.4	65.8	0.1	0.27	100.0	26.8
				Pedon 6 : Sujatpur				
0-20	Ap	9.8	36.8	53.4	0.6	0.21	77.2	22.0
20-37	A	7.9	35.4	56.7	0.2	0.23	86.1	21.5
37-60	Bw	7.6	30.2	62.2	0.1	0.25	95.3	23.8
60-100	Bss1	7.3	27.9	64.8	0.02	0.27	100.0	28.1
100-145	Bss2	6.4	26.4	67.2	0.01	0.26	100.0	26.4

in Vertisols; however C_2S_1 rating water can be used for irrigation where moderate amount of leaching occurs.

The semiarid climate of the study area is the prime factor responsible for starting the pedogenetic process which result in the depletion of Ca^{2+} ion from the soil solution in the form of $CaCO_3$, and also in the simultaneous increase of both SAR and ESP with pedon depth (Balpande *et al.*, 1996). This was evident from significant negative relationship between exchangeable calcium and $CaCO_3$ (r = -0.83) and exchangeable calcium and ESP (r = -0.80). The HCO_3/Ca ratio of the soils ranged between 1.6 to 15.3 and generally increased with depth indicating the potential of these soils for calcium precipitation with increase in evaporation of the soil solution. It is again supported by a positive significant correlation (p=0.01) between HCO_3/Ca ratio and SAR of the saturation extract of soils (r = 0.86). However, uncontrolled and/or over irrigation further aggravates the situation during the dry period and there was upward movement of sodium salt (mostly as bicarbonates) through capillary action and its accumulation in the upper horizons (depending upon the exhaustive demand) of soil profile. This effect resulted in the accumulation of Na in A and Bw horizons of all the soils, except pedon 3. Furthermore, the long term effect of irrigation was also seen in the accumulation of sodium in pedon 1 and 4 to 6 which are irrigated since last 12 years whereas, very

Table 3. Chemical properties of soils

Depth (cm)	Horizon	pH (1:2.5)	ECe dS m^{-1}	Extractable bases Ca	Mg	Na	K	Sum	CEC	Base Satu. (%)	Exch. Na (%)	Exch. Mg (%)	Ex. Ca/ Mg	SAR (mmol L^{-1})$^{1/2}$	HCO_3/ Ca
				<————		cmol (p$^+$) kg^{-1}			————>						
							Pedon 1 : Mandala								
0-15	Ap	8.5	0.36	32.5	14.6	2.2	0.4	49.7	51.2	97	4.3	28.5	2.2	2.4	2.3
15-30	A	8.7	0.44	30.1	15.4	4.6	0.6	50.7	52.3	97	8.8	29.4	2.0	6.5	2.5
30-60	Bw	8.6	0.85	27.9	17.1	5.8	0.7	51.5	52.9	97	11.0	32.3	1.6	8.6	3.4
60-85	Bss1	8.5	0.89	25.1	21.6	3.4	0.5	50.6	53.1	95	6.4	40.7	1.2	5.3	3.9
85-123	Bss2	8.4	0.65	24.8	23.5	2.6	0.4	51.3	53.6	96	4.9	43.8	1.1	3.8	4.5
							Pedon 2 : Wardha-maneri								
0-15	Ap	8.1	0.32	38.4	11.8	1.5	0.9	52.6	53.4	98	2.8	22.1	3.3	2.5	1.8
15-30	A	8.2	0.35	36.4	12.8	2.5	0.5	52.2	55.4	94	4.5	23.1	2.8	3.6	2.2
30-54	Bw	8.2	0.62	36.1	13.1	1.8	0.6	51.6	55.9	92	3.2	23.4	2.8	2	1.9
54-76	Bss1	8.5	0.82	33.2	14.8	2.9	0.6	51.5	57.2	90	5.1	25.9	2.2	4.2	3.7
76-126	Bss2	8.5	0.53	29.4	16.8	3.4	0.7	50.3	56.4	89	6.0	29.8	1.8	5	2.8
							Pedon 3 : Jambnera								
0-18	Ap	8.0	0.26	36.8	9.7	0.5	1.0	48	48.5	99	0.9	20	3.8	0.6	1.6
18-40	A	8.1	0.22	35.2	11.1	0.5	0.8	47.6	48.6	98	1.0	22.8	3.2	0.7	1.6
40-73	Bw	8.1	0.32	32.4	14.3	0.6	0.7	48	49.5	97	1.2	28.9	2.3	0.6	2.0
73-120	Bss	8.3	0.36	30.6	15.6	0.9	0.8	47.9	49.9	96	1.8	31.3	2.0	1.3	2.1
							Pedon 4 : Talegaon								
0-13	Ap	8.1	0.29	29.8	16.2	1.8	0.8	48.6	49.8	98	3.6	32.5	1.8	3.1	2.2
13-35	A	8.3	0.45	28.5	16.2	4.5	0.8	50	50.6	99	8.9	32	1.8	8.0	3.5
35-60	Bw	8.5	0.66	25.4	19.7	3.4	0.9	49.4	51.7	96	6.6	38.1	1.3	5.2	2.7
60-100	Bss1	8.7	1.40	19.4	24.4	5.2	0.8	49.8	52.5	95	9.9	46.5	0.8	10.2	4.4
100-150	Bss2	8.9	1.70	16.4	26.3	7.4	0.7	50.8	52.9	96	14.0	49.7	0.6	12.4	5.6
							Pedon 5 : Parsoda								
0-11	Ap	8.3	0.36	31.3	15.8	2.2	1.0	50.3	51.2	98	4.3	30.8	2.0	3.6	2.5
11-33	Bw	8.5	0.64	30.2	16.1	4.6	1.1	52	52.4	99	8.8	30.7	1.9	7.3	3.5
33-86	Bss1	8.6	1.2	26.1	21.5	3.5	1.0	52.1	53.4	98	6.6	40.3	1.2	5.3	4.6
86-132	Bss2	8.8	0.94	22.5	21.3	9.1	0.9	53.8	56.6	95	16.1	37.6	1.1	14.6	15.3
							Pedon 6 : Sujatpur								
0-11	Ap	8.1	0.61	30.2	18.5	4.1	1.4	54.2	55.8	97	7.3	33.2	1.6	6.7	3.6
11-33	A	8.6	0.74	29.1	18.8	4.6	1.2	53.7	55.8	96	8.2	33.7	1.5	8.2	4.3
33-86	Bw	8.6	1.0	25.2	21.5	8.4	1.3	56.4	59.6	95	14.1	36.1	1.2	12.0	9.0
86-132	Bss1	8.7	1.2	20.3	25.3	10.2	1.4	57.2	59.5	96	17.1	42.5	0.8	15.6	11.6
100-145	Bss2	8.8	1.1	18.7	27.4	8.6	1.7	56.4	59.5	95	14.5	46.1	0.7	14.1	9.2

low sodium was observed in pedons 2 and 3, which are being irrigated since the last 5 -6 years only.

The increased ESP and SAR of these soils affected the hydraulic conductivity due to dispersion and swelling of smectitic clay resulting to poor internal drainage. The relationship between clay and hydraulic conductivity, water dispersible clay and hydraulic conductivity, COLE and hydraulic conductivity and VSP and COLE indicated the highly significant negative correlation with 'r' values - 0.75, -0.87, -0.84 and -0.99, respectively . However, the significant correlation ($p=0.01/0.05$) was noticed between hydraulic conductivity and ESP ($r = -0.81$), exchangeable Ca/ Mg ratio ($r = 0.91$), EMP ($r = - 0.81$) as well as ESP + EMP ($r = - 0.88$) clearly suggested that cation saturation on the clay surface had a distinct influence on permeability and or drainage characteristics of these soils. The increase in ESP and or EMP with depth have adversely affected the HC and other properties that are essential for crop growth. The exchangeable sodium content influences significantly the physical and chemical properties of Vertisols (Nayak *et al.,* 2004 a,b,c). As the ESP tends to increase, the soil tends to become more dispersed. Some times distinction is made between alkali and sodic soils especially in Vertisols, where the term 'sodic' is preferred as pH of these soils increases slowly with increase in ESP.

Black cotton soils exhibit higher pH in the lower horizon than the upper layer. This is due to progressively increasing accumulation of $CaCO_3$ in the lower horizon. Nayak *et al.*, (2004a) further reported that in the lower layer where calcium carbonate has accumulated during pedogenesis, sodium accumulation generates sodium bicarbonate and carbonate increasing the soil pH above 9.0, in addition to the toxicity of carbonate and bicarbonate species. This may lead to Fe, N, Cu, Zn and P deficiency. The subsoil salinity (transient salinity) occurring in dry land dominated by subsoil sodicity may lead to further complication with rising saline ground water.

The general increase of both COLE and WDC and the decrease of hydraulic conductivity with depth suggest that swelling of clay smectite, together with dispersion of clay, have adversely affected the hydraulic conductivity of these soils. The observed correlation between water dispersible clay and EMP ($r = 0.78$) indicates that saturation of these soils, not only with Na^+ ions but also with Mg^{2+} ions which leads to greater dispersion of the clay, which is the opposite effect from that of saturation with Ca^{2+} which leads to the blocking of small pores in the soil. In other words, Mg^{2+} ions are less efficient than Ca^{2+} ion in flocculating soil colloids (Rengasamy *et al.*, 1986). The exchangeable Ca^{2+} showed reverse trend with hydraulic conductivity ($r = 0.83$) than magnesium. Similar results were reported by Kadu *et al.* (1993, 2003), Balpande *et al*. (1996).

On the basis of above, it is indicated that the sodification process is initiated in the lower part of the soils due to aridity of climate and soils are derived from basaltic alluvium rich in bases are potentially able to supply the large amount of Ca^{2+}, Mg^{2+}, and Na^+ cations, furthermore the Deccan basalt is rich in Plagioclase feldspar, which is a good source of sodium (Pal *et al.*, 1989) as it is evidenced in the mineralogy of these soils. The over-irrigation with canal water accelerated their dissolution and change underground water with salts. This has resulted in secondary sodification due to capillary rise of ground water in the soils of study area (Somawanshi and Patil, 1986). The high amount of clay, dominance of smectite in the clay fractions, high amount of sodium and CEC were responsible for high shrink swell potential of these soils. The high ESP along with EMP dispersed the soil clay and reduces the hydraulic conductivity, which was major cause for water logging situation in study area.

Management considerations

In view of the physico-chemical conditions of these soils, it should be cultivated with considering the following points

i. Tilling these soils (Vertisols) in both moist and dry condition is very difficult therefore for maximum advantage to be derived, these soils will be primarily tilled early in the dry season and left to dry. It will help in both reducing the evaporation by cutting up capillaries and conserve moisture and thus reduced the salinity build up in the soil.

ii. The broad-bed and furrow technology has been found to be suitable for Vertisols (Bharambe *et al.*, 1999).

iii. In order to improve and sustain soil productivity, organic manuring and crop residue management should be given top priority. The development of adverse physical conditions in these soils might possibly be prevented by surface application of gypsum before the rainy season. As the gypsum dissolves it will release enough Ca^{2+} ions to prevent clay dispersion, swelling of clays and decline in hydraulic conductivity, both at the surface and up to the depth of mixing of gypsum within the soil profile (Balpande *et al.*, 1996).

iv. Scheduling of irrigation is very difficult in these soils, which were affected by varying degree of salinization and sodification. Cracking and surface sealing affect the water-use efficiency. The cardinal point of scheduling of irrigation lies on keeping the cracks to a minimum level either by adjusting the frequency of irrigation or by mulching. The irrigation scheduling should be planned and framed in such a way that the net depth of soil penetrated by water should not exceed more than 60-70 cm which is well within the reach of root zone.

v. As the use of saline water on long term may lead to deterioration of the soil structure, constant monitoring of water quality and the salinity status of soil and consequent modification and adjustment in both cyclic and mixing modes are needed for the success of irrigation management in Vertisols.

vi. Since growing high water requiring crops might lead to salinity development, preference should be given for low water requiring and highly remunerative crops.

vii. Canal seepages should be controlled by taking lining works to avoid sodicity development in low lying areas.

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Mapping of groundwater quality of Beri block of Jhajjar district in Haryana

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ABSTRACT

The present study examined the quality of groundwater in 35020 ha area comprising Beri block of Jhajjar district of Haryana state. Groundwater samples (75 in number) from running tube wells in the block were collected and analyzed for ionic concentrations of CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+. Parameters such as electrical conductance (EC), sodium absorption ratio (SAR) and residual sodium carbonate (RSC) were evaluated. According to AICRP classification, it was found that 32.0 % water samples were of good quality and 56.0 % saline and 12.0 % alkali in nature. Out of the saline water, 34.7, 2.7 and 18.6 % were marginally saline, saline, and high SAR saline, respectively. In alkali group, 2.7 and 9.3 % were alkali and highly alkali, respectively. Among the six categories, on the basis of GIS mapping a maximum area of 18270 ha in the block was found to be in the category of good quality followed by the marginally saline covering 9360 ha and minimum area 130 ha was found to be alkali dominated. The study revealed that 82.6 % of the samples had an EC up to 4 dS m^{-1} with a maximum EC of 8.70 dS m^{-1} in village Paharipur. Residual sodium carbonate (RSC) and sodium adsorption ratio (SAR) varied from nil to 7.00 me L^{-1} and 3.06 to 29.03 (m mol $L^{-1})^{1/2}$, respectively. Spatial maps of EC, SAR, RSC and water quality of groundwater used for irrigation in the block were prepared through GIS to study spatial variability.

Key words: alkalinity, geographical information system, groundwater, residual sodium carbonates, salinity, sodium adsorption ratio

Introduction

India has 2.2 per cent of the global land, 4 per cent of the world water resources and 16 per cent per cent of the world's population (Ramesh and Elango, 2011). Amongst water resources, groundwater is the major source for domestic, agricultural and industrial purposes in semiarid and arid regions of India. This has lead to the overexploitation of groundwater and is proven by the fact that "overexploited" and "dark blocks" in the country have increased from 250 in 1985 to 1098 in 2005 (India, 2006). The present trend of declining groundwater depth (0.66 % per year) could reduce India's total food grain production by around 25 % or more by 2050 (Gupta and Deshpande, 2004). Apart from water table decline, groundwater quality is also a major concern in many parts of the country. Groundwater quality is influenced by natural and anthropogenic effects including local climate, geology, irrigation practices and industrial pollution. Groundwater contamination reduces its safe supply for irrigation and drinking purpose, posing a threat to agriculture and public health and a challenge to water managers and strategists.

In the area of Beri block of Jhajjar district, surrounding the western part of Delhi, intensive agriculture is the back bone of livelihood of the people residing in these areas and for this, they are extracting huge amount of groundwater resulting in depletion of the water table and deterioration of groundwater quality. The poor quality of groundwater is mainly due to drawing of salty water from lower aquifers. The indiscriminate use of agro-chemicals like fertilizers and pesticides and their leaching with the rain and irrigation water further deteriorate the quality of groundwater, hence there is an urgent need for planners and decision makers to characterize groundwater quality for putting in place a useful and sound method for monitoring of groundwater resources. Adhikary *et al.* (2009) also indicated that nitrate pollution is predominant in western part of Delhi. Therefore, the present study envisaged categorization of the groundwater of Beri Block in Jhajjar District and illustrates the spatial variability of various parameters of groundwater quality i.e. electrical conductivity (EC), residual sodium carbonate (RSC), sodium adsorption ratio (SAR) and quality categorisation by using the geographic information system (GIS). GIS can be used as a powerful tool for developing solutions for water resources problems for assessing water quality, determining water availability, preventing flooding, understanding the natural environment and managing

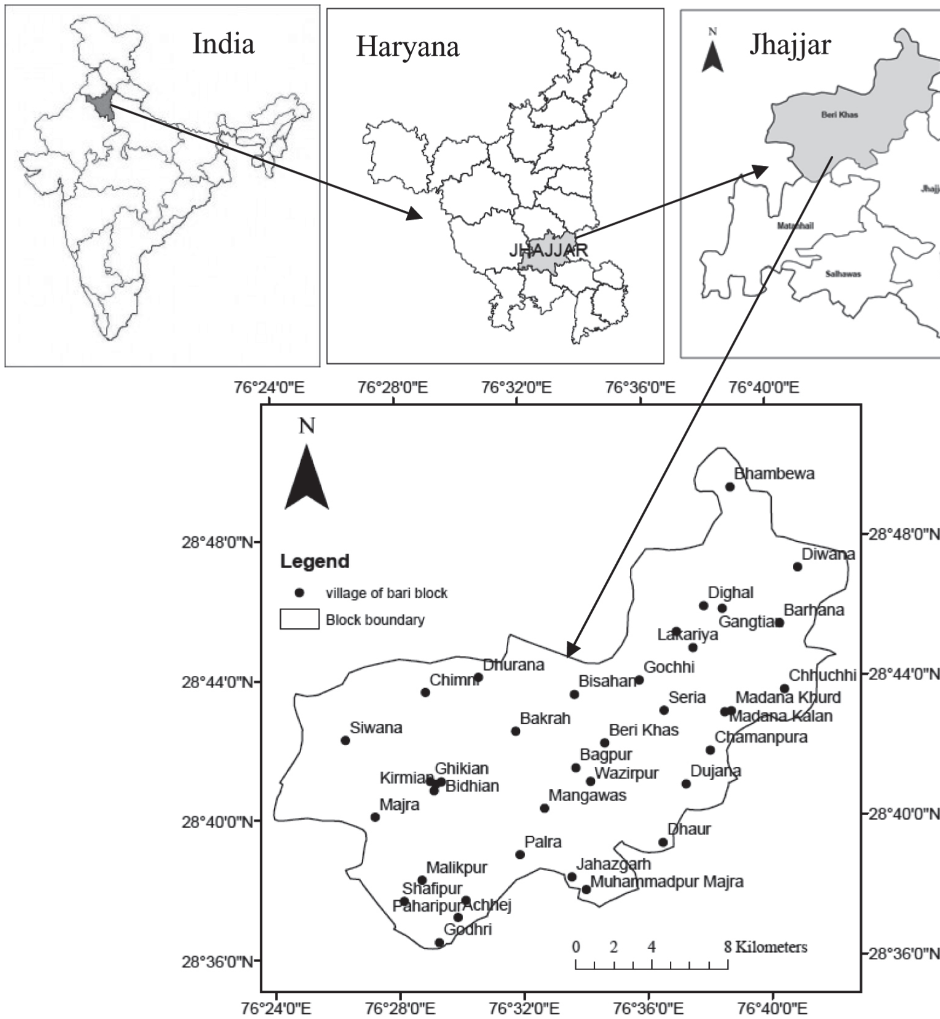

Fig. 1. Location map of the Beri block of Jhajjar district in Haryana state

water resources on a local or regional scale (Ferry *et al.*, 2003).

Material and methods

The survey and characterization of groundwater of Beri block was undertaken during 2012-13. It lies on the west-northern side of Jhajjar district between 28º36'15''to 28º50'29" N latitude and 76º23'59" to 76º42'41" E longitude (Fig.1). The block consists of 36 villages with flat and level area of 35020 ha. In order to avoid floods, the KCB drain has been dug that is connected to the west Jua drain and ultimately joins the Mungeshpur drain in the western part of Delhi. Chhapra and Rampur Sikander distributaries complete the water requirement of the block. The average rainfall of Jhajjar district is 520 mm (average of last 20 years). In shallow aquifer zones, groundwater remains close to the surface, whereas, in the deeper zones, confined/semi-confined conditions exist.

Seventy five groundwater samples were collected from running tube wells during the year 2012 randomly at an interval of three to four km. These tube wells were being extensively utilized for irrigation purposes (Fig.2). The elevation, longitude and latitude angles of the sampling points were recorded by GPS at each location. The samples were analyzed for EC, pH, CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and K^+ by following the procedures outlined in USDA Handbook No. 60 (Richards, 1954) and categorized on the basis of criteria adopted by All India Coordinated Research Project (AICRP) on Management of Salt Affected Soils and Use of Saline Water in Agriculture, through the values of EC, SAR and RSC of the samples (Gupta *et al.*, 1994).

Results and discussion

In the present study, it has been found that the electrical conductivity (EC) ranged from 0.50 to 8.70 dS m^{-1} with a mean of 2.74 dS m^{-1} (Table 1) in Beri block. The lowest EC (0.50 dS m^{-1}) in groundwater samples was observed in village Majra and the highest (8.70 dS m^{-1}) in village Paharipur. The study revealed that 82.6 % of the samples showed EC up to 4 dS m^{-1}. Location specific variability of EC of groundwater has been depicted in

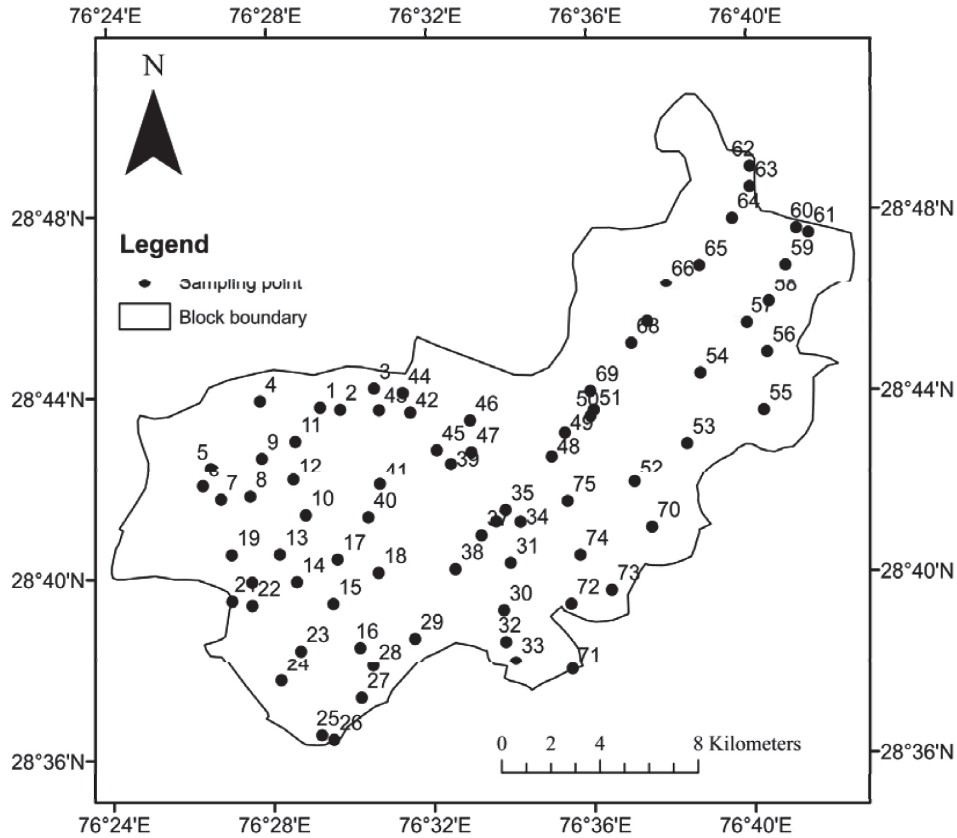

Fig. 2. Location map of the sampling points in Beri block of Jhajjar district

Figure 3. It was found that the EC of groundwater was very scatter but EC in the central and southern parts of the block is higher than other parts of the block. The most dominating range of EC in the block is 1-2 dS m^{-1}. The highest EC range (>7 dS m^{-1}) was observed at four spots. The areas with high EC can be reclaimed by leaching with good irrigation canal water along with provision of underground drainage system.

Table 1. Range and average of different water quality parameters in Beri block

Sr. No.	Parameters	Range	Average
1	EC (dS m^{-1})	0.50 - 8.70	2.74
3	CO_3^{-2} (me L^{-1})	0.00 - 3.40	0.51
4	HCO_3^- (me L^{-1})	1.00 - 8.50	4.13
5	Cl^- (me L^{-1})	1.40 - 76.30	20.69
6	SO_4^{-2} (me L^{-1})	0.00 - 11.00	1.94
7	Ca^{+2} (me L^{-1})	0.15 - 6.10	1.92
8	Mg^{+2} (me L^{-1})	0.45 - 19.50	5.72
9	Na^+ (me L^{-1})	2.90 - 60.20	20.19
10	K^+ (me L^{-1})	0.10 - 2.10	0.51
11	RSC (me L^{-1})	0.00 - 7.00	0.69
12	SAR (m mol $L^{-1})^{½}$	3.06 - 29.03	10.67

Calculation of SAR value for groundwater provides a useful index of the sodium hazard when applied to soils and for crops. The high sodium water may produce harmful levels of exchangeable sodium in most soils and requires special soil management such as irrigation with good quality canal water for leaching of soluble salts and addition of gypsum, organic matter and green manuring. The SAR in the block ranged from 3.06 - 29.03 (m mol $L^{-1})^{½}$ with a mean value of 10.67 (m mol $L^{-1})^{½}$. The lowest SAR was observed in village Majra and the highest value in Bahrana village. The variations in values of SAR of this block is shown by Figure 4 in which the SAR values are divided into 7 classes with an interval of 4 (m mol $L^{-1})^{½}$. It is observed from the spatial variability map that the maximum area of the block is under 8-12 (m mol/l)^{½} except some spots in the eastern and southern corners of the block. The highest SAR range (28-32) was observed at one spot in the eastern part of the block.

The RSC varied from nil to 7.00 me L^{-1} with an average value of 0.69 me L^{-1}. Maximum value of the RSC was found in the village Majra. It is observed from the variability map (Fig.5) that the RSC of groundwater is almost absent except in some pockets on the eastern and western sides of the block. Variation of RSC did not match this EC_2 (Fig.3) which indicates that the RSC has no relation with the EC.

In case of cations, sodium was the dominant ion which ranged from 2.90 to 60.20 me L^{-1} followed by magnesium (0.45 to 19.50 me L^{-1}), calcium (0.15 to 6.10 me L^{-1}) and potassium (0.10 to 2.10 me L^{-1}). The mean

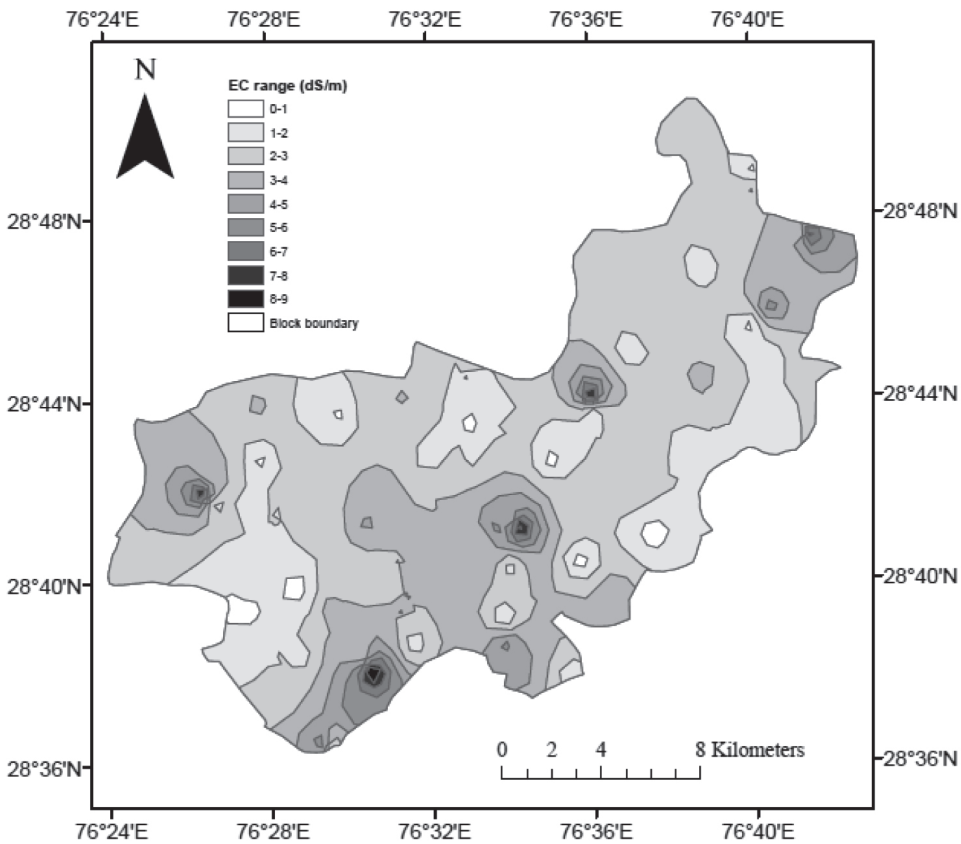

Fig. 3. Spatial variable map of EC of groundwater in Beri block

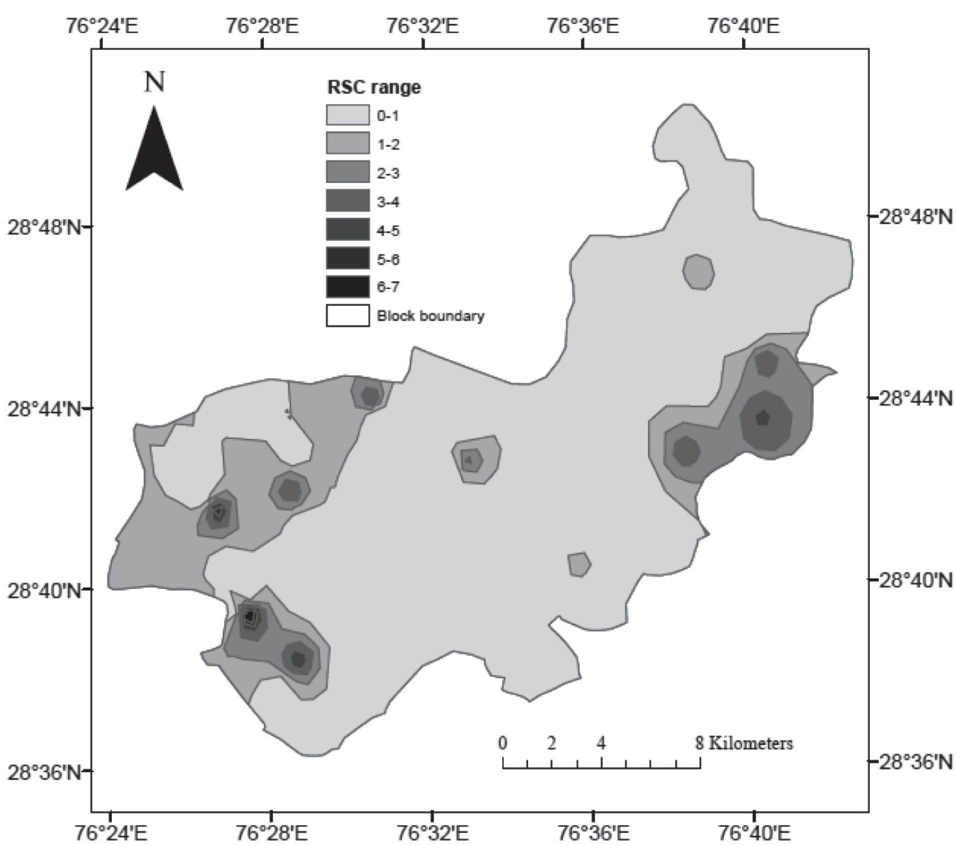

Fig. 4. Spatial variable map of SAR of groundwater in Beri block

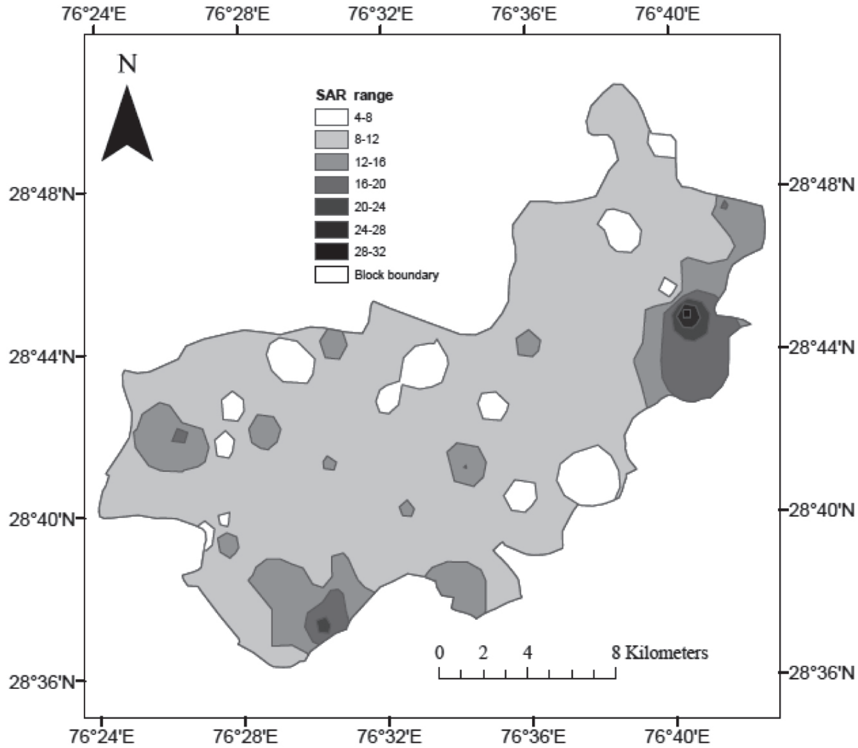

Fig. 5. Spatial variable map of RSC of groundwater in Beri block

values for Na^+, Mg^{2+}, Ca^{2+} and K^+ were 20.19, 5.72, 1.92 and 0.51 me L^{-1}, respectively. In case of anions, chloride was the dominant ion with a maximum value of 76.30 me L^{-1} observed in village Wazirpur and minimum value of 1.40 me L^{-1} in village Majra. The mean value for CO_3^{-2}, HCO_3^-, Cl^- and SO_4^{-2} were found to be 0.51, 4.13, 20.69 and 1.94 me L^{-1}, respectively. Shahid *et al*. (2008) and Kumar (2011) also reported similar results in Julana block of Jind district and Kanina block of Mahendragarh district, respectively. Analytical results of groundwater quality indicated that the order of abundance of cation concentration were $Na^+ > Mg^{+2} > Ca^{+2} > K^+$ while those of the anions were $Cl^- > HCO_3^- > SO_4^{-2} > CO_3^{-2}$. In arid and semi-arid regions, various workers have reported the dominance of sodium and chloride ions in irrigation waters (Shahid *et al*., 2008).

The mean chemical composition and related quality parameters in different EC ranges for Beri Block are given in Table 2. Maximum number of samples collected (25.3%) were in the EC range of 1-2 dS m^{-1}. The number of samples up to an EC of 2 dS m^{-1}were significantly higher but with further increase in EC beyond 4 dS m^{-1} there was significant decline in number. The Na^+, Mg^{2+} and Ca^{2+} contents increased with increase in the EC of the water samples and the magnitude of increase in Na^+ and Mg^{2+} concentration was much higher than Ca^{2+}. Similarly, concentration of Cl^- anions increased with the increase in the EC of the water samples. SO_4^{2-} and HCO_3^-

Table 2. Chemical composition of groundwater samples of Beri Block in different EC classes

EC classes (dS m^{-1})	% of samples	CO_3	HCO_3	Cl	SO_4	Ca	Mg	Na	K	RSC	SAR
		- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	(me L^{-1})	- - - - - - -	- - - - - - -	- - - - - - -	- - - - - - -	(m mol L^{-1})^{½}
0-1	17.3	0.20	2.82	5.06	0.36	0.64	1.91	6.47	0.16	0.95	6.15
1-2	25.3	0.38	4.02	9.49	1.82	0.84	2.34	12.08	0.39	1.66	10.81
2-3	22.7	0.24	3.89	19.91	1.46	1.81	4.44	19.36	0.68	0.47	11.29
3-4	17.3	1.55	4.55	24.28	2.48	2.58	8.48	23.71	0.64	0.00	10.08
4-5	4.0	0.00	7.57	32.17	2.07	3.27	9.90	33.27	0.25	0.00	12.99
5-6	6.7	0.18	3.08	47.00	2.54	3.84	11.78	38.35	0.54	0.00	14.18
6-7	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7-8	4.0	0.00	7.00	58.37	8.37	4.77	16.03	51.70	1.27	0.00	16.18
8-9	2.7	1.70	6.30	72.60	2.65	6.00	18.65	58.40	0.90	0.00	16.64

Table 3. Per cent samples and per cent area lies in different categories of Beri block of Jhajjar district

Sr. No.	Category of groundwater of the block	Per cent sample categories (hectares)	Area under different of the block	Per cent area
1.	Good	32.0	18270	52.2
2.	Saline			
	i. Marginally saline	34.7	9360	26.7
	ii. Saline	2.7	360	1.0
	iii. High SAR saline	18.6	5350	15.3
	Total saline water	56.0	15070	43.0
3.	Alkali			
	i. Marginally alkali	0.0	0	0.0
	ii. Alkali	2.7	130	0.4
	iii. High alkali	9.3	1550	4.4
	Total alkali water	12.0	1680	4.8

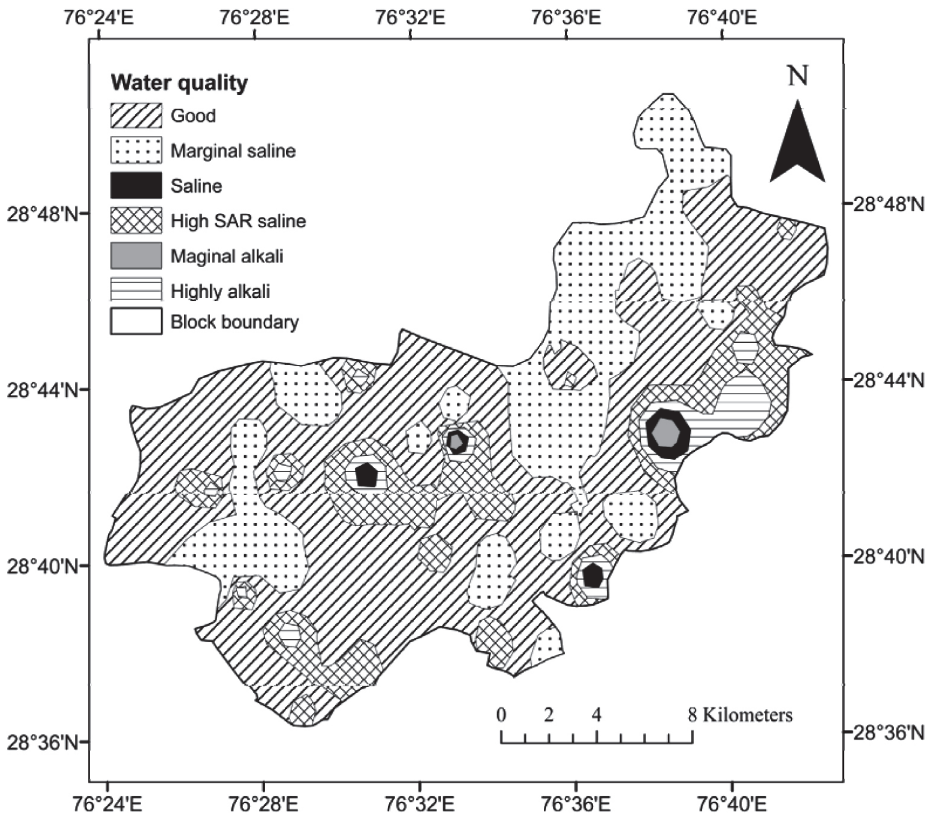

Fig. 6. Spatial variable map of groundwater quality in Beri block

were also found to be in appreciable quantities, whereas, K^+ and CO_3^{2-} were in low quantities and their concentration did not show any relation with EC of irrigation water.

According to AICRP classification (Gupta *et al*., 1994), it was found that 32.0 % water samples were of good quality, 56.0 % saline and 12.0 alkalis in nature (Table 3). Of the saline water samples, 34.7, 2.7 and 18.6 % were marginally saline, saline and high SAR saline, respectively. In the alkali group, 2.7 and 9.3 % were alkali and highly alkali, respectively. Out of seven categories of the water, identified a maximum of 34.7 percent of samples were found to be marginally saline and 2.7 % were in the saline as well as alkali categories.

There was no in marginally alkali category. To study the spatial trend of groundwater quality, spatial variably map was plotted (Fig.6) and by using different features of GIS, area under different category was also calculated and presented in Table 3.

No particular trend in the variation of groundwater quality is present in the block but western parts of the block have greater area under good quality groundwater in relation to other parts of the block. This indicates that the quality of groundwater is better in areas away from

Delhi. In the central part of the block, quality of groundwater is good as well as high SAR saline, whereas, in the northern side, quality of groundwater is varying from marginally saline to good. The better quality of groundwater in western and central parts of the block may be due to Chhapra and Rampur Sikander distributaries that are a source of supply good quality surface water for irrigation. By analysing the area under different categories (Fig. 6), it was found that out of six categories, a maximum area of 18270 ha in the block had good quality water followed by the marginally saline category (9360 ha) and at least area of 130 ha was alkali water. Percent samples in the marginally saline category were highest (34.7 %) but larger area (52.2%) of the block is under good quality. This means the evaluation of area under different categories through GIS technique is more realistic in comparison to percent samples in different categories because GIS works on the principle of spatial variability and not on the per cent samples.

Conclusion

The assessment of groundwater (following AICRP guidelines) demonstrated the utility of GIS technology combined with laboratory analysis in evaluation and mapping of groundwater quality in Beri block. Out of six categories a maximum area (18270 ha) of the block was found under the good quality water category and minimum area (130 ha) was found to be under the alkali category. The results conclude that spatial distribution maps generated using GIS techniques for various physicochemical parameters could be useful for planners and decision makers for initiating groundwater quality development in the area.

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Genetic diversity and association for yield and its contributing traits in Jatropha (*Jatropha curcas* Linn.) for partially reclaimed sodic soils

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ABSTRACT

Experiments were conducted to assess the genetic diversity and magnitude of association of different characters in a set of 35 diverse genotypes of Jatropha. All the component traits showed positive and highly significantly correlation with fruit weight except for the number of productive branches which showed negative correlation. Maximum contributions toward total divergence were observed in case of fruit size, length, plant height, number of fruits per plant and fruit weight per plant. The highest number of genotypes appeared in cluster III with 17 entries followed by cluster I and cluster II with 9 and 5 genotypes, respectively, whereas clusters IV, V, VI and VII had 1 genotype each. The highest intra-cluster distance was observed in cluster III, while, the lowest intra-cluster distance was noted in clusters IV, V, VI and VII. It is suggested that for varietal improvement, selection followed by hybridization among the genotypes will be a suitable approach for better exploitation of heterosis in Jatropha.

Keywords: *Jatropha curcas*, quantitative characters, correlation coefficient, cluster pattern, D square analysis, principal component analysis, heterosis

Introduction

Jatropha is a subtropical plant that produces high quality oil that can be sustainably harvested and processed as a feedstock for biodiesel, renewable jet fuel, or speciality products. Being a non-edible feedstock it can be effectively cultivated on marginal lands not suitable for food crops without any impact on food supplies. It is an undomesticated plant with origin in Central America. It has been reported to grow well in different types of soils, tolerates drought conditions and not browsed by animals (Henning, 2002 and Patil, 2004). It is a versatile plant with multiple uses and gained more popularity due to its potential as a biofuel. Jatropha helps in increasing rural economy and self sustainability for agro-industries (Openshawm, 2000). As with any crop, successful domestication and the generation of elite cultivars requires breeding of genetically diverse germplasm. Earlier reports showed only limited genetic variation in *Jatropha curcas* germplasm collections from Brazil, India, China, and Southeast Asia (Rosado *et al.*, 2010 and Sun *et al.*, 2008). Recently, some researchers reported genetic variation based on morphologic and agronomic characters revealed by using morphological and molecular techniques in the Jatropha populations from India, China, Latin America, Malaysia and Africa (Ginwal *et al.,* 2005; Kaushik *et al.,* 2007; Rao *et al.,* 2008; Rafii *et al.,* 2012a; Arolu *et al.,* 2012; Shabanimofrad *et al.,* 2013). In contrast, remarkable genetic diversity in the SGB germplasm collection using HRM screening techniques were reported. The present study was aimed to estimate the genetic diversity in the available germplasm set, selection of the parents and estimate the association of different traits in partially reclaimed sodic soils.

Materials and method

The experimental materials comprised of 35 diverse Jatopha genotypes collected from different areas (Table 1). All the genotypes were planted in randomised block design with three replications in 2006 in a semi-reclaimed alkali soil field having pH 9.0 at Central Soil Salinity Research Institute (CSSRI), Karnal situated at 29.43º N Latitude and 76.58º N Longitude and 245 m above sea level. The plantation was monitored for six years. Five plants from each genotype were randomly tagged in each replication and the data recorded for plant height, stem diameter, number of total branches, number of flowering branches, number of fruiting branches/plant, number fruits/plant, fruit size length, fruit size width, seed weight and fruit weight/plant from third harvest and was used to analyse for genetic divergence of genotypes using Mahanalobis (1936) distance (D^2) values and analysis of association between different characters as suggested by Dewey and Lu (1959).

Table 1. List of 35 Jatropha genotypes and their locations

Sr. No.	Genotype	Locations/Source	Sr. No.	Genotype	Location/Source
1	Raipur	Chhattisgarh	18	TNMC-23	Tamil Nadu
2	CSMCRI-4	Gujarat	19	TNMC-2	Tamil Nadu
3	CSMCRI-9	Gujarat	20	SDAUJ-1	Gujarat
4	Cutting	Gujarat	21	TNMC-4	Tamil Nadu
5	TNMC-5	Tamil Nadu	22	TNMC-7	Tamil Nadu
6	TNMC-22	Tamil Nadu	23	Tissue Culture Line	Haryana
7	TNMC-20	Tamil Nadu	24	Tissue Culture Line	Haryana
8	Urlikanchan	Maharashtra	25	BTP/A	Uttar Pradesh
9	Hansraj	-	26	BTP/K	Uttar Pradesh
10	S.K.N. J-2	Gujarat	27	BTP/N	Uttar Pradesh
11	TNMC-6	Tamil Nadu	28	NTJH-1	Uttar Pradesh
12	TNMC-28	Tamil Nadu	29	ISH-1	Uttar Pradesh
13	TNMC-19	Tamil Nadu	30	High Yielding -I	Haryana
14	S.K.N. Big	Gujarat	31	High Yielding -II	Haryana
15	TNMC-33	Tamil Nadu	32	High Yielding -III	Haryana
16	Phule J-1	Maharashtra	33	High Yielding -IV	Haryana
17	Hisar-J-1	Haryana	34	High Yielding -V	Haryana
			35	High Yielding -VI	Haryana

Results and discussion

Analysis of variation

Analyses of variance for ten characters are presented in Table 2. The mean sum of squares of all the traits was highly significant indicating the presence of significant variability in the genotypes.

Correlation coefficient

The correlation coefficients for all the traits showed positive and highly significantly correlations with fruit weight per plant except for number of flowering branches per plant and number fruiting branches per plant (Table 3). Highly significant and positive correlations were observed between fruit weight per plant with plant height (0.39), stem diameter (0.28), number of total branch (0.18), number of fruits per plant (0.51), fruit size length (0.24), fruit size width (0.21), and seed weight (0.98). We also noticed positive and significant correlation among the studied traits. The results showed trends similar to those reported by Rao *et al.* (2008), Ginwal *et al.* (2005), Das *et al.* (2010), Alireza *et al.* (2012) and Rafii *et al.* (2012b). Thus plant height, number of total branches and number of fruiting branches are the important traits that could be considered as the major selection index. Number of branches are very important in Jatropha because inflorescences are terminal so for more yield must increase number of branches in plant.

Cluster analysis

Unweighted Paired Group Method using Arithmetic average (UPGMA) is used to construct the dendogram. The relative advantages of UPGMA clustering algorithm have been indicated by many studies in terms of consistency in grouping of biological materials with relation to compound from different type of data. Fruit size length exhibited maximum contribution (37.44%) towards total divergence and was followed by plant height (24.54%), number of fruits per plant (10.76%), fruit weight per plant (10.59%), fruit size width (9.08%), stem diameter (7.90%), seed weight (4.87%), number of flowering branch per plant (2.86%), number of total branches (0.67%). The least contribution was observed for number of fruiting branches per plant (0.17%) towards total divergence (Table 4).

The genetic divergence of 35 Jatropha genotypes was studied by employing non-hierarchical Euclidean cluster analysis for 10 quantitative characters and the genotypes were group into seven clusters (Fig. 1). The highest number of genotypes appeared in cluster III containing 17 genotypes, followed by cluster I and II with 9 and 5 genotypes and clusters IV, V, VI and VII had 1 genotype each, respectively.

The intra and inter cluster distance of 35 genotypes are presented in Table 5. The highest intra-cluster distance was observed in case of cluster III (2.19) followed by cluster I (1.49) and cluster II (1.24). The maximum inter-cluster distance was observed between cluster II and IV (7.11) followed by cluster II and V (6.41), cluster II and VII (6.37), cluster II and III (6.11) and cluster II and VI (6.03). It is noteworthy to mention that the selection of genotypes from cluster II and cluster IV could be useful in breeding programme to exploit the heterosis of yield in reclaimed sodic soils. This information can be utilized

Table 2. Analysis of variance (ANOVA) of yield and its contributing characters in Jatropha

Characters	d. f.	Plant height (cm)	Stem diameter (cm)	Number of total branches	Number of flowering branches	Number of fruiting branches/plant	Number fruits/ plant	Fruit size length (cm)	Fruit size width (cm)	Seed weight (g)	Fruit weight/ plant (g)
Replication	2	72.20	0.07	2.46	2.57	5.53	278.00	0.01	0.01	2021.34	848.81
Treatment	34	25313.03**	14.82**	2121.03**	283.34**	492.40**	45869.66**	2.50**	1.81**	1454808.98**	498391.85**
Error	68	879.08	0.19	85.31	18.99	16.91	4831.07	0.06	0.06	51113	23547.65

** Significant at p=0.1 level

Table 3. Correlation coefficient of yield and its yield components in Jatropha

Characters	Plant height (cm)	Stem diameter (cm)	Number of total branches	Number of flowering branches	Number of fruiting branches/plant	Number fruits/ plant	Fruit size length (cm)	Fruit size width (cm)	Seed weight (g)	Fruit weight/ plant (g)
Plant height (cm)	1	0.36**	0.77**	0.60**	0.62**	0.55**	0.54**	0.47**	0.38**	0.39**
Stem diameter (cm)		1	0.36**	-0.05	0.36**	0.24**	0.21**	0.25**	0.31**	0.28**
Number of total branches			1	0.71**	0.71**	0.39**	0.37**	0.34**	0.19**	0.18**
Number of flowering branches/plant				1	0.69**	0.32**	0.31**	0.28**	-0.02	-0.02
Number of fruiting branches /plant					1	0.43**	0.40**	0.38**	-0.04	-0.06
Number of fruits /plant						1	0.43**	0.38**	0.50**	0.51**
Fruit size length (cm)							1	0.93**	0.22**	0.24**
Fruit size width (cm)								1	0.20**	0.21**
Seed weight (g)									1	0.98**

Note: * & ** Significant at 5% and 1% probability level, respectively

Table 4. Per cent contribution of different characters towards total genetic divergence in Jatropha

Characters	Contribution %
Plant height (cm)	24.54%
Stem diameter (cm)	7.90%
Number of total branch	0.67%
Number of flowering branch/plant	2.86%
Number of fruiting branch /plant	0.17%
Number of fruits /plant	10.76%
Fruit size length (cm)	28.57%
Fruit size width (cm)	9.08%
Seed weight (g)	4.87%
Fruit weight/ plant (g)	10.59%

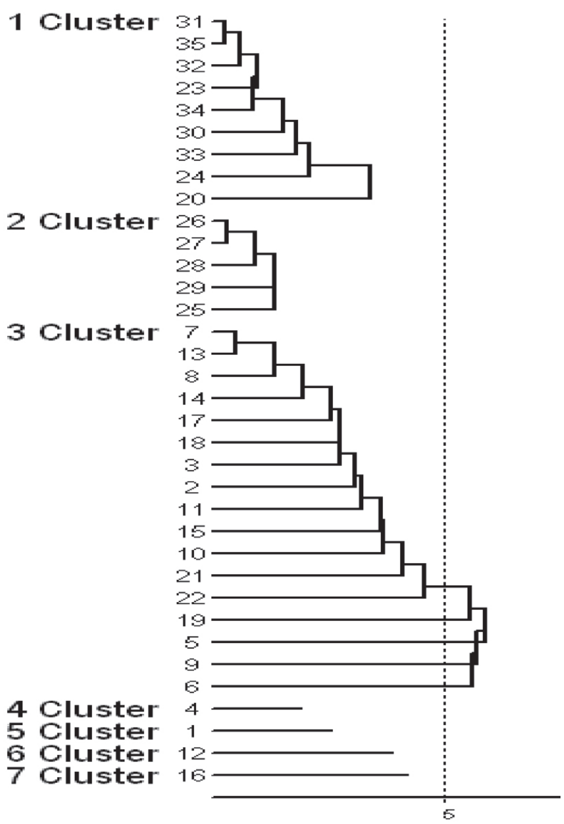

Fig. 1. Dendrogram of 35 Jatropha genotypes based on the 10 quantitative traits

to select some genotypes from the cluster II and cluster IV and use in the hybridization programme.

Highest cluster mean value for the number of fruits per plant was recorded in cluster VI (364.33) followed by cluster V (360.33) and cluster VI (313.33).The genotypes of cluster IV were responsible for plant height (272.33) followed by entries of cluster VII (262.33) and cluster III (253.57), while the lowest mean of 150.57 was observed in cluster II (Table 6). The highest cluster mean for the stem diameter was recorded in case of cluster IV (5.57) followed by cluster V (5.43) and cluster VII (5.37). The lowest cluster mean was noticed in cluster VI (4.63). Highest cluster mean for the number of total branches was recorded in cluster V (19.67) followed by cluster VI (15.00), cluster VII (13.67) and cluster III (13.37) while, the lowest mean was observed in cluster I (5.22). Considering the variation in the number of flowering branches per plant, cluster V (19.33) showed the highest mean value, while cluster I (3.41) and cluster II (4.4) had the lowest value for number of flowering branch per plant. The genotypes occurring in cluster V (18.33) followed by cluster VI and VII (10.33) respectively showed the highest cluster mean number of fruiting branches per plant, while the genotypes of cluster II (0.00) were responsible for the lowest mean. Gohil and Pandya (2006) have also pointed out in *Salicornia brachiata* Roxb (a non-traditional oilseed plant) that selection of parents for hybridization should be done from two clusters having wider inter-cluster distance to get maximum variability.

Principal component analysis (PCA)

The first principal component accounted for more than 59.94 per cent of total variance thereby indicating that plant height and fruit size length were the variables that contributed most positively and also registered those with high yield component values (Table 7). The first component identified mainly phenological variables, denoting a clear delimitation and positive contribution of phases and on the contrary of yield component and discriminatory.

The second principal component accounted for more than 18.91 per cent of total variance. Variables highly and

Table 5. Intra (bold) and inter cluster distance for 35 Jatropha genotypes

ClusterDistances	I	II	III	IV	V	VI	VII
I	**1.49**	5.77	3.17	4.1	3.75	3.88	3.29
II		**1.24**	6.11	7.11	6.41	6.03	6.37
III			**2.19**	2.58	2.6	2.62	2.71
IV				**0.00**	3.06	2.28	2.69
V					**0.00**	3.42	3.63
VI						**0.00**	3.26
VII							**0.00**

Note: bold figures are represented intracluster values

Table 6. Mean values of seven clusters for different characters in 35 genotypes of Jatropha

Cluster Means	Plant height (cm)	Stem diameter (cm)	Number of total branches	Number of flowering branches	Number of fruiting branches/plant	Number of fruits/ plant	Fruit size length (cm)	Fruit size width (cm)	Seed weight (g)	Fruit weight/ plant (g)
I	154.89	4.8	5.22	3.41	2.67	51.33	2.43	2.17	91.47	47.78
II	150.27	4.86	6.73	4.4	0.001	0.001	0.001	0.001	0.001	0.001
III	253.57	4.92	13.37	11.06	9.71	229.25	2.36	1.95	421.29	202.00
IV	272.33	5.57	9.33	9.33	9.00	364.33	2.57	2.07	835.3	403.63
V	250.67	5.43	19.67	19.33	18.33	360.33	2.27	2.07	532.33	318.33
VI	239.67	4.63	15.00	7.67	10.33	313.33	2.17	1.43	690.97	311.00
VII	262.33	5.37	13.67	10.67	10.33	115.33	2.37	2.13	616.43	268.93

Table 7. Coefficients and vectors associated with three principal components

Particulars	First component	Second component	Third component
Eigen value	147.99	46.70	16.12
Variance (%)	59.94	18.91	6.53
Cumulative Variance (%)	59.94	78.86	85.40
		Coefficient Vector	
Plant height (cm)	0.32	0.63	0.24
Stem diameter (cm)	-0.02	0.10	0.26
Number of total branches	-0.09	-0.23	-0.26
Number of flowering branches/plant	0.03	0.04	-0.05
Number of fruiting branches /plant	0.16	0.11	-0.02
Number of fruits /plant	0.22	0.30	-0.37
Fruit size length (cm)	0.84	-0.42	0.15
Fruit size width (cm)	0.20	-0.21	-0.20
Seed weight (g)	-0.01	-0.17	-0.57
Fruit weight/ plant (g)	-0.21	-0.40	0.50

positively correlated were the plant height and number of fruits per plant. The second component, therefore, identified yield component variables presenting positive contribution and the main characters responsible for classification. The third principal component accounted for 6.53 percent and was positively associated with plant height, stem diameter, and fruit weight per plant (Table 7).

Conclusions

Variability is an important component in breeding programme to exploit the heterosis. Presence of considerable variability in the present set of Jatropha is indicated for most of the plant characteristics and the same could be exploited for improvement in yield and economic value. Plant height, number of fruits per plant, and seed weight would be helpful for indirect selection for improvement in yield. The breeder is always concerned for the selection of superior genotype on the basis of phenotypic expression. However, for the quantitative characters, genotypes are influenced by environment, thereby effecting the phenotypic expression. Information regarding the nature and extent of association of morphological character would be helpful in developing suitable plant type, in addition to the improvement of yield, a complex character for which direct selection is not effective. Plant morphology suggested that the genotypes could be grouped as potential donors according to specific traits. Such groupings are helpful to breeders in identifying possible genotype that may be used as "donor parents" in breeding for any of the morphological traits.

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Evaluation of rice genotypes for yield, physiological and biological traits in sodic soils

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ABSTRACT

The present investigation was conducted to determine the physiological and biochemical basis of salt tolerance with particular reference to sodicity employing forty seven rice genotypes. The field experiment was conducted in sodic soil at Central Soil Salinity Research Institute, Regional Research Station, Lucknow. The pigment chlorophyll a/b ratio, chlorophyll stability index, soluble protein and proline content recorded higher values in the genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 indicating their tolerance to salt stress. The genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 expressed low Na/K ratio and grouped as salt tolerant. Among the 47 genotypes evaluated, IR 76393-2B-7-1-1-3-1 recorded the highest yield and was followed by IR 77664-B-25-1-2-1-3-12-5-AJY1 and IR 71991-3R-2-6-1 The number of productive tillers, number of filled grains panicle^{-1} and spikelet fertility were contributing for higher grain yield in these tolerant cultivars. Days to 50 per cent flowering and 1000-grain weight established negative relationship while significantly positive correlation was noticed between total dry matter accumulation and grain yield.

Key words: *Oryza sativa*, salt stress, pigments, proteins, enzymes, nutrients and yield attributes.

Introduction

Rice is the second most important cereal crops in the world after wheat, with exceptional agricultural and economic importance as being a staple food for more than 50% population worldwide. Asian farmers produce more than 90% of the total rice, with India and China, growing more than half of the total crop (IRRI, 2011). It is the most important food crop in the developing countries, accounting for about 29 per cent of the total calories in terms of food intake. Soil salinity is a major problem in the arid and semi-arid regions throughout the world (Demir and Mavi, 2008; Sima *et al.,* 2009) where rainfall is insufficient to leach salts and excess sodium ion down and out of the root zone. Today, salinization of millions ha of land causes severe reduction in crop productivity. With increased irrigation facilities and poor water management practices, the problem of salt stress is increasing day by day. Generally, salt stress affects rice growth and yield through osmotic effects, ion-specific effects, and oxidative stress in Asia and Africa (Lee *et al*., 2007). However, the yield of rice, especially Asian rice (*Oryza sativa*), is highly susceptible to salt stress particularly at seedling stage (Geo *et al.,* 2007, Munns and Tester, 2008, Khan and Panda, 2008). Screening of rice genotypes for the salt tolerant potential has been carried out using various screening methodologies to screen tolerant potential of the genotypes (Surekha *et al.*, 2008). According to an FAO report, nearly seven per cent of the world's land area is salt affected (Flower *et al.*, 1997). Therefore, there is a great deal of urgency for developing rice genotypes, which can sustain and set seed under high salt stress condition. Efforts to improve productivity of rice under salt stress condition need understanding of the mechanisms to identify traits required for productivity improvement programme.

In agriculture, the problem of salt stress is becoming severe every year as the saline soils and waters are increasingly exploited to accommodate the growing demand for food and plant products. There is a need for technological and biological solutions to increase productivity. These efforts to improve productivity of rice under salt conditions require understanding of the mechanisms of the plant so as to identify the traits required for productivity improvement programmes. Salt tolerance is the manifestation of morphological, physiological and biochemical variations, which allow the crop to survive, grow and maximize yield under salt conditions.

Materials and methods

The field experiment was conducted in sodic soil (pH 9.5) at Central Soil Salinity Research Institute, Regional

Table 1. Modified standard evaluation system of visual salt injury at seedling stage

Score	Observation	Tolerance
1	Normal growth, no leaf symptoms	Highly tolerant
3	Nearly normal growth, but leaf tips of few leaves whitish and rolled	Tolerant
5	Growth severely retarded, most leaves rolled	Moderately tolerant
7	Complete cessation of growth, most leaves dry, some plant dying	Susceptible
9	Almost all plant dead or dying	Highly susceptible

Research Station, Lucknow. The study was conducted in the *Kharif* season 2011 in randomized block design replicated thrice. Forty seven rice genotypes were raised in the nursery in a field having normal soil. Transplanting of 30 days old seedlings was done in the main field having sodic soil (pH 9.5). Two to three seedlings hill^{-1} were transplanted with the spacing of 20 × 15 cm. Rapid screening method for evaluation of responses of genotypes to salt stress standard evaluation system (SES) of visual salt injury at seedling stage as presented in Table 1 was followed. The physical and chemical properties of the soils of the experimental field were analysed (Table 2). Plant samples were collected at all phenological stages of the crop and their physiological, biochemical, nutrients and yield parameters analysed.

Biochemical characters

The biochemical characters were estimated at the flowering stage. The chlorophyll ('a', 'b' and total) contents were estimated in flag leaf by adopting the procedure of Yoshida *et al.* (1981) and expressed as mg g^{-1} on fresh weight basis. The chlorophyll a/b ratio was also worked out. The chlorophyll stability index (CSI) was estimated as per the method described by Murty and Majumder (1962) and the value expressed as percentage. Soluble protein content was determined by the procedure given by Lowry *et al.* (1951) and expressed as mg g^{-1} on fresh weight basis. The amino acid proline content was estimated in fully expanded leaves at the flowering stage following the method of Bates *et al.* (1973) and expressed on µg g^{-1} on fresh weight basis.

Nutrient analysis

Potassium and sodium contents of the plant samples drawn at various phenophases were analysed by flame photometer using triple acid extract and expressed as mg g^{-1} on dry weight basis. The Na/K ratio was worked out for flowering stage based on the respective nutrient contents.

Table 2. Soil characteristics of the experimental field.

S.No.	Property	
1	Soil pH	9.5
2	EC dS m^{-1}	0.53
3	CEC me 100 mg^{-1}	10.2
4	ESP	40
5	Available nitrogen (kg ha^{-1})	178
6	Available phosphorus (kg ha^{-1})	7
7	Available potassium (kg ha^{-1})	170

Productive characters

After harvest, five plants from each genotype were selected and number of grains per spikelet was counted for each replication and the average was recorded. The number of filled grains per panicle was counted from five plants in each of the three replications and mean values worked out. The ratio of well-filled grains to the total number of spikelets in the primary panicle of each plant was expressed as per cent. After the harvest, the grains were dried and 1000-grain weight for each variety in three replications was recorded at random and average was expressed in grams. After the harvest, five plants from each treatment and replication were selected for measuring the panicle length and average was expressed in cm. The panicle weight from five plants from each treatment and replication was recorded after oven-drying and mean was worked out and expressed in g. The straw and grain yields from each plot were recorded after drying and the values were computed on hectare basis and the respective values were expressed in kgha^{-1}. Harvest index (HI) of the selected genotypes was calculated by using the formula of Yoshida *et al.,* (1972) and the values were expressed as percentage. The mean values of the above mentioned observations were subjected to statistical analysis and the genotypes were tested for their significance by adopting the procedure of Panse and Sukhatme (1961).

Results and discussion

In the present study, attempts were made with the main objective of finding that the physiological factors responsible for tolerance nature of rice genotypes at different phonological stages of crop growth. The genetic variability and physiological characters would help greatly in breeding for high yielding off springs suited to the salt stress condition. The results of the field experiments carried out in the present investigation are presented and discussed below with more emphasis on the relationship with grain yield.

Chlorophyll

The pigment chlorophyll content can be considered as one of the indices to screen the genotypes for salt stress, since salinity induced chlorophyll reduction and consequently the reduction in photosynthesis is well established by Weisel (1981). Chloroplasts are the primary light absorbing pigments found in the leaves. Chlorophyll 'a' has twice the concentration of chlorophyll 'b' reported by Parker and Biggins (1964). Significant variation among genotypes for chlorophyll 'a' and 'b' content was observed. Chlorophyll a/b ratio has often been considered as a measure of the activity of chlorophyll synthesising mechanism in plants under stress condition (Kupke and Huntington,1963). In the present study, significant variation for the chlorophyll a/b ratio was noticed among the 47 genotypes tested (Table 4). Sodicity affects the chlorophyll content in plants. Maximum chlorophyll a/b ratio was found in genotype IR-29 followed by IR-28, IR 77674-3B-8-2-2-14-2-AJY 3, IR 70023-4B-R-12-2-3-1, IR 71866-3R-1-2-1 and IR 77664-B-25-1-2-1-3-12-3-AJY 1.

Contents of chlorophyll 'a' and total chlorophyll were higher in both susceptible and tolerant cultivars and productivity of rice under salt condition require understanding of the mechanisms of the plant so as to identify the traits required for productivity improvement programmes.

Chlorophyll stability index (CSI)

The CSI is an important index for screening of genotypes for abiotic stresses (Michael *et al., 2002* and Yogameenakshi, 2002). Significant variation was recorded among the 47 genotypes for this parameter (Table 4). The genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 recorded higher value for CSI indicating their tolerance to sodicity. The association between grain yield and CSI was positive and significant (r =0.48**).

Soluble protein content

The genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 registered comparatively higher values for the soluble protein implying their salt tolerance (Table 4). A positive correlation between soluble protein and grain yield was established in this study (r=0.463*). Protein contents in leaves were found to be correlated with plant growth rate, leaf area index, tiller and panicle number Jayabalan *et al.,* (1990). Jha and Singh (1997) reported higher protein content of stressed seedlings of the tolerant rice cultivars as compared to the susceptible cultivars.

Proline content

Significant variation in proline content was recorded in the 47 rice genotypes (Table 4). Genotypes such as IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 recorded higher proline content. The positive association of proline with grain yield (r =0.31*) exhibits the tolerant nature of the above mentioned genotypes under salt stress and association of this trait with sodicity tolerance. The proline accumulation may be due to either non-incorporation of free amino acid proline into protein synthesis due to salt stress or the breakdown of the existing protein molecules into various constituent amino acids with proline being predominant (Mukerjee, 1974, Singh and Singh 1999). The loss of turgor due to salt stress triggers proline accumulation in plants contributing to osmotic adjustment and stress tolerance was observed by Aslam *et al.,* (1982). Besides this, proline can also serve as a protector of enzyme denaturation, a reservoir of nitrogen and carbon or as a stabiliser of the machinery for protein synthesis (Hamada and Khulaef, 1995).

Na/K contents

In this study, the genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 expressed low Na/K ratio and are therefore grouped as the tolerant types (Table 4). The high Na/K ratio leads to metabolic disorders such as reduction in protein synthesis and enzyme activities (Brady *et al.,* 1984).

Presence of high K content in the tolerant genotypes observed in this study resulted in higher yielding ability even under salt environment. This is in accordance with Joshi e*t al.,* (1980). The tissue concentration of sodium and potassium and the ratio Na/K has been suggested as useful parameters for screening genotypes of any crop under salt stress condition. Increase in K content acts as an osmoticum, which prevents Na-influx into the root and its further translocation to the more sensitive shoots (Jacoby, 1999).

Yield attributes

The correlation matrix worked out between grain yield and yield attributes indicated that the attributes namely, number of productive tillers, number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, spikelet fertility, total dry matter accumulation (TDMA) and harvest index (HI) showed a significant positive association with grain yield. Significant variation among the genotypes was observed for most of these characters (Table 5, 6). Similar results were reported by Krishnamurthy et al, (2014) in rice under saline stress conditions and Ali et al, (2013) under both saline and sodic stress environments. Among the 47 cultivars used, the salt tolerant variety CSR 36 recorded the highest yield of 5363.9 kg ha^{-1} followed by

Table 3. Effect of salt stress on stress score of different genotypes at reproductive stage

S. No.	Designation	Cross	Origin	Stress Score at reproductive stage
1	IR 77664-B-25-1-2-1-3-12-4-AJY 1	NSIC RC 110/PSB RC 86	IRRI	4
2	IR 76393-2B-7-1-1-3-1	IR 71657-5R-B-12 PB/IR 52713-2B-8-2B-1-2	IRRI	3
3	IR 76393-B-B-10-1-1-1	IR 52713-2B-8-2B-1-2/IR65195-3B-13-2-3	IRRI	5
4	IR 07T114	IR71730-51-2/NSIC RC 106	IRRI	5
5	IR 77664-3B-8-2-2-14-2-AJY 4	IR 71730-51-2/NSIC RC106	IRRI	7
6	IR 77664-B-25-1-2-1-3-12-3-AJY 1	NSIC RC 110/PSB RC 86	IRRI	7
7	IR 77674-3B-8-2-2-14-2-AJY 3	IR 71730-51-2/NSIC RC106	IRRI	8
8	IR 78806 -B-B-16-1-2-2-AJY 1	PSB RC 86/IR 64	IRRI	6
9	IR 77664-B-25-1-2-1-3-12-5-AJY 1	NSIC RC 110/PSB RC 86	IRRI	3
10	IR 71829-3R-10-3	IR 20/IR 55182-3B-14-3-2	IRRI	4
11	IR 72048-B-R-16-2-3-3	IR 55182-3B-14-3-2*2/IR 44699-26-3-1-1	IRRI	7
12	IR 71866-3R-1-2-1	IR 10198-66-2/IR66-2/IR65195-3B-13-2-3	IRRI	8
13	IR 72046-B-R-8-3-1-3	IR 31406-333-1/2*IR 31142-14-1-1-3-2	IRRI	6
14	IR 75395-2B-B-19-2-1-2	IR 63731-1-1-4-3-2-2/IR 68144-2B -2-2-3-9	IRRI	5
15	IR 65833-4B-17-1-3	IR 8192-200-3-3-1-1/KETUMBAR	IRRI	6
16	IR 71895-3R-9-3-1	IR 55182-3B-14-3-2/IR 651853B-8-3-2	IRRI	6
17	IR 71907-3R-2-1-2	IR 63731-1-1-4-3-2-2/IR 52713-2B -8-2B-1-2	IRRI	5
18	IR 71907-3R-2-1-1	IR 63731-1-1-4-3-2-2/IR 52713-2B-8-2B-1-2	IRRI	7
19	IR 71999-3R-3-2-2-B-1-1	IR 20/IR 10198-66-2	IRRI	7
20	IR 72580-B-24-3-3-3-2	IR 20/2*IR 9884-54-3-1E-P1	IRRI	7
21	IR 51499-2B-29-2B-1-1	IR 5657-33-2/POKKALI	IRRI	5
22	IR 61919-3B-24-3	IR 8192-200-3-3-1-1/RAMINAD STR 3	IRRI	5
23	IR 71829-3R-82-1-1	IR 20/IR 55182-3B-14-3-2	IRRI	5
24	IR 72049-B-R-22-3-1-1	IR 55182-3B-14-3-2*2/IR 44699-29-2-2-2	IRRI	6
25	IR 50184-3B-18-2B-1	IR 17491-5-4-3-3/POKKALI//IR 17491-5-4-3-3/ IR 10206-29-2-1	IRRI	5
26	IR 730055-8-1-1-3-1	IR 71656-5R-B-12 PB/IR 60494-2B-18-3-2-3	IRRI	6
27	IR 70023-4B-R-12-3-1	IR 50184-3B-8-2B-1/IR 10198-66-2	IRRI	5
28	IR 71991-3R-2-6-1	IR 5/IR 52713-2B-8-2B-1-2	IRRI	3
29	IR 70023-4B-R-12-2-3-1	IR 20184-3B-8-2B-1/IR 10198-66-2	IRRI	8
30	IR 63731-1-1-1-3-3-2	IR 8/NONA BOKRA	IRRI	4
31	IR 71829-3B-28-1	IR 20/IR 55182-3B-14-3-2	IRRI	5
32	IR 70023-4B-R-12-3-1	IR 50182-3B-8-2B-1/IR 10198-66-2	IRRI	6
33	IR 72579-B-2R-3-1-1	CSR 10/IR 20/IR 26	IRRI	6
34	IR 68652-3B-20-3	IR 20/POKKALI B	IRRI	6
35	IR 10T117	IRRI 147/IR 66946-3R -178-1-1	IRRI	6
36	POKKALI (ACC 108921)	POKKALI	SRI LANKA	3
37	NONA BOKRA		INDIA	5
38	IR 29	IR 833-6-2-1-1/// IR 1561-149-1// IR 661-1-140-3*4/O.NIVARA	IRRI	9
39	IR 28	IR 833-6-2-1-1/// IR 1561-149-1// IR 661-1-140-3*4/O.NIVARA	IRRI	9
40	IR 66946-3R-178-1-1 (FL 478)	IR 29/POKKALI B	IRRI	4
41	CSR 28	IR 42/IR 4630-22-2-5-1-3	INDIA	5
42	IR 55179-3B-11-3	IR 4630-22-2-5-1-3/N. BOKRA	IRRI	7
43	AT 401		SRI LANKA	5
44	IR 45427-2B-2-2B-1-1	CHERIVIRUPPU/ IR 10205-37-1-3	IRRI	6
45	A 69-1	BG 94-1/POKKALI	SRI LANKA	7
46	AGAMI MI		EGYPT	5
47	LOCAL CHECK (CSR 36)		INDIA	3

Table 4. Effect of salt stress on chlorophyll a/b ratio, chlorophyll stability index, protein content, proline content and Na/K ratio in 47 rice genotypes at flowering stage

S. No.	Genotypes	Chlorophyll a/b ratio	Chlorophyll stability index(%)	Protein content (mg g^{-1})	Proline content (mg g^{-1} fr. wt.)	Na/K ratio
1	IR 77664-B-25-1-2-1-3-12-4-AJY 1	1.59	76	11.42	1.86	0.109
2	IR 76393-2B-7-1-1-3-1	1.36	82	17.25	2.44	0.102
3	IR 76393-B-B-10-1-1-1	1.66	70	11.86	1.40	0.135
4	IR 07T114	1.64	64	11.78	1.38	0.140
5	IR 77664-3B-8-2-2-14-2-AJY 4	1.79	42	10.94	0.81	0.203
6	IR 77664-B-25-1-2-1-3-12-3-AJY 1	1.87	43	10.42	0.98	0.194
7	IR 77674-3B-8-2-2-14-2-AJY 3	1.99	37	12..72	0.68	0.245
8	IR 78806 -B-B-16-1-2-2-AJY 1	1.75	62	11.27	1.28	0.152
9	IR 77664-B-25-1-2-1-3-12-5-AJY 1	1.40	85	16.14	2.11	0.105
10	IR 71829-3R-10-3	1.51	81	14.59	1.90	0.111
11	IR 72048-B-R-16-2-3-3	1.81	41	10.18	0.91	0.199
12	IR 71866-3R-1-2-1	1.87	46	10.86	0.79	0.213
13	IR 72046-B-R-8-3-1-3	1.78	44	10.66	1.05	0.185
14	IR 75395-2B-B-19-2-1-2	1.68	70	12.09	1.56	0.120
15	IR 65833-4B-17-1-3	1.71	52	10.90	1.13	0.177
16	IR 71895-3R-9-3-1	1.81	57	11.22	1.26	0.155
17	IR 71907-3R-2-1-2	1.65	65	11.62	1.35	0.145
18	IR 71907-3R-2-1-1	1.80	47	11.20	0.99	0.193
19	IR 71999-3R-3-2-2-B-1-1	1.86	48	10.26	0.94	0.197
20	IR 72580-B-24-3-3-3-2	1.82	46	10.34	0.97	0.196
21	IR 51499-2B-29-2B-1-1	1.62	64	12.18	1.59	0.111
22	IR 61919-3B-24-3	1.66	65	12.02	1.46	0.125
23	IR 71829-3R-82-1-1	1.66	61	11.54	1.34	0.145
24	IR 72049-B-R-22-3-1-1	1.78	54	11.06	1.22	0.165
25	IR 50184-3B-18-2B-1	1.57	78	12.34	1.77	0.110
26	IR 730055-8-1-1-3-1	1.76	57	10.82	1.10	0.179
27	IR 70023-4B-R-12-3-1	1.71	68	11.94	1.44	0.130
28	IR 71991-3R-2-6-1	1.64	80	15.92	2.01	0.107
29	IR 70023-4B-R-12-2-3-1	1.94	41	11.64	0.69	0.225
30	IR 63731-1-1-1-3-3-2	1.45	77	13.45	1.94	0.108
31	IR 71829-3B-28-1	1.60	74	12.26	1.66	0.111
32	IR 70023-4B-R-12-3-1	1.85	49	10.74	1.08	0.181
33	IR 72579-B-2R-3-1-1	1.70	55	11.38	1.29	0.151
34	IR 68652-3B-20-3	1.74	56	10.92	1.21	0.167
35	IR 10T117	1.67	60	11.46	1.32	0.150
36	POKKALI (ACC 108921)	1.18	81	15.54	2.45	0..125
37	NONA BOKRA	1.12	84	17.62	2.76	0.112
38	IR 29	2.45	35	8.72	0.60	0.314
39	IR 28	2.36	35	9.32	0.64	0.358
40	IR 66946-3R-178-1-1 (FL 478)	1.34	87	17.54	2.38	0.191
41	CSR 28	1.41	77	15.52	2.34	0.103
42	IR 55179-3B-11-3	1.86	49	10.02	0.85	0.199
43	AT 401	1.29	78	16.57	1.97	0.119
44	IR 45427-2B-2-2B-1-1	1.72	60	11.13	1.24	0.161
45	A 69-1	1.35	84	10.10	2.86	0.124
46	AGAMI MI	1.29	78	15.58	2.46	0.125
47	LOCAL CHECK (CSR 36)	1.29	88	18.50	2.51	0.101
	Std	**0.26**	**15.88**	**3.08**	**0.61**	**0.585**
	SEd	0.37	2.47	4.36	0.86	0.083
	CD(P=0.05)	0.74	42.48	4.78	1.73	0.166

Table 5. Effect of salt stress on yield and yield attributes in 47 rice genotypes.

S. No.	Genotypes	Days to 50% flowering	No. of productive tillers	Filled grain/ panicle	Unfilled grain/ panicle	Total grains / panicle	Spikelet fertility (%)
1	IR 77664-B-25-1-2-1-3-12-4-AJY 1	98	16.7	121	43	163	73.88
2	IR 76393-2B-7-1-1-3-1	100	15.9	178	48	226	78.76
3	IR 76393-B-B-10-1-1-1	88	11.0	68	41	109	62.27
4	IR 07T114	96	15.4	75	47	121	61.54
5	IR 77664-3B-8-2-2-14-2-AJY 4	85	9.7	48	75	123	39.02
6	IR 77664-B-25-1-2-1-3-12-3-AJY 1	88	9.0	78	88	166	46.99
7	IR 77674-3B-8-2-2-14-2-AJY 3	90	7.7	44	89	133	33.08
8	IR 78806 -B-B-16-1-2-2-AJY 1	94	9.5	114	88	202	56.51
9	IR 77664-B-25-1-2-1-3-12-5-AJY 1	114	12.0	175	49	224	78.13
10	IR 71829-3R-10-3	136	12.0	87	27	113	76.47
11	IR 72048-B-R-16-2-3-3	135	9.8	46	58	104	44.23
12	IR 71866-3R-1-2-1	125	7.9	45	78	123	36.59
13	IR 72046-B-R-8-3-1-3	108	8.5	75	78	153	49.02
14	IR 75395-2B-B-19-2-1-2	109	12.9	69	37	106	65.41
15	IR 65833-4B-17-1-3	110	8.9	89	82	171	52.15
16	IR 71895-3R-9-3-1	125	10.0	154	120	274	56.20
17	IR 71907-3R-2-1-2	118	10.0	54	34	88	61.13
18	IR 71907-3R-2-1-1	108	9.2	58	63	121	47.93
19	IR 71999-3R-3-2-2-B-1-1	125	7.8	56	65	121	46.28
20	IR 72580-B-24-3-3-3-2	135	8.1	51	58	109	46.79
21	IR 51499-2B-29-2B-1-1	125	11.0	200	80	280	71.43
22	IR 61919-3B-24-3	83	11.0	102	54	156	65.38
23	IR 71829-3R-82-1-1	126	11.7	57	37	95	60.56
24	IR 72049-B-R-22-3-1-1	84	8.9	94	78	172	54.56
25	IR 50184-3B-18-2B-1	115	11.0	108	38	146	73.80
26	IR 730055-8-1-1-3-1	120	10.0	105	98	203	51.72
27	IR 70023-4B-R-12-3-1	125	14.6	90	49	139	64.75
28	IR 71991-3R-2-6-1	90	14.9	236	68	304	77.63
29	IR 70023-4B-R-12-2-3-1	97	9.7	51	85	136	37.50
30	IR 63731-1-1-1-3-3-2	132	13.0	97	29	126	76.78
31	IR 71829-3B-28-1	133	13.7	123	48	172	71.84
32	IR 70023-4B-R-12-3-1	132	8.0	47	47	94	49.65
33	IR 72579-B-2R-3-1-1	126	9.9	90	68	158	56.96
34	IR 68652-3B-20-3	85	11.5	106	93	199	53.10
35	IR 10T117	86	10.0	106	73	179	59.22
36	POKKALI (ACC 108921)	134	8.1	45	92	137	32.85
37	NONA BOKRA	126	7.9	48	81	129	37.21
38	IR 29	92	6.0	39	94	133	29.40
39	IR 28	98	6.9	50	102	152	32.89
40	IR 66946-3R-178-1-1 (FL 478)	86	8.7	38	88	126	30.16
41	CSR 28	99	12.9	102	65	167	61.08
42	IR 55179-3B-11-3	124	8.0	65	98	163	39.88
43	AT 401	111	14.2	58	61	119	48.74
44	IR 45427-2B-2-2B-1-1	104	9.0	100	84	184	54.35
45	A 69-1	112	7.0	47	63	110	42.60
46	AGAMI MI	103	10.5	47	77	124	37.90
47	LOCAL CHECK (CSR 36)	112	17.8	170	44	214	79.47
	Std	7.07	2.76	26.05	22.20	19.19	8.78
	SEd	11.14	3.91	31.12	31.40	29.57	11.91
	CD(P=0.05)	23.61	7.86	61.09	67.22	50.05	24.10

Table 6. Effect of salt stress on yield and yield attributes in 47 rice genotypes

S. No.	Genotypes	Panicle wt (g)	Panicle length (cm)	1000 seed wt (g)	TDMA/ hill (g)	Grain yield (kg ha^{-1})
1	IR 77664-B-25-1-2-1-3-12-4-AJY 1	2.64	23.7	25.6	52.8	4589.3
2	IR 76393-2B-7-1-1-3-1	2.78	28.5	27.6	57.7	5055.6
3	IR 76393-B-B-10-1-1-1	2.22	20.1	24.6	46.7	4222.7
4	IR 07T114	2.55	20.0	24.5	46.3	4197.4
5	IR 77664-3B-8-2-2-14-2-AJY 4	1.68	18.1	22.7	33.6	2944.9
6	IR 77664-B-25-1-2-1-3-12-3-AJY 1	1.80	18.7	23.8	36.0	3638.7
7	IR 77674-3B-8-2-2-14-2-AJY 3	1.22	17.7	21.0	18.7	2416.7
8	IR 78806-B-B-16-1-2-2-AJY 1	2.05	19.4	24.3	41.6	4027.5
9	IR 77664-B-25-1-2-1-3-12-5-AJY 1	3.01	26.9	27.4	56.9	4868.1
10	IR 71829-3R-10-3	2.32	24.6	25.7	54.1	4621.1
11	IR 72048-B-R-16-2-3-3	1.77	18.2	23.2	35.5	3440.4
12	IR 71866-3R-1-2-1	1.67	18.0	22.6	28.8	2936.4
13	IR 72046-B-R-8-3-1-3	1.82	18.7	23.9	38.8	3722.2
14	IR 75395-2B-B-19-2-1-2	2.67	20.9	25.0	49.6	4444.1
15	IR 65833-4B-17-1-3	1.94	19.0	24.1	38.2	3800.9
16	IR 71895-3R-9-3-1	2.34	19.2	24.2	41.3	4000.0
17	IR 71907-3R-2-1-2	2.46	19.8	24.4	43.0	4199.5
18	IR 71907-3R-2-1-1	2.24	18.7	23.9	37.5	3618.9
19	IR 71999-3R-3-2-2-B-1-1	1.60	18.3	23.3	35.7	3572.2
20	IR 72580-B-24-3-3-3-2	1.78	18.4	23.8	35.7	3611.9
21	IR 51499-2B-29-2B-1-1	2.31	21.0	25.6	50.3	4539.5
22	IR 61919-3B-24-3	2.26	20.3	24.8	47.2	4388.9
23	IR 71829-3R-82-1-1	2.12	19.6	24.4	42.5	4055.6
24	IR 72049-B-R-22-3-1-1	1.99	19.0	24.1	40.9	4072.2
25	IR 50184-3B-18-2B-1	2.38	22.8	25.2	52.8	4578.9
26	IR 730055-8-1-1-3-1	2.12	18.9	24.0	38.1	3745.5
27	IR 70023-4B-R-12-3-1	2.45	20.3	24.7	46.8	4347.5
28	IR 71991-3R-2-6-1	2.52	26.8	27.2	54.0	4751.9
29	IR 70023-4B-R-12-2-3-1	1.32	17.8	21.4	21.5	2611.1
30	IR 63731-1-1-1-3-3-2	2.85	25.6	26.6	51.8	4644.7
31	IR 71829-3B-28-1	2.53	21.9	25.8	51.0	4527.8
32	IR 70023-4B-R-12-3-1	1.89	18.8	24.0	38.2	3852.4
33	IR 72579-B-2R-3-1-1	2.25	19.4	24.3	41.6	4038.7
34	IR 68652-3B-20-3	2.09	18.9	24.1	40.7	3814.2
35	IR 10T117	2.19	19.5	24.3	41.8	4045.1
36	POKKALI (ACC 108921)	1.34	17.5	20.5	18.1	2222.2
37	NONA BOKRA	1.42	17.9	21.6	26.4	2916.7
38	IR 29	0.68	16.0	20.0	14.5	1250.6
39	IR 28	1.25	17.0	20.2	17.5	2083.9
40	IR 66946-3R-178-1-1 (FL 478)	0.97	16.3	20.1	15.0	2027.8
41	CSR 28	2.17	20.0	24.5	43.2	4178.9
42	IR 55179-3B-11-3	1.78	18.1	23.1	34.3	3241.1
43	AT 401	1.85	18.7	23.9	37.5	3666.7
44	IR 45427-2B-2-2B-1-1	2.12	19.1	24.2	41.3	3994.2
45	A 69-1	1.69	18.1	23.2	34.3	3416.7
46	AGAMI MI	1.56	17.9	21.8	27.5	2926.1
47	LOCAL CHECK (CSR 36)	3.21	27.4	27.9	58.1	5363.9
	Std	0.53	2.08	1.88	11.40	559.69
	SEd	0.74	3.35	2.66	14.20	1115.79
	CD(P=0.05)	1.50	5.77	5.37	27.62	2047.25

Table 7. Correlations of the 16 traits between each other and with grain yield.

Traits	Chlorophyll a/b ratio	Chlorophyll stability index	Protein content	Proline content (mg/g fr.wt.)	Na/K ratio	Days to 50% flowering	No. of productive tillers	Filled grain/ panicle	Unfilled grain/ panicle	Total grain/ panicle	Spikelet fertility (%)	Panicle wt (g)	Panicle length (cm)	1000 seed wt (g)	TDMA/ hill(g)
Chlorophyll stability index	-0.884	1													
Protein content	-0.897	0.862	1												
Proline content(mg g^{-1} fr.wt.)	-0.906	0.940	0.842	1											
Na/K ratio	0.839	-0.830	-0.779	-0.742	1										
Days to 50% flowering	-0.192	0.107	0.137	0.100	-0.203	1									
No. of productive tillers	-0.454	0.582	0.555	0.438	-0.662	-0.040	1								
Filled grain/panicle	-0.231	0.407	0.407	0.304	-0.515	-0.071	0.602	1							
Unfilled grain/panicle	0.356	-0.448	-0.339	-0.313	0.549	-0.251	-0.570	-0.095	1						
Total grain /panicle	-0.056	0.179	0.229	0.144	-0.235	-0.180	0.306	0.894	0.362	1					
Spikelet fertility (%)	-0.347	0.539	0.449	0.349	-0.718	0.108	0.784	0.767	-0.661	0.420	1				
panicle wt (g)	-0.372	0.483	0.450	0.308	-0.708	0.154	0.781	0.694	-0.614	0.373	0.930	1			
panicle length (cm)	-0.411	0.585	0.548	0.464	-0.620	0.084	0.773	0.766	-0.581	0.455	0.880	0.828	1		
1000 seed wt (g)	-0.350	0.462	0.462	0.306	-0.705	0.133	0.746	0.771	-0.606	0.449	0.950	0.946	0.877	1	
TDMA/hill (g)	-0.346	0.475	0.435	0.297	-0.732	0.132	0.750	0.720	-0.653	0.380	0.966	0.950	0.828	0.978	1
Grain yield (kg ha^{-1})	-0.390	0.478	0.463	0.313	-0.755	0.147	0.734	0.707	-0.629	0.378	0.946	0.951	0.799	0.970	0.982

the genotypes IR 76393-2B-7-1-1-3-1 and IR 77664-B-25-1-2-1-3-12-5-AJY1 registering 5055.6 and 4868.1 kg ha^{-1} respectively. The yield components *viz*., productive tillers m^{-2}, spikelet number $panicle^{-1}$, number of filled grains $panicle^{-1}$ and spikelet fertility were found to be higher in all the high-yielding cultivars mentioned above. Krishnamurthy *et al.,* (1987) confirmed that the salt tolerant cultivars had lower reduction in the number of panicle and number of filled grains per panicle under salt stress. Balasubramanian and Rao (1972) were also of the opinion that the yield reduction was due to the decrease in the number of filled grains per panicle. Similar effects of salt stress on yield attributes were reported by Pandey and Srivastava (1987), Compos *et al.,* (1989) and Zeng and Shannon, (2000). Further, Farah *et al.,* (1978) indicated that increased salt concentrations decreased plant height, tillering, grain and straw yield more in the sensitive rice than in the tolerant genotypes. Grain yield in rice is a function of proper balance between source and sink strength and their capacity. The sink capacity is the product of panicle number, spikelet number $panicle^{-1}$ and 1000-grain weight which was also reported by Akita, (1989). All the 47 genotypes selected for this study showed wide variation for grain yield. Among the 47 genotypes, the salt tolerant CSR 36 followed by the genotypes IR 76393-2B-7-1-1-3-1 and IR 77664-B-25-1-2-1-3-12-5-AJY1 recorded higher grain yield with the tolerance score of 3-4. This variation was significant leading to the identification of tolerant genotypes showing high degree of salt tolerance. These tolerant genotypes were endowed with higher values for most of the components of sink capacity as mentioned above. The correlation studies also showed a strong positive significant correlation of total dry matter accumulation (TDMA) with grain yield (r=0.98**).

Conclusions

The tolerant genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1, IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 were having higher yield, chlorophyll pigments, soluble protein, amino acid and proline content. Low Na/K ratio and higher salt tolerance (score 3-4) in the above tolerant genotypes resulted in higher grain yield. Hence, the salt tolerant genotypes IR 76393-2B-7-1-1-3-1, IR 77664-B-25-1-2-1-3-12-5-AJY1, IR 71991-3R-2-6-1,IR 63731-1-1-1-3-3-2 and IR 71829-3R-10-3 may be effectively utilized in further breeding program for the improvement of rice for higher grain yield and salt tolerance, which could pave way for evolving stable, high yielding varieties for salt affected areas.

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Effect of Boron on nutrient uptake and yield of Bt cotton grown on calcareous soil

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ABSTRACT

A field experiment was conducted during the *kharif* season from 2011 to 2012 at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola to study the effects of soil application of fertilizer boron on soil properties, nutrient uptake and yield of Bt cotton (*Gossypium hirsutum* L.) grown on calcareous soils. Soil applications of fertilizer boron significantly increased organic carbon, available nutrient status in soil, nutrient uptake, number of bolls per plant (30), seed cotton (1.48 t ha^{-1}) and cotton stalk yield (5.56 t ha^{-1}). Cotton seed yield was increased by 24.88% over control. The results obtained from this study suggest that application of fertilizer boron not only increase the soil fertility and nutrient uptake but also increase the yield of Bt cotton.

Key words: boron, Bt cotton, fertility, nutrient uptake, calcareous soil, foliar application

Introduction

Cotton is one of the most important fiber crops and plays a dominant role in industrial and agricultural economy of India. The genetically modified Bt cotton containing the cry gene sourced from the soil bacterium *Bacillus thurengensis* ssp *kurstaki*, providing resistance against boll worms, represents a landmark in cotton research and development. The large scale adoption of Bt cotton by Indian farmers in a span of 8 years is the power of this technology (Venugopalan *et al.*, 2009). Boron (B) has been universally recognized as the most important micronutrient for cotton production. Boron deficiency in plants and optimistic B response to application has been reported in 80 countries and for 132 crops (Shorrocks, 1997). B is implicated directly and indirectly as it involves in growth of cells in newly emerging shoot and root while in some plants it is crucial for boll formation, flowering, pollination, and seed development (Brown *et al.*, 2002; Dordas *et al.*, 2007). Although, cotton is well adapted to a wide range of growing conditions and soils, nutritional disorders caused by B deficiency are quite common especially on calcareous soils where B availability is significantly reduced (Shorrocks, 1997; Goldberg, 1997). Cotton has a relatively high requirement for B and many times B is applied as soil or foliar application (Shorrocks, 1997; Bell, 1997; Zhao and Oosterhuis, 2002). Soil pH and moisture conditions directly affect population of soil microbes that help decompose soil organic matter for onward mineralization of several essential macro and micro elements including B. Further, it has also been revealed that some amount of B in soil is precipitated due to calcium carbonate ($CaCO_3$) and it becomes quite unavailable for plant growth (Goldberg, 1997). However, there is very little information regarding the effect of B on soil fertility, yield and nutrient uptake by Bt cotton grown on calcareous soils. An attempt has been made to study the effects of soil application of fertilizer B on soil properties, nutrient uptake and yield of cotton.

Materials and methods

Experimental site

The experiment was conducted at the Agricultural Research Farm, Department of Soil Science and Agricultural Chemistry, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola (20°42'N, 70°02'E, 307.4m msl). The sites received mean annual rainfall of 764.7 mm, mostly occurring during June to September. The soil (Typic Haplustert) is clay in texture with smectite as the dominant minerals, having swell and shrink properties and deficient in B.

Experimental details

The field experiment was laid out in randomized block design (5.4m x 6m plot) during the *kharif* season of 2011-2012 with the following treatments:

T_1 = Control;

T_2 = Recommended dose of fertilizer (RDF);

T_3 = RDF + borax @ 5kg ha^{-1};

T_4 = RDF through boronated suphala-A + urea;

T_5 = RDF through boronated suphala-B + urea;

T_6 = RDF through suphala (non boronated) + urea;

T_7 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-A;

T_8 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-B.

Bt cotton cv. Mallika was used as test crop. This crop is widely grown in the region. The recommended dose of fertilizer (RDF) $N:P_2O_5:K_2O$::60:30:30, was applied through urea, SSP and MOP for T_2 and T_3, for T_4- N, P_2O_5, K_2O and B applied through boronated suphala A (15:15:15: 0.1%) and remaining N through urea, for T_5- N, P_2O_5, K_2O and B applied through boronated suphala B (15:15:15: 0.2%) and remaining N through urea and for treatments T_7 and T_8 suphala non boronated + borax equivalent to 0.1 and 0.2 per cent B.

A few important yield related observation *viz.*, number of bolls per plant, cotton stalk yield and seed yield was recorded.

Collection of samples

After harvesting the crop, their representative samples were collected for analysis. The initial and post harvest surface (0-20 cm depth) soil samples were also collected from each of the experimental plot. Soil samples were dried, ground and sieved through 2 mm sieve and used for subsequent chemical analysis.

Soil and plant analysis

The initial soil samples were analyzed for sand, silt and clay by international pipette method (Black, 1965), pH (soil:water, 1:2.5), electrical conductivity (EC) was determined in the supernatant liquid of the same extract, organic carbon by wet oxidation method (Walkley and Black, 1934), calcium carbonate ($CaCO_3$) by rapid titration method (Jackson, 1973), available nitrogen (N) by alkaline permanganate method by using micro-processor based automatic distillation system (KES-12L), available phosphorus (P) by Olsen's method (Watanabe and Olsen, 1965), available potassium (K) was determined by 1 *N* ammonium acetate method using flame photometer, and available micronutrients *viz.,* Fe, Mn, Zn and Cu were determined by extracting soil with DTPA (Lindsay and Norvell, 1978) using atomic absorption spectrophotometer (AAS), available B content (hot-$CaCl_2$ extractable; Parker and Gardner 1981). The post harvest samples were also analyzed for the same. Nitrogen in plant samples was determined by Kjeldahl method as described by Jackson (1973); for phosphorus, samples were digested with di-acid mixture and vanadomolybdate yellow colour method was used for colorimetric estimation, potassium was estimated from same extract by using flame photometer; and for B, samples were a shed in a muffle furnace at 550°C subsequently extracted with 0.1*N* HCl and the extract was determined for B using azomethine-H method (Wolf, 1971).

Results and discussion

Soil characteristics

The soil was clay in texture (Table 1). It was also moderately alkaline in reaction with medium organic C content. Soil rated low in nitrogen, medium in phosphorus and high in potassium. The soil is sufficient in DTPA extractable micronutrients and deficient in hot calcium chloride extractable B.

Analysis of residual soil

The soil pH, electrical conductivity and $CaCO_3$ were found non-significant and value ranged from 8.07 to 8.12, 0.265 to 0.283 dS m^{-1} and 6.06 to 6.23%, respectively (Table 2). Significant influenced in organic carbon content of soil in all the treatments except control. The highest

Table 1. Some physical and chemical properties of the experimental soil

Soil properties	Value
pH	8.10
Electrical conductivity (dS m^{-1})	0.26
Organic carbon (g kg^{-1})	5.20
Calcium carbonate (%)	6.10
Sand (%)	9.68
Silt (%)	30.21
Clay (%)	60.11
Major nutrients:	
Available N (kg ha^{-1})	203
Available P (kg ha^{-1})	14.7
Available K (kg ha^{-1})	314
Micronutrients:	
Hot calcium chloride extractable B (mg kg^{-1})	0.42
DTPA extractable micronutrients (mg kg^{-1})	
Zinc	0.61
Iron	13.55
Manganese	4.16
Copper	1.98

Table 2. Soil chemical properties after harvest of cotton as influenced by various treatments

Treatments	pH	EC (dS m^{-1})	Organic C (g kg^{-1})	$CaCO_3$ (%)
T_1	8.11	0.265	5.27	6.06
T_2	8.09	0.268	5.53	6.13
T_3	8.07	0.267	5.65	6.2
T_4	8.06	0.279	5.70	6.16
T_5	8.09	0.277	5.73	6.22
T_6	8.07	0.283	5.63	6.21
T_7	8.11	0.278	5.71	6.23
T_8	8.12	0.267	5.70	6.19
SEm (±)	0.033	0.005	0.095	0.089
LSD (p=0.05)	NS	NS	0.28	NS

(Where T_1 = Control; T_2 = Recommended dose of fertilizer (RDF); T_3= RDF + borax @ 5kg ha^{-1}; T_4 = RDF through boronated suphala-A + urea; T_5 = RDF through boronated suphala-B + urea; T_6 = RDF through suphala (non boronated) + urea; T_7 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-A; T_8 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-B.)

Table 3. Nutrient status influenced by various treatments after harvest of cotton

Treatments	Avai. N (kg ha^{-1})	Avai. P (kg ha^{-1})	Avai. K (kg ha^{-1})	Avai. B (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})
T_1	201	14.35	317	0.41	0.6	13.65	4.18	2.08
T_2	206	15	323	0.43	0.63	13.78	4.24	2.18
T_3	209	16.74	324	0.45	0.65	13.81	4.31	2.21
T_4	211	18.13	327	0.47	0.68	13.86	4.42	2.44
T_5	212	19.66	330	0.49	0.70	13.99	4.45	2.49
T_6	207	17.7	325	0.42	0.65	13.81	4.29	2.29
T_7	210	18.1	326	0.46	0.67	13.82	4.41	2.4
T_8	211	18.87	328	0.46	0.69	13.91	4.42	2.44
SEm (±)	2.26	0.58	1.95	0.004	0.013	0.058	0.03	0.059
LSD (p=0.05)	6.85	1.77	5.92	0.014	0.041	0.17	0.093	0.18

(Where T_1 = Control; T_2 = Recommended dose of fertilizer (RDF); T_3= RDF + borax @ 5kg ha^{-1}; T_4 = RDF through boronated suphala-A + urea; T_5 = RDF through boronated suphala-B + urea; T_6 = RDF through suphala (non boronated) + urea; T_7 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-A; T_8 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-B.)

increase in organic carbon content was associated with the treatment T_5 followed by others. The results are close proximity with the findings of Yadav and Meena (2009). Available nitrogen content increased significantly with RDF alone or through boronated suphala and it varied from 201 to 212 kg N ha^{-1} (Table 3). However, the highest increased in available nitrogen (212 kg N ha^{-1}) was observed in treatment T_5. The application of RDF through suphala (non-boronated) T_7 and T_8 were found beneficial in improving of nitrogen status and recorded respectively to extent of 210 and 211 kg N ha^{-1}. The significant increase in available nitrogen in soil with application of B was also reported by Brar *et al.* (1983) and Sankaranarayanan *et al.* (2010). The data (Table 3) showed that available phosphorus in soil varied from 14.35 to 19.66 kg P ha^{-1}. However, the available phosphorus (19.66 kg P ha^{-1}) was significantly increased with the application of RDF through boronated suphala-B (0.2%B) in T_5. All treatments significantly improved available phosphorus over control may be due to RDF which provides sufficient quantity of phosphorus. Significant positive correlation of available B with available phosphorus and it was associated with mutually synergistic effect of each other was also recorded by Hadwani *et al.* (1989) and Sankaranarayanan *et al.* (2010). The available potassium was also significantly influenced under different fertilizer treatments and the value ranges from 317 to 330 kg K ha^{-1}. The significantly highest available potassium was recorded in treatments T_5 (330 kg K ha^{-1}). The magnitude of response was $T_5 > T_8 > T_4 > T_7 > T_6$. These results are in close proximity with the earlier findings reported by Sankarnarayanan *et al.* (2010).

The availability of B after harvest of cotton was significantly increased in all treatments over control. The highest value for available B (0.49 mg kg^{-1}) of was recorded in treatment T_5 followed by others. The results are in close agreement with findings of Roselem and Costa (2000). Applications of boron fertilizers significantly increase the availability of micronutrients over control. The value ranged from 0.60 to 0.70, 13.65 to 13.99, 4.18 to 4.45 and 2.08 to 2.49 mg kg^{-1} for Zn, Fe, Mn and Cu, respectively. The highest increase in available Zn (0.70 mg kg^{-1}), Fe (13.99 mg kg^{-1}), Mn (4.45 mg kg^{-1}) and Cu (2.49 mg kg^{-1}) was found in T_5. Zinc deficiency is more frequently noticed in calcareous soil and also in soils that are excessively high in phosphorus. The phosphorus fertilization, high clay and $CaCO_3$ content immobilized the applied phosphorus and resulted in increased zinc adsorption to form soluble Zn-PO_4 complex (Malewar, 1980). The availability of micronutrients increased with increase in organic carbon and clay content due to formation of chelate complexes in the soil (Yadav and Meena, 2009).

Effect of B on nutrient uptake

Results (Table 4) showed that application of fertilizer B caused significant increase in N, P and K uptake by cotton. The N uptake by cotton seed, stalk and total uptake ranged from 12.74 to 17.94, 22.19 to 39.82 and 34.93 to 57.76 kg ha^{-1}, respectively. Such increase was higher with T_5 treatment than the other. The uptake was higher with the higher dose i.e. 0.2% boron. Ahmad *et al.* (2011) reported increase in nitrogen concentration in leaves, buds, seeds and lint over control. Application of fertilizer B also caused significant increase in P uptake cotton seed, stalk and total uptake from 4.30 to 7.19, 12.14 to 21.71 and 16.44 to 28.90 kg ha^{-1}, respectively. Such increase in P uptake was higher with the T_5 treatment than others. The results, therefore, indicated that better response of cotton crops in respect to P nutrition was observed in B fertilized soil than in non B fertilized soil. Similar results were also reported by Nehra (2007). The application of fertilizer B also enhanced K uptake in cotton plant. Such increase in uptake was higher with the treatment T_5 (80.27 kg ha^{-1}). Increase in K uptake on B application was also reported by Nehra (2007) and Ahmad *et al.* (2011). Boron application significantly increased B uptake over that of the control treatment (Table 5). Its value for cotton seed, stalk and total uptake ranged from 31.74 to 57.12, 79.43 to 167.43 and 111.17 to 224.55 g ha^{-1}, respectively. Such increase in uptake was higher with the treatment T_5. The uptake was higher with the higher dose. Malewar *et al.* (1992) also reported that the application of P and B at different levels to cotton were significantly increased the uptake of B by cotton.

Effect of B on yield

Boron application significantly increased number of bolls per plant over control from 24.76 to 30.06 over that of the control treatment (Table 5). Highest number of bolls per plant was observed in the treatment T_5. This suggested that B has direct effect on fertilization and especially on boll formation in cotton. One of the major problems in cotton seed production is boll abscission (Silvertooth *et al.*, 1999; Crozat *et al.*, 1999). From the present results, it is possible that B can play a significant role in boll abscission. Increased in number of bolls per plant was also reported by Dordas (2006) and Ali et al. (2011). Result showed that application of B significantly increased seed cotton and cotton stalk yield from 1.11 to 1.48 and 3.91 to 5.56 t ha^{-1}, respectively. Such increased was higher in the treatment T_5. Boron has direct function

Table 4. Effect of various treatments on nutrient uptake by cotton

Treatments	Nutrient uptake (kg ha^{-1})						Total uptake (kg ha^{-1})		
	Cotton seed			Cotton stalk					
	N	P	K	N	P	K	N	P	K
T_1	12.74	4.30	12.55	22.19	12.14	34.96	34.93	16.44	47.51
T_2	15.53	5.39	16.44	26.18	15.09	43.51	41.71	20.48	59.95
T_3	16.59	6.38	18.52	32.12	17.27	53.87	48.71	23.65	72.39
T_4	16.92	6.50	20.43	35.82	19.54	58.43	52.74	26.04	78.86
T_5	17.94	7.19	21.96	39.82	21.71	58.31	57.76	28.90	80.27
T_6	15.46	5.87	17.59	29.32	15.91	45.54	44.78	21.78	63.13
T_7	16.36	6.18	18.28	34.14	18.24	54.57	50.50	24.42	72.85
T_8	16.73	6.56	19.15	40.26	20.08	59.40	56.99	26.64	78.55
SEm (±)	0.54	0.15	0.90	1.38	0.84	3.74	1.59	0.89	4.17
LSD $_{(p=0.05)}$	1.65	0.45	2.73	4.18	2.56	11.37	4.84	2.72	12.65

(Where T_1 = Control; T_2 = Recommended dose of fertilizer (RDF); T_3= RDF + borax @ 5kg ha^{-1}; T_4 = RDF through boronated suphala-A + urea; T_5 = RDF through boronated suphala-B + urea; T_6 = RDF through suphala (non boronated) + urea; T_7 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-A; T_8 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-B.)

Table 5. Effect of various treatments on boron uptake, number of bolls per plant and yield of cotton

Treatments	Boron uptake (g ha^{-1})			Number of bolls $plant^{-1}$	Yield (t ha^{-1})	
	Cotton seed	Cotton stalk	Total		Cotton seed	Cotton stalk
T_1	31.74	79.43	111.17	24.76	1.11	3.91
T_2	40.44	99.41	139.86	26.73	1.32	4.42
T_3	48.29	139.23	187.52	27.86	1.39	4.85
T_4	53.10	148.94	202.04	29.03	1.43	5.28
T_5	57.12	167.43	224.55	30.06	1.48	5.56
T_6	43.51	108.41	151.92	27.33	1.33	4.55
T_7	49.91	144.95	194.86	28.80	1.42	4.98
T_8	52.79	152.09	204.88	29.23	1.46	5.37
SEm (±)	0.79	1.29	1.11	0.32	0.43	2.18
LSD $_{(p=0.05)}$	2.26	3.93	3.38	0.99	1.31	6.64

(Where T_1 = Control; T_2 = Recommended dose of fertilizer (RDF); T_3= RDF + borax @ 5kg ha^{-1}; T_4 = RDF through boronated suphala-A + urea; T_5 = RDF through boronated suphala-B + urea; T_6 = RDF through suphala (non boronated) + urea; T_7 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-A; T_8 = RDF through suphala (non boronated) + urea + borax equivalent to suphala-B.)

on flowering, pollen germination and growth, seed, and fruit formation (Brown *et al.*, 2002). Similar results were also observed by Dordas (2006), Rattan *et al.* (2008) and Sankaranarayanan *et al.* (2010).

Conclusion

Result of this study help to optimize the rate of B fertilization for Bt cotton grown in rainfed condition on B deficient calcareous soils. Application of B through boronated suphala had significant increase in the soil fertility, uptake of nutrient, number of bolls per plant and yield of Bt cotton. The farmer community can get economic benefits from B fertilization in cotton.

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Effects of dates of sowing and planting geometry on yield and quality of sugar beet under saline Vertisol of Tungabhadra Project (TBP) area of Karnataka

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ABSTRACT

A field experiment was carried out during 2010-11 to 2012-13 at Agricultural Research Station, Gangavati, Karnataka to see the effect of different date of sowing and planting geometry on yield and quality performance of sugar beet crop under salt affected soils. Four dates of sowing viz., August 1st fortnight, August 2nd fortnight, September 1st fortnight and September 2nd fortnight as main plot treatments and four planting geometry viz., 45 x 20 cm, 45 x 30 cm, 60 x 20 cm and 60 x 30 cm were as subplot treatments. The variety Indus was used as a test hybrid. The study of three years revealed that, August 1st fortnight sowing of sugar beet seeds had significantly higher root yield (39.67 t/ha), weight of 10 beets (13.99 kg), more number of beets per plot (182) and total soluble solids (TSS) per cent (21.66%) than other dates of sowing. The weight of 10 beets and number of beets per plot was differed significantly with respect to planting geometry, but there was no significant difference in root yield and TSS% of sugar beet. The sugar beet sown at 60 x 30 cm recorded significantly higher weight of 10 beets (14.91kg) followed by at 60 x 20 cm, 45x 30 cm and 45 x 20 cm spacing (14.30, 12.97 and 13.78 kg, respectively). The interaction of dates of sowing and planting geometry was found non-significant. The August 1st fortnight sowing had given significantly higher gross return, net returns and benefit cost ratio (Rs. 71410, Rs.43968 ha^{-1} and 2.61, respectively) as compared to other dates of sowing.

Key words: dates of sowing, economics, spacing, saline soils, sugar beet, root yield.

Introduction

Sugar beet (*Beta vulgaris* Linn. var. *Saccharifera*) is a sugar producing tuber crop, grown in temperate climates. With the development of tropical hybrids of sugar beet, now it is possible to raise this crop in tropical and subtropical regions of India (http//www.vsi.in). In India, sugar beet was tried first at Indian Institute of Sugarcane Research (IISR), Lucknow in 1970, under All India Co-ordinated Research Project (AICRP) on sugar beet (http//www.vsi.in). After that, Vasantdada Suagr Institute (VSI) initiated cultivation of sugar beet in Maharashtra. On the basis of agronomic trials conducted at various locations in India, the sugar beet cultivation was taken up in Sriganganagar area of Rajasthan for sugar production and in Sundarban area of West Bengal for alcohol production (VSI, 2009). In Karnataka, the first initiative of sugar beet cultivation was taken by Shree Renuka Sugars (a leading sugar factory) in Athani and Gokak Taluka of Belgaum district with a target to increase the capacity of sugarbeet processing to 50,000 tons by 2013-14 (Times of India, April 18th 2013).

Sugar beet root contains 16-19% sucrose and is not only the source of sugar, but also provides several by-products like ethanol, cattle feed and vitamin B_{10}. Molasses can be used in pharmaceutical industry for the manufacture of vitamin B_{12}. Hence, sugar beet can be considered as a supplementary source for production of white sugar as well as ethanol in India (VSI, 2009). The key advantages of sugar beet in comparison with sugarcane are well-known: a shorter growing cycle (around 5 months), lower water requirement (about 1/3rd to half of the water needed to grow sugar cane) and a slightly higher sugar (16-19% sucrose) and ethanol yield per acre (1000 to 1200 liters/ha). In addition, sugar beet is well known tolerant crop to soil salinity (Steven Cosyn *et al*., 2011). More over due to short growing season in comparision to sugar cane the sugar beet provides an opportunity of crop rotation to farmers, and is probably one of the efficient ways to maintain soil fertility and to control pests and disease. Finally, by processing sugar beet after or before the regular sugar cane crushing period, factories can stretch their operations over a longer period of time and reduce their production costs (Steven Cosyn *et al.*, 2011).

In Karnataka, most of the salinity affected area are in the irrigated commands. The Tungabhadra Project (TBP) is one of the severely-affected commands (96,215 ha), that alone accounts for more than 32 per cent of the total command area of the project (36 thousand ha). The excessive use of irrigation water in this command area with poor soil drainage had led to the salinity and water logging problems. The paddy-paddy cropping system followed in the command could also be another reason for that. Although the sugarcane was one of the important crops of Tungabhadra command in the past, it was slowly gone out of cultivation due to non availability of sufficient water from canal system and some local problems.

As we know sugar beet can be grown under saline soil but sugarcane cannot be grown under such soils. Based on experiments conducted during last few years, it was observed that, the sugar beet crop may be cultivated during winter with the production of 60-75 t/ha. The variety, HI0064 of Syngenta has given the best performance followed by the IISR, Lucknow varieties (LS-6 and IISR Comp-1). Based on the experiments conducted at VSI, Pune and Research Station, Digraj in Maharashtra, it was found that sugar beet optimum time was found to be September, October and November. However, the information on agronomic requirements of sugar beet on saline vertisols of TBP command is lacking. Therefore, an experiment was conducted to find out optimum time of sowing and spacing requirements of sugar beet under saline conditions.

Material and methods

The study was conducted from 2010 to 2013 under All India Co-ordinated Research Project (AICRP) on "Management of Salt Affected Soils and Use of Saline Water in Agriculture" at Agricultural Research Station, Gangavati, Karnataka, India; situated at latitude of 15^0 15' 40'' N and longitude of 76^0 31' 40'' E and at an altitude of 419 m above mean sea level. Average annual rainfall of the station is 537.7 mm. The soil of the experimental site was having medium deep black soil with ECe ranges between 6.0 to 8.0 dS/m and pH less than 8.5. The experiment was laid out in a split plot design with three replications. Four dates of sowing viz., D_1: August 1^{st} fortnight, D_2: August 2^{nd} fortnight, D_3: September 1^{st} fortnight and D_4: September 2^{nd} fortnight as main plot treatments and four planting geometry viz., S_1: 45 cm x 20 cm, S_2: 45 cm x 30 cm, S_3: 60 cm x 20 cm and S_4: 60 cm x 30 cm were as subplot treatments. The variety Indus from Syngenta Seeds Pvt Ltd. was used as a test hybrid. Sugar beet was planted manually as per different sowing dates and spacing. Plants were thinned fifteen days after sowing so that only one plant per spot was maintained. The fertilizer was applied at the rate of 120:60:60 kg N, P_2O_5 and K_2O per hectare, respectively. Half of the nitrogen and full dose of phosphorus and potassium was applied at one month after sowing and another 50% of nitrogen was applied after three months of sowing. Intercultural operations, plant protection measures and irrigations were applied as per recommendations for the location. Net plot was harvested for calculating number of beets per plot and beet yield per hectare. For taking weight of ten beets and for determining quality, ten beets were randomly selected from each plot. The same samples were used for processing and determining the total soluble solids (TSS). The TSS% was analyzed with the help of Brix meter. The data was statistically analyzed as per the method given by Gomez and Gomez (1984).

Results and discussion

Pooled data of three years (2010-11, 2011-12 and 2012-13) on the root yield (kg/ha) and number of beet roots per plot are presented in Table 1. The august 1^{st} fortnight sowing of sugar beet seeds recorded significantly higher root yield of sugar beet (39.67 t/ha) than sowing in August 2^{nd} fortnight (35.54 t/ha), September 1^{st}

Table 1. Effect of date of planting and planting geometry on root yield (t/ha) and number of beets per plot of sugar beet (pooled over three years)

Treatment	Root yield of sugar beet (t/ha) in spacing treatments of					Number of beets per plot in spacing treatments of				
	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean
August 1^{st} fortnight	39.39	39.30	40.22	39.78	39.67	205	179	181	161	182
August 2^{nd} fortnight	37.80	34.30	35.05	35.03	35.54	189	162	163	135	162
September 1^{st} fortnight	29.57	29.61	30.24	29.57	29.75	171	146	147	128	148
September 2^{nd} fortnight	27.93	26.67	26.99	27.44	27.26	151	137	138	120	136
Mean	33.67	32.47	33.12	32.96		179.06	156.02	157.25	135.90	
Comparison		S. Em±		LSD (p=0.05)			S. Em±		LSD (p=0.05)	
Between dates of planting		0.59		2.67			1.67		7.49	
Between spacing		0.46		NS			2.39		8.15	
Dates of planting x Spacing		1.13		NS			5.85		NS	

Table 2. Effect of date of planting and planting geometry on weight of ten beets (kg) and total soluble solids (%) of sugar beet (pooled over three years)

Treatment	Weight of ten beets (kg) in spacing treatments of					TSS (%)				
	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean
August 1st fortnight	12.97	13.78	14.30	14.91	13.99	22.08	21.62	21.49	21.47	21.66
August 2nd fortnight	11.60	12.34	12.81	13.02	12.44	21.06	20.85	20.74	20.12	20.69
September 1st fortnight	11.05	10.84	11.59	12.25	11.43	20.10	19.74	19.80	20.05	19.92
September 2nd fortnight	9.92	9.93	10.68	11.40	10.48	19.62	19.40	19.04	19.37	19.36
Mean	12.97	13.78	14.30	14.91	13.99	20.71	20.40	20.27	20.25	
Comparison		S. Em±		LSD (p=0.05)			S. Em±		LSD (p=0.05)	
Between dates of planting		0.17		0.78			0.15		0.69	
Between spacing		0.14		0.75			0.21		NS	
Dates of planting x Spacing		0.33		NS			0.20		NS	

Table 3. Effect of date of planting and planting geometry on cost of cultivation and gross returns (Rs./ha) (pooled over 3 years)

Treatment	Cost of cultivation (Rs/ha) in spacing treatments of					Gross returns (Rs/ha) in spacing treatments of				
	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean
August 1st fortnight	28803	28013	26980	25973	27442	70902	70742	72388	71610	71410
August 2nd fortnight	28803	28013	26980	25973	27442	68040	61734	63092	63048	63978
September 1st fortnight	28803	28013	26980	25973	27442	53224	53302	54430	53234	53547
September 2nd fortnight	28803	28013	26980	25973	27442	50274	48006	48582	49390	49063
Mean	28803	28013	26980	25973		60610	58446	59623	59320	
Comparison		S. Em±		LSD (p=0.05)			S. Em±		LSD (p=0.05)	
Between dates of planting		-		-			1069.50		4812.77	
Between spacing		-		-			829.94		NS	
Dates of planting x Spacing		-		-			2032.92		NS	

fortnight (29.75 t/ ha) and September 2nd fortnight (27.26 t/ha). This could be due to water logged situation was observed during the year 2010-11 and 2012-13 at early growth stages of the crop as sugar beet is highly sensitive to water logging and hence, the sowing time should not coincide with rainy period. Generally, in TBP command August 2nd fortnight and September 1st fortnight coincides with heavy rainfall. In the years of study, the crop received 288.50 mm, 29.50 mm and 142.75 mm rainfall during the year 2010, 2011 and 2012, respectively between August 2nd fortnight to September 2nd fortnight which is estimated to 39.94%, 7.17% and 38.34% of the total rainfall received i.e 722.25 mm, 411.25 mm and 372.29 mm, respectively during the years of experimentation. On the contrary, the agronomic trials conducted by VSI (2009) under normal soils the sugar beet root yield ranged from 60 to 75 t/ha. Under saline soils, over all lower root-yield could be attributed to the effect of salinity constraints. However, in another study at Digraj in Maharashtra, it was found that, the September, October and November sowing is the optimum sowing period for sugar beet in Maharashtra.

Similarly, sowing in August 1st fortnight was recorded significantly more number of beets per plot (182) and higher weight of 10 beets (13.99 kg) than other dates of sowing (Table 2). TSS % of sugar beet roots was recorded significantly higher in August I fortnight (21.66%) as compared to the other dates of sowing (Table 2).

Among different planting geometry, there was no significant difference with respect to root yield and TSS%. But, there was a significant difference in number of beets per plot and weight of 10 beet roots in different planting geometry. Significantly higher number of beets per plot was recorded in sowing at 45 cm x 20 cm (179.06) followed by sowing at 45 cm x 30 cm, 60 cm x 20 cm and 60 cm x 30 cm (156, 157 and136, respectively). This could be due to variation in spacing and hence number of plants per plot was different. Similarly, significantly higher weight of 10 beets was recorded in sowing at 60 cm x 30 cm (14.91 kg) followed by sowing at 60 cm x 20 cm, 45 cm x 30 cm and 45 cm x 20 cm (14.30, 13.78 and 12.97 kg, respectively). The higher weight of beets could be due to larger area associated with each plant and sufficient availability of plant nutrients along with lesser pest and disease incidence leading to higher weight of ten beets at wider row spacing as compared to closer spacing. As no relevant references on weight of ten beets as influenced

Table 4. Effect of date of planting and planting geometry on net returns (Rs./ha) and B:C ratio (pooled over three years)

Treatment	Net returns (Rs./ha)					B:C ratio				
	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean	45 × 20 cm	45 × 30 cm	60 × 20 cm	60 × 30 cm	Mean
August 1st fortnight	42098	42728	45408	45636	43968	2.47	2.54	2.69	2.76	2.61
August 2nd fortnight	39236	33720	36112	37074	36536	2.37	2.21	2.34	2.43	2.34
September 1st fortnight	24420	25288	27450	27260	26105	1.86	1.91	2.02	2.05	1.96
September 2nd fortnight	21470	19992	21602	23416	21620	1.75	1.73	1.81	1.90	1.80
Mean	31806	30432	32643	33347		2.11	2.10	2.22	2.29	
Comparison		S. Em±		LSD (p=0.05)			S. Em±		LSD (p=0.05)	
Between dates of planting		1083		4876			0.04		0.17	
Between spacing		826.32		NS			0.03		0.17	
Dates of planting x Spacing		2024		NS			0.33		NS	

by different spacing was available. Hence, further confirmation on this line is needed.

Economics

The cost of cultivation was same for all the four dates of sowing (Rs 27442 ha^{-1}), while, it differed with planting geometry mainly due to difference in the requirement of seeds (Table 3).

The closer spacing of 45 cm x 20 cm and 45 cm x 30 cm incurred Rs 28803 and Rs 28013 ha^{-1}, respectively. Whereas, wider spacing of 60 cm x 20 cm and 60 cm x 30 cm incurred the cost of Rs 26980 and Rs 25973 ha^{-1}, respectively. However, significantly higher gross returns was obtained with August 1st fortnight (Rs 71410 ha^{-1}) followed by August 2nd fortnight (Rs 63978 ha^{-1}). Similarly, net returns and B: C ratio was significantly higher with August 1st fortnight (Rs 45636 ha^{-1}and 2.61, respectively) followed by August 2nd fortnight (Rs 36536 ha^{-1}and 2.34, respectively) (Table 4). This could be due to lower cost of cultivation of sugar beet as compared to sugar cane and it is also getting higher price of Rs 2000-2500 per ton (Times of India, 2013). However, significantly lower net return and B:C ratio was obtained with September 1st fortnight and September 2nd fortnight sowing. This could be due to lower beet yield obtained with delayed sowing. Planting geometry did not differ significantly with respect to gross returns, net returns add B: C ratio. Interaction effect also found non-significant.

Conclusion

Three years study indicated that, among the different dates of sowing August 1st fortnight sowing is ideal for higher root yield of sugar beet. Further delay in sowing of sugar beet under Tungabhadra Project (TBP) command area may lead to lower root yield as rainy period coincides with sowing time resulting in to poor germination and poor crop stand. Planting geometry did not have significant influence on root yield of sugar beet however; wider spacing (60 cm x 30 cm) gave slightly more root yield as compared to closer spacing (45 cm x 30 cm). As sugar beet is a short duration, salt tolerant, less pest and disease incidence crop incurred less cost of cultivation as compared to sugar cane which cannot be grown under salt affected soils. It yields more under saline conditions and having good market value as that of sugar cane (2000 to 2500 per ton). Hence, Sugar beet could be more remunerative especially under saline soils of TBP area.

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Removal of heavy metals - lead, cadmium and nickel by fungi and bacteria from liquid medium

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ABSTRACT

Microbes act as adsorbent to remove heavy metals from wastewater at low cost in eco-friendly way. The ability to remove heavy metals from wastewater varies greatly among microbes. This needs to be exploited for removal of heavy metals from wastewater through efficient microbes. Six fungi i.e. *Aspergillus niger*, *Aspergillus terreus, Phanerochaete chrysosporium, Aspergillus awamori*, *Trichoderma longibrachiatum*, *Trichoderma fasciculatum* and two bacteria namely *Bacillus cereus*, and an unidentified species of *Bacillus* were tested for removal of Pb, Cd and Ni from liquid medium containing 20, 40 and 60 ppm concentration of these heavy metals. Out of six fungi, highest removal of Pb, Cd and Ni was observed by *T. longibrachiatum* (9.63 mg/g), *T. fasciculatum* (18.59 mg/g) and *A. terreus* (3.88 mg/g) at 60 ppm concentration, respectively. In case of bacteria, maximum removal of Pb by *Bacillus cereus* (16.66 mg/g), Cd by *Bacillus. sp.* (49.95 mg/g) and Ni by *Bacillus sp.* (2.51 mg/g) at 60 ppm concentration of these metals. These microbes could thus be deployed for remediation of heavy metal laden waste waters.

Keywords: removal of heavy metals; biomass; microbes; liquid medium, waste water

Introduction

Discharge of heavy metals from industries like electroplating, tanneries and paints contains high quantity of heavy metals like Pb, Cd, Cr and Ni, which are toxic to living organisms even at low concentration. These heavy metals enter into human beings and animals through food chain and cause many metabolic disorders (Malik, 2004; Chuah *et al.*, 2005). Unlike organic chemicals, metals persist in environment indefinitely posing threats to all the organisms which are exposed to them. Wastewater may be of simple composition if derived from single industry, e.g., electroplating wastewater, or in other cases could be a heterogeneous mix (coming from different industries) of many dissolved metal ions at various pH with salts, colloidal and particulate matters. Using microorganisms as biosorbents for heavy metals is an attractive alternative to existing methods such as chemical precipitation, chemical oxidation or reduction, electrochemical treatment, filtration, ion exchange and membrane technologies for toxicity reduction and recovery of valuable metals from industrial effluents, because of good performance and low cost of biosorbent material (Brierley *et al.*, 1986). These processes may be ineffective or expensive, especially when dissolved heavy metals concentration in the solution ranged from 1-100 mg/l (Nourbakhsh *et al.,* 1994). Bioremediation of heavy metals involving microorganisms could be brought about by employing methods such as bio-accumulation, biosorption, bio-precipitation and uptake by purified biopolymers from microbial cells (Macaskie, 1991; Churchill *et al.,* 1995). Therefore, it is desirable to remove heavy metals from wastewater through environment friendly low cost technology before its use in agriculture or discharge into water bodies (Gadd, 1990; Veglio and Beolchini, 1997; Elizabeth and Anuradha, 2000; Bai and Abraham, 2003). Recently, research studies on use of biomass of fungi, algae and bacteria as an adsorbent material to remove heavy metals has gained interest. In the present study, the efficient fungi and bacteria were tested for removal of Pb, Cd, and Ni from liquid medium containing different concentrations of Pb, Cd and Ni.

Materials and methods

Microorganism and growth conditions

The two heavy metal tolerant and organic matter decomposing fungi i.e. *Aspergillus awamori, Phanerochaete chrysosporium* were procured from Department of Microbiology, Indian Agricultural Research Institute (IARI), New Delhi. Four heavy metal tolerant fungi (*Trichoderma fasciculatum, A. niger*, *A. terreus, T. longibrachiatum*) and two bacteria (*Bacillus cereus*, *Bacillus. sp*) isolated at Central Soil Salinity Research Institute (CSSRI), Karnal from samples of sewage, sludge and industrial effluents of Karnal, Panipat and Sonepat districts of Haryana were included in this study. *Trichoderma fasciculatum* (ID-7547-09), *A. niger* (ID-7059-08), *T. longibrachiatum* (ID-7062-08) got identified by Division of Plant Pathology, Indian Agricultural Research Institute, New Delhi while *A. terreus* was identified by sequencing of ITS1-5.8S rDNA-ITS2 and 28S rDNA by IMTECH, Chandigarh (MTCC-9618). *Bacillus cereus* (MTCC-9490) and *Bacillus sp*. (MTCC-9491) were identified by IMTECH, Chandigarh by sequencing of 16S rRNA. All the fungal and bacterial cultures were maintained on potato dextrose agar (PDA) and nutrient agar (NA) medium at 28 °C, respectively.

Preparation of heavy metal solutions

The 1000 ppm stock solutions of Pb, Cd and Ni were prepared in double distilled water using $Pb(NO_3)_2$, $NiCl_2.6H_2O$ and $CdCl_2$ (S.d fine-chem limited, Mumbai, India). Solutions of 20, 40 and 60 ppm of these heavy metals were prepared from 1000 ppm stock solution by dilution with double distilled water. The stock solution thus prepared was sterilized separately through bacteriological filters and added to sterilized potato dextrose and nutrient broth to make its concentration 20, 40 and 60 ppm.

Removal of heavy metals by fungal and bacterial cultures from liquid media

The fungal and bacterial cultures were evaluated for uptake of heavy metals in potato dextrose and nutrient broth containing 20, 40 and 60 ppm concentration of Pb, Cd and Ni individually. Broth was dispensed in100 ml lots in 250 ml conical flasks and sterilized at 15 lbs/psi for 15 minutes. Required amount of bacteriological sterilized stock solution of Pb, Cd and Ni was added in sterilized broth in flasks to make its concentration 20,40 an 60 ppm individually. These flasks were inoculated with 1 ml of freshly prepared bacterial (10^8-10^9 cells/ml) and fungal (10^6 to10^7 spores/ml) of each culture individually and put on shaker at 150 rpm at 28 °C for 120 h. Un-inoculated flasks at 20, 40 and 60 ppm concentration of Pb, Cd and Ni served as control. Fungal growth was harvested after 120 h through filtration using Whatman filter No. 42. After 72 h of incubation at 28 ^{0}C, bacterial biomass was harvested by centrifugation at 8000 rpm for 10 minutes. The harvested fungal and bacterial biomass was rinsed with double distilled water 3-4 times and dried in hot air oven at 80 ^{0}C for 18 h. The dried fungal and bacterial biomass was weighed and heavy metal concentration in it was estimated by digestion with nitric acid and perchloric acid (3:1 ratio). The digested fungal and bacterial biomass was filtered through Whatman filter No. 42 and made the volume of filtrate to 50 ml in volumetric flask. The heavy metals concentration in filtrate was estimated (Greenberg *et al.,* 1985) by Atomic Absorption Spectrophotometer. All the treatments were kept in triplicate in randomized design and average values are expressed for analysis. The uptake of heavy metal by fungal and bacterial biomass was calculated using the following equation:

$$q_e\,(mg/g) = \frac{C \times V \times 1000}{W} \quad \ldots(1)$$

q_e concentration of heavy metal accumulated by fungal/bacterial biomass, (mg/g); C concentration of heavy metal (ppm); V (ml) the volume of the aqueous medium and W the dry weight (g) of the fungal/bacterial biomass.

Results and discussion

Removal of Pb by different fungi and bacteria from liquid medium

The results showed that uptake of Pb by fungi and bacteria increases as the concentration increases from 20 to 60 ppm. In case of fungi, order of uptake at 60 ppm Pb by different fungi was *T. longibrachiatum* (9.63 mg/g)> *P. chrysosporium* (8.30 mg/g)> *A. terreus* (8.18 mg/g)> *T. fasciculatum* (6.04 mg/g) > *A. awamori* (5.12 mg/g)> *A. niger* (4.65 mg/g) (Fig.1) whereas, order of uptake of Pb by different bacteria was *B. cereus* (16.66 mg/g)> *B. sp*. (12.34 mg/g) (Fig. 4). This increase may be due to an increase in electrostatic interactions (relative to covalent interactions), involving sites of progressively lower affinity for metal ions (Al-Asheh and Duvnjak, 1995). The level of lead and copper ions uptake by *Fusarium poe* increased as the initial concentration of metal ions increased from 4 to 12 mM in medium (Siham, 2007). According to Faryal *et al.* (2007) *A. niger* RH 17 and *A. niger* RH showed 92.04% and 93.09 % Pb removal at 1000 mg/l metal concentration. Dursun *et al.* (2003) indicated that *A. niger* was capable of removing of copper (II) and lead (II) with a maximum specific uptake capacity of 15.6 and 34.4 mg/g at 100 ppm initial copper (II) and lead (II) concentration, respectively. Abou Zeid *et al.* (2009) studied the effect of increasing concentrations of heavy metals

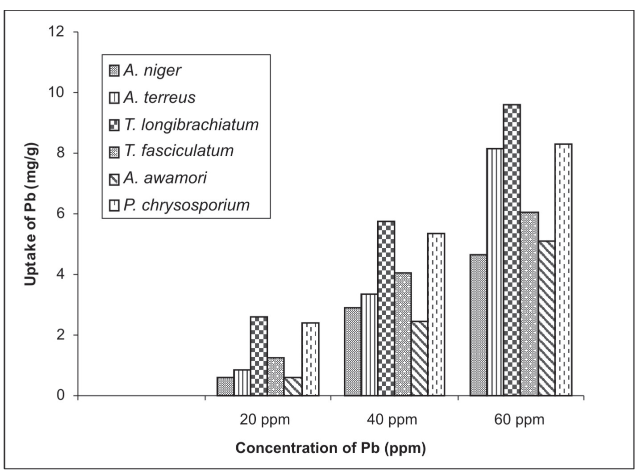

Fig .1. Uptake of Pb from liquid medium by fungi at different level of Pb concentration ions on the biological uptake and revealed that the maximum uptake of Pb^{+2} and Cd^{+2} occurred at sub minimum inhibitory concentration (MIC) concentrations for bacterial isolates II and IV (150 ppm & 2.5 ppm), respectively.

Removal of Cd by different fungi and bacteria from liquid medium

Results indicated that as the concentration increases from 20 to 60 ppm, uptake of Cd by different fungi (*T. fasciculatum, A.awamori, P. chrysosporium, A. niger*, *A. terreus* and *T. longibrachiatum*) and bacteria (*Bacillus* sp) increases except in case *B. cereus* where uptake was increased up to 40 ppm. In case of fungi, *T. fasciculatum* removed more Cd from liquid medium than other fungi and order of uptake of Cd by different fungi was *T. fasciculatum* (18.59 mg/g) > *A. terreus* (5.41 mg/g) > *T. longibrachiatum* (4.93 mg/g) > *A. niger* (3.31 mg/g) > *A. awamori* (3.00 mg/g) > *P. chrysosporium* (2.73 mg/g) at 60 ppm of Cd (Fig. 2). Similarly, the order of uptake of Cd by bacteria was *B.* sp. (49.95 mg/g) > *B. cereus* (22.20 mg/g) at 60 ppm of Cd (Fig. 5). Higher fungi such as Deuteromycetes *T. viride* have cell wall composed of chitin and glucal polymers which help in binding of heavy metals like Cd. Yazdani *et al.,* (2010) reported that the uptake capacity of *T. atroviride* for Cu ranged from 0.77 to 11.20 mg/g in potato dextrose broth in liquid media over the Cu concentration range of 25 to 300 mg/l. Baldrian *et al*. (1996) observed that the Basidiomycetes *Phanerochaete chrysosporium*, *Pycnoporus cinnabarinus* and *Pleurotus ostreatus* stopped growing when a concentration of 11.2 mg/l of cadmium was added to their culture medium. Similar results with respect to Cd removal by bacteria and fungi have been reported earlier (Chang *et al.*, 1997; Kefala *et al.*, 1999; Puranik and Paknikar, 1999; Ghoslan *et al.*, 1999; Costa *et al.*, 2001; Say *et al.*, 2001; Watanabe *et al.*, 2003; Pardo *et al.*, 2003; Ozdemir *et al.*, 2004; Qi *et al.*, 2006).

Removal of Ni by different fungi and bacteria from liquid medium

Uptake of Ni by fungi and bacteria increased with increase in concentration of Ni from 20 to 60 ppm. The order of uptake by different fungi was *A. terreus* (3.88 mg/g) > *T. longibrachiatum* (3.13 mg/g) > *A. awamori* (3.02 mg/g) > *P. chrysosporium* (2.87 mg/g)> *T. fasciculatum*

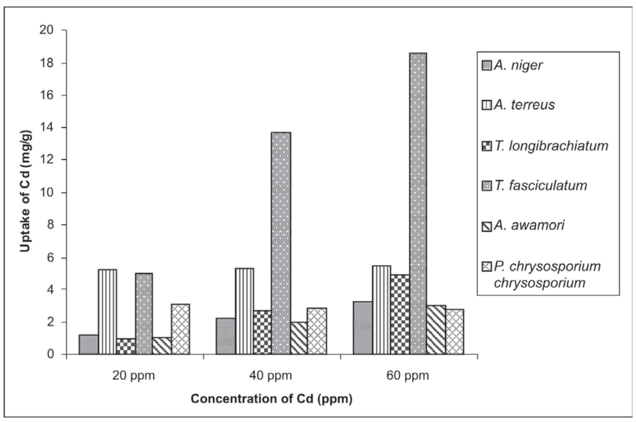

Fig. 2. Uptake of Cd from liquid medium by fungi at different level of Cd concentration

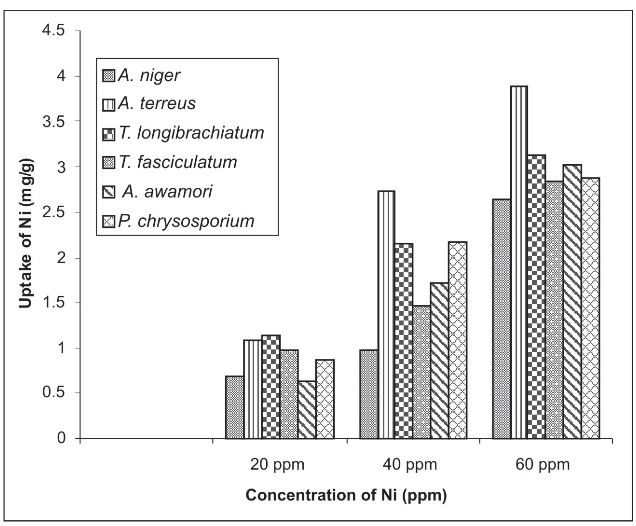

Fig. 3. Uptake of Ni from liquid medium by fungi at different level of Ni concentration

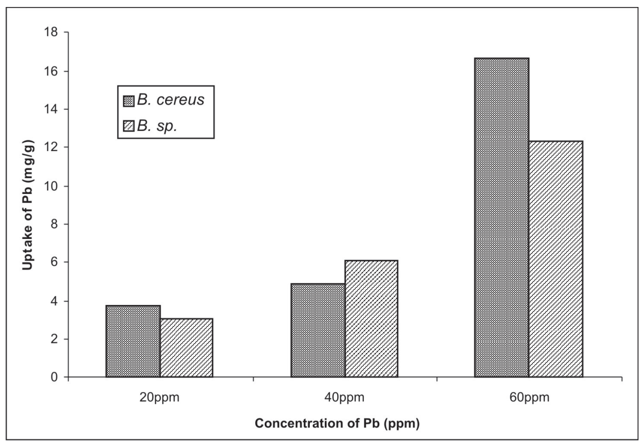

Fig. 4. Uptake of Pb from liquid medium by bacteria at different level of Pb concentration

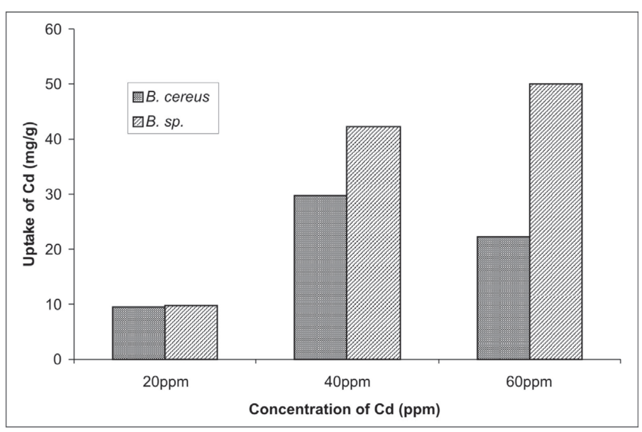

Fig. 5. Uptake of Cd from liquid medium by bacteria at different level of Cd concentration

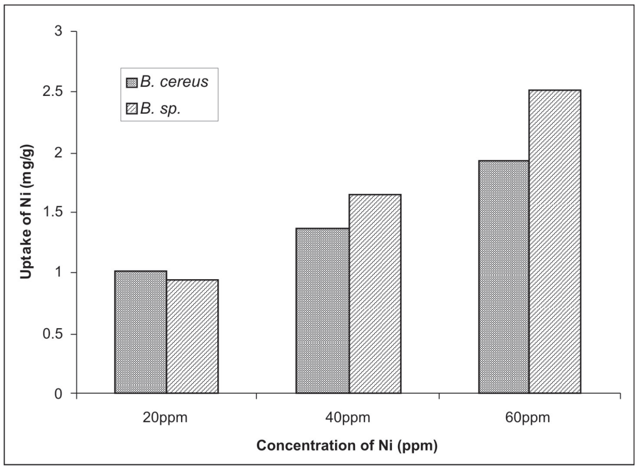

Fig. 6. Uptake of Ni from liquid medium by bacteria at different level of Ni concentration

(2.84 mg/g) > *A. niger* (2.64 mg/g) (Fig. 3) while the order of Ni uptake by bacteria was *B.* sp. (2.51 mg/g) > *B. cereus* (1.93 mg/g) at 60 ppm concentration of Ni (Fig. 6). Maximum biosorption of Cr (32.8%) and Ni (86.86%) by *A. niger* was observed at 50 ppm. However, increase in concentration of Cr and Ni leads to decrease in removal of both metal ions (Munir *et al*., 2010). The toxicity of high concentration of Ni to growing biomass of *A. niger* resulted in negative effects on the enzyme machinery (Rajendran *et al*., 2002). Öztürk (2007) showed that Ni (II) ion uptake of *B. thuringiensis*'s spore crystal mixture at 250 ppm was 15.7%, whereas the vegetative cell metal uptake was 10%. The effect of Ni initial concentrations of 20–200 ppm on uptake capacity of bacterial strain (NRC-BT-1) was studied by Ghafourian *et al*. (2005). They found that there was increase in uptake capacity of bacterial biomass up to 150 ppm and the same increased from 150 to 200 ppm. Ansari and Malik (2007) reported that the biosorption of Ni increased from 6.96 to 55.31 mg/g and Cd from 4.96 to 45.37 mg/g by cells of bacterial isolates at a concentration ranging from 50 to 400 ppm after 2 h of incubation in a single metal solution.

Conclusions

There was increase in uptake of Pb, Cd and Ni by different fungi and bacteria with increase in concentration from 20 to 60 ppm of these heavy metals. Maximum removal of Pb was observed by *T. longibrachiatum* (9.63 mg/g), Cd by *T. fasciculatum* (18.59 mg/g) and Ni by *A. terreus* (3.88 mg/g) at 60 ppm concentration of each metal whereas in case of bacteria, maximum removal of Pb was observed by *B. cereus* (16.66 mg/g), Cd by *B.* sp. (49.95 mg/g) and Ni by *B.* sp. (2.51 mg/g) at 60 ppm concentration. The removal of heavy metals (Pb, Cd and Ni) from liquid media indicated the real potential of these fungi and bacteria. These fungal and bacterial cultures can be used for bioremediation of industrial waste water for heavy metals.

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Return to investment made for alkali land reclamation technology in India

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ABSTRACT

Total economic surplus generated from the reclaimed alkali land in India has been evaluated to Rs 6004 million from 1975-76 to 2006-07. It was Rs 3.88 million in 1975-76 which increased to Rs 5090 million in 1979-80; Rs 70.88 million in 1984-85; and Rs 261.89 million in 1999-2000. The net present worth (NPW) of research investment made for evolving the technology to reclaim alkali land was Rs 424.51 million during the period of 37 years from 1969-70 to 2006-07. The benefit-cost ratio (BCR) was 7.83, whereas internal rate of return (IRR) estimated to 65.46% for these research investments. The NPW, BCR and IRR estimates clearly highlighted the fact that the research investment made for developing alkali land reclamation technology in the India proved highly remunerative, technically sound and economically viable. It has quite visible impact in the area by providing much high return as against the research investment made for it. The technology evolved for reclaiming alkali land contributed remarkably in rehabilitation and managing salt affected soils. The findings indicated that alkali soil reclamation has considerably increased soil productivity, sustainability of agricultural production system, yield of crops and income of the beneficiary farm-families. Looking at the sizeable areas affected in the country and highly successful technology available for reclaiming the problematic land, it is necessary to increase budgetary allocations substantially for research and developmental programs in this vital sector.

Key words: economic surplus, research investment, impact assessment, alkali land reclamation, internal rate of return, benefit cost ratio.

Introduction

The socio-economic analysis is mandatory and an integral component of the process of technology design, testing and delivery. It is important to demarcate the potential end users of a given technology before it is designed or evaluated. Indeed, this is what determines the criteria for socio-economic evaluation. The land reclamation and management practices encompass an entire spectrum of land use systems including crop production and rearing of animals (Lundgren and Raintree, 1982). It is advocated that the soil reclamation and proper managing problematic lands are one of its primary benefits (Young, 1989). The presence of crops and other vegetations like woody perennials in the form of crop production and agroforestry systems may affect several bio-physical and bio-chemical processes that determine the health of the soil substrate (Nair, 1993). The less disputed effects of vegetation on soil include: control of erosion, primarily surface litter cover, maintenance or increase of organic matter and diversity, continuous degeneration of roots and decomposition of litter; nitrogen fixation; enhancement of physical properties such as soil structure, porosity and moisture retention due to the extensive root system and the canopy cover; and enhanced efficiency of nutrient use through the interception of plant/ tree-root system which absorb and recycle nutrients in the soil that would otherwise be lost through leaching.

There has been considerable economic research on the causes of change in agricultural productivity in general; conventional economics has rarely been used to understand the role of natural resources such as soil in providing flows of non-market services such as soil conservation (Pagiola, 1993). The paucity of economic valuations of land reclamation technologies can be explained by several factors including: the spatial and temporal complexity of land use systems; heterogeneous farm conditions at the inter and intra household level; multiple inputs and outputs; and the existence of several non-markets costs and benefits. All these factors need rigorous statistical analysis. Understanding the long run impact of a change in soil quality on agricultural productivity in particular and societal welfare in general, requires extensive economic and agro-ecological panel data with significant length and width (time series and cross sectional variation). Considering importance of the salt affected land reclamation in food production and livelihood security of the country (Joshi *et al.*, 1987; Tripathi, 2009), the present study was undertaken with the twin objectives (i) to estimate pattern of investment in research for alkali soil reclamation and (ii) to assess the benefits of these investments.

Research methodology

Data and data collection

The present study is based on three states of India namely Haryana, Punjab and Uttar Pradesh, where alkali land is predominant. The research on reclamation and management of alkali soils was initiated first at Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. But it gained a momentum in 1969 when the Central Soil Salinity Research Institute (CSSRI) was established, where a complete package for alkali land reclamation has been developed. The gypsum based alkali land reclamation technology became most popular and adopted by the farmers in a massive way that has reclaimed about 2 million ha land in the country. The research institutions like Narendra Dev University of Agriculture & Technology, Faizabad; Chaudhari Charan Singh Haryana Agricultural University, Hisar and Punjab Agricultural University, Ludhiyana also made some efforts to develop alkali land reclamation technology. Therefore, the year-wise investment made by these institutions for evolving alkali land reclamation technology was collected from these institutions and pooled for estimation of the total research investment. The year-wise and item-wise details of expenditure was collected from official records of all the related institutions including CSSRI- one of the pioneer research institutes on reclamation of salt affected soils. Besides this, the other research set-ups working in the same areas under State Agricultural Universities were also visited to collect research investment made for alkali land reclamation. The total funds utilized by a particular institute were grouped under two broad heads *viz.,* (i) research investments for alkali soils reclamation technology and (ii) other related research.

To estimate returns of research investment and benefits of the alkali soil reclamation technology, a sample of 240 farmers was drawn from Haryana, Punjab and Uttar Pradesh through multistage stratified mixed sampling technique. The farmers were spreading in six districts (two from each state) and twelve villages (2 from each district). The data on alkali land reclamation were collected from the selected farmers who had adapted alkali soil reclamation technology on their farms.

Analytical techniques and empirical model

Two types of evaluation techniques are often used to measure impact of research investment. The first is ex-ante evaluation, which is used for estimating the impact before execution of a project by using approaches like (i) congruence analysis, (ii) scoring method, (iii) economic surplus method, (iv) mathematical programming, (v) econometric approaches, and (vi) crop loss models. The second technique, i.e., ex-post evaluation includes (i) economic surplus approach, and (ii) production function approach to measure the impact of research investment (Ramaswamy *et al.,* 1997). The economic surplus method is preferred over other approaches because this concept underlies the conventional economic rationale for government intervention in agricultural research through public sector (Alston et al., 1995). It estimates returns on investment (weighted average rate of return over time) by (i) calculating the change in consumer and producer surpluses that results from technological change brought about through research, and (ii) using estimated economic surplus together with research costs to estimate the Net Present Value or Internal Rate of Return (Maredia and Byerlee*,* 2000).

The theory underlying the economic surplus approach is based on the material benefits to society from technological change(s). The adoption of innovations reduces the unit cost of production, shifting the supply curve to the right and increasing consumer and producer surpluses. Consumers gain from the new technology as they can consume more at a lower price, and producers gain because their unit costs of production fall. The distribution of benefits between producers and consumers depends on the elasticities of demand and supply curves and on the magnitude and nature of the supply shift. The combined total benefit to consumers and producers, measured in monetary units, is the change in economic surplus. The basic formula for estimating the change in economic surplus in a year (ΔES_t) is as follows (Horstkotte - Wesseler *et al.,* 2000):

$$\Delta ES_t = K_t P_t Q_t \left(1 + \frac{0.5 K_t \varepsilon \eta}{\varepsilon + \eta}\right) \quad \ldots(1)$$

Where P_t is the price of commodity affected by research in year t, Q_t is the quantity of production in year t of the commodity affected by research, ε is the elasticity of supply, η is the elasticity of demand, and K_t is the proportionate downward shift in supply curve in year t due to research. The most critical parameter K_t is calculated as the net change in the cost of production due to new technology (which is sometimes approximated by the yield increment due to the new technology), weighted by the rate of adoption of the new technology in year t (or $K_t = \alpha_t k_t$; where α_t is the adoption rate of technology in year t and k_t is the per unit cost reduction in year t resulting from technological change).

A simplified form of the economic surplus approach is used for calculating research benefits in year t as the product of K_t P_t Q_t by the following equation:

$$\Delta ES_t = K_t P_t Q_t \quad \ldots(2)$$

The cost–benefit analysis assumes that demand and supply elasticities are polar, i.e., the demand is infinitely elastic and supply is completely inelastic. If the purpose of the economic analysis is to measure only the total economic surplus and not its distribution between consumers and producers, then this simplified approach gives reasonable estimates of the economic benefits. The simplified form of economic surplus method was, therefore, adapted in the present study.

In the alkali soil reclamation technology, the total cost of crop enterprises is treated as k_t because of the fact that in most of the cases there was no crop cultivation on barren alkali lands before reclamation. Thus, the entire cost of production is considered as the shift in cost of the commodity affected by research (*i.e.* k_t). The formula for estimation of ΔES_t, mentioned above at equation (2), is modified as per requirements of the situation. The modified form of the model is as follows:

$$\Delta ES_t = \Sigma\,(P_{it}\,Q_{it} - K_{it}) \quad \ldots(3)$$

Whereas;

$\Sigma P_{it} = P_{Rt} + P_{Wt} + P_{Ot}$

$\Sigma Q_{it} = Q_{Rt} + Q_{Wt} + Q_{Ot}$

$\Sigma K_{it} = K_{Rt} + K_{Wt} + K_{Ot}$

P_{Rt} = Price of rice affected by alkali soil reclamation research in year t

P_{Wt} = Price of wheat affected by alkali soil reclamation research in year t

P_{Ot} = Price of other crops affected by alkali soil reclamation research in year t

Q_{Rt} = Quantity of rice production affected by alkali soil reclamation research in year t

P_{Wt} = Quantity of wheat production affected by alkali soil reclamation research in year t

P_{Ot} = Quantity of other crops production affected by alkali soil reclamation research in year t

$k_{Rt} = \alpha_{Rt}\, k_{Rt}$

$k_{Wt} = \alpha_{Wt}\, k_{Wt}$

$k_{Ot} = \alpha_{Ot}\, k_{Ot}$

α_t = Adoption rate of the alkali reclamation technology in year t

k_t = Shift in per unit cost of production from technological changes in year t

R, W, O = Rice, wheat and other crops grown on the reclaimed alkali soils, respectively

Measures for financial assessment

The economic evaluation of the projects related to the technology evolved for sodic land reclamation may be based on the financial as well as economic parameters. A project is financially viable under the "equity capital" approach when the resulting IRR exceeds the cost of equity contribution of the proponent while NPW should be greater than zero using the cost of equity capital as discount rate. The IRR is that discount rate which equates the present values of the project's benefits and costs so that the NPW is zero, and the BCR is one. The Net Present Worth, Internal Rate of Return and Benefit-Cost Ratio criteria are mainly used for assessing the project. Therefore, these parameters have been estimated to find out benefits generated by alkali soil reclamation research. The appropriate yardstick to judge whether the investment is acceptable is NPW. The NPW is the sum of all costs and benefits over the life of investment with discounted opportunity cost of capital. The expected NPW takes into account the entire range of possible NPWs by weighting all possible project outcomes with their corresponding relative frequencies or probabilities. The Net Present Worth, also known as Net Discounted Value (NDV), of an investment is the present value of its revenues minus the present value of its costs where *T* is the horizon of the investment. NPW considers the benefits and costs over the entire span of the project. According to the decision rule of the NPW, an investment is acceptable if the NPW is equal or more than 0. A remark about this criterion is that it is difficult to interpret which one is more profitable for investments with different scales. The BCR, also called the profitability index, is the present value of revenues divided by the present value of costs. The decision rule states that an investment is accepted if the BCR equal or more than 1. The Internal Rate of Return (IRR) is the interest rate at which the present value of revenues equals the present value of costs.

The NPW can be calculated by taking the difference between present worth of benefits and present worth of costs. Once the year wise benefits and costs have been expressed in terms of present values, these are added to find out the NPW of the technology. The formula adapted for estimation of NPW (Gittinger, 1977; Bibhakar *et al.*, 1997) is as under.

$$NPW = \sum_{t=1}^{n} Bt\left(1+i\right)^{t} - \sum_{t=1}^{n} Ct\left(1+i\right)^{t}$$

Where;

B = Benefits received from the reclaimed alkali lands brought under cultivation in year t, *i.e.*, ΔES_t in Rs per annum,

C = Cost incurred on the research to evolve alkali soil reclamation technology in Rs per annum,

t = Time in years,

n = Number in years of the project duration, and

i = Rate of interest for compounding the costs and benefits.

The basic purpose of benefit-cost analysis is to assess the economic attractiveness of an action or project. A single project may be assessed to see whether it is profitable or meets a minimum profitability standard. BCR is also commonly used to rank alternate projects and select the most attractive option. Project assessment is based on a comparison of the costs of the project against the expected benefits. There are several ways in which the costs and benefits can be compared, but all of these measures share certain key characteristics. In land reclamation projects, the benefits and costs are often incurred over a long period of time and they have to be discounted to allow for a consistent comparison. The benefit-cost ratio is the most popular criterion in social project appraisals. It is the ratio of present worth of benefit and present worth of cost expected at different points of time for a particular project. The BCR is often the most popular criterion in social project appraisals, which is calculated by dividing the total compounded benefits by total compounded costs. The formula adapted for estimation of present worth of benefits and present worth of costs ratio for research investment in alkali soil reclamation is as under (Gittinger, 1977; Bibhakar and Hitzhusen, 1997).

$$BCR = \frac{\sum_{t=1}^{n} Bt\left(1+i\right)^{t}}{\sum_{t=1}^{n} Ct\left(1+i\right)^{t}}$$

The Internal Rate of Return (IRR) is the discount rate that generates a zero net present value for a series of future cash flows. This means that IRR is the rate of return that makes the sum of present value of future cash flows and the final market value of a project (or an investment) equals its current market value. Internal Rate of Return provides a simple 'hurdle rate', whereby any project should be avoided if the cost of capital exceeds this rate. It can be mathematically calculated using the following formula:

$$CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \frac{CF_3}{(1+r)^3} + \frac{CF_n}{(1+r)^n} = 0$$

In the above formula, CF is the Cash Flow generated in the specific period (the last period being 'n'). The internal rate of return or discounted cash flow rate of return is the marginal efficiency of capital or discounted cash flow of the investment on a project. It is the rate at which the discounted cash flows are equal to the investment outlay of the enterprises. So, the IRR is that rate of interest which applies to the expenditures incurred at different times for finding compounded sums equal to revenues compounded at the same time. The rate of discount which makes NPW of the investment exactly equal to zero is known as internal rate of return of a project. Thus, IRR is that rate of discount which makes present value of benefits zero.

A related yardstick for determining whether investment is acceptable is the project's IRR which is the interest rate at which the NPW equals zero. The IRR is used to find out the rate of return, which the projected technology has earned during the specified period of time. In other words, it is the rate at which the compounded cash flows are equal to the investment outlay of the enterprises. The rate of discount which makes NPW of the investment exactly equal to zero, is considered as internal rate of return of the projected technology. The formula adapted for estimation of IRR for research investment in alkali soil reclamation is as under (Gittinger, 1977; Bibhakar et al., 1997).

$$IRR = \frac{\sum_{t=1}^{n} Bt(1+i)^{t}}{\sum_{t=1}^{n} Ct(1+i)^{t}} = 0$$

Where; B, stands for benefits; C, for costs; i, for rate of discount; and t, for time in years

Results and discussion

On the basis of the number of crops grown in a year and productivity level of the crops grown, the sodic lands in India were classified in three categories. These includes (i) 'C Class' land, (ii) 'B Class' land, and (iii) 'B+ Class' Land. In the 'C Class' land, no crop could be grown before reclamation because of severe problem of sodicity and these lands were lying barren through out the year. In B Class land, only one crop could be grown in a year before reclamation and hardly 50 percent yield of the normal crop was realized. In B+ Class land, the farmers could grow two crops in a year but productivity of the crops was significantly lower than the normal productivity, raging between 25 and 50 percent.

Details of the various types of alkali land (C Class land, B Class land and B+ Class land) reclaimed annually from 1969-70 to 2006-07 in the country and economic surplus generated from these lands during the reference period are presented in Table 1. It is evident from the data that economic surplus generated from the alkali land reclaimed during the period of 37 years (from 1969-70 to 2006-07) was not at the same rate because of the fact that productivity of these lands was different before reclamation.

The economic surplus of the reclaimed land started from the year 1975-76. There was 5-6 years gestation period between technology evolved and adopted on the field. The economic life of the alkali land reclamation project is considered as 10 years, out of that during the first 3 years, there was no surplus generated and yield was hardly sufficient to meet the cost of cultivation of

Table 1. Alkali land reclaimed and economic surplus generated during the year 1969-70 to 2006-07 in India

Year	Area Reclaimed (in 000 ha)				Total Economic Surplus generated (Rs)
	C Class land	B Class land	B+ Class Land	Total	
1969-70	0	0	0	0	0
1970-71	0	0	0	0	0
1971-72	0	0	0	0	0
1972-73	0	0	0	0	0
1973-74	0	0	0	0	0
1974-75	0	0	0	0	0
1975-76	1939	970	970	3878	3878100
1976-77	7756	3878	3878	15512	15512400
1977-78	9695	4848	4848	19391	19390500
1978-79	19391	9695	9695	38781	38781000
1979-80	25452	12726	12726	50904	50904000
1980-81	30941	15471	15471	61882	74258400
1981-82	27311	13655	13655	54621	71007300
1982-83	24975	12487	12487	49949	69928600
1983-84	26643	13322	13322	53286	74600400
1984-85	23626	11813	11813	47252	70878000
1985-86	22937	11469	11469	45874	68811000
1986-87	16948	8474	8474	33896	50844000
1987-88	17891	8946	8946	35782	57251200
1988-89	36478	18239	18239	72956	124025200
1989-90	37357	18679	18679	74714	149428000
1990-91	47798	23899	23899	95596	191192000
1991-92	35899	17949	17949	71797	179492500
1992-93	24223	12112	12112	48446	145338000
1993-94	27704	13852	13852	55407	182843100
1994-95	22286	11143	11143	44572	156002000
1995-96	29767	14883	14883	59533	220272100
1996-97	27687	13843	13843	55373	238103900
1997-98	22001	11001	11001	44003	202411822
1998-99	24815	12407	12407	49629	248146900
1999-00	24476	12238	12238	48952	261893949
2000-01	46899	23449	23449	93797	525264040
2001-02	26483	13241	13241	52966	304552775
2002-03	25092	12546	12546	50183	288553687.5
2003-04	21227	10614	10614	42455	254728320
2004-05	48911	24455	24455	97821	586927080
2005-06	44214	22107	22107	88427	530562000
2006-07	39154	19577	19577	78309	548160690
Total	867972	433986	433986	1735944	6003942964

the crops. Yield of the crops grown on the land under reclamation achieved its potential level in 4th to 5th year just after adoption of the technology. The reclamation technology was considered to be effective up to the 10th year of its commencement in a field to generate economic surplus effectively, although the yield potential remains almost the same in several successive years.

Total economic surplus generated from the reclaimed alkali land was Rs 6004 million during the last 3 decades from 1975-76 to 2006-07. It was Rs 3.88 million in 1975-76 which increased to Rs 5090 million in 1979-80 and 70.88 million in 1984-85. It increased further to Rs 149.43 million in 1989-90, Rs. 156 million in 1994-95 and Rs 261.89 million in 1999-2000. The total economic surplus generated because of the alkali land reclamation technology adopted in the country was the highest in 2004-05 being Rs 586.93 million. It declined to Rs. 548.16 million on 2006-07.

Cash flow of the technology

The cash flow and discounted costs and benefits of the research investment for alkali land reclamation have worked out and is presented in Table 2. It was found that the total cash flow of the technology was Rs 5269 million during a period of 37 years (from 1969-70 to 2006-07). It was negative for the first 7 years from (1969-70 to 1975-76) as there was 5-6 years gestation period of the technology and no surplus could be generated during this period. The cash flow was Rs 12.23 million in 1976-77 and it increased continuously during the whole life of the project in general. The costs and benefits were discounted at the rate of 10 percent. The total discounted cost for technology development was Rs 62.20 million from 1969-70 to 2006-07 where as discounted benefits of the technology estimated Rs 486.72 million for the reference period.

Table 2. Cash flow and discounted costs and benefits of the research investment made for alkali land reclamation during the year 1969-70 to 2006-07 in India

Year	Research Investment made (Rs)	Economic Surplus Generated (Rs)	Cash flow (Rs)	Discounted cost @ 10% (Rs)	Discounted Benefit @ 10% (Rs)
1969-70	427354	0	-427354	388504	0
1970-71	748190	0	-748190	618339	0
1971-72	1022289	0	-1022289	768061	0
1972-73	1283467	0	-1283467	876685	0
1973-74	1836000	0	-1836000	1139665	0
1974-75	2150567	0	-2150567	1213638	0
1975-76	3944196	3878100	-66096	2023703	1989790
1976-77	3284315	15512400	12228085	1531863	7235261
1977-78	4748369	19390500	14642131	2013727	8223282
1978-79	5068615	38781000	33712385	1953976	14950270
1979-80	4229685	50904000	46674315	1482540	17842271
1980-81	4739767	74258400	69518633	1510442	23664245
1981-82	4362971	71007300	66644329	1263897	20569902
1982-83	6047330	69928600	63881270	1592660	18416803
1983-84	7191492	74600400	67408908	1721688	17859804
1984-85	8045235	70878000	62832765	1750867	15425027
1985-86	9362976	68811000	59448024	1852587	13615156
1986-87	10170172	50844000	40673828	1829168	9144604
1987-88	9905940	57251200	47345260	1620736	9367016
1988-89	10136508	124025200	113888692	1506839	18436926
1989-90	14641240	149428000	134786760	1978546	20192973
1990-91	12910425	191192000	178281575	1586047	23487961
1991-92	15300540	179492500	164191960	1708794	20046069
1992-93	16484586	145338000	128853414	1673562	14755127
1993-94	20193162	182843100	162649938	1863697	16875228
1994-95	21205704	156002000	134796296	1779301	13089612
1995-96	22914411	220272100	197357689	1747857	16801838
1996-97	24563015	238103900	213540885	1703281	16510915
1997-98	29914737	202411822	172497085	1885818	12759996
1998-99	38219034	248146900	209927866	2190328	14221268
1999-00	37101405	261893949	224792544	1932969	13644574
2000-01	43214133	525264040	482049907	2047093	24882238
2001-02	48887493	304552775	255665282	2104498	13110322
2002-03	45749190	288553688	242804498	1790575	11293686
2003-04	56037352	254728320	198690968	1994212	9065065
2004-05	56939312	586927080	529987768	1842100	18988259
2005-06	69897791	530562000	460664209	2055817	15604765
2006-07	61860000	548160690	486300690	1654011	14656703
Total	734738971	6003942964	5269203992	62198093	486726955

Table 3. NPW, BCR and IRR of the research investment made for alkali land reclamation in India during the year 1969-70 to 2006-07

S. No.	Parameters	Units	Estimates
1	Net Present Worth	Rupees in million	424.52
2	Internal Rate of Return	Percentage	65.46
3	Benefit-Cost Ratio	Ratio	7.83

Net present worth

Net Present Worth, Benefit-Cost Ratio and Internal Rate of Return of the research investment made for alkali land reclamation in the country during the year 1969-70 to 2006-07 are presented in Table 3. The net present worth estimated on the basis of research investment made for evolving the technology to reclaim alkali land was Rs 424.52 million during the study period which clearly indicates that the sodic land reclamation technology has quite visible impact by providing high return as against the research investment made for evolving the technology. The technology evolved for reclaiming alkali land contributed remarkably in rehabilitation of the problematic area and managing salt affected degraded lands. Further, it indicate that the alkali soil reclamation has increased return of the beneficiary farms. There had also been considerable increase in soil productivity and sustainability of the agricultural production system developed. Looking at the sizeable areas affected and also the highly successful technology available, it is strongly recommended that government may substantially increase budgetary allocations for research and developmental in this vital sector.

Present worth of benefit-cost ratio

The benefit- cost ratio of the research investment made for evolving technology to reclaim alkali land (Table 3) was 7.83. It is obvious from the BCR that the sodic land reclamation technology is economically sound and generated benefits at a quite higher rate. The BCR estimates depict the fact that Rs 7.83 was realized by the country in terms of crops yield out of each rupee invested for evolving alkali land reclamation technology. It is a very encouraging rate of return and attracts more investment on such types of the researches on priority basis.

Internal rate of return

The internal rate of return (Table 3) was 65.46% for the research investment made for evolving technology to reclaim alkali land which clearly indicates that the research investment made for evolving the technology to reclaim alkali land has proved quite remunerative in the salt affected areas where such technology is adopted for reclaiming the problematic land. It is obvious from IRR that sodic land reclamation is economically sound and capable to make significant impact in salt affected areas.

Results of this study agree with the findings reported in the number of similar evaluations. More than 150 empirical studies, carried out world wide on agricultural research evaluation have supported the results of this study in terms of estimated net present worth and internal rates of return. As many as 90 percent of the studies show rates of return in excess of 20 percent while 46-63 percent of the studies show excess of 50 percent (Evenson and Jha, 1973; Singh and Kaur, 1992). A number of evaluation studies have been conducted for India revealed the fact that such evaluations, even on discounting the rates of returns estimates heavily, these still remain quite high in comparison with other investment opportunities. Indian experience is thus quite consistent with the consensus on high productivity of agricultural research.

Conclusion

The present investigation finds that the alkali land reclamation technology in India is highly remunerative in both in technical and economical. It has quite visible impact in the country by providing much high return as against the research investment made for it. The technology evolved for reclaiming alkali land contributed remarkably in rehabilitation of the problematic land and managing salt affected soils. The research findings clearly indicated that alkali soil reclamation has considerably increased soil productivity, sustainability of agricultural production system, yield of crops and income of the beneficiary. Looking at the sizeable areas affected in the country and highly successful technology available for reclaiming the problematic land, it is strongly recommended that Government may substantially increase budgetary allocations for research and developmental programmes in this vital sector.

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- The article should be as concise as possible. All the full length papers should comprise of Short title, Title, Author(s)' name(s), Affiliations, email ID of corresponding author, Abstract, Key words, Introduction, Material and Methods, Results and Discussion, Conclusions, Acknowledgement (if any), References, Tables and Figures (if any). The text under each section should throughout have 12 fonts in MSW, Times New Roman, justified with 1.5 line spacing. However in the Abstract part, text should be 11 font with 1.5 line spacing and should not exceeds 250 words.
- The total length of article should not exceed 15 typed pages (2.5 cm. margin on each side of A4 paper) including Tables and Figures.
- All headings should be bold in capital letters with 12 fonts except Title which should be in Title Case and have 14 fonts. However, the subheadings within each section wherever necessary should be in title case bold in 14 font, further headings should be in Sentence case and bold; whereas further sob-sub titles should be bold italic. All main and subheadings should be aligned left.

Title Page

It should be a separate page and comprise of following:

Short Title : It should have a short title (not exceeding five words in italics) on the top of right hand corner.

Title : It should not exceed 15 words and should reflect the contents of paper. It should be in title case like "Alleviation of Sodicity Stress on Rice Genotypes by Phosphorous Fertilization".

Author(s) : Name of author(s) should be 12 font bold (without their official designations), aligned in center and in the title case like "A.K. Aggarwal and M.K. Tiwari".

Address : Each author's name should have number as superscript to indicate the address. The corresponding author's name should have number as superscript to indicate more than one address. The corresponding author's name should have asterisk (*) mark as superscript e.g. A.K. Aggarwal[*1] and M.K. Tiwari[2]. The address should be written in italics as shown below:

[*1]: Central Soil Salinity Research Institute, Zarifa Farm, Kachhwa Road, Karnal-132001, Haryana, India

[2]: Indian Institute of Soil Science, Nabibagh,, Berasia Road, Bhopal-462038, Madhya Pradesh, India.

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First Page

Actual paging (on right lower corner) of the manuscript should start from this page. It should have full title of paper followed by Abstract, Keywords and Introduction, etc. To ensure anonymity of the author(s), author's names and addresses should not be indicated on this page.

Abstract : Its contents should be in 11 font, single space and single paragraph with justified alignment.

Key words : Key words should appear just after the abstract and to be written as key words (11 fonts). These may be up to 7 in alphabetic order each separated by a comma and in title case. The scientific names (if any) should be italicized. e.g.

Key words : Agroforestry model, Biodrainage, Gypsum, *Oryza sativa* L., Salt tolerance,

Tables and figures

Each table and figure should have 12 font and be given on separate page after References part. Table 1 and Figure 1 should be written as **Table 1** (bold) and **Fig. 1** (bold), respectively. Table caption should appear on the top of table whereas figure caption should be just below the figure. Figures captions and matter should be legible with 8-12 font size. Maximum size of tables and figures should be such that these can be conveniently accommodated in A4 size page. Approximate position of the tables and figures should be indicated in the text of the manuscript.

References

References should be in alphabetic and chronological order and should not be serial numbered. The author(s) names should start with surname, comma after initials. If first author has two publications in a year, single author paper should appear first. Year should be bracketed. The journal names should be in full without abbreviation and should be italicized. Volume No. should be in bold. Few examples are given below:

Journal : Dagar JC, Tomar OS, Minhas PS and Kumar M (2013). Lemon grass productivity as affected by salinity of irrigation water, planting methods and fertilizer doses on a calcareous soil in a semi-arid region of northwest India. *Indian Journal of Agricultural Sciences* **83(7):** 734-738.

Book : Singh NT (2005). *Irrigation and Soil Salinity in the Indian Subcontinent- Past and Present.* Lehigh University Press, Bethlehem, USA, pp 404.

Book Chapter: Tyagi NK (1998) Management of salt-affected soils. In: Singh GB and Sharma BR (eds) *50 Years of Natural Resource Management Research*. Indian Council of Agricultural Research, New Delhi, India, pp 363-401.

Online Reference: Rhoades JD, Kandiah A and Mashali AM (1992). The use of saline waters for crop production-FAO irrigation and drainage paper 48. Food and Agriculture Organization, Rome. (http://www.fao.org/docrep/t0667e00.HTM.)

Conference/Symposium Proceedings: Suarez DL and Lebron I (1993) Water quality criteria for irrigation with highly saline water. In: Lieth H and Al Masoom AA (eds) *Towards the Rational Use of High Salinity Tolerant Plants*, Vol 2-*Agriculture and Forestry under Marginal Soil Water Conditions*. Proceedings of the first ASWAS Conference (December 8-15, 1990), United Arab Emirates University Al Ain, UAE. Kluwer Academic Publishers, Dordrecht, the Netherlands, pp 389-397.

M.Sc/ Ph.D. Thesis: Ammer MHM (2004). Molecular Mapping of Salt Tolerance in Rice. Ph.D. Thesis, Indian Agricultural Research Institute, New Delhi, India.

Bulletin: Abrol IP, Dargan KS and Bhumbla DR (1973) *Reclaiming Alkali Soils*. Bulletin No. 2. Central Soil Salinity Research Institute, Karnal, 58p.

Short communication: While writing Short Communication one should focus on studies of limited scope, preliminary data, unique observations or research technique and apparatus. The length of short communication should not exceed 3 published pages. Short communication should comprise of short title, title, names with affiliations and text dealing with material and methods, results and discussion and references but there should not be any main head except of references. It should not have abstract and keywords.

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Units to be followed

The international system of units (SI units) should be used throughout. Authors may consult Clark's Tables: Science Data Book by Orient Longman, New Delhi (1982) for guidance.

The terms like Nitrogen, Phosphorous, Potassium and Zinc may be denoted as N, P, K and Zn, respectively and dose expressed as kg ha^{-1} for field experiments. For pot studies, units like mg kg^{-1} should be followed.

Common units and symbols

time=t, metre=m, second=s, centimeter=cm, cubic centimeter=cm^3, cubic metre=m^3, degree Celsius=ÚC, day=d, gram=g, hectare= ha ($10^4 m^2$), Hour=h, Kilometer=km, Kilogram=kg, litre=l, Megagram=Mg (tons to be given in Mg), Microgram=µg, Micron=µm, milimole=mmol, milliequivalent=meq, micromol=µmol, milligram=mg, milliliter=ml, minute=min, nanometer=nm, square centimeter=cm^2, square kilometer=km^2,electrical conductivity= (EC)=dS m^{-1} (deci Siemens m^{-1}), gas diffusion=g m^2 s^{-1}, water flow=m^3 $m^2 s^{-1}$, ion uptake= mol kg^{-1} of dried plant material, leaf area=$m^2 kg^{-1}$, nutrient content in plants= mg g^{-1} (dry matter basis), root density or root length density= m m^{-3}, soil bulk density= g cm^{-3}, transpiration rate=mg m^2 s^{-1}, water content of soil=kg kg^{-1}, water tension=kPa, yield (grain or forage)= Mg ha^{-1}, organic carbon content of soil= percent (%), cation exchange capacity of soil= cmol (p+) kg^{-1}

Style Guidelines

All soils discussed in the manuscript should be identified according to the U.S Soil Taxonomic System at first mention. The Latin binomial or trinomial and authority must be must be shown for all plants, insects, pathogens, microorganisms and animals when first mentioned. Both the accepted common name and the chemical name of any chemicals mentioned (including pesticides) must be provided. SI units must be used throughout the manuscript. Corresponding metric or English units may be added in parentheses at the discretion of the author. For spelling, Webster's *New Collegiate Dictionary* should be used as reference. If a commonly available product is mentioned, the name and the location of manufacturer should be included in parentheses after first mention. Responsibility of the facts and opinions expressed in the articles rests entirely with the author(s) and not with the journal.

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1	Place of Publication	Karnal
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I, Dr. P.C. Sharma, hereby declare that the particulars given above are true to the best of my knowledge and belief.

Sd/-
P.C. SHARMA
General Secretary
Indian Society of Soil Salinity and Water Quality

Application Form for Life/Annual/Associate/Institutional Membership*

Indian Society of Soil Salinity and Water Quality

(Registered under Act. XXI of 1860)

Registration No. ROS-088, Dated: 6-8-2008

Registered Office: Central Soil Salinity Research Institute, Zarifa Farm, Karnal-132001, Haryana, India

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2. Designation or Position: ____________
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