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Soil Fertility Constraint Assessment Using Spatial Nutrient Map at Three Selected Villages of Coastal Sundarbans

Tarik Mitran*[1], Pabitra Kumar Mani[1], Nirmalendu Basak[1], Biswapati Mandal[1] and Subrata Kumar Mukhopadhyay [2]

[1]*Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani-741 252, Nadia, West Bengal, India*
[2]*National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Kolkata-700 091, West Bengal, India*
**Email: tarik.bckv@gmail.com*

Abstract

Soil fertility constrains were studied in three representative villages *i.e.* Tushkhali, Duchnikhali and Korakati with collecting and interpreting a large number of geo-referenced soil samples of Sundarbans. The Global Positioning System (GPS) based soil reaction, salinity and nutrient maps were prepared by Inverse Distance Weighted (IDW) spatial interpolation method using ArcGIS Ver. 10 software. Soils were mostly heavy in texture (clay > 50%), highly acidic to neutral in reaction and associated with marginal salinity. Although an extreme acidity (< 4.8) or higher salinity level > 4.0 dS m^{-1} was detected in some of the pockets. Among the three villages, Tushkhali showed comparatively higher electrical conductivity (EC) with highest value of 5.23 dS m^{-1}. There was a decreasing trend in EC recorded with higher level of organic C with irrespective of sampling sites. On an average, organic C of the studied area was medium to high in nature. Soils were poor in available nitrogen and medium to low in available P and Zn. Higher availability status of K, Mn, Cu, Fe and S were found in such soils. Nutrient Index values for all the studied plant nutrients were generated. These values revealed that area is poor in available N; medium in available P and Zn but the native supply of available K, S and micronutrients are in much pronounced. The available N, P and Zn contents significantly increased with increase in organic C of soil.

Key words: Acid soil, ArcGIS, Salinity, Soil fertility, Spatial nutrient map, Sundarbans

Introduction

Coastal regions, home to a large and growing proportion of the world's population, are undergoing environmental decline. The problem is particularly acute in developing countries. The reasons for environmental decline are complex, but population factors play a significant role. Today, approximately 3 billion people-about half of the world's population live within 200 kilometres of a coastline. By 2025, figure is likely to be double. The Coastal agro-ecosystem occupies vast area of land in India. About 20% of the population of India lives in coastal areas. In coastal areas of India, salt affected soils stand to be one major challenge in preventing agricultural activities. On global basis salt affected soils occupy an estimated area of 952 million ha, nearly 7% of total land area or approximately 33% of the potential arable land area of the world (Szabolcs, 1979). In India, out of an estimated area of 187.7 million hectares of total degraded land, 9.38 million hectares are salt affected soil (Dagar, 2005) and out of which 3.1 million hectares are in the coastal region (Yadav *et al.*, 1983). Among the states in India, West Bengal has the largest area (0.82 million hectares) of the salt affected soils in the coastal region, between 87º25' E and 89º.0' E latitude and longitude 21º30' N and 23º15' N covering the district of North and South 24-Parganas, Howrah and East Midnapore. The great Sundarbans, the delta region of the river Ganges, occur in the coastal tracts of North and South 24-Parganas constitute a major portion of coastal region of India with wide variability in climatic, topographical and edaphic conditions. The climate is typical tropical with wide variation in the annual rainfall from 300-3000 mm. The rainfall is mainly concentrated during the South-West monsoon from June to September when more than 80% of the rainfall is experienced in the region. The rainfall in the rest of the period of the year is meagre. Beside that the entire area of Sundarbans faces the problem of salinity, waterlogging and drainage congestion. In the absence of upland water supply the area is exposed to tidal action making the water highly brackish. The soil salinity shows wide spatial and seasonal variability, being minimum in the monsoon season and maximum in the summer season (Bandyopadhyay *et al.*, 2001). The degraded soil and water

*Corresponding author, Present address: Soil and Land Resources Assessment Division, Land Resources, Land use Mapping and Monitoring Group, National Remote Sensing Centre, Hyderabad, India

quality together with climatic adversities like cyclone, tsunami, heavy rains, flood etc. contributed to the poor livelihood security and low agricultural productivity of the area. The coastal area is generally mono-cropped with only rice during the monsoon season. In this region, soil salinity, imbalance of nutrients, unfavourable pH, lack of good quality irrigation water etc. account for poor yields of crops (Sen and Bandyopadhyay, 2001). Due to presence of brackish water table at a shallow depth there is always an increase in soil and water salinity in dry months. The land remains almost fallow throughout the year after *Kharif* season (wet season, July-October). During the remaining part of the year (*Rabi* and *Summer*), 90% of the land remains fallow due to soil and water salinity and lack of good quality irrigation water. Thus, continuous cropping of the land by almost a single crop along with non-scientific fertility management has resulted in low soil productivity. A suitable soil management strategy is, therefore, required to mitigate the ill effects of degraded coastal land for sustained productivity by identifying the constrains. The present study has undertaken to make an inventory of nutrients status of such coastal soils to identify the fertility constraints by preparing spatial nutrient map as Global Positioning System (GPS) and Geo-graphical Information System (GIS) help in collecting a systematic set of georeferenced samples and generating spatial data regarding distribution of nutrients.

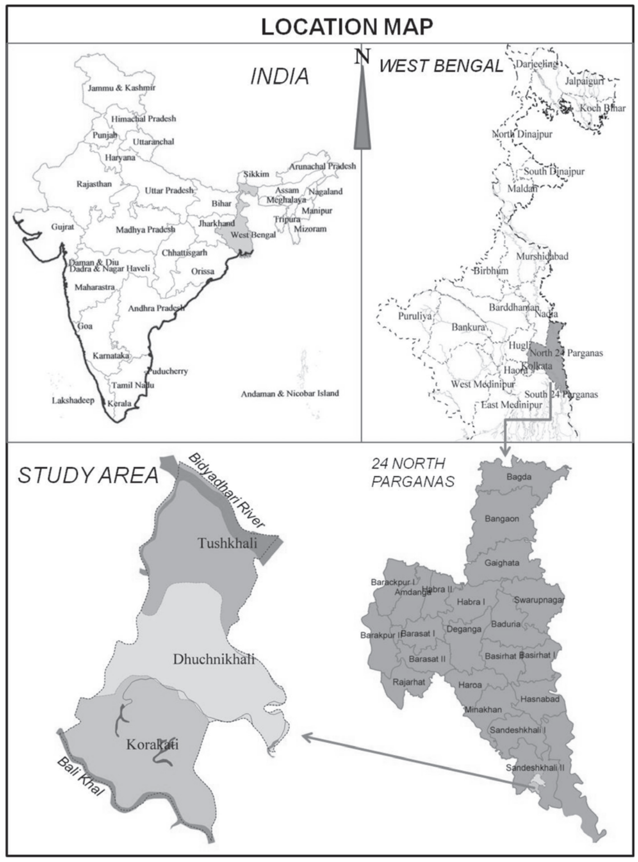

Fig. 1. Location of the study area

Materials and Methods

A total of 150 GPS based soil samples (0-20 cm depth) containing 50 samples each from the representative villages such as Tushkhali, Duchnikhali and Korakati of (22°22′ N latitude and 88°54′ E, Longitude) Sandeshkhali-II, North-24-Parganas, West Bengal, were collected during the peak summer month during May 2011.

Particle size distributions of the soils were determined following the Boyoucous hydrometer method (Gee and Bouder, 1986). Bulk density was determined by core sampler method following the method of Blake and Hartge (1986). The pH of the soil was determined in 1: 2.5:: soil: water and 0.02 M $CaCl_2$ solution, respectively suspension, by using digital pH meter described by Jackson (1973). Electrical conductivity of the soil saturation extract was determined at room temperature in a soil water suspension ratio of 1:2.5 with the help of Wheatstone Conductivity Bridge as described by Jackson (1973). Organic C in soil was determined by methods describe by Nelson and Sommers (1982). Estimation of Available N was done by alkaline permanganate method (Subbiah and Asija, 1956). Available phosphorus in soil was determined calorimetrically following ascorbic acid reluctant method as outlined by Bray and Kurtz (1945). Available potassium of the soil samples was extracted with neutral 1*N* ammonium acetate solution followed by measured by a Flame Photometer as described by Jackson

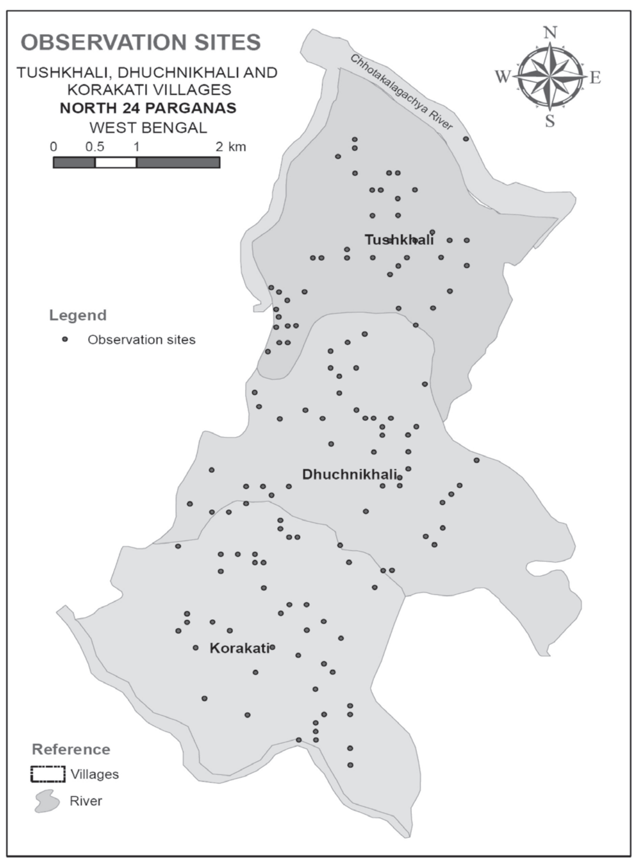

Fig. 2. Location of the observation sites at different villages of Sandeshkhali-II

(1973). The available DTPA extractable Fe, Mn, Zn and Cu of the soil samples were estimated using atomic absorption spectrophotometer (AAS) following the method of Lindsay and Norvell (1978). Available sulphur (S) was estimated by turbidmetrically barium chloride procedure as described by Chesnin and Yien (1951). Nutrient index values (NIV) calculated from the proportion of soils under low, medium and high available nutrient categories, as represented by the following expression:

$$NIV = \frac{N_l + 2N_m + 3N_h}{N_l + N_m + N_h}$$

Where, NIV is nutrient index value., N_l, N_m and N_h are the number of soil samples falling in the category of low, medium and high nutrient status and are given weightage of 1, 2 and 3, respectively. Accordingly, areas with nutrient index value > 2.33 could be considered high, those with NIV between 1.34 and 2.33 or 1.51-2.50 could be considered medium, and those with values < 1.5 or < 1.33 could be regarded low in native supply of that nutrient.

Spatial soil nutrient maps were prepared by inverse distance weighted (IDW) interpolation method available in the sub-mode of interpolation in the spatial analyst tools of ArcGIS Ver. 10 by using a linearly weighted combination of a set of sample points. The IDW method for spatial interpolation estimates values of cells by weighting of values (point) of geometric data in the neighbourhood of each processed cell. The points located closer to the cell center have more influence or weight in the process of weighting. Soil fertility levels were classified into low, medium, or high categories according to existing norms (Ali, 2005) used for nutrient indexing and preparation of nutrients map. Ranges of soil salinity (EC), pH and organic C are depicted in Fundamentals of Soil Science (ISSS, 2009) used for map preparation. Simple correlation coefficients and regression analysis were performed by the windows based SPSS program (ver. 16.0, SPSS Inc.).

Results and Discussion

Physico-chemical properties of soils

The soils were mostly heavy in texture with high clay content generally more than 50% (Table 1). The clay content varied marginally from 50.7 to 66.1% that might be due to the origin of soil, parent materials and soil variability. The textural compositions of soils under different villages were more or less similar and fall under clayey class. These finding was corroborated with Bandyopadhyay *et al.* (1998) and Maji *et al.* (1998) who reported that coastal soils are mostly heavy textured and vary widely from place to place depending on their physiographic locations, climatic conditions and soil parent materials. Among representative villages, bulk

Table 1. Physico-chemical characteristics of soils

Sites	Sand	Silt	Clay	Bulk density	pH_W	pH_{Ca}	$EC_{2.5}$	Organic C	Av. N	Av. P	Av. K	Av. S	Av. Fe	Av. Mn	Av. Zn	Av. Cu
	%			Mg m^{-3}	1:2.5		dS m^{-1}	g kg^{-1}	kg ha^{-1}			mg kg^{-1}				
Tushkhali (n= 50)																
Range	3.3-13.2	28.0-38.0	54.7-62.7	1.26-1.36	4.36-7.53	4.06-7.19	1.12-5.23	4.5-9.8	104.5-286.4	10.1-28.5	303.4-682.0	10.2-46.2	14.1-87.8	8.36-38.2	0.44-3.61	3.35-9.81
Mean+SE_m (±)	8.0±3.2	34.0±3.7	58.0±2.5	1.3±0.03	5.54±0.93	5.25±0.91	3.16±1.02	7.3±1.6	193.0±52.7	17.3±4.64	496.0±94.2	21.3±8.1	56.5±21.3	20.9±8.32	1.4±0.47	7.1±1.62
Duchnikhali (n= 50)																
Range	1.3-13.3	26.4-38.0	50.7-61.3	1.22-1.36	5.16-7.15	4.82-6.88	1.04-4.89	2.1-10.5	90.5-323.4	9.6-27.4	337.3-665.3	10.7-38.1	7.04-124.5	10.9-42.2	0.56-2.27	3.5-9.39
Mean+SE_m (±)	9.0±3.8	33.0±3.9	58.4±2.5	1.29±0.04	6.06±0.46	5.67±0.42	2.84±0.95	8.0±2.0	208.6±65.9	19.2±4.86	549.5±87.8	25.4±7.17	59.3±7.9.0	23.7±7.38	1.31±0.44	6.75±1.37
Korakati (n= 50)																
Range	5.3-13.3	22.6-37.0	52.7-66.1	1.23-1.31	4.85-7.58	4.65-7.26	1.1-4.3	2.8-9.7	98.3-330.9	8.8-28.8	357.1-709.1	10.1-44.2	8.5-163.4	5.20-38.3	0.18-3.18	2.9-9.35
Mean+SE_m (±)	9.0±3.3	32.0±4.0	59.0±3.6	1.27±0.03	5.85±0.75	5.47±0.74	2.92±0.90	7.4±1.9	192.5±74.3	18.1±4.65	562.9±89.4	25.5±9.05	79.00±41.61	22.8±8.42	1.76±0.88	7.06±1.49

densities of the soils under Korakati village were comparatively lower than the others; this might be due to the marginally higher clay and organic matter content of such soils. It was found from the correlation study that the bulk density was negatively correlated with both organic carbon (*r*= -0.071; p <0.05) and clay content (*r*= -0.024; p <0.05) under the studied soil. Gulser (2006) and Hillel (1998) reported that bulk density had significant negative correlation with soil organic matter as organic matter is generally lowers in density. The soil reactions of the studied areas were highly acidic to neutral in nature. These results are in agreement with Sarkar *et al.* (2001) who reported the pH of the soils of the Sunderbans delta ranged from 5.3 to 8.1. However, an extreme acidity (pH < 4.8) was observed in some pockets of studied villages, might be due to the occurrence of acid sulphate soils. Kalyan and Sarkar (2009) also reported on nature of acidity of some coastal acid soils of Sunderbans of West Bengal and found that the soils under study were extremely acidic in reactions having pH value marginally above 4.0. Highly acidic soils with abundance of appreciable amount of sulphate at surface/ sub-surface soil horizons were reported in Coastal areas of Kerala, West Bengal, Orissa and Andaman and Nicobar group of Islands (Bandyopadhyay and Bandyopadhyay, 1984; Bandyopadhyay and Maji, 1995). Among the three villages, Tushkhali showed comparatively higher EC with highest value of 5.23 dS m^{-1} whereas a lowest value of EC ~1.04 dS m^{-1} was detected in soils under Duchnikhali village. Some locations showed higher salinity level > 4.0 dS m^{-1} indicated critical condition for crop cultivation. On an average the studied area was marginally saline to saline in nature. However, a decreasing trend in EC had recorded with increment in level of organic C irrespective to the sampling sites (Table 2). The correlation study showed that EC is negatively correlated with the organic C (*r*= -0.594; p <0.01). This might be due to the fact that carbon content improves soil physical properties *i.e.* soil structure, permeability, infiltration rate etc; which facilitates the leaching and drainage of soluble salts. Tripathi *et al*. (2006) reported that the organic C content of soil decreased by increasing salinity (*r*= -0.38; p <0.01). Kaur *et al*. (1998) also reported significant negative relationship between organic C and EC. It is documented that EC of coastal soils of West Bengal mostly varied from 0.5 dS m^{-1} during monsoon to 50 dS m^{-1}; during summer months. Bandyopadhyay *et al*. (1988, 2003) also reported similar salinity pattern in coastal areas. Kalyan and Sarkar (2009) reported that EC of some coastal acid soils of Sunderbans of West Bengal was high and varied from 1.9 to 3.9 d Sm^{-1}. On an average the organic C of the studied area was medium to high in nature. However, among the sites soil samples from Duchnikhali showed comparatively higher organic C compared to others. The organic C in the coastal soils are relatively high compared

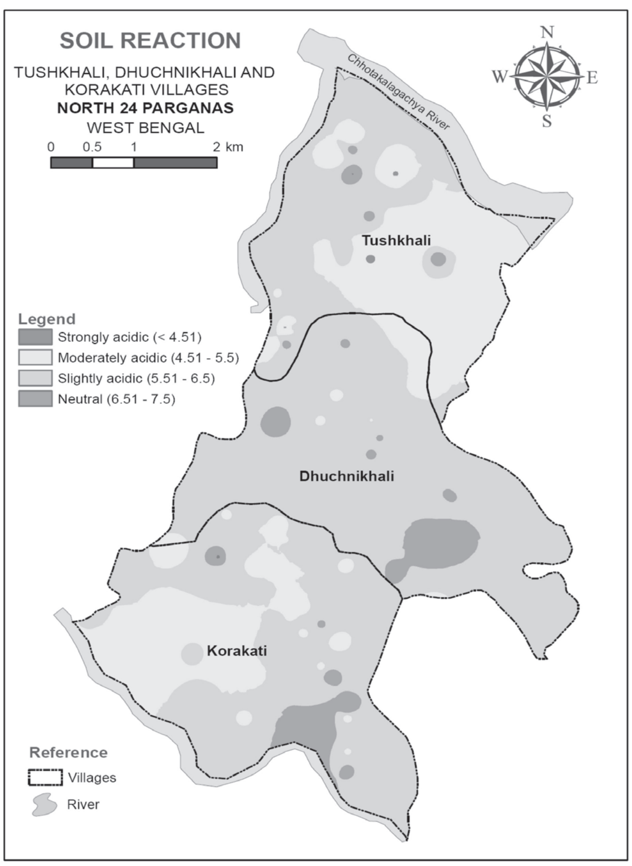

Fig. 3. Spatial soil reaction (pH) Map of the studied area

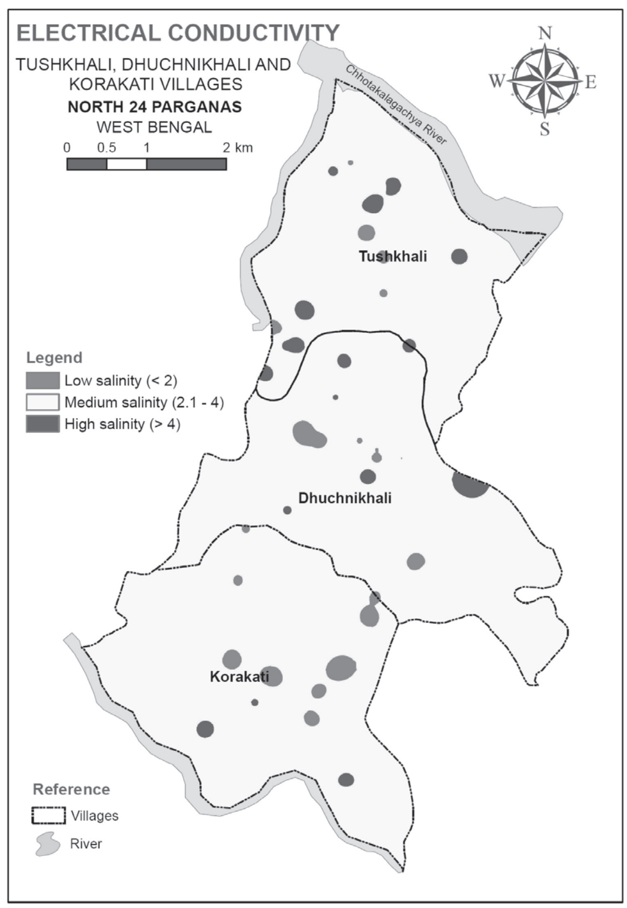

Fig. 4. Spatial soil salinity (EC dS m^{-1}) Map of the studied area

with that in similar types of soils located in identical climatic zones in non-coastal regions of India (Bandyopadhyay and Bandyopadhyay, 1983). Joshi and Kadrekar (1987) reported that organic C in the coastal soils varied from < 0.5% to > 0.75%. However, we found low organic C in some pockets. Available nitrogen content of the studied sites did not varied significantly. On an average the studied area was low in available nitrogen (Fig. 6).

The observed result detected a higher availability of N in soil is usually associated with the higher level of organic C (r= 0.776; p <0.01). Mineralization of organic matter may release plant available N in soil. The available phosphorus content of the studied soils was low to medium in range. Soils were high in available potassium content. The available sulphur content under different sites was more or less similar. The highest value (46.2 mg kg^{-1}) was associated with the soil samples collected from Tushkhali, where the lowest (10.1 kg ha^{-1}) was recorded in soils collected from Korakati. On an average the available S content of the studied area was medium to high. The available Zn content of soil under different sites was more or less similar. However, higher Zn content was recorded with the samples collected from Korakati. Analytical values described that studied areas were medium to low in available Zn (Fig. 7). The available Mn content of the soils under Duchnikhali and Korakati did not significantly differed and more or less similar; whereas, available Mn content of the soil samples collected from Tushkhali were medium in range (Fig. 8). This might be due to the lower pH of soils in Tushkhali compared to Duchnikhali and Korakati. Available Cu content of the soils in different sites did not differed significantly and was high in status. From the correlation matrix it was observed that pH was negatively correlated with available Zn (r = -0.097*; p <0.05), Fe (r = -0.170; p <0.01) and Cu (r = -0.277; p <0.01) among the soils collected from Sandeshkhali-II (Table 2). The available Fe showed a negative correlation (r= -0.194; p <0.01) with EC and positive correlation (r= 0.156; p <0.05) with organic C. Organic C showed a significant and negative correlation with EC (r = -0.594; p <0.05) and bulk density (r= -0.071; p <0.05) and positive correlation (r = 0.198; p <0.01) with Zn content of soils. The available nitrogen content of the soil showed a significant and positive correlation with organic carbon (r= 0.776; p <0.01) and negative correlation with EC (r= -0.383; p <0.01). From the results it can be inferred that the available P was negatively correlated with Zn (r= -0.443; p <0.01) content of soil and positively correlated with the organic carbon (r= 0.056; p<0.05) and Fe (r= 0.538; p <0.01).

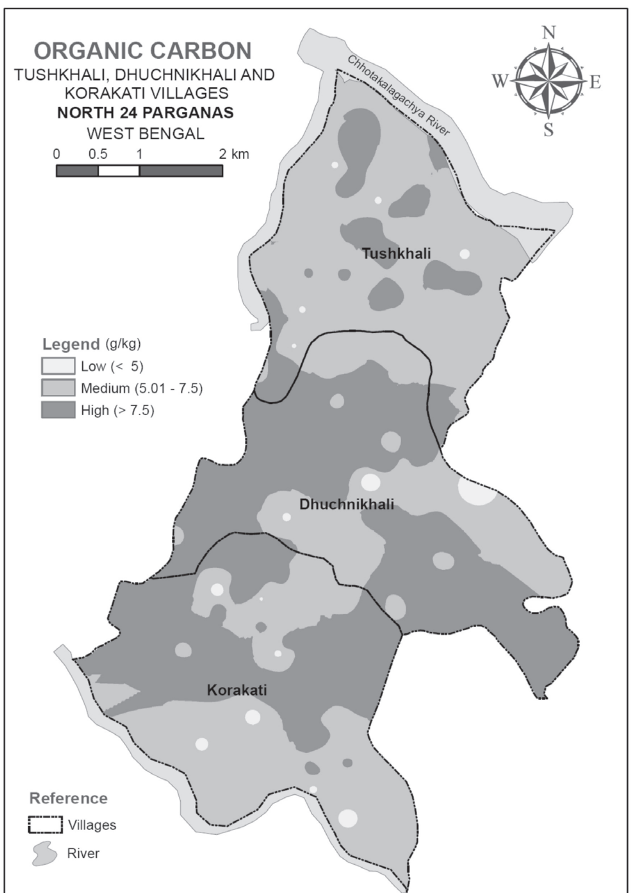

Fig. 5. Spatial map of organic C (g kg^{-1}) content of the studied soil

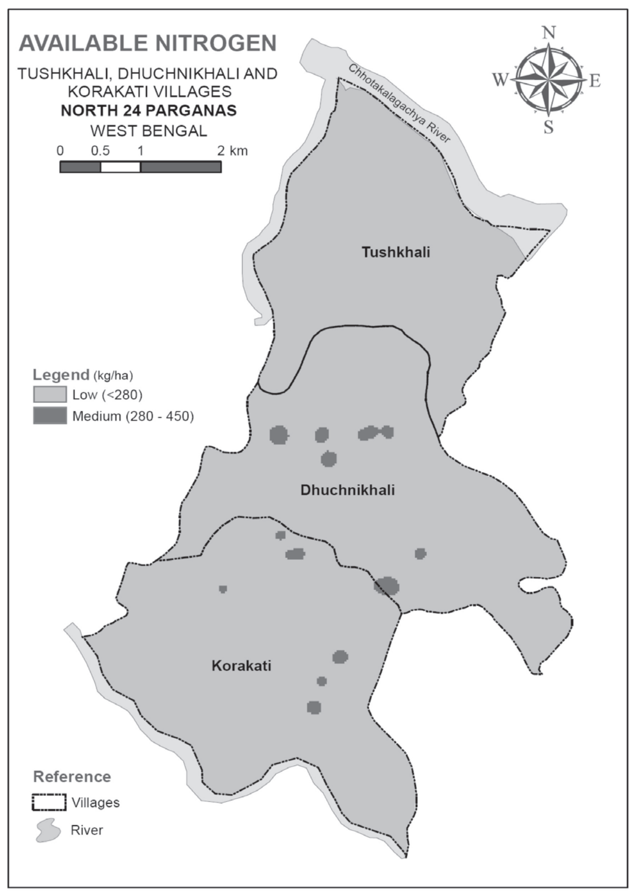

Fig. 6. Spatial map of available nitrogen (kg ha^{-1}) content of the studied soil

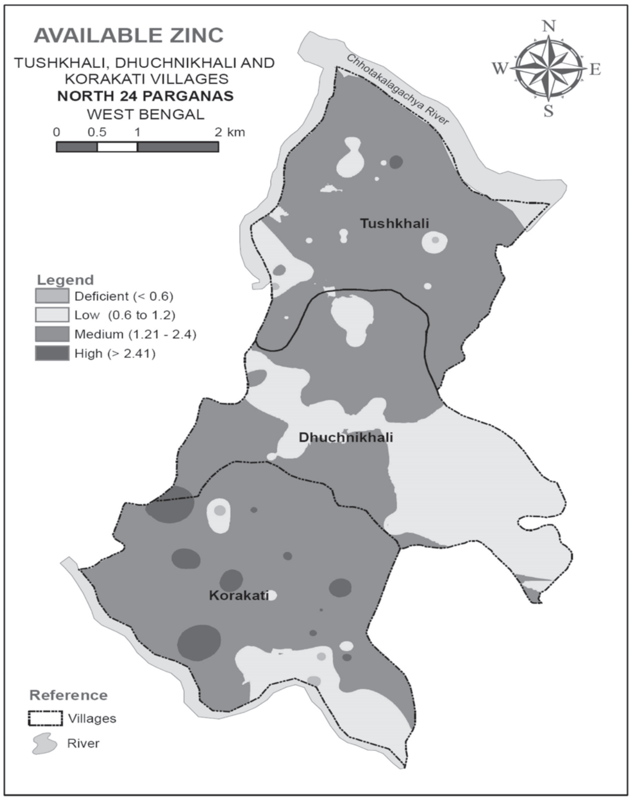

Fig. 7. Spatial map of available Zn (mg kg^{-1}) content of the studied soil

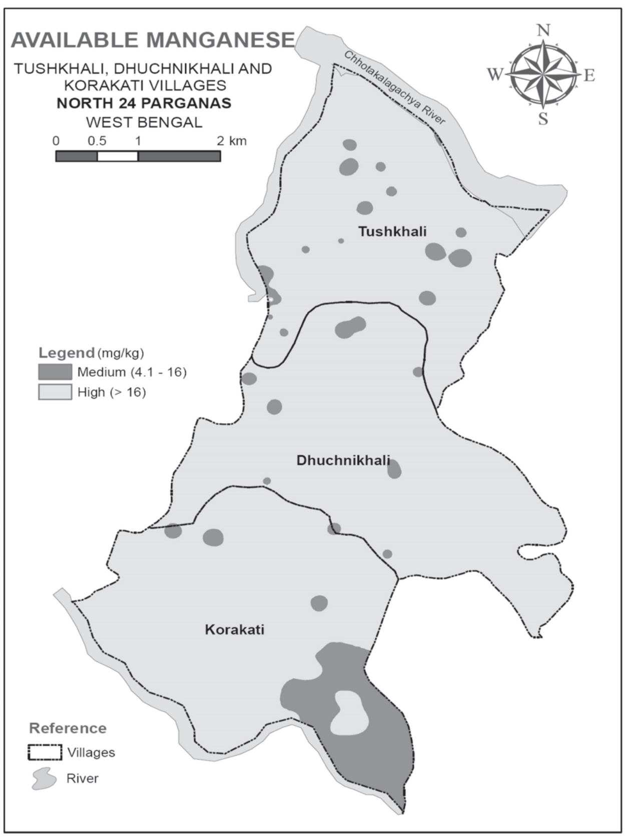

Fig. 8. Spatial map of available Mn (mg kg^{-1}) content of the studied soil

Table 2. Correlation among the physico-chemical characteristics of soils

Parameters	pH_{Ca}	$EC_{2.5}$	Organic C	Av. N	Av. P	Av. Fe	Av. Mn	Av. Zn	Av. Cu	Av. K	Av. S	BD	Clay
pH_{Ca}	1.000												
$EC_{2.5}$	ns	1.000											
Organic C		-0.594**	1.000										
Av. N	ns	-0.383**	0.776**	1.000									
Av. P	ns	ns	0.056*	ns	1.000								
Av. Fe	-0.170**	-0.194**	0.156**	0.114**	-0.538**	1.000							
Av. Mn	0.010*	-0.134*	0.147*	0.062	-0.288**	0.710**	1.000						
Av. Zn	-0.097*	-0.167**	0.198**	0.146	-0.443**	0.902**	0.785**	1.000					
Av. Cu	-0.277**	0.020*	0.149**	0.170*	0.839**	-0.471**	-0.363**	-0.388*	1.000				
Av. K	ns	ns	ns	ns	-0.485**	-0.396**	-0.420**	-0.449**	-0.442**	1.000			
Av. S	ns	ns	0.160**	0.221**	ns	ns	ns	ns	0.227**	ns	1.000		
BD	ns	ns	-0.071*	ns	ns	ns	ns	ns	ns	ns	ns	1.000	
Clay	ns	ns	ns	ns	ns	ns	ns	ns	0.021*	ns	ns	-0.024*	1.000

** indicates significant at 1% level and * indicates significant at 5% level. ($n=150$)

Nutrient index

The Nutrient index value (NIV) of available nitrogen ranged from 1.04 to 1.20 for the studied area which indicated that the area was low in available nitrogen. On the other hand the NIV for available P ranged from 1.92 to 1.99 which showed a medium status in terms of fertility. The NIV for available K was much (Table 3) higher *i.e.* 3.00 irrespective to the sampling sites which indicated that the native supply of K was high in the studied area. NVI for available sulphur ranged from 2.72 to 2.88 which indicated a higher availability of sulphur in such soil. The area was medium in available Zn content with nutrient index values ranged from 1.64 to 2.04. Among the representative sites, soil samples collected from Korakati showed a higher NIV for available Zn compared to others. The soils of the studied area were high in available Fe, Mn and Cu content with nutrient index value of 2.78 to 2.82, 2.60-2.84 and 3.00, respectively. The results indicated that the area is poor in available nitrogen content and medium in available phosphorus and Zn but the native supply of K, S and micronutrients except Zn are much pronounced. However, among the three representative villages soil samples collected from Tushkhali showed a comparatively lower nutrient index values for all nutrients followed by Korakati and Duchnikhali, respectively.

Conclusions

The unique set of characteristics of a region arises from the location specific variations of the natural resource base. The sites selected for the present study was in the Sundarbans region on the Bay of Bengal, West Bengal, India. The soils of this region are naturally saline and agriculture is severely constrained. Rice is the principal crop of this area, which is mainly grown during monsoon season. Improving productivity of crop by identifying fertility constrains using spatial nutrients map followed by suitable soil management strategies was the primary focus of the study. This study produced high-quality spatial soil nutrient maps to apply the site-specific management for crop cultivation in villages of coastal Sunderbans. The spatial soil nutrient maps indicated that most of the studied soils were marginally saline to saline in nature. In some of the locations soil shows higher salinity level > 4.0 dS m^{-1} which was critical for crop cultivation. The available N, P and Zn content showed low content which significantly increased with increase in organic C. On the other hand organic C was negatively correlated with the soil salinity level. Nitrogen based fertilization supplemented with organic inputs should be recommended for the studied area for optimum growth and yield of crops.

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Ground Water Recharge and its Effective Use Through Micro-irrigation for Crop Production in Coastal Gujarat

G. Gururaja Rao[1*], Sanjay Arora[2], Anil R. Chinchmalatpure[3], M.K. Khandelwal[1], S.K. Kamra[3] and D.K. Sharma[3]

[1]Central Soil Salinity Research Institute, Regional Research Station, Bharuch-392 012, Gujarat
[2]Central Soil Salinity Research Institute, Regional Research Station, Lucknow-226 002, Uttar Pradesh
[3]Central Soil Salinity Research Institute, Karnal-132001, Haryana
*E-mail: ggrao54@yahoo.com; salinityguj@gmail.com

Abstract

Groundwater, a reliable resource for drinking purpose and agricultural crop production, has become a major natural resource contributing to the water supply system. Due to its continued withdrawal, it requires replenishment through recharge. Artificial recharge of ground water through recharge bores is an important strategy that helps in improving both the ground water level and quality. In the absence of assured irrigation supply, majority of the crops in Bharuch district of Gujarat used to face water shortages leading the crop failure or reduced crop yields. To tackle this problem, Regional Research Station of CSSRI installed artificial groundwater recharge structures in 15 farmers' fields in Bharuch, Amod, Valia, Ankleshwar, Netrang and Jhagadia Talukas in coastal Gujarat region. The performance of these structures was evaluated in terms of rise in groundwater levels, improvement in its quality and enhancement of farmers' income during 2008 to 2010. Subsequently Micro Irrigation Systems (MIS) were implemented in 10 sites, including five at groundwater recharge project sites and the effect of MIS on crop production in divergent crops like sugarcane, cotton, banana, water melon and cotton was studied. Detailed results at two sites indicated that enhanced availability and reduction in groundwater salinity due to recharge interventions resulted in increase in crop yields and consequently farmers' income to the tune of 14, 38, 50 and 100 % in papaya, banana, soybean and mango, respectively. The ground water with improved quality, when used with MIS also resulted in substantial increase of crop yields leading to B/C ratio of 4.35, 2.94, 2.84 and 1.22 in water melon, Bt. Cotton, banana and sugarcane, respectively and more importantly water productivity of more than 12 kg/cum in high water demanding sugarcane.

Key words: Ground water recharge, Micro irrigation system, Water productivity, Watertable decline

Introduction

"Water is the Elixir of Life and Cleanser of Sins". This is a pivotal component in agriculture and its conservation and judicious use are of paramount importance. Water is a renewable resource, to a point. The current population of the world is using water at such alarming rates with which nature cannot cope up. Water scarcity, a major problem in most arid regions of the world, is adversely affecting food security, natural ecosystems, plant and human health (Seckler *et al.*, 1999). Water scarcity is resulting from a number of factors, the foremost being depletion of groundwater, currently the most reliable resource in terms of quantity and quality for drinking and agricultural crop production. Though groundwater is an important source of irrigation in India, its availability is non- uniform in space and time. Rainwater harvesting and artificial groundwater recharge interventions can play an important role in augmenting groundwater and also to improve its quality. Rainwater harvesting is essential considering our increasing dependence on groundwater to meet water demands of different sectors (irrigation, domestic, industry and recreation) and diminishing natural recharge due to falling watertables and rapid urbanization.

Natural recharge of groundwater occurs by infiltration of precipitation or excess irrigation water into the soil and movement in the form of moisture through the vadose zone down to the saturated zone. Artificial recharge is the process by which the groundwater reservoir is augmented at a rate exceeding that under natural conditions or replenishment (Bhattacharya, 2010). It is accomplished by constructing simple civil structures, including among others tubewells and open wells (Gururaja Rao *et al.*, 2010) which are getting increasingly accepted due to failure or delay in arrival of natural or artificially recharged water to deeper aquifer zones with surface methods. By demarcating and preserving the

*Corresponding author

recharging area within the aquifer basin, the groundwater resources of a region can be sustained to varying degrees of success.

Groundwater recharge stores water during the wet season for use in the dry season, when demand is highest and improvement in groundwater quality can also help in improving productivity of crops, in particular of high value cash crops through the use do micro- irrigation and even for drinking purposes (Sivanappan, 2006). Micro-irrigation is another approach to meet the challenges of water scarcity since it leads to improving water use efficiency, i.e. maximizing crop production with minimum water use, arresting salinity build-up, conserving fertilizer use and reducing labour input substantially.

With this background, the paper presents the features and effectiveness of 15 groundwater recharge wells, installed in farmers' fields, in raising watertable and improving its quality in Bharuch district of Gujarat. The second part of the paper presents the scope of drip irrigation in improving water productivity and farmers' income through cultivation of sugarcane, cotton, banana and water melon in 10 farmers' fields, including at 4 recharge well sites. The farmers' fields were selected in deep watertable areas with less chances of salinity build-up and where progressive farmers were ready for diverse crop interventions with micro- irrigation system using ground water.

Ground water resources of Bharuch district and Gujarat state

Gujarat is one of the most water scarce and drought-prone regions in India (IRMA, 2001, Shah and Mistry, 2013). Water is identified as one of the fifteen major indicators for sustainability and it is a major issue for fast growing economy of Gujarat. The water utilization pattern of Gujarat, a predominantly semi-arid state in western India, is 89% for irrigation, 7% for domestic and drinking water, and four percent for industry and other uses (IRMA, 2001). The state is characterized by semi- arid climate with hot and dry pre-monsoon March to May summer months followed by south western monsoon (June to September). The subsequent period of October to November receives uncertain and infrequent showers followed by fair, dry and mild winter (December to February). The annual rainfall is highly variable, ranging from 1480 mm in South Gujarat, 700-800 mm in Central Gujarat to 250-350 mm in North Gujarat and Kutch region. The maximum and minimum areas under groundwater irrigation are low rainfall North Gujarat and high rainfall southern districts of the state.

The state often experiences drought during the crop growth period and at times crop failure occurs due to limited availability of irrigation waters. While 9 lakh ha area is irrigated with tube wells, about 19.9 lakh ha area is irrigated with open wells. The agricultural utilization of groundwater is mainly through open wells (7.8 lakh wells) followed by tube wells (0.3 lakhs). In Ahmedabad, Bharuch and Narmada districts, tube well irrigation tend to dominate over open wells.

Out of state's 21.5 lakh ha irrigation potential created through groundwater, the maximum potential of 4.8 lakh ha is created in Bharuch district. Due to skewed utilization, the net groundwater balance is positive (recharge more than draft) in all districts of Gujarat except Banaskantha, Gandhinagr and Mehsana districts where overdraft of groundwater is leading to negative balance. The annual groundwater recharge of Bharuch district has been estimated at 499 million cubic meter (MCM), of which 100 MCM/ year is utilized for domestic and industrial use, resulting in about 399 MCM/ year utilizable groundwater recharge. Since the groundwater draft is less than that of the groundwater recharge, the level of groundwater development is moderate in this district.

Materials and Method

(a) Groundwater recharge wells

Selection of groundwater recharge sites was based on local hydrogeology, topography, and types of facilities available for harvesting of rainwater for recharge purpose. A total of 15 farmers' field sites (Fig. 1) were chosen for constructing the recharge wells. At most locations, bore wells of 400 mm ϕ (diameter) were drilled to about 30 m (100ft) depth in middle of which 5 PVC pipes of 6 m length each and 125 mm (outer ϕ) were placed. Of the 5 pipes, 2 were blind (non- perforated) while 3 were perforated with 3- 7.5 mm size slits to act as strainer wells in the sandy zones of aquifer. The space between bore hole and pipe was filled gravel aggregates of 8-20 mm ϕ and standard air compression technique was applied to activate water pathways in strainer zones of aquifer for recharging.

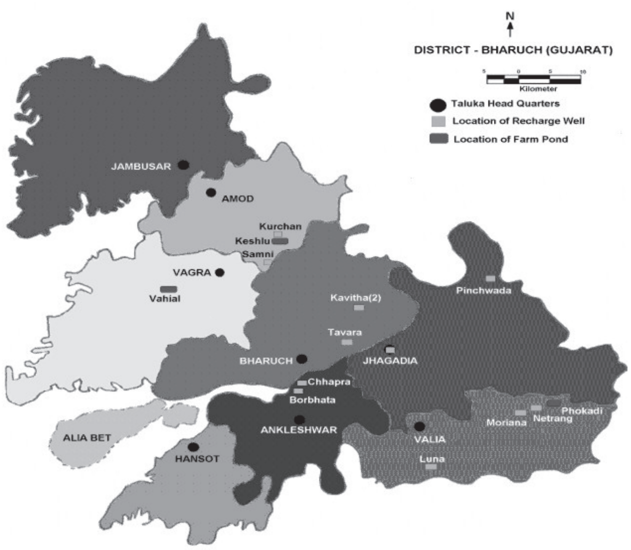

Fig. 1. Location map of recharge wells constructed in Bharuch district

Table 1. Location, design features and cost of recharge wells in different *Talukas* of Bharuch (Gujarat)

Taluka: Villages, (No. of wells, year of construction)	Well Depth (m)	Diameter, ϕ (mm)		Lithology	Cost (INR)
		Bore	Pipe		
Valia: Luna1, Luna2, Pansoli, Sodgam (4, June 2009- May 2010)	30	400	125	Medium to light black soils, sand after 23- 30 m	23,500-33,600*
Valia: Moriyana, Netrang (2, June- Nov. 2008)	45, 40	300/ 175**	200	Rocky below upper 6 m medium black soil	14850-16650
Ankleshwar: Chhapra, Borebhata (2, June 2008)	30	400	125	Deep to medium black soils, river sand after 12 m	22,535-25760
Amod: Kurchan, Samni (2, April 2009)	30	400	125	Deep black soils with *kankar* upto 5.6 m depth	24,620-30,727
Jhagadiya: Jhagadiya,Finchwara (2, April 2009)	30	400	125	Medium black soils, river sand and *murram* at 27- 30 m	21,500-25,100
Bharuch: Kavitha1, Kavitha2, Juna Tavra (3, March– June 2009)	30- 35	400	125	Medium – deep black soil, *kankar* from 24- 30 m	21,500-29,800

*Different year of construction; **300 mm ϕ in upper 6 m, followed by 175 mm ϕ in lower rocky stratum

The representative lithology, basic design features and cost of the recharge wells in different blocks of Bharuch district are summarized in Table 1. At most locations, where light to medium or deep black soils overly the sand zones at different depths, recharge wells of 30 m depth were constructed and developed through air compression, except at Chhapra were compression was restricted to 24 m depth due to blowing in of quick sand at lower depth. At one village (Moriyana in Valia Taluka), rocky formations were encountered after 6 m. At this location, 300 mm ϕ bores in the upper 6 m were followed by 175 mm bores drilled with a special cutter in the rocky zones to 45 m depth. A PVC pipe of 200 mm ϕ was fixed only in the upper 6 m bore of 300 mm ϕ. Similar rocky formation was found at another nearby village Netrang, where drilling to 40 m depth was done on the same pattern. A circular or rectangular brick masonry recharge chamber of 2 m x 2m x 2m size, filled with a filtering material of boulders (at bottom), gravel (in middle) and coarse sand (at top) and having provision of inflow of flood water to be recharged was constructed around each well. It was necessary to remove sediments from the recharging water to prevent clogging of well slits. Rao *et al.* (2010) presented details on the designs and features of the recharge well and filter at different locations.

Subsequent to the installation of recharge wells, the water table depths from the recharge wells were measured periodically and groundwater samples were collected during pre and post monsoon periods to understand the efficacy of rainwater in improving groundwater quality. Electrical conductivity (EC) and pH of the water samples collected from different sites were determined. Since farmers continued to pump water from nearby tube wells, data pertaining to improvement in farm income and profit during pre- and post-implementation phases are presented for two study sites viz., Netrang representing rocky and Borebhata representing black soils- sand lithology.

(b) Micro-irrigation system (MIS)

For improving water use efficiency, maximizing production with minimum water use as per crop needs was studied with micro- irrigation systems. For installation of MIS, farmers with initiatives to diversify to micro-irrigation and cash crops were selected in areas having relatively deep water tables. MIS (drip systems), supplied by M/s Nagarjuna Fertilizers and Chemicals Ltd. were got installed in association with Gujarat Green Revolution Company (GGRC) Ltd., Vadodara (availing State Government subsidy) at ten locations as per details of villages, crops and cost component presented in Table 2. It is seen that the average cost of drip irrigation for above mentioned crop comes out to be about INR 1.05 *lakh* per ha for which the state government provided 40- 75 % subsidiary, the remaining cost shared by CSSRI and farmers.

The soils in the selected villages are silty clay loam with small to marginal salinity (EC_2) ranging from 1.56 – 2.78 dS/m (Table 3), while the water tables depth varied from 30 to 45 m. The groundwater salinity (EC) in these villages was marginally high at 1.72- 2.98 dS/m for conventional crops but quite high for cash crops, while the pH was normal at 7.70- 8.22. The dominant cation and anion in groundwater, in general, are Na and Cl. Soils of Jhagadiya are of Vertic Ustochrept type and moderately deep with water table ranging from 30-35 m. The yields of principal crops viz., sugarcane, banana, cotton and water melon, were collected along with the cost of inputs from the respective farm units. Benefit- cost (B: C) ratios were calculated for banana, sugarcane and water melon. The water productivity in terms of economic produce was estimated as per relation presented below:

Water Productivity = Produce Yield (kg)/ Quantity (cu.m) of water applied

Table 2. Details of crops, location and cost of MIS in Bharuch district

Village	*Taluka*	Crop	Area (ha)	Cost of MIS System (INR)	% Contribution of		
					GGRC	CSSRI	Farmer
Luna	Valia	Sugarcane	0.80	67558	50	50	0
Luna	Valia	Sugarcane	0.80	87483	50	42	8
Fokdi	Jhagadiya	Cotton	0.80	68807	75	25	0
Jhagadiya	Jhagadiya	Banana	0.80	68807	50	50	0
Kambodiya	Valia	Sugarcane	0.80	85427	65	30	5
Luna	Valia	Sugarcane	0.40	37219	75	25	0
Luna	Valia	Cotton	0.80	87520	43	42	15
Rampura	Nandod	Banana	0.80	113392	41	32	28
Luna	Valia	Cotton	0.80	83969	66	34	0
Kavachia	Valia	Cotton	0.80	92894	59	40	1
	7.60	**7,93,076**	**55.4**	**37.3**	**6.5**		

Table 3. Chemical characteristics of soil and groundwater at different MIS locations

Village	Crop	EC_{gw}, dS m^{-1}	pH_{gw}	Ionic composition of ground water (meq/l)			Soil salinity (EC_2), dS m^{-1}	Soil pH
				Na^+	K^+	Cl^-		
Luna	Sugarcane	2.32	7.70	64.35	66.72	74.10	2.62	7.81
Luna	Sugarcane	2.20	7.82	85.0	22.78	198.20	2.54	8.68
Fokdi	Cotton	2.98	7.88	95.19	11.42	162.0	2.21	7.88
Jhagadiya	Banana	1.72	8.12	73.80	45.52	70.20	2.02	8.12
Kambodiya	Sugarcane	2.32	8.20	98.40	39.43	102.20	1.56	8.12
Luna	Sugarcane	2.30	8.10	89.42	21.62	95.60	1.68	8.48
Luna	Cotton	2.50	8.15	94.49	27.25	94.80	1.98	7.95
Rampura	Banana	1.80	8.22	71.22	21.27	86.20	1.96	7.74
Luna	Cotton	2.68	8.08	98.12	21.25	108.20	2.78	7.54
Kavachia	Cotton	2.84	7.98	102.20	23.24	100.20	1.96	8.06

Results and Discussion

(a) Effect of groundwater recharge on watertable depth and quality

Recharge of runoff from each event of excess rainfall resulted in rise of watertable at different locations. The pre and post monsoon watertable depths at different locations are presented in Fig. 2. Water table levels increased from depth of 8 m during pre-monsoon phase (June) to 2-4 m during post-monsoon period at most locations, except Kavitha, Kurchan and Tavra, where the increase in water table was very marginal due to relatively deeper depths of groundwater.

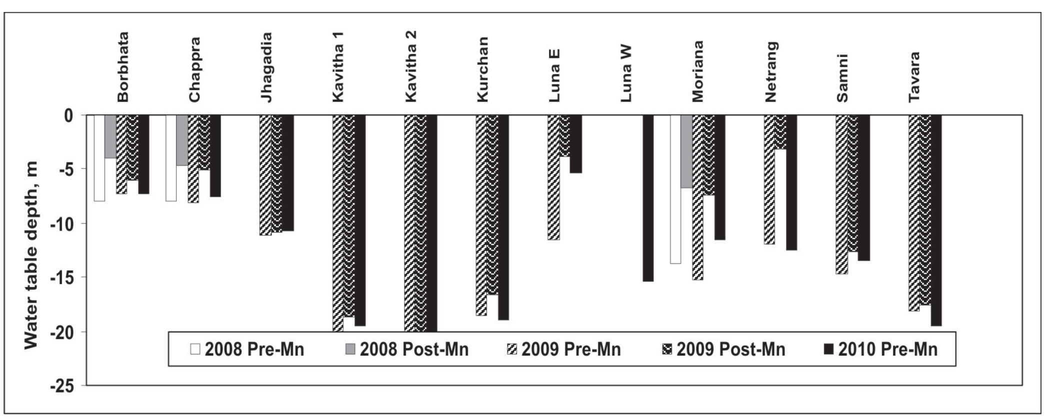

Fig. 2. Effect of groundwater recharge on watertable depth at different locations

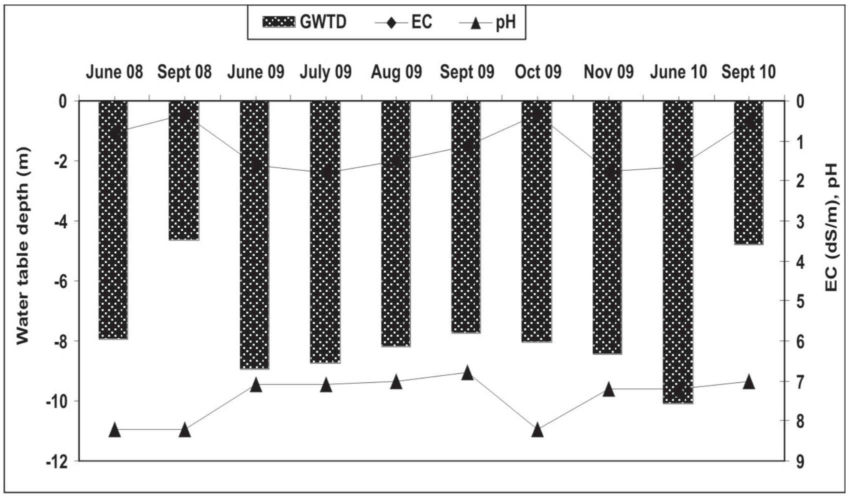

Fig. 3. Temporal Changes in water table depth and ground water quality due to ground water recharge at Chhapra village in Bharuch district

Ground water recharge, while raising the water table also improved the water quality i.e., reduced salinity of water and pH. Month wise changes in watertable depth and groundwater salinity and pH at one such location, Chhapra village is presented in Fig. 3. At this and other locations, there was there was significant (3-4 m) rise in water table during monsoon, particularly during high rainfall years of 2008 and 2010. In addition to watertable rise, the groundwater quality also improved significantly reflected by reduction in EC of ground water from 2.8 dS/m to 0.5 dS/m (Fig. 3). The increased water availability due to watertable rise enabled the farmers to go for additional irrigations with improved quality of water, helping in gaining higher returns from their crops as discussed in subsequent sections.

(b) Impact of groundwater recharge on farm income

The groundwater recharge wells implemented by CSSRI RRS in different villages of Bharuch district yielded improved groundwater regime in terms of groundwater quantity and quality. This resulted in improvement in farmers' income at all locations; the results relating to 2 locations, Borebhata and Netrang villages representing alluvial and rocky substratum are briefly presented in this paper. Increase in crop yields and farm income from horticultural crops, *Papaya* and banana in Borebhata and *mango* and soybean in Netrang before and after implementation of recharge interventions are discussed below:

Borebhata: The groundwater EC was 1.9 dS/m prior to monsoon (June 2008), which reduced to 0.3 and 0.4 dS/m due to groundwater recharging during monsoon of 2008 and 2009 respectively, indicating more than 80 % reduction in groundwater salinity during both years. The average farm income of the farmer from drip irrigated banana prior to the installation of recharge well was Rs. 80,000/ acre which increased to Rs. 110,000/ acre representing 37.5 % increase. Similarly income from papaya increased from Rs. 140000/ acre to Rs. 160000/ acre indicating 14.3 % increase in the first year after the installation of recharge well.

Netrang: The water-table at 5.5 m depth, prior to the installation of recharge well in November 2008, rose to 3.2 m in July 2009, indicating 2.3 m rise while the corresponding groundwater salinity improved from 1.02 dS/m (pre-monsoon) to 0.14 dS/m (post-monsoon). Prior to the construction of recharge well during 2008, the yield of soybean was 10 q/ha which increased to 15.2 q/ha during 2009 season. The recharging of groundwater resulted in adequate groundwater resources enabling farmer to provide required irrigations as per needs of the crop. Similarly the farm income from drip irrigated 6 acre mango crop was Rs. 85000/ in 2009 which increased to Rs. 165000/ after construction of recharge well representing an increase of Rs. 13300/ acre or more than 100 % increase in farmers' income. Mango being a sensitive crop to salinity responded well to the improved quality of pumped water being used with drip irrigation, highlighting the beneficial effects of ground water recharge.

(c) Impact of micro irrigation system in yields and productivity of crops

In the second part of the study, water and soil samples were collected and analyzed for salinity, pH and ionic composition following installation of MIS (Table 3). Crop yield data from banana, sugarcane, water melon and Bt. cotton was collected and economic returns were recorded. Results (Table 4) indicated water melon followed by Bt. cotton, banana and sugar cane are good money earners under drip irrigation system having benefit: cost ratio (B/C) more than 1. The economics worked out of different crop interventions indicated highest B/C ratio (4.35) in water melon, followed by Bt. Cotton (2.94), banana (2.84) and sugarcane (1.22) under MIS.

Table 4. Crop production and monetary returns under sugarcane, banana, water melon crops and Bt. Cotton under MIS

Crop (No. of locations, Taluka)	Average production (t ha^{-1})	Cost of cultivation (Rs ha^{-1})	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	B/C ratio
Sugarcane (4 locations in Valia*)*	132	56000	124452	68452	1.22
Banana (2 locations, Jhagadiya)	74.0	75000	288400	213400	2.84
Watermelon(1 location, Valia)	32.12	48000	256960	208960	4.35
Bt. Cotton (4 locations, Valia and Jhagadiya)	2.24	26365	104044	77679	2.94

Table 5. Water productivity of sugarcane, banana, water melon and Bt. Cotton under MIS (water applied from rainfall and MIS)

Village/Taluka	Crop	Total (rain + irrigation) water applied, cm	Production, t/ha	Water productivity, kg/cu.m
Luna/Valia	Sugarcane	101.3	133.6	13.05
Luna/Valia*	Sugarcane	101.8	128.6	12.63
Luna/Valia*	Sugarcane	101.6	126.8	12.48
Khambodiya/ Valia	Sugarcane	100.0	139.0	13.90
Jhagadia / Jhagadia*	Banana	100.5	75.4	7.50
Rampur/ Nandod	Banana	99.5	72.6	7.30
Luna/Valia*	Water melon	100.4	32.1	3.20
Luna/Valia*	Bt. Cotton	66.8	2.28	2.93

* Sites having both groundwater recharge and MIS interventions

For calculating the cost of cultivation (Table 4), cost of seed, land preparation, weeding, plant protection chemicals, plucking and transportation to market were taken into consideration. It is also seen that the cost of cultivation of sugarcane, banana and watermelon are almost 2-3 times more than that of Bt. Cotton, while the net income from banana and water melon crops of more than Rs. 2 lakh/ ha are significantly higher than sugarcane and Bt. cotton. The comparable B/C ratios of banana and Bt. Cotton are achieved because of relatively much smaller cost of cultivation of Bt. Cotton.

The irrigation water from the tube well was found slightly saline with sodium and chloride as the dominant ions. Continued use of ground water for irrigation through MIS did not result in salinity build up in the soil, suggesting the beneficial effects of MIS in these crops. Though not indicated in Table 4, the production and B/C ratio of Bt. Cotton was higher in clay textured soils of Jhagadiya than in loamy soils of Valia *Taluka* where relatively easy water losses warranted more frequent irrigations. Water melon, being a short duration crop, its overall water requirement is also significantly less when compared to banana and sugarcane.

The total crop production and water productivity of different crops under different crops under MIS are presented in Table 5.

It is seen that 126.8 – 139 t/ha production of sugarcane, 72.6- 75.4 t/ha of Banana, 32.1 t/h of water melon and 2.28 t/ha of Bt. Cotton production are quite high at different locations in Bharuch district under MIS and slightly saline groundwater conditions. Based on preliminary surveys conducted in flood irrigated adjoining farmers fields and experimental results of this study, it can be reported that MIS in sugarcane can lead to 50- 64 % saving of water and 10 % increase in crop yield over flood irrigation practices. Further, the water productivity of sugarcane under MIS at > 12 kg/cum and of banana at > 7 kg/cum are much higher than other crops highlighting the high potential of drip irrigation in these crops to meet challenges of water scarcity in Gujarat.

Summary and Conclusions

Ever increasing demands of galloping population and urbanization are exerting extreme pressure and challenges on management of on water resources. Due to easy access and ease of extraction of groundwater through pumping, the water tables are declining very rapidly and accentuating water scarcity problems. This situation can be improved by evolving strategies for groundwater recharge through artificial recharge wells and by shifting to micro- irrigation systems. The results of performance evaluation studies of artificial recharge through bore wells in 15 farmers' fields in Bharuch district indicate high effectiveness of such structures in not only augmenting the groundwater, improving its quality but also significantly increasing farmers' income, particularly in horticultural crops like mango, banana and papaya and also in soybean. The efficacy of recharging was further improved by adopting drip irrigation (MIS) which can result in high production, water productivity, income and benefit cost ratios in crops like banana, sugarcane, water melon and Bt. cotton. In summary, the results of this study indicate immense scope of artificial groundwater recharge and its combination with MIS for water conservation and its economic use in several parts of Gujarat, particularly in horticultural and commercial crops and more importantly in high water demanding sugarcane.

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Phytoremediation of Brass and Electroplating Industry Effluent through *Eichornia crassipes*

Rama Pal[1]*, J.P.N. Rai[2] and S.K. Dubey[1]

[1]*Central Soil and Water Conservation Research and Training Institute, Research center, Chhalesar, Agra-282 006, Uttar Pradesh, India*

[2]*Department of Environmental Science, C.B.S.H., GBPAUT, Pantnagar, Uttarakhand*

**Email: rama.env@gmail.com*

Abstract

An experiment was conducted to evaluate the phytoremediation potential of *Eichornia crassipes* exposed to different dilutions (i.e., 25%, 50% and 75%) of brass and electroplating industry effluent. A supporting experiment was also conducted in parallel with synthetic binary and single metal solutions of Cd and Cr to assess their impact on growth of plants. The maximum removal of heavy metals was observed under 50% dilution effluent (i.e., 89% for Cd and 87% for Cr) followed by 75% (i.e. 81% for Cd and 77% for Cr) and 25% (i.e. 51% for Cd and 50% for Cr) dilutions. Richard's model fitted to shoot growth data showed highest growth and rate in 50% diluted effluent (k=0.372; Kc=0.49 for Cd and 0.45 for Cr). The study suggested that *E. crassipes* can be a good plant species for remediation of water bodies moderately contaminated with brass and electroplating industry effluent.

Key words*: Phytoremediation, Heavy metals, Richard's model, Industrial effluent, *Eichornia crassipes

Introduction

Heavy metal pollution is a global problem, although contamination persists with varying degree from place to place. Common toxic heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr) etc. are detected in wastewater from mining operations, tanneries, electronics, electroplating, batteries and petrochemical industries as well as textile mill products (Singh *et al.*, 2011). The conventional technologies used for their removal from aquatic bodies include reverse-osmosis, ion-exchange, electro dialysis, adsorption, etc. Most of these technologies are quite costly, energy intensive and metal specific. Contrary to this, phytoremediation offers a cost-effective and environment friendly technology for heavy metals removal from waste water (Singh *et al.*, 1996; Schwitzguebel, 2000; Miretzky *et al.*, 2004). The impact of heavy metals on growth/yield of plants under different environment has been extensively studied (Liao and Chang, 2004; Pal and Rai, 2010; Khandkar *et al.*, 2012). Contaminated water bodies pose a major environmental and human health problem, which may be partially solved by phytoremediation.

The hyperaccumulators are slow growing, small and do not produce large biomass. Biotechnology has provided an option to engineer large biomass producing plant species with hyperaccumulating genes in order to develop an efficient phytoremediator. But the technology is very cost-expensive and still needs improvement. So, again our focal point is naturally available hyperaccumulators which can be used efficiently if the plant-metal system specific phytoremediation process can be optimized in terms of time and metal concentration using mathematical model. The most widely used model for describing plant growth in terms of dry weight, length or volume etc. is Richard's function (Causton and Venus, 1981), which is a modified logistic model.

In the present study, Water-hyacinth (*Eicchhornia crassipes* Solms) was used to assess its potential in the remediation of brass and electroplating industry effluent as well as phytoremediation process was optimized with respect to this plant-effluent specific system using Richard's model.

Material and Methods

Sampling site: The mixed effluent of brass and electroplating industries was collected from Karula *nala*, situated on old Delhi by-pass road, Moradabad. The effluent flowing in this *nala* finally joins Ramganga River (Fig. 1). On the way, besides being used for irrigation, the effluent often spreads on the sides and thus affects the soil and ground water quality of the region.

Collection and analysis of effluent: The effluent was collected form *kaccha* (non-bricked) *nala* in pre-sterilized plastic containers, brought to the laboratory and analysed

*Corresponding author

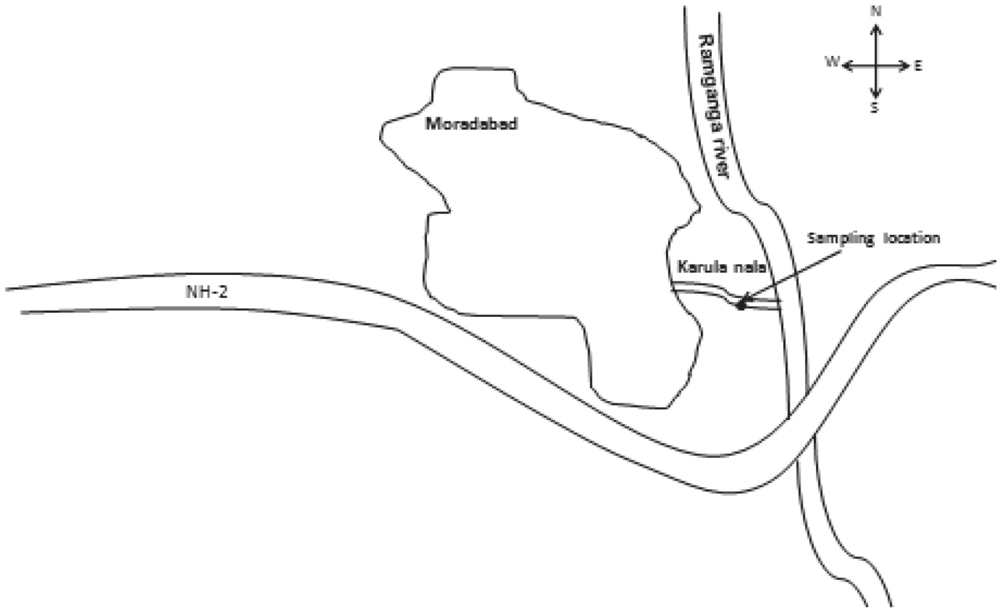

Fig. 1. Sampling site location at Moradabad (Uttar Pradesh)

for various physico-chemical parameters following standard methods (APHA, 1998).

Water-hyacinth (*Eicchhornia crassipes* Solms) plants were collected from a natural stand. The plants were washed thoroughly with running tap water followed by distilled water to avoid any surface contamination and blotted with clean blotting paper for any surface moisture avoiding damage to root and leaf apices and were maintained in a plastic tank for 10 days prior to experimentation. The order to assess impact of effluent on initial growth parameters of Water-hyacinth, three dilutions of brass and electroplating industry effluent (i.e. 25, 50 and 75 %) were prepared with distilled water. Three replications were maintained for each dilution treatment. For experiment, an average weight (g) was maintained individually in 5-L tub (inner diameter 40 cm). The experiment was also conducted with Hoagland's solution containing Cd and Cr binary metal solutions {i.e., 1ppm Cd + 1ppm Cr ($1^{Cd}+1^{Cr}$), 2.5ppm Cd + 3ppm Cr ($2.5^{Cd}+3^{Cr}$) and 3.5ppm Cd + 4ppm Cr ($3.5^{Cd}+4^{Cr}$)} and single metal solutions {i.e., 1, 2.5 and 3.5 ppm for Cd (1^{Cd}, 2.5^{Cd} and 3.5^{Cd}) and 1, 3 and 4 ppm for Cr (1^{Cr}, 3^{Cr} and 4^{Cr})} having concentrations equivalent to their corresponding effluent dilutions. In order to provide dissolved oxygen to the plant roots mechanical aeration was given by pump at the rate of 10 min/tub at three days interval throughout the experimental period. The analysis of Cd and Cr in the phytoremediated effluent and synthetic metal solutions was done after 2, 5, 10, 15, 20, 25, 30, 35, 40 and 45 days through atomic absorption spectrophotometer. Simultaneously, plants were harvested, washed with distilled water and cut into roots and shoot. Both the shoot parts were analyzed for affected biomass. One control group of plants was also prepared where effluent was not added.

Quantitative analysis of plant growth data using Richard's mathematical model

The growth dynamics, considered as a continuous process, can be described by the equation,

$$y = a[1+(d-1)e^{-k(x-xc)}]^{1/(1-d)}, d \neq 1 \qquad \text{Eq.1}$$

where y (g) represents shoot biomass, *a* is the carrying capacity (g), which in this case represents the final shoot biomass, *k* is the growth rate and *d* is the Richards exponent, adding flexibility to the dynamic response through modulation of the inflexion point, *x* is time, x*c* is the centre of the curve representing time of maximum growth.

Results and Discussion

Physico-chemical characteristics of effluent

The physico-chemical characteristics of brass and electroplating industry effluent before and after remediation are given as mean ±SE in Table 1. The effluent was light grey to brackish gray in appearance and slightly acidic (pH 6.4) in nature. The content of total, suspended and dissolved solids (i.e., 3129, 920 and 2209 mg/l, respectively) were substantially higher than their permissible limits as recommended by ISI, 1981 for effluent discharge in surface water bodies. Similarly, the ISI recommendation for COD value is 250 mg/l, whereas, the effluent had a COD value of 2456 mg/l which indicates a high organic and inorganic load. The content of Cd (4.98 mg/l) and Cr (5.4 mg/l) were also quite higher than their permissible limits. However, the concentrations of Zn (3.35 mg/l), Cu (2.04 mg/l) and Ni (1.113 mg/l) were low.

Table 1. Physico-chemical characteristics (±SE) of brass and electroplating industry effluent before and after phytoremediation with *E. crassipes*

Parameters	ISI Standards		Effluent (before phytoremediation)	Effluent dilutions (after phytoremediation)		
	Surface water	Land irrigation		75%	50%	25%
pH	5.5-9.0	5.5-9.0	6.40±0.01	6.85±0.01	6.98±0.02	6.56±0.03
EC (dS m^{-1})	-	-	1.59±0.01	0.86±0.01	0.54±0.03	1.2±0.05
TS (mg l^{-1})	-	-	3129±6.33	312±1.23	564±1.86	1643±6.92
TSS (mg l^{-1})	100	200	920±9.53	77±0.24	177±1.64	645±3.54
TDS (mg l^{-1})	500	-	2209±5.24	167±1.14	390±2.34	1005±5.23
COD (mg l^{-1})	250	-	2456±6.86	307±2.5	409±2.68	1228±6.84
Na (mg l^{-1})	-	-	155.10±1.05	-	-	-
K (mg l^{-1})	-	-	725±2.69	-	-	-
Zn(mg l^{-1})	5.0	-	3.35±0.02	-	-	-
Cu(mg l^{-1})	3.0	-	2.04±0.03	-	-	-
Cd(mg l^{-1})	2.0	-	4.98±0.01	0.90±0.03	0.56±0.06	2.43±0.06
Cr(mg l^{-1})	2.0	-	5.4 ±0.03	1.20±0.05	0.70±0.02	2.70±0.07
Ni(mg l^{-1})	3.0	-	1.113±0.01	-	-	-

The physico-chemical characteristics of effluent were analysed after 45 days of phytoremediation with Water-hyacinth. The pH of 75%, 50% and 25% diluted effluent increased to 6.85, 6.98 and 6.56, respectively, whereas, EC decreased to 0.86, 0.54 and 1.2 dS m^{-1}, respectively. The maximum decrease in content of Cd (89%) and Cr (87%) was observed under 50% diluted effluent treatment. The COD of the effluent also decreased substantially. Other heavy metals like Zn, Cu and Ni became negligible. Total solids decreased by 60%, 64% and 30% in 75%, 50% and 25% diluted effluent treatments, respectively. Similarly, TDS and TSS showed maximum decrease in 50% diluted effluent treatment. The 50% dilution treatment was found to be best because it contains microelements like Zn, Cu and Ni at optimum level, which promote plant growth and hence producing large biomass for accumulating more amounts of heavy metals at a faster rate.

Plant growth as a function of metal concentration and exposure duration

The growth of *E. crassipes* at different concentrations of brass and electroplating industry effluent and synthetic binary and single metal solutions of Cd and Cr estimated in terms of shoot dry weight are shown in Fig.2.

The dry weights of shoot were inversely related with ambient metal concentration and exposure duration except for 75% and 50% diluted effluent treatments (wherein dry weights increased or remain equivalent to control which can be explained on the basis that replenishing of microelements present in the effluent at optimum level promoted the growth of plants) and followed the order: 50% diluted effluent >75% diluted effluent e”Control >(1^{Cr}) >(3^{Cr}) >(4^{Cr}) >25% diluted effluent >(1^{Cd}) >(2.5^{Cd}) >(3.5^{Cd}) >$(1^{Cd}+1^{Cr})$ >$(2.5^{Cd}+3^{Cr})$ >$(3.5^{Cd}+4^{Cr})$.

The reduction in dry weights of Water-hyacinth was observed due to Cd stress as it was present at super optimal levels. Hasan et al. (2006) have also reported decrease in Water-hyacinth biomass on Cd exposure at 1-6 ppm. However, the dry weight reduction under single metal (Cr) treatment was not severe as the concentration of Cr (1-4 ppm) used were below the toxic level. Mishra and Tripathi (2008) also showed that removal of Cr by Water-hyacinth in 1-5 ppm range was harmless showing no symptom of toxicity.

During the 45 days experiment, the shoot dry weights increased till 35 days and thereafter reached a characteristic maximum value related to metal

Table 2. Richard's parameter for shoot dry weight of *E. crassipes* exposed to different heavy metal treatments

Parameters	Control	Heavy metal treatments											
		Effluent dilutions			Binary metal solutions			Single metal solutions					
		75%	50%	25%	$1^{Cd}+1^{Cr}$	$2.5^{Cd}+3^{Cr}$	$3.5^{Cd}+4^{Cr}$	1^{Cd}	2.5^{Cd}	3.5^{Cd}	1^{Cr}	3^{Cr}	4^{Cr}
a	0.90	0.96	1.86	0.46	0.6	0.49	0.4	0.75	0.6	0.48	0.85	0.86	0.79
X_c	22.97	24.35	17.69	18.43	20.2	18.6	18.0	15.8	15.4	15.0	23	22.5	22
d	6.50	6.87	4.73	8.148	6.8	6.9	7.1	6.7	6.8	7	6.52	6.54	6.58
k	0.332	0.368	0.372	0.185	0.196	0.194	0.19	0.189	0.187	0.182	0.33	0.32	0.3

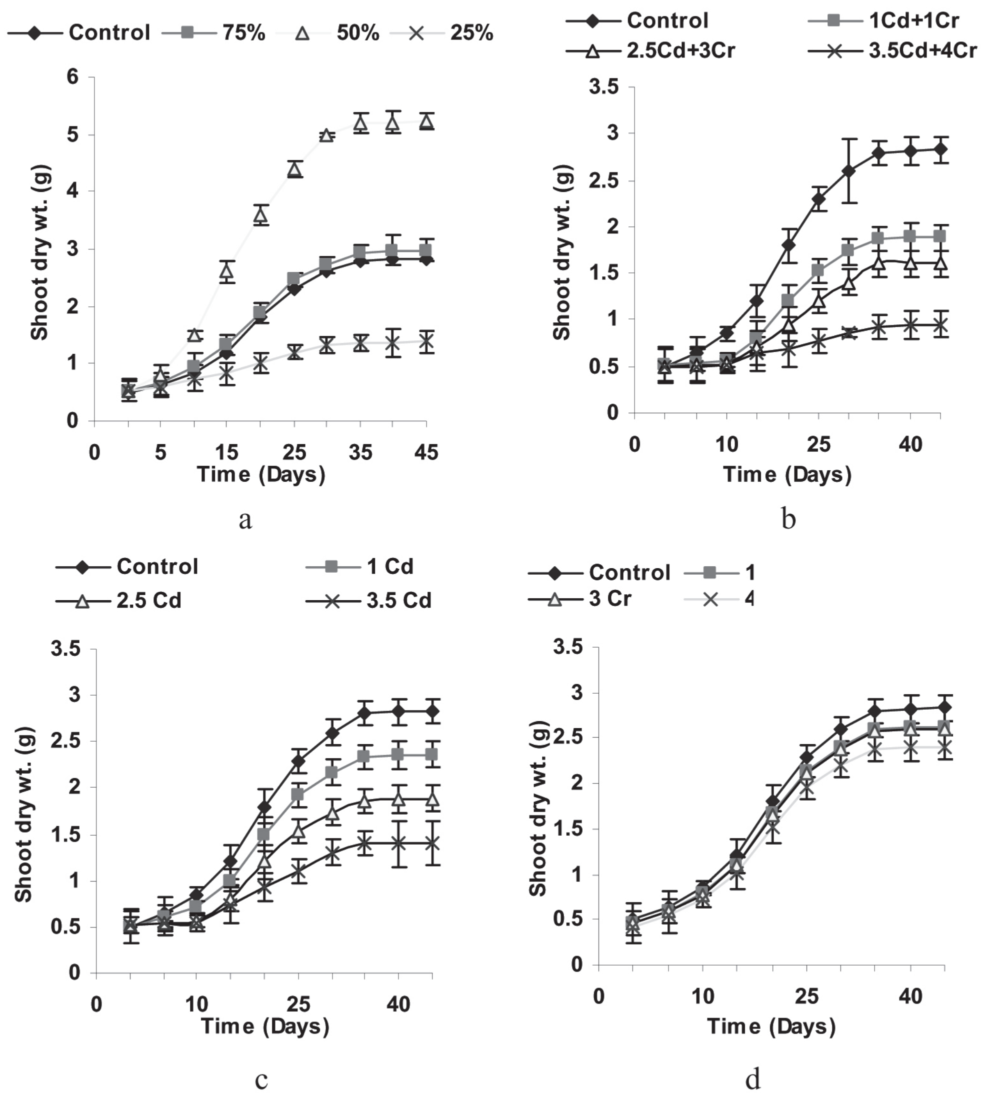

Fig. 2. Effect of heavy metal treatments on shoot dry weight (g) of *E. crassipes* in a) effluent-dilution treatment, b) Cd and Cr binary metal treatment, c) Single metal Cd treatment, and d) Single metal Cr treatment.

concentration in the medium. The Richard's Eq. 1 using software Origin6 was fitted adequately to shoot growth data and the varied parameter values obtained are given in Table 2.

The values of Richard's parameter *k* for Water-hyacinth indicate that the growth rate was highest in 50% diluted effluent. Similarly, the highest values of'factor '*a*' indicates the maximum biomass production in 50% diluted effluent treatment.

Conclusion

It may be concluded that brass and electroplating industry effluent collected from Moradabad city possessed contaminants above the prescribed limit. The 50% diluted effluent can be remediated efficiently by *E. crassipes*. However, 75% diluted effluent can also give satisfactory results. However, the phytoremediation process is governed by several site specific factors like climate and soil/water bodies characteristics and also plants to be used, therefore, further research is required to optimize these factors in order to apply this technology at commercial scale.

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Grouping of Advanced Rice Breeding Lines Based on Grain Yield and Na:K Ratio under Alkaline Conditions

Y.P. Singh*[1], Dhananjaya Singh[1] and S.L. Krishnamurthy[2]

[1]*Central Soil Salinity Research Institute, Regional Research Station, Lucknow- 226 005, Uttar Pradesh, India*
[2]*Central Soil Salinity Research Institute, Karnal-1320 01, Haryana, India*

Abstract

A field experiment was conducted to monitor the performance of rice genotypes for alkalinity tolerance and assess their yield potential under alkaline condition. Forty seven rice genotypes received under International Rice Soil Stress Tolerance Screening Nursery Trial (IRSSTN) from International Rice Research Institute (IRRI) were evaluated for yield and physiological traits. On basis of the grain yield and Na: K ratio, the rice genotypes were grouped in four categories viz. highly tolerant, tolerant, susceptible and highly susceptible**.** The rice genotypes from the high salt tolerant and moderate salt tolerant groups reported lower values for the Na accumulation and Na: K ratio and higher values for grain yield over the susceptible and highly susceptible genotypes. The lowest sodium accumulation and sodium and potassium ratio and highest grain yield was recorded in rice genotype IR74095-AC 64 as compared to the checks (tolerant and susceptible). The rice genotype IR 74095-AC 64 is considered potentially tolerant to alkaline stress and could be used for further breeding programme

Key words: Rice genotypes, Salt stress tolerance, Physiological traits, Na: K ratio

Introduction

Salt is a key constraint among the abiotic stresses which affect the physiological processes of plants and it is the most important factor which severely affects crop growth and development, as well as productivity, especially in rice crops. The adverse effects of three major hazards associated with salt stress are; osmotic (water) stress arising from more negative osmotic potential (higher osmotic pressure) of the root zone, specific ion toxicity, excess of exchangeable sodium which lead to soil swelling and dispersion causing water infiltration, aeration and root penetration problem and nutritional imbalance (Munns and Tester, 2008; Patade et *al.,* 2008). Selection of highly salt tolerant genotypes within a species can be expected to provide useful material in comparisons with the salt sensitive ones. Even the yield of most tolerant traditional varieties reduced to one third. It is intrinsic to a screening procedure that the phenotype should be adequately reflecting the potential of the genotype; and salt tolerance has been treated as a single factor which could include a genetically linked group of factors. The salt tolerance in non- halophytes is the product of several independent factors. Two important factors play key role. Firstly, the salt resistance in rice can be increased beyond the present phenotypic range because there is no reason to expect that, in the absence of selection process, current varieties have evolved the optimal combination of characters for salt resistance. Secondly, such characters will commonly be cryptic, i.e. the genotype for one may not on its own influence the phenotype sufficiently for that phenotype to be selected in a screening process. This study was undertaken to examine the salt tolerance potential in rice genotypes on the basis of ionic accumulation, Na: K ratio and grain yield.

*Corresponding author

Material and Methods

The experiment was conducted under sodic soil (pH 9.6-9.7) condition at Central Soil Salinity Research Institute, Regional Research Station, Research Farm, Shivri, Lucknow-Uttar Pradesh. The site is geographically located at 26^0 47'N latitude and 80^0 46'E longitude and 120 m altitude. Forty seven rice advance breeding lines developed by International Rice Research Institute (IRRI) were evaluated under International Rice Soil Stress Tolerance Screening Nursery Trial (IRSSTN). The nursery of these rice genotypes was raised under normal soil and 30 days old seedlings were transplanted during *kharif* 2011 in the field having soil pH 9.6-9.7. Three times replicated trial was conducted in randomized block design. Two to three seedlings hill^{-1} were transplanted at a spacing of 20 cm × 15 cm. The recommended dose of fertilizers for sodic soils *viz.,* 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1}, 40 kg K ha^{-1} and 25kg zinc were applied uniformly to all the genotypes. Half dose of nitrogen through urea and diammonium phosphate, full dose of P_2O_5 through diammonium phosphate and full dose of zinc through

Table 1. Soil characteristics of the experimental field

S. No.	Property	
1.	pH	9.7
2.	ECe (dS m^{-1})	1.33
3.	CEC (meq100^{-1} g soil)	7.9
4.	ESP (meq100^{-1} g soil)	50
5.	Organic matter (%)	0.12
6.	Available nitrogen (kg ha^{-1})	178
7.	Available phosphorus (kg ha^{-1})	6
8.	Available potassium (kg ha^{-1})	160

zinc sulphate were applied as basal and remaining half dose of N was applied in two equal splits at 30 and 60 days of transplanting. The physical and chemical properties of the soils of the experimental field are given in Table 1. The flag leaf sample was collected from each genotype for analysis of ionic accumulation. Required amounts of 300 mM glacial acetic acid were subsequently added to the same solution to make final concentrations 100 mM. The tissue was re-extracted for 2 h at 90 °C for the determination of Na^+ and K^+ content of leaves as described in Yeo and Flowers (1983). The ionic concentrations of flag leaves was determined following wet digestion method using flame spectrophotometer as described by Sharma *et al.* (2011). Ion concentrations were calculated as m mol g^{-1} fresh weight in case of leave sample. This Na: K ratio which is balanced between Na and K in shoot is also a valid criterion in measuring salt stresses. Grouping of genotypes was done on the basis of Na: K ratio and grain yield which are good indicators for tolerance to salt stress (Gregorio *et al.*, 1997). Based on modified standard evaluation score (SES) of visual salt injury at vegetative stage as given in Table 2, the genotypes were grouped in to four categories viz.

Highly salt tolerant: The first group consist of rice genotypes which gave maximum yield and having tolerant potential to a salt stress.

Tolerant: The second group consist of the rice genotypes which are moderately salt tolerant.

Susceptible: The third group consist of rice genotypes which are low yielding and susceptible to salt stress.

Highly susceptible: The fourth group consist of rice genotypes which are very low yielding and highly susceptible to salt stress.

Results and discussion

Evaluation of salt stress symptoms at vegetative and reproductive stage

Salt toxicity of rice genotypes were monitored based on salt injury symptoms. This scoring discriminates the highly susceptible to highly tolerant genotype. Scoring was conducted at vegetative and reproductive stage. the first group representing highly tolerant genotypes namely, IR 10T107, IR 74095-AC 64,IR 71895-3R-60-3-1, IR 73571-3B-14-2, IR 74099-AC7, IR 72046-B-R-8-3-1-2, IR 72579-B-2R-1-3-2, IR 10T 105, IR 10T 108, IR 10T 101, IR 10T 110, IR 10T 103, POKKALI (ACC 108921), NONA BOKRA, IR 66946-3R-178-1-1 (FL 478), CSR 28 and CSR 36 was recorded the salt injury score 3, 2, 3, 3, 4, 4, 2, 3, 4, 3, 4, 4, 2, 3, 2, 2 and 3 respectively (Table 3).The second group categorized as tolerant consist of genotypes namely, IR 74095-AC 45, IR 07 T101, IR 59418-7B-21-3, IR 68144-2B-2-2-3-3, IR 58427-5B-15, IR 68144-2B-2-2-3-2, IR 77674-3B-8-2-2-14-4-AJY1, IR 71829-3R-89-1-1, IR 72593-B-13-3-3-1, IR 72593-B-18-2-2-2, IR 72593-B-3-2-3-3, IR 76397-2B-6-1-1-1-1, IR 77674-3B-8-2-2-14-4-AJY 2, IR 10T 109 and AGAMI MI reported 5, 6, 4, 3, 3, 5, 6, 5, 6, 6, 4, 4, 5, 4 and 6 salt injury score respectively. The third group i.e. sensitive consist of genotypes namely, IR 77674-3B-8-2-2-12-5-AJY 2, TCCP 266-1-3B-10-2-1, IR 77674-3B-8-2-2-13-4-AJY 2, IR 10T 102, IR 10T 115, IR 55179-3B-11-3, AT 401, IR 45427-2B-2-2B-1-1 and A 69-1 had found the salt injury score 7, 7, 5, 7, 5, 5, 7, 6 and 7 respectively.The fourth group categorized as highly sensitive consist of rice genotypes namely, IR 07T 113, IR 70870-B-P-2-2, IR 77674-3B-8-2-2-8-3-AJY 4, IR 77674-3B-8-2-2-14-1-AJY 5, IR 29 and IR 28 had salt injury score 7, 8, 7, 8, 8, and 8 respectively (Table 3). The results of present findings are in accordance with the reports given by Babu *et al* (2014) and Krishnamurthy *et al.* (2014).

Ionic accumulation

The ionic accumulation (Na, K and Na: K ratio) in flag leaves of salt tolerant rice genotypes was significantly different. In first group (highly salt tolerant), the rice genotype namely, IR 74095-AC 64 recorded lower Na accumulation (3.28 mg g^{-1}) and lower the Na: K ratio (0.10) in flag leaves (Table 4). This shows that it was not affected by salt stress as compared to other genotypes.

Table 2. Modified standard evaluation score (SES) of visual salt injury at vegetative stage.

Score	Observation	Tolerance
1	Normal growth, no leaf symptoms	Highly tolerant
3	Nearly normal growth, but tips or few leaves whitish/burn and rolled	Tolerant
5	Growth severely retarded; most leaves roll; only a few are elongating	Moderately tolerant
7	Complete cessation of growth; most leaves dry; some plants dying	Susceptible
9	Almost all plants dead or dying	Highly Susceptible

Table 3. Salt injury score of 47 genotypes of rice.

Genotype	Origin	Stress injury score at vegetative stage	Stress injury score at reproductive stage	Grade
IR 10T107	IRRI	3	4	Highly tolerant
IR 74095-AC 64	IRRI	2	2	Highly tolerant
IR 71895-3R-60-3-1	IRRI	3	3	Highly tolerant
IR 73571-3B-14-2	IRRI	3	4	Highly tolerant
IR 74099-AC7	IRRI	4	5	Highly tolerant
IR 72046-B-R-8-3-1-2	IRRI	4	5	Highly tolerant
IR 72579-B-2R-1-3-2	IRRI	2	3	Highly tolerant
IR 10T 105	IRRI	3	4	Moderately tolerant
IR 10T 108	IRRI	4	5	Highly tolerant
IR 10T 101	IRRI	3	4	Moderately tolerant
IR 10T 110	IRRI	4	5	Highly tolerant
IR 10T 103	IRRI	4	5	Moderately tolerant
POKKALI (ACC 108921)	Sri Lanka	2	4	highly tolerant
NONA BOKRA	India	3	5	highly tolerant
IR 66946-3R-178-1-1 (FL 478)	IRRI	2	4	highly tolerant
CSR 28	India	2	4	highly tolerant
LOCAL CHECK (CSR 36)	India	3	4	Moderately tolerant
IR 74095-AC 45	IRRI	5	6	Moderately tolerant
IR 07 T101	IRRI	6	6	Tolerant
IR 59418-7B-21-3	IRRI	4	5	Moderately tolerant
IR 68144-2B-2-2-3-3	IRRI	3	5	Tolerant
IR 58427-5B-15	IRRI	3	5	Tolerant
IR 68144-2B-2-2-3-2	IRRI	5	5	Tolerant
IR 77674-3B-8-2-2-14-4-AJY 1	IRRI	6	7	Tolerant
IR 71829-3R-89-1-1	IRRI	5	6	Tolerant
IR 72593-B-13-3-3-1	IRRI	6	7	Tolerant
IR 72593-B-18-2-2-2	IRRI	6	7	Tolerant
IR 72593-B-3-2-3-3	IRRI	4	5	Tolerant
IR 76397-2B-6-1-1-1-1	IRRI	4	5	Tolerant
IR 77674-3B-8-2-2-14-4-AJY 2	IRRI	5	6	Tolerant
IR 10T 109	IRRI	4	5	Tolerant
AGAMI MI	Egypt	6	6	Tolerant
IR 77674-3B-8-2-2-12-5-AJY 2	IRRI	7	8	Susceptible
TCCP 266-1-3B-10-2-1	IRRI	7	8	Susceptible
IR 77674-3B-8-2-2-13-4-AJY 2	IRRI	5	6	Susceptible
IR 10T 102	IRRI	7	8	Susceptible
IR 10T 115	IRRI	5	7	Susceptible
IR 55179-3B-11-3	IRRI	5	7	Susceptible
AT 401	Sri Lanka	7	7	Susceptible
IR 45427-2B-2-2B-1-1	IRRI	6	8	Susceptible
A 69-1	Sri Lanka	7	8	Susceptible
IR 07T 113	IRRI	7	8	Highly Susceptible
IR 70870-B-P-2-2	IRRI	8	9	Highly Susceptible
IR 77674-3B-8-2-2-8-3-AJY 4	India	7	8	Highly Susceptible
IR 77674-3B-8-2-2-14-1-AJY 5	IRRI	8	9	Highly Susceptible
IR 29	IRRI	8	9	Highly Susceptible
IR 28	IRRI	8	9	Highly Susceptible

Table 4. Rice genotypes based on grain yield, Na, K content (mg g^{-1} dry weight) and Na^+/ K^+ ratio in the flag leaves at flowering stage

Designation	Grain Yield (kg/ha)	Na	K	Na: K ratio
Highly salt tolerant				
IR 10T107	3680.56	5.86	43.60	0.13
IR 74095-AC 64	3905.56	3.28	31.75	0.10
IR 71895-3R-60-3-1	3541.67	3.26	25.55	0.13
IR 73571-3B-14-2	3250.00	3.97	25.18	0.16
IR 74099-AC7	3388.89	2.74	20.80	0.13
IR 72046-B-R-8-3-1-2	3472.22	3.96	25.55	0.15
IR 72579-B-2R-1-3-2	3736.11	3.26	28.43	0.11
IR 10T 105	3611.11	2.87	22.73	0.13
IR 10T 108	3611.11	3.83	21.13	0.18
IR 10T 101	3638.89	3.63	22.30	0.16
IR 10T 110	3638.89	3.53	20.96	0.17
IR 10T 103	3472.22	3.97	27.18	0.15
POKKALI (ACC 108921)	2644.44	3.78	29.78	0.13
NONA BOKRA	2597.22	4.14	36.24	0.11
IR 66946-3R-178-1-1 (FL 478)	3150.00	4.08	35.45	0.12
CSR 28	3172.22	5.68	39.23	0.14
LOCAL CHECK (CSR 36)	3730.56	4.22	35.10	0.12
Tolerant				
IR 74095-AC 45	2888.89	15.36	41.13	0.37
IR 07 T101	2569.44	13.15	29.48	0.45
IR 59418-7B-21-3	2666.67	5.47	17.48	0.31
IR 68144-2B-2-2-3-3	2847.22	5.86	28.45	0.21
IR 58427-5B-15	2986.11	6.26	31.83	0.20
IR 68144-2B-2-2-3-2	3027.78	9.92	36.60	0.27
IR 77674-3B-8-2-2-14-4-AJY 1	2555.56	10.07	23.48	0.43
IR 71829-3R-89-1-1	3041.67	8.07	27.18	0.30
IR 72593-B-13-3-3-1	2638.89	11.23	28.48	0.39
IR 72593-B-18-2-2-2	2527.78	18.99	40.48	0.47
IR 72593-B-3-2-3-3	2916.67	6.16	19.33	0.32
IR 76397-2B-6-1-1-1-1	3027.78	5.16	18.33	0.28
IR 77674-3B-8-2-2-14-4-AJY 2	2638.89	12.39	30.48	0.41
IR 10T 109	2500.00	13.91	45.48	0.31
AGAMI MI	2638.89	15.31	35.48	0.43
Susceptible				
IR 77674-3B-8-2-2-12-5-AJY 2	2083.33	18.49	31.13	0.59
TCCP 266-1-3B-10-2-1	2055.56	19.46	28.93	0.67
IR 77674-3B-8-2-2-13-4-AJY 2	2208.33	10.54	29.68	0.36
IR 10T 102	2152.78	18.56	22.13	0.84
IR 10T 115	2430.56	12.76	22.75	0.56
IR 55179-3B-11-3	2083.33	15.66	33.78	0.46
AT 401	2236.11	17.56	26.13	0.67
IR 45427-2B-2-2B-1-1	2416.67	15.84	21.50	0.74
A 69-1	2347.22	14.01	24.35	0.58
Highly susceptible				
IR 07T 113	1805.56	22.10	20.25	1.09
IR 70870-B-P-2-2	1597.22	22.12	20.68	1.07
IR 77674-3B-8-2-2-8-3-AJY 4	1944.44	21.86	24.13	0.91
IR 77674-3B-8-2-2-14-1-AJY 5	1805.56	22.37	19.13	1.17
IR 29	1166.67	25.29	21.10	1.20
IR 28	1527.78	20.29	18.10	1.12
SE	1009.41	10.71	8.93	0.39
LSD (p= 0.05)	2146.57	21.56	17.97	0.78

The same results are reported by Bajwa (1982) in rice. The second group of rice genotypes ranges Na accumulation from 5.16-18.99 mg g^{-1} and Na: K ratio from 0.20-0.47 in flag leaves. In this group, the genotype namely, IR 58427-5B-15 recorded lower Na accumulation (6.26 mg g^{-1}) and lower the Na: K ratio (0.20) in flag leaves. The genotypes in this group were not affected due salt stress as compared to other genotypes. The third group (susceptible) of genotypes ranges Na accumulation from 10.54-19.46 and Na: K ratio from 0.36-0.84. In this group genotype namely, IR 77674-3B-8-2-2-13-4-AJY 2 recorded lowest (10.54 mg g^{-1}) ionic accumulation of Na and lowest the Na: K ratio (0.36). The fourth group representing highly sensitive group of genotypes ranges 21.86 - 25.29 mg g^{-1} Na and 0.91-1.20 Na: K ratio. In this group genotypes namely, IR 66946-3R-178-1-1 recorded higher Na accumulation (25.29 mg g^{-1}) and higher Na: K ratio (1.20) in flag leaves causing a significant decline the grain yield. Genotypes belong to this category were highly affected by salt stress as compared to other genotypes. This indicates that rice genotype was highly susceptible to sodicity during maturity stage because of accumulation of higher Na and higher Na: K ratio in flag leaves. This is in accordance with finding of Islam and Salam (1997), Islam *et al*. (1998), Hakim *et al*. (2005), Sen *et al*. (2004) and Ali *et al.* (2013).

Grain yield

Classification of salt tolerant potential of rice genotypes on the basis of average grain yield and Na: K ratio is given in Fig 1. The rice genotypes IR 74095-AC 64, IR 72579-B-2R-1-3-2, CSR 36, IR 10T107, IR 71895-3R-60-3-1, IR 74099-AC7, IR 10T 105, IR 72046-B-R-8-3-1-2, IR 10T 103, IR 73571-3B-14-2, IR 10T 101, IR 10T 110, POKKALI (ACC 108921), NONA BOKRA, IR 66946-3R-178-1-1 (FL 478), CSR 28 and IR 10T 108 grouped as highly salt tolerant recorded higher grain yield and lower accumulation of Na and lower Na: K ratio in flag leaves (Table 4). They have not affected by salt stress at pH 9.7 however, other genotypes severely affected at this level of sodicity. This indicates that they are not sensitive to salt stress during the maturity stage of the crop growth. The results of present findings are in accordance with the reports given by Afria and Narnolia (1999) and Gonzales and Ramirez (1998). Grain yield reduction of rice genotypes due to salt stress is also reported by Linghe *et al.* (2000) and Gain *et al.* (2004) and Krishnamurthy *et al.* (2013).

The genotypes namely, IR 74095-AC 45 , IR 07 T101, IR 59418-7B-21-3, IR 68144-2B-2-2-3-3, IR 58427-5B-15, IR 68144-2B-2-2-3-2, IR 77674-3B-8-2-2-14-4-AJY 1, IR 71829-3R-89-1-1, IR 72593-B-13-3-3-1, IR 72593-B-18-2-2-2, IR 72593-B-3-2-3-3, IR 76397-2B-6-1-1-1-1, IR77674-3B-8-2-2-14-4-AJY2, IR 10T 109 and AGAMI MI grouped as tolerant recorded lower grain yield as compared to genotypes grouped under highly tolerant. The accumulation of Na and Na: K in flag leaf was comparatively higher in these genotypes.

The genotypes namely, IR 77674-3B-8-2-2-12-5-AJY 2, TCCP 266-1-3B-10-2-1, IR 77674-3B-8-2-2-13-4-AJY 2, IR 10T 102, IR 10T 115, IR 55179-3B-11-3, AT 401, IR 45427-2B-2-2B-1-1 and A 69-1 categorized as susceptible have produced significantly lower yield than the genotypes stands under highly tolerant and tolerant categories. The accumulation of Na and Na: K in flag leaf was also higher in these genotypes.

The genotypes namely, IR 07T 113, IR 70870-B-P-2-2, IR 77674-3B-8-2-2-8-3-AJY 4, IR 77674-3B-8-2-2-14-1-AJY 5, IR 29, and IR 28 found highly susceptible and produced lowest grain yield. They were severely affected by salt stress as compared to other genotypes. Trend of Na: K ratio in the flag leaf showed that, as to increase grain yield, the accumulation of Na: K ratio was decreased**.** The correlations between grain yield and Na: K ratio of rice genotypes s given in Fig. 2. This indicates the sensitivity to salt stress during maturity stage in rice. This is in accordance with the findings of Powar and

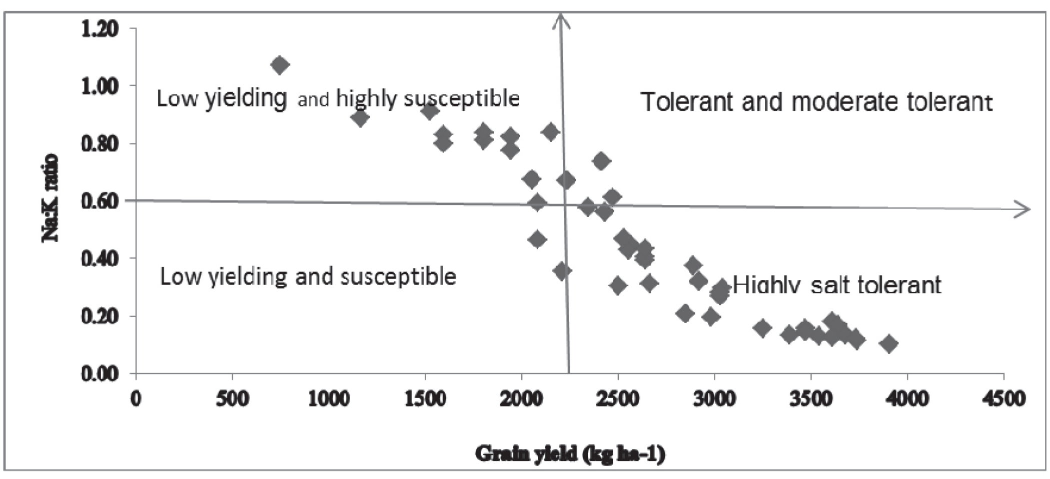

Fig.1. Classification of salt tolerant potential of rice genotypes on the basis of average grain yield and Na: K ratio

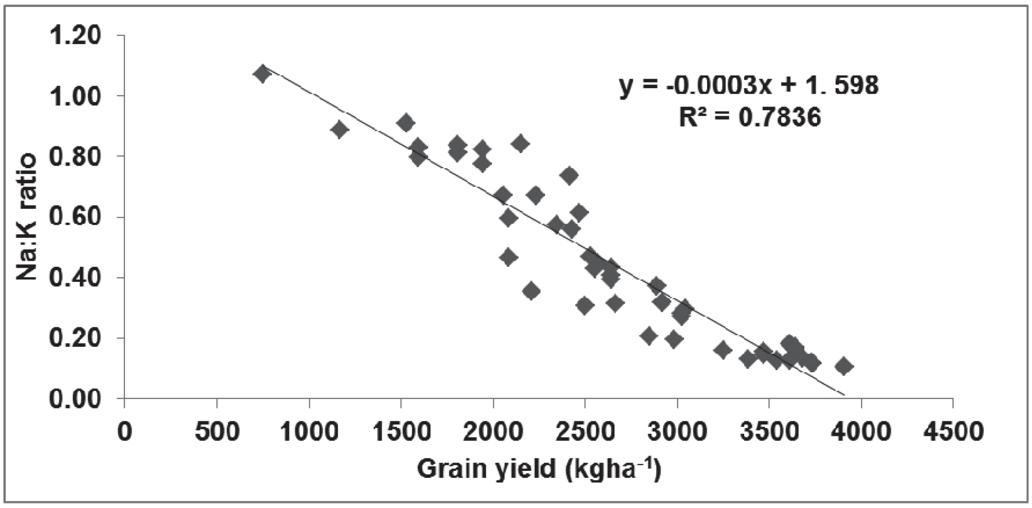

Fig. 2. Correlations between Grain Yield and Na: K ratio of rice genotypes of salt tolerance

Mehta (1997) who reported that grain and straw yields decreased with increasing salt stress and similar finding is reported by (Quadar, 1991 and Surekha *et al*., 2008).

Conclusions

Based upon the grouping of rice genotypes for sodicity tolerance and yield, the rice genotypes from highly salt tolerant group recorded a lower value for the Na: K ratio higher grain yield. The lowest Na: K ratio and higher grain yield was recorded by rice genotype namely, IR 74095-AC 64 as compared with and others in high yield and tolerant genotypes. This rice genotypes IR 74095-AC 64 could be used in further breeding programme to enhance the productivity of salt affected soils.

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Productive Utilization of Sodic Water for Aquaculture-led Integrated Farming System: A Case Study

S.K. Singh*, Ranbir Singh, S. Kumar, Bhaskar Narjary, S.K. Kamra and D.K. Sharma

Central Soil Salinity Research Institute, Karnal, Haryana, India
**Email: sharad@cssri.ernet.in*

Abstract

In many parts of the country there is sodic groundwater with high residual sodium carbonate (RSC), which is considered unsuitable for agricultural crops and aquaculture purposes. In present investigation a case study was undertaken on farmer's field utilizing high RSC water in a aquaculture based farming system. A pond of 0.4ha (water area of 0.3ha and 2.0m depth) having sodic water, along with the adjoining 500 m^2 nursery pond located in the village Lotani, Kurukshetra District was renovated. A platform of 2.0 m width with an area of 0.1 ha was made along the inner periphery of the pond for growing field crops. Gypsum treatment was given for neutralizing the RSC effect in the pond water. The pond was filled with pumped water from a 50 m deep tube well that had RSC ranging from 2.5-4.1 meq l^{-1} and also supplemented with rainwater. Normal pond management practices were followed which included application of raw buffalo dung. Pond water was used for irrigation. Gypsum treatment and application of raw buffalo dung in the pond created RSC neutralizing effect. In general, pond water had an electrical conductivity (EC) of 0.4dS m^{-1}, RSC of < 0.8meq l^{-1} and dissolved oxygen of 4.0-8.2 mg l^{-1} during fish culture operation. Fish growth in the adopted pond was found to be 625-1150g in 12 months, depending on species of Indian major carps and exotic carps. Fish production was recorded to be at the level of 6000 kg $ha^{-1}yr^{-1}$. Production of field crop per ha were 1000 kg potato, 400 kg onion, 200 kg maize (bhutta),100 kg garlic, 40 kg pigeon pea and 100 kg turmeric beside considerable quantity of consumable vegetables (cauliflower, chillies, radish, *methi, palak*, ladies'finger, brinjal, banana) and green fodder from the dyke (inner platform of the pond, during the year of observation. The study demonstrated that sodic water with certain chemical and organic remediation can be used for aquaculture-led integrated farming practices with success.

Key words: Sodic water, High RSC water, Chemical remediation, Integrated farming system.

Introduction

Water with high proportion of sodium salts in the total salt concentration is termed sodic. Sodium is a highly soluble chemical element and often naturally found in ground water. All ground waters contain some sodium because most rocks and soils contain sodium compounds from which sodium is easily dissolved. It is estimated that 32 to84 percent of total ground water in the country is of poor quality. This is ranging from marginally saline to highly alkaline (EC <4dS m^{-1}, SAR <10 and RSC >4.0 meq l^{-1} (Gupta, 2010). Alkali water is commonly seen in central and south-western parts of Punjab covering about 25 percent of the total area of state. In Haryana, alkali water aquifers are found in almost 21 percent of the total area of the state. Utilization of sodic water for agricultural purpose containing high sodium compared to calcium and magnesium ion and high carbonate and bi-carbonates leads to high alkalinity and sodium saturation in the soils. Long term use of residual sodium carbonate (RSC) water deteriorates the soil properties and results in soil conditions similar to sodic /alkali soils. The soil sodification effects are reflected in terms of poor crop stand or bare soil spots due to reduced seedling establishment and retardation of crop growth and yield that, in turn adversely affects agricultural production. Increased intake of sodium from water medium is problematic to the animal and fish also. However sodium is a principal chemical in the body fluids, and it is not considered harmful at normal levels of combined intake from food and water sources. Inadequate ionic concentration of hard water (Ca+Mg) and low alkalinity (CO_3 + HCO_3) pose problem to fish and its growth. In general, freshwater fish in moderate hard water tend to spend less energy on osmoregulation, resulting in better growth. The very high limit of alkalinity may also be related to its effect on osmoregulation at high ion concentrations. As a general rule for fish culture, the most productive water should have approximately the same magnitude of total hardness and total alkalinity values (Boyd, 1984). Introduction of aquaculture practice alone and in integrated farming mode with and without sodic soil led pond with good water quality was documented

*Corresponding author

(a) (b) (c)

Fig. 1. Pre-adoption survey (a) Location map (Google earth) of study area, (b) Initial soil sampling of salt affected pond bottom, (c) Barren view of pond area

by many authors (Chung, et al., 1995; Rao, et al., 1999; Luu, 2001; Prein, 2002; Sarkar, 2004; Abdullah,2004; Jharendu,et al., 2005; CSSRI, 2008a, 2009; Singh,2012). However, there is no report available on the utilization of sodic (RSC) water for aquaculture practice alone or in combination of integrated farming system mode (Edwards, 2000; Gopakumar et al.,2000). In the present study where farmer was not able to produce desired fish production (above national average) due to adverse effects of residual sodium carbonate (sodic water) on pond soil carried forward from ground water supply in the pond and lack of technical know how. Considering the importance of sodic water problem in aquaculture and crop productivity, a farmer and scientist-led participatory study was conducted at a farmer's field in the integrated farming system mode with a view to solve the problem and provide various options with multiple scientific interventions.

Materials and Methods

Pre adoption scenario: As per mandate of the Institute, the scientists of CSSRI Karnal were in search of salt affected problem oriented aquaculture practice at farmers' field in the state of Punjab and Haryana. After extensive survey in the year 2011, a suitable site was found at village Lotani. After adoption, one study was conducted in collaboration with a farmer Shri Ramchandra on a field of 0.7 ha area located in the village Lotani, Kurushetra District (70 km from Karnal). Farmer's family was earning livelihood from a 0.4 ha shallow pond (Fig. 1) at a location of N-30^0 4' 4.7''; E-76^0 39' 27.6''; MSL 256 m; a small 500 m^2 nursery pond, and agroforestry plants. He also owned a non milking buffalo, a calf, 0.1 ha fodder land and small house.

Post adoption scenario: With the intervention of CSSRI scientists, the main pond area was renovated after soil profile study. Initially salt affected soil of the shallow pond was scrapped. Mechanical digging of pond was done and soil up to 1.0 meter depth was removed. Reshaping of pond was done. Pond area was made to 0.3ha (60m x 50m) water depth of 2.0 meter. An inner platform (0.1ha) was made throughout inner periphery of the main pond (Fig. 2). Farmer's family size and pond scenario after renovation is depicted below.

Total farm area	0.7 ha
Family size	06 members (03 adults + 03 minors)
Pond number	02
Main stocking pond area	0.3ha (2.0 meter depth)
Inner platform area	0.1 ha
Old dyke area	0.1ha (Poplar trees-150, Eucalyptus-500 trees)
Nursery pond area	0.05 ha, depth 1.0 m
House and cattle (03No)	0.05 ha yard area
Fodder land area	0.1 ha

(a) (b) (c)

Fig. 2. Various post adoption intervention of pond (a) Pond bottom profile study, (b) Renovation of pond, (c) Pond area preparation

Aquaculture pond and crop management

To treat sodic water in pond gypsum was applied @1000kg ha^{-1}along with fertilizer in the form of di-ammonium phosphate (DAP) @ 750 kg $ha^{-1}yr^{-1}$. The later was applied in ten equal splits. Similarly raw buffalo dung @15.0 t $ha^{-1}yr^{-1}$ in ten equal installments was applied in the pond. The pond was stocked with 10,000 ha^{-1}fingerlings (5-10g size) of different carps in the ratio of *Catla catla* (C-15%), *Labeo rohita* (R-30%), *Cirrhinus mrigala* (M-25%) and *Cyprinus carpio* (CC-20%) and *Ctenopharyngodon idella* (GC-10%). The recommended method of pond management practices were followed during one year experimental trial period (2011-12). The physico-chemical and hydro biological parameters of soil and water of the pond were recorded following standard methods (Bhargava et al., 2003; Saharan et al., 2004) with permissible modification. Feeding to the fishes was done @1-5% of body weight of fishes with oil cake and rice polish (1:1) ratio besides the leafy material of different crops and plants and kitchen waste. Field crops were grown as per recommended practices with certain modification as per need of the system. Nutrient enriched pond-water was used through pitcher method (www.icar.org.in) for irrigation of field crops on the inner platform of pond.

Results and Discussion

Soil health- Physico-chemical properties of soil are depicted in Tables 1 and 2. Profile study reveals that initial soil of pond bottom was 0-30cm (silt –clay), 30-60 cm (sandy clay-loam) and 60-120 cm (clay loam). Spatial variability in pond soil parameters was observed. Initial soil parameters of different locations of pond area up to 0-15 centimeter depth were pH_2 (7.32- 8.12), EC_2 (0.76-4.14dS m^{-1}) and organic carbon (0.03-0.6%). Appearance of pond got changed due to renovation of the pond and agronomical activities on inner platform of pond and leaf litter fall from trees grown on dyke. Bottom soil got changed over the months of aquaculture operation and status of the same is depicted in the Table-3. Just after renovation, soil parameters of inner platform of the pond are pH_2 (8.02-8.26), EC_2 (0.50-0.60, dS m^{-1}) organic carbon (0.02-0.08%). However, pond bottom soil parameters $pH_{2,}$ EC_2 and organic carbon ranged from (7.93-8.46), (0.56-0.6dS m^{-1} and (0.03-0.07%), respectively. After one year of experimentation the change in pH, EC and organic carbon were observed in case of inner platform and pond bottom soil. However, there was no significant change was noticed in case of pond dyke soil parameter.

Unproductive nature of soil is reflected in deficiency in status of available nitrogen, phosphorus and organic carbon in pond dyke soil which was brought from the initial digging of pond. High level of basic salts of sodium in the soil leads to clay and organic matter dispersion resulting in structural deterioration restricting the water and air movement in soil. As a result, the overall growth of crops was adversely affected. In this context amendment of low dozes of gypsum along with buffalo

Table 1. Initial soil properties of pond area (0-15cm soil depth)

Sampling area of pond	pH_2	EC_2 (dS m^{-1})	OC (%)	Av.N (kg ha^{-1})	Av.P (kg ha^{-1})	Av.K (kg ha^{-1})	ESP (%)
Margin area	7.37-7.64	4.04-4.14	0.04-0.1	6.8-10.2	4.8-5.6	108.0-116.2	Less than 12.0
Bottom area	7.32-7.42	3.1-3.61	0.3-0.6	15.0-24.6	6.8-15.2	146.8-168.5	Less than12.0
Dyke	7.8-8.12	0.76-0.85	0.03-0.06	6.0-8.4	4.0-5.2	98.4-110.6	More than12

Table 2. Soil status of pond area after intervention

Parameter	Pond area after renovation (0-15cm soil depth)			Pond area after one year experimentation(0-15cm soil depth)		
	Inner platform area	Bottom area	Dyke	Inner platform area	Bottom area	Dyke
pH_2	8.02-8.26	7.93-8.46	7.8-8.12	8.03-8.70	7.23-7.34	7.8-8.12
EC_2(dS m^{-1})	0.5-0.6	0.56-0.63	0.76-0.85	0.28-1.82	1.51-1.54	0.48-0.63
OC (%)	0.02-0.08	0.03-0.07	0.03-0.06	0.12-0.20	0.3-0.7	0.06-0.10
Av.N(kg ha^{-1})	15.0-24.6	6.8-10.2	6.0-8.4	20.6-30.4	28.6-42.2	6.2-8.6
Av.P(kg ha^{-1})	10.8-15.2	4.8-10.6	4.0-5.2	15.8-25.8	10.6-30.8	4.0-6.8
Av.K(kg ha^{-1})	126.8-168.5	98.4-106.2	98.4-110.6	132.2-176.0	140.6-246.8	101.2-111.8
Exchangeable Sodium Percentage(ESP)(%)	Less than12.0	Less than12.0	More than12	Less than12.0	Less than12.0	More than12.0

Table 3. Physico-chemical and biological parameter adopted pond water

Parameter	Tube Well	Pond
Water depth (m)	Deep(50m)	2.0
Transparency(cm)	Clear water	16-24
Water temperature(^{0}C)	20-28	10-36
pH_2	7.5-8.20	7.2-8.3
EC_2 (dS m^{-1})	0.4-0.85	< 0.4
D.O.(mg l^{-1})	3.0-3.4	4.0-8.2
Free CO_2	8.0-10.6	4.2-8.4
RSC (meq l^{-1})	2.5-4.1	< 0.8
CO_3 (meq l^{-1})	Nil	Nil
HCO_3 (meq l^{-1})	4.2-8.6	3.6-6.2
Ca+Mg (meq l^{-1})	1.7-4.5	3.2-5.4
NO_3–N (mg 1^{-1})	3.0-6.2	3.1-7.3
Total Phosphorous (mg 1^{-1})	0.01-0.04	0.10-0.24
Potassium (mg 1^{-1})	1.6-2.4	1.2-1.8
Plankton production (ml/100 l water)	-	2.5-3-0
Bottom biota (Nos m^{-2})	-	10-12
Fish production(kg $ha^{-1}yr^{-1}$)	-	6000

dung was helpful for both soil and water improvement. Obviously for amendment of sodic soils, application of nitrogen and phosphorus carriers at recommended rates is necessary. This could only be met by addition of higher dozes of organic waste (raw buffalo dung and DAP fertilizer). The improvement in pH, EC and organic carbon of the inner platform and bottom soil after one year of experimentation was found to be pH_2 (8.03-8.70), EC_2 (0.28-1.82 dS m^{-1}) and organic carbon (0.12-0.20%) for inner platform and pH_2 (7.23-7.34), EC_2 (1.51-1.54 dS m-^{1}) and organic carbon (0.3-0.7%) for bottom is quite considerable as for as aquaculture is concerned (Banerjea,1967; Rao *et al.*,1999; Pandey and Kumar,1998; Sarkar, 2004; Singh, 2012). Soil organic carbon affects the soil fertility and physical conditions and more so in salt-affected soils. The organic carbon enhancement due to aquaculture operation in salt affected soils is noticed in the present study, which indicated good fertility status of pond bottom soil (Masuda and Boyd, 1994; Chatterjee and Saha, 2000). Leaf litter fall from pigeon pea and agroforestry plants also added soil organic carbon improvement on the inner platform of the pond (Gill et al., 1987; Singh et al., 1997).

Water use and fish production: Water is of vital importance for the existence of aquatic life. Precipitation and ground water are the major sources of water for aquaculture. Pure water is unable to support aquatic life but when it is enriched with various substances from both soil and air, it can sustain life. The amount of these dissolved substances depends on their status in soil and also dissolution in water through physco-chemical and bio-chemical process. Thus, depending on the geological formations, most of the minerals present in soil are also found to be present in varying concentration in water and the amount of these substances including the gases dissolved alter the water quality. Some of the water quality parameters recorded in this study (Table 3) revealed that water depth, water transparency, water temperature, water pH and EC were very much with in the range of optimum values as suggested by Boyd (1984), Banerjee (1967), Rao, et al. (1999) and Singh (2012). The RSC of water used was neutralized by the application of gypsum and raw buffalo dung. As we know the RSC is measure of Ca and Mg in the water supply which reacts with HCO_3 and CO_3 to precipitate as insoluble lime. Reaction of the sulfur source gypsum ($CaSO_4$) is beneficial for alleviating sodic conditions if leaching is sufficient to remove the Na in the form of Na_2SO_4 (Carrow et al., 2007). Application of raw buffalo dung with its acidic character helps to evolve CO_2 gas plus water from the HCO_3 and CO_3. It is highly desirable since it allows any Ca and Mg in the water source to remain soluble so that they could displace Na from the soil and also it allows soil- applied amendments to be more effective in producing relatively soluble Ca. It is generally accepted that addition of organic materials reduced sodicity both in soil and water and beneficial effects of this are mainly attributed to improving soil properties and their role in reducing nitrogen volatilization losses and enhancing nitrogen use efficiency (Choudhary, 2013). Shading effects of agroforestry trees (Fig.3) and ground water temperature (Table 3) help to maintain congenial temperature regime in the pond water during winter and summer as well and ultimately help in enhancing higher fish productivity which corroborate findings of Halver (1972) and Adrian (2004). Pond's inherent productive capacity has been enhanced through manuring of raw buffalo dung (Table 2). Addition of farm yard manure and pond water also increased productivity of the inner platform of pond (Table 3). However, leaching of salts from the pond dyke especially during monsoon created higher pH and EC of soil on the inner platform; which also corroborate the findings of Rao *et al.* (1999) and Singh (2012). Growth of fish in one year of culture operation under neutralized unproductive RSC water condition is found to be 625-1150g (Table 4 and Fig. 3). The fish production in such conditions has been found to be 6.0 ton/ha/year (Table 4).

The higher fish productivity in sodic soil with good water condition has been observed by other workers (Rao *et al.,* 1999; Singh, 2012). Stocking of adequate size of fish resulted higher growth and production during the experimentation. General checkup of pond water level maintenance especially during summer and monsoon were given due care. It is well known that the prevention is better than cure. So prior to stocking, the fingerlings have been given bath with 3ppm $KMnO_4$ for 30-60 seconds. Feed is the main governing factor in determining the growth rate of fish. Natural fish food production was limited (Table 3), therefore for getting higher production

Table 4. Fish productivity parameters of the pond

Sp.	Stocking details				Harvesting details						
	Stocking ratio (%)	Nos.	Av. wt (g)	Total wt(g)	Recovery (No.)	Recovery (%)	Av. wt. (g)	Total wt.(kg)	Net wt. (g)	Yield (kg $ha^{-1}yr^{-1}$)	Species yield(%)
R	30	900	5	4500	729	70.0	975	614.3	609.7	2045.0	33.73
C	15	450	10	4500	351	52.0	1050	245.7	241.2	818.0	13.49
CC	20	600	8	4800	534	71.0	625	266.3	261.5	886.6	14.62
M	25	750	7.5	5625	660	70.O	850	446.3	440.6	1486.0	24.51
GC	10	300	8.5	2550	276	82.0	1150	248.4	245.8	827.2	13.64

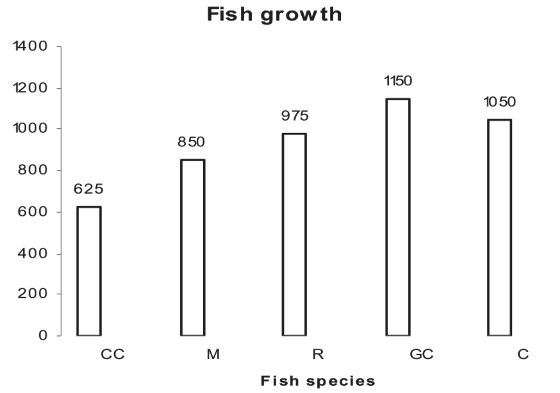


Fig. 3. Species wise growth of different type fishes

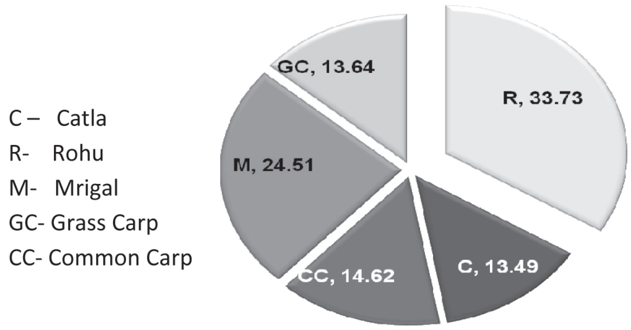
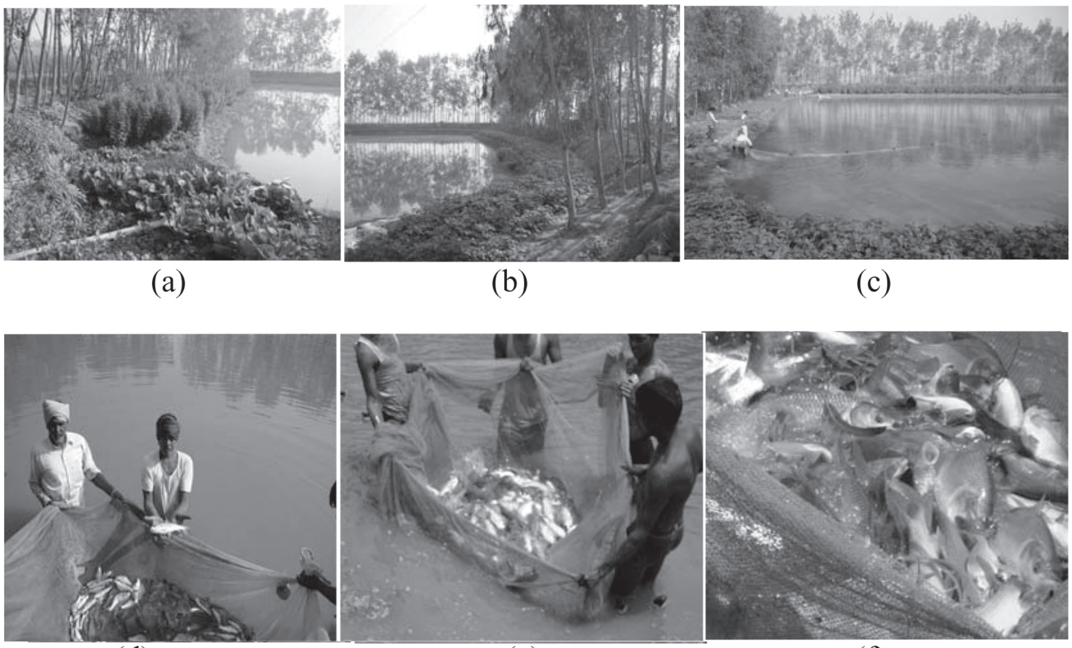


Fig. 4. Species wise yield contribution (%) in total fish production

application of feed from outside in terms of leaves of various seasonal plants, kitchen waste, rice bran and oil cake in the proper ratio was found beneficial. Terrestrial grasses and forages were useful for the growth of grass carp. The study also indicated the possibility of higher productivity of fish after further better management and scientific interventions in terms of species diversification and balanced supplementary feed. The physico-chemical and hydrobiological parameters of the pond are comparable to normal soil and freshwater ponds. However, higher level of nitrate, phosphate and potassium provided nutrient enhancement in the pond water which resulted beneficial effect for plankton production (Table 3). The species recovery from the pond after harvest were found in the order of *Catla catla*< *Ctenopharyngodon idella*< *Cyprinus carpio*< *Cirrhinus mrigala* < *Labeo rohita* respectively (Fig. 4).This indicated proper utilization of natural food, plant waste and supplementary feed by the fish. Bottom seepage of pond water provided nutrient enriched water movements towards root zone of agroforestry plants grown on the pond dyke which corroborate the findings of other studies (Muendo *et al.,* 2005; Stone and Boyd, 1989; CSSRI, 2008b). In one other study it was observed that sodic soil having soil pH more than 10.5 is good source of sealing material of water seepage of pond (Shah *et al.*, 1986) but in the present study all the cases of pond area soil pH were below the above range (Tables 1- 3). Aquaculture-agro forestry system is good for utilizing nutrient loss from pond ultimately reflected in tree growth in terms of appearance of higher

Table 5. Economics of pond aquaculture

Item	Cost (Rs)
Operational cost	
Pond value (small farmers own pond)	Nil
Renovation of pond	15,000
Water filling charges	5,000
Cost of 300kg Gypsum	250
Cost of buffalo dung/own cattle dung	Nil
Cost of feed (Mustard oil cake-1000kg+ Rice bran1000kg)	25,000
Cost of 250kg DAP	3000
Cost of 3000 Nos fingerlings	6,000
Manpower/Family involvement	Nil
Netting charges(Adjusted with fish sale to the party	Nil
Other expenses	5,700
Total operational cost	60,000
Interest@10%/yr	6,000
Total expenditure	66,000
Output/Return	
Cost of per kg fish production	36.30
Income from 1820 kg fish @ Rs 90/kg farm gate price	1,63,800
Benefit cost ratio	2.48
Net profit	97,800
Net return	148%



(a) (b) (c)

(d) (e) (f)

Fig 5. Different stages of aquaculture led integrated farming practice (a) cultivation of pigeon pea &vegetable crop on inner platform,(b) cultivation of potato on inner platform of the pond,(c) Pond netting operation and all integration view including agroforestry plants, (d) Initial fish sampling, (e) Haul of fish harvest, (f) Growth of fishes and final fish harvest.

girth compared to near by other places in lesser span of time. Oxygen production from the plants is added benefit for pond surrounding environment and emphasize mutual benefit for agroforestry and aquaculture (Fig. 5).

Crop productivity and profitability

The production of different field crops is depicted in the Table 6 and Figs. 5 and 6.

Dalai (1989) and Chandra (2012) documented the cultivation of pigeon pea on pond dyke in the normal soil and water conditions of the eastern parts of the country. Importance of cultivation of pigeon pea in the north western part of country was a cause of concern (ICAR, 1998). In the present unique venture it has been grown lateral side of dyke after developing suitable inner platform where shading of tree and nearby low line pond water was with in reach without hindering netting operation (CSSRI, 2011-12). It was observed that potato, pigeon pea grown on the inner platform had no adverse impact of winter chill and frost (Fig.5 a,b,c). Whereas the potato grown on nearby plot outside the study area, was severely damaged. No damage to potato crop on the inner platform was observed mainly due to ambient floating latent heat generated from the pond water during winter which corroborates findings in case of heat transfer from small cylindrical fish rearing pool by Sarkar et al., 2006 and occurrence of congenial microclimatic conditions in the plant based surrounding. This reflected

Table 6. Multiple production of different crop and their benefit cost ratio

Crop	Production (kg)	Expenditure (Rs)	Income (Rs)	BC ratio
Fish	1820	66,000	1,63,800	2.48
Potato	1000	3000	10,000	3.33
Onion	400	1000	6,000	6.0
Garlic	100	500	2000	4.0
Turmeric	100	500	2000	4.0
Maize	200	500	2000	4.0
Pigeon pea	40	500	2000	4.0
Total	1,02,000	1,90,000	1.9	

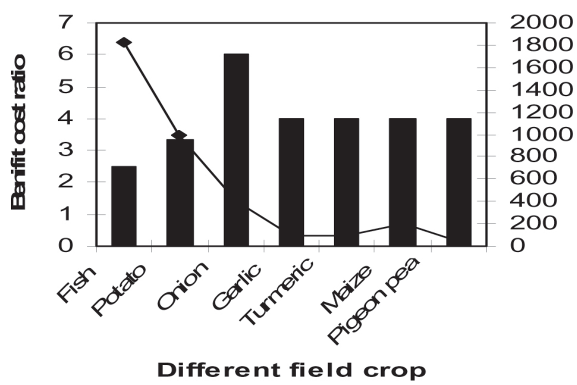


Fig. 6. Cropwise production & their benefit cost ratio

the importance of this system as climate smart aquaculture- led integrated farming. The profitability analysis of adopted farmer's pond is presented in Table 5.

The gross and the net return of fish produced from the 0.3 ha pond were Rs 1,63,800 and 97,800, respectively. The benefit cost ratio (BCR) is depicted in the Table 5 and Fig. 3 and it was 2.48 for fish, 3.33 for potato, 6.0 for onion, 4.0 for garlic, 4.0 for turmeric, 4.0 for maize and 4.0 for pigeon pea (Fig. 6). Overall combine BCR for all the produce was 1.9. Economic profitability analysis of fish culture-led integrated farming system showed higher BCR for all the produce in overall perspective. This is mainly due to irrigation on field crops from nutrient enriched pond water. The study revealed that there is scope for increasing productivity and profitability of aquaculture led integrated farming system in poor ground water supply condition. It also reflected that pond water has provided beneficial effects due to its nutrient enriched utility for irrigating field crops. Outcome of this type of farmer-scientist led innovation will provide livelihood option to the resource poor farmers in problematic areas.

Conclusion

The sodic (high RSC) water with certain amendments (chemical & organic) can be used for productive utilization of aquaculture-led integrated farming practice. Besides the higher income, the family meets the nutritional requirement by in-house production of quality nutrient-rich products such as pulses, milk, different type of vegetables, fruits and fish. Due to the interventions made in the farming systems practice, the family gets additional employment besides eco-friendly environments and cooking fuel from branches of trees.

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Water Management and Usage of Nallamada Drain Water – A Quantitative Assessment

A. Sambaiah, G.V. Lakshmi, M. Raghu Babu, K. Hema and M. Latha

AICRP-Saline Water Scheme, Bapatla

Abstract

The Krishna Western Delta is drained naturally by 7 major natural drains, out of which Nallamada drain is very important source of irrigation, which falls in Guntur and Prakasam districts. It was found that the total quantity of water flows in Nallamada drain in a year was 49 TMC. Peak outflow in all the years was observed in the month of November. The highest salinity was observed during July to August. Only 6 TMC of water was used for all the Lift irrigation schemes and for all the crops under Nallamada command in Krishna Western Delta and the remaining 43 TMC of quantity of water joins sea every year. As the existing cross section is unable to carry the climate change induced impulsive peak discharges, the cross section has to be enhanced. The electrical conductivity of Nallamada drain water below Kommamuru Canal zone during cropping season is found well below 1.5 dS/m and during pre-monsoon season, it ranges between 4 dS/m to 14 dS/m from the year 2008-2013, which is due to back water flow from the sea to the drain till 21.2 km. The enhanced flows of the Nallamada drain are causing floods damaging standing crops and nearby habitats, which can be avoided by increasing the existing cross section, upper catchment soil and water conservation treatment, and strengthening of the bunds/banks of the drain through making dykes or concrete coring.

Key words: Discharge, Drain cross section, Electrical conductivity, Floods, Nallamada drain, Waterlogging, Drainage water, Yields.

Introduction

Irrigated agriculture is already the largest consumer of developed water resources. At the same time, drainage return from irrigated lands is one of the major causes of water logging (usually in lower lying regions) and of water pollution (with respect to salts, nitrates, agricultural chemicals and certain natural, potentially toxic trace elements).

Drainage water, once thought of as wastewater, is now used in many countries for irrigation. The salinity levels vary, but often the salt levels are higher than those of conventional primary irrigation water sources. Reuse of drainage effluent is important when the supply of good quality irrigation water is limited, and it is also an efficient means of reducing water pollution.

Drainage water is used for crop production on many farms in California, USA. The saline sub-surface drainage water is blended with Delta-Mendota Canal water in the Broadview Water District of California to form blended water of a salinity equivalent to 3.2 dS/m and since 1956 is used to grow a variety of crops. Over time, the cropping pattern in this district has changed as the water quality has decreased. Crops now grown are mostly cotton, barley and alfalfa. Representative salinities and potentials for use as irrigation waters and drainage waters from the major irrigated areas of the USA are described by Rhoades (1977).

The development of crops with increased salt tolerance and the adoption of new crop and water management strategies will further enhance and facilitate the use of saline waters for irrigation and crop production, while keeping soil salinity from becoming excessive. The reuse of drainage waters for irrigation will also help to conserve water and to minimize the hazardous effects of irrigation on the environment and ecology.

The coastal districts of Andhra Pradesh were subjected to frequent cyclones during the years 1990,1994,1997,1998 and heavy floods in 2000 caused irrecoverable damage to the infrastructure in Andhra Pradesh, which calls for immediate attention to the drainage system in the basin. The Krishna Western Delta is drained naturally by 7 major natural drains, out of which Nallamada drain which falls in Guntur and Prakasam districts assumes important role in mitigation of floods.

In coastal regions, surface water sources can become saline due to the tidal influence of the sea. As the high tide moves into the coastal area, seawater moves into streams and drainage canals and travels inland. This upstream migration of seawater alters the quality of water in affected streams and drainage canals significantly. This phenomenon is also observed during times of drought.

*Corresponding author

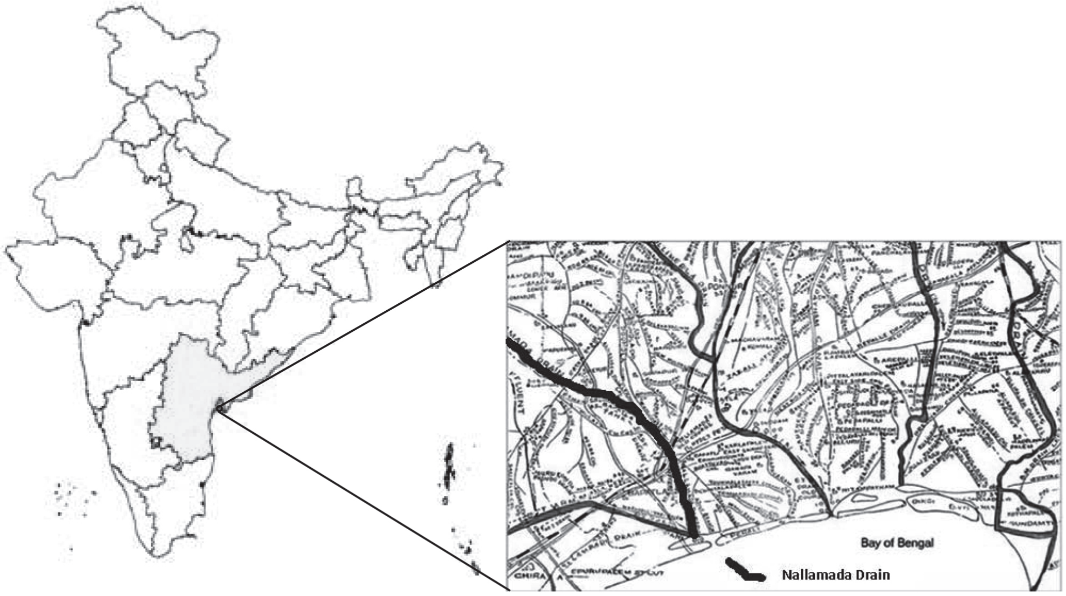

Fig. 1. Nallamada drain during rainy season

The water flows from this drain is being used for cultivation on either side using lift irrigation schemes since no canal water is available for cultivation in this region for upland command. The farmers have been using this drain water for ID Crops like Maize, Chillies, Bengalgram and vegetables for the last few years. Hence, it is essential to carry out further investigations on quantitative assessment of Nallamada drain water during different periods, back water flow influence, quantification of drain water withdrawal and depth of irrigation for different crops at different growth stages and salt accumulation. Further investigations on suitable soil reclamation techniques and crop management practices as well as drain water application techniques need to be formulated by considering the water budgeting and quality under different lift irrigation schemes existing along the Nallamada drain.

Study Area

Nallamada drain originates and passes through Kondaveedu Hills, Vinukonda, Narasaraopeta and Chilakaluripeta in Guntur district. The total length of the Nallamada drain is 77 km, with a bed width of 90 m and maximum flood depth of 4.5 m with side slopes of 3:1. The maximum flow velocity is 1.35 m/s. The Nallamada drain has upland catchment of 162227.24 ha and 11129.23 ha of lowland (Delta) catchment. During floods, the water from this drain flushes into nearby canals and is damaging the existing irrigation systems. The total length of the drain can be divided into 5 sections, 0 to -1.3 km into sea, 0 to 8.4 km till Nallamada diversion, 8.4 to 21.2 km (Nallamada below Kommamuru Canal), 21.2 to 39.6 km (Nallamada above Kommamuru Canal) and 39.6 to 77.0 km (Vogeru Vagu). The tidal effect in this drain was identified upto 15.5 km upstream.

Gupta (1990) has treated the subject of saline water use in India comprehensively. He reported that the salinity level of the Ganges river in India is very low and average total dissolved salt concentration is less than 200 mg/l.

Material and Methods

Collected monthly and annual discharges at fortnightly interval both from Nallamada drain above Kommamuru Canal, Nallamada drain below Kommamuru canal and Kommamuru canal (Appapuram Canal) for time series analysis and comparative studies. The water samples were analysed for the electrical conductivity and pH to study the suitability of Nallamada drain water for irrigating the crops. The basic data on existing lift irrigation schemes were collected for lift irrigation scheme LIS) efficiency and conducted crop water use survey under Pedanandipadu Lift Irrigation Scheme and collected information. The lift irrigation scheme field use efficiency is

$$\text{LI Scheme field water use efficiency} = \frac{\text{Total WR of crops}}{\text{Maximum Pumped Water}} \times 100 \quad \ldots(1)$$

Stream velocity distribution over a cross section

The velocity of a river, stream or channel varies throughout the cross section and depends upon such things as the shape of the cross section, roughness of the stream bed and depth of water. Minimum velocity occurs at the bed (surface friction) and maximum velocity a little below the surface well clear of the banks in deepest water. In fast flowing streams the position of maximum velocity moves from bank to bank. Figure 2 shows a stream cross section with the dotted curves representing lines of equal velocity.

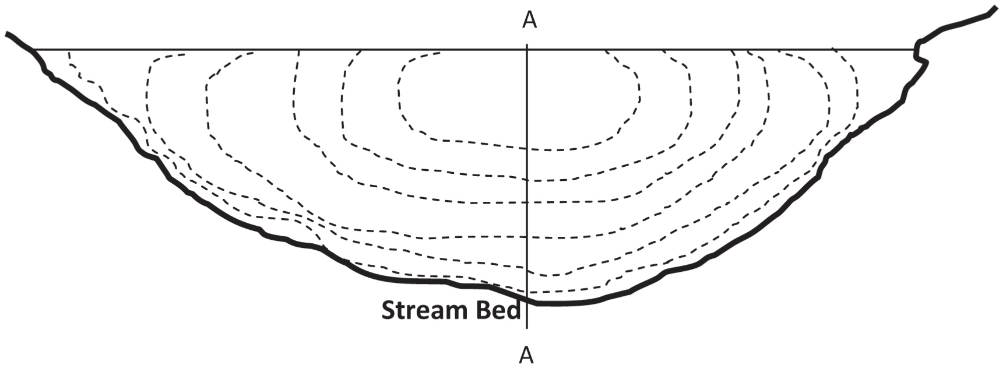

Fig. 2. Stream Cross-section and velocity distribution

In regular shaped channels (rectangular, trapezoidal and circular), the Velocity–Depth curve is approximately parabolic with maximum velocity situated below the surface at 0.2 to 0.3 depth.

Peak discharge estimation using Ryve's Formula (1884):

$$Q_p = C_R A^{2/3} \quad \ldots(2)$$

where,

Q_p = maximum flood discharge (m^3/s)

A = catchment area (km^2)

C_R =Ryve's co-efficient (ranges from

Results and Discussion

Quantitative analysis of Nallamada drain water

The Nallamada drain discharges have been collected month wise for the years from 2005-2013, it was observed that during the months of May there were meager or no out flows in the drain. As per the information through interaction with the farmers, no cultivation is practiced during this period. Peak outflow in all the years was observed in the month of November. High drain flows were observed during September to December month i.e. in the tune of 4.5 TMC. During January to April and August months the outflows were in the tune of 0.5 to 1.5 TMC.

Table 1. Nallamada drain water flow quantities during 2005-13

Year	Annual discharge, Q(TMC)
2005-06	19.02
2006-07	48.69
2007-08	52.67
2008-09	54.97
2009-10	48.42
2010-11	60.24
2011-12	58.67
2012-13	49.23
Average	**49.00**

The results indicated that more than 49 TMC per year flow through the gauging station and moved to sea during 2006-13 (Table 1). As large quantities of good quality water flowing in the drain during different periods and if planned for better utilization, higher agricultural productivity can be achieved and more area can be brought under irrigation.

The drain water quality was found increasing when the drain discharge showed negative trend during the year 2012-13 (Fig.3).

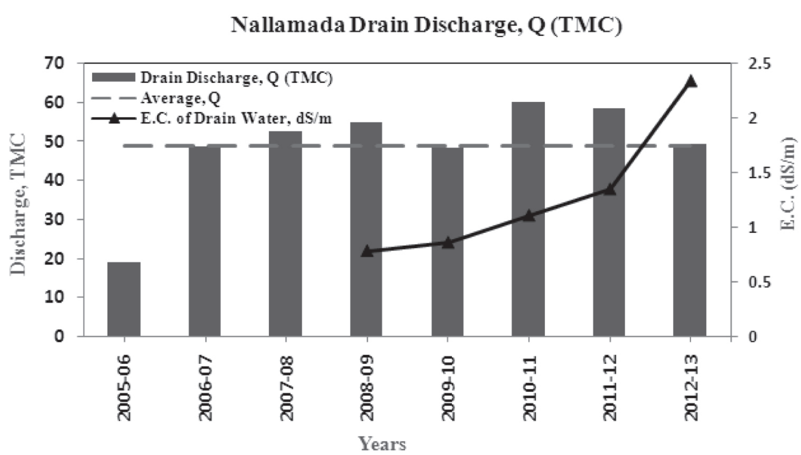

Fig. 3. Time series annual Nallamada drain discharges (TMC) vs EC from 2005 to 2013

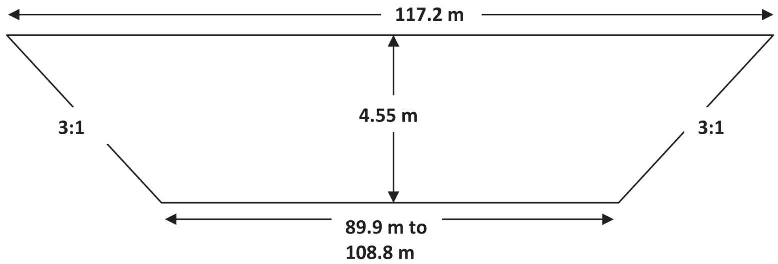

Fig. 4. The existing average cross sectional details of Nallamada drain

During 2009-10 despite increase in discharges, the salinity of drain water continued to increase which might be due to sea water back flow into the drain from Nallamada diversion. The discharge of water in the drain from 2006-07 is well above the average flow (49.0 TMC) in the drain. During 2005-06 the drain flows are found very minimum. As the existing dimensions of the drain are depicted through the following figure. 4.

The drain water flow velocities are in the range of 1.35 to 1.56 m/s with a bed slope of 1 in 5280 m to 1 in 4125m. The existing free board provided is 1 m. The top width of the banks is 5.50 m with a berm width of 5.0 m.

As the existing cross section is unable to carry the increased peak discharges, the above drain cross section has to be enhanced to carry such impulse responses causing floods on the neighboring agricultural lands and habitats. The construction of check dams on this drain can be constructed with adequate consideration of peak discharges in the climate change scenario. The option of construction of balancing reservoirs is limited by the soil type i.e., largely black soils which cracks in summer and cakes in winter resulting huge seepage developing waterlogged and saline soils around. Further, the land acquisition, compensation and cost is a long-term issue and not easily tenable for construction of reservoirs alongside. The upper catchment treatment with soil and water conservation measures like percolation ponds, farm ponds, check dams as a part of watershed development is to be taken up immediately for in-situ water harvesting which substantially reduces the flood flows and siltation into the Nallamada drain.

Due to low velocity distribution at the bottom of the drain, the sediments collected from the catchment area got deposited in the bed of the Nallamada drain, which reduced the carrying capacity of flows substantially. This resulted into occurrence of floods in the area at a rate one in every alternate year. This can be overcome by enhancing the carrying capacity of the drain by improving the cross-section of the drain by increasing the design e.g., Ryve's co-efficient from the existing.

Irrigation Efficiency of Nallamada drain water in a LIS: Nagulapadu a case study

Andhra Pradesh State Irrigation Development Corporation has designed and executed the lift irrigation scheme (LIS) in Nagulapadu command in the year 2005. To assess, whether the LIS was under designed or overdesigned, the total capacity of the LI scheme with the design capacity was worked out with practically observed reasonable assumptions with a due feedback from the beneficiary farmers. The system's water delivery and farmers' actual crop consumption in the field were compared (as follows) for estimation of the lift irrigation scheme efficiency as it is a prerequisite for extending irrigation benefits to the other tail end of the command.

Designed discharge of LIS Project	=	17.60 cusec (Total from 3 pump sets)
1 hour discharge	=	101916 l.
1 Day (8 hours discharge)	=	815328 l.
1 month discharge	=	24459840 l.
1 year (10 months) discharge	=	244598400 l.
Water pumped for utilization per year	=	0.150656 TMCH≈ 0.151 TMC
LI Scheme field use efficiency	=	$\frac{0.135}{0.151} \times 100=89.4$ % (Say 90%)

It is obvious that remaining 10 % of the pumped water from the scheme may be due to the ground water recharge, canal seepage or for deep percolation losses in all the fields or application losses within the fields.

Crop water requirements of various crops in Nallamada Drain command

The crops grown in the nallamada drain command area under lift irrigation schemes are cotton, tobacco, chilli, maize and Bengal gram. The choice of crops sometime change due to soil problems (salinity, alkalinity etc.) and rainfall pattern in the region. The water requirement by these crops is shown in Table 2.

It was found from the Table 2, the total quantity of water flow in Nallamada command in a year was 49 TMC. Out of which only 6 TMC of water was used for all the LI schemes and for all the crops under Nallamada command in Krishna Western Delta. The remaining 43 TMC of quantity of water joins sea every year. Under the Nallamada command the maximum water was utilized by Cotton crop and the minimum water was utilized by Bengal gram. The water quality of Nallamada

Table 2. Estimation of crop water requirements and Nallamada water consumed through LIS

S.No	Crops	Extent, ha	Water Requirement					
			mm	ha.mm	ha.m	Cu.m	Cu.ft	TMC
1.	Cotton	4528.6	743	3364750	3364.75	33647498	1187337835	1.187337835
2.	Tobacco	4286.58	505	2164723	2164.72	21647229	763877719	0.763877719
3.	Chilli	3830.24	486	1861497	1861.5	18614966.4	656876594.8	0.656876595
4.	Maize	3884.26	374	1452713	1452.71	14527132.4	512626940	0.51262694
5.	Bengal Gram	3394.72	249	845285.3	845.285	8452852.8	298280482.7	0.298280483
						Sub-Total		3.620824481
	Total command	19924.4		Assuming conveyance losses @ 60%, Total estimated water requirement				6.034

Table 3. Mean yield of different crops under Nallamada LIS (t ha^{-1})

Crops/ Year	2008-09	2009-10	2010-11	2011-12	2012-13
Cotton	3.75	3.50	2.25	2.47	4.94
Chillies	7.50	8.13	7.50	2.35	4.69
Tobbaco	4.75	4.75	4.00	1.98	1.98
Maize	10.00	10.00	10.00	9.88	10.25
Bengal gram	2.50	2.75	2.50	1.73	2.10
Paddy	NC*	NC	NC	5.37	5.00
GreenGram	NC	NC	NC	1.11	1.36
Blackgram	NC	NC	NC	0.74	0.99
Soyabean	NC	NC	NC	0.99	1.24
Fodder Jowar	NC	NC	NC	5.93	5.44
White jowar	NC	NC	NC	5.56	5.56
Cluster Bean	NC	NC	NC	0.99	1.11

* NC – Not Cultivated

drain remained useful for irrigation throghout except during July, 2011 & 2012.

Yield patterns in Nallamada Command Area

During 2008-09 to 2010-11, the farmers cultivated cotton, chillies, tobacco and maize due to availability of water from the LIS on Nallamada. But later on, the flows have increased, but flow is getting drained into sea at impulse rated due to high intensity rainfalls, which forced the farmers to diversify their cropping pattern by adding other crops like Bengal gram, green gram, paddy, black gram, soyabean, fodder sorghum, white sorghum and cluster bean, as a measure to combat the water and saline stresses on their cropping systems. The yields of different crops grown in this area were presented in Table 3.

From the figure 5 and 6, it can be inferred that the as the EC of drain water increased from the year 2008-09 to 2012-13 where the pH remained almost constant, the yields decreased till 2011-12 and started increasing for all the crops. The maize crop showed substantial tolerance against electrical conductivity of drain water used for irrigation. The increase in EC from 1.00 dS/m to 1.5 dS/m, resulted in sharp decrease in the crop productivity of

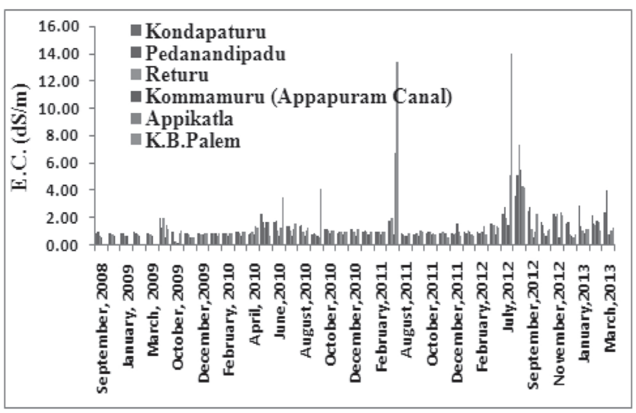

Fig. 5. EC (dS/m) of the Nallamada drain water from 2008-2013

chillies, tobacco and Bengal gram where as the cotton productivity increased slightly due to better management practices.

The figure 7 reveals that during 2011-12 and 2012-13, the productivity of paddy, green gram, maize, black gram, Bengal gram, soya bean, tobacco, fodder sorghum, white sorghum, cluster bean, cotton and chillies is almost same.

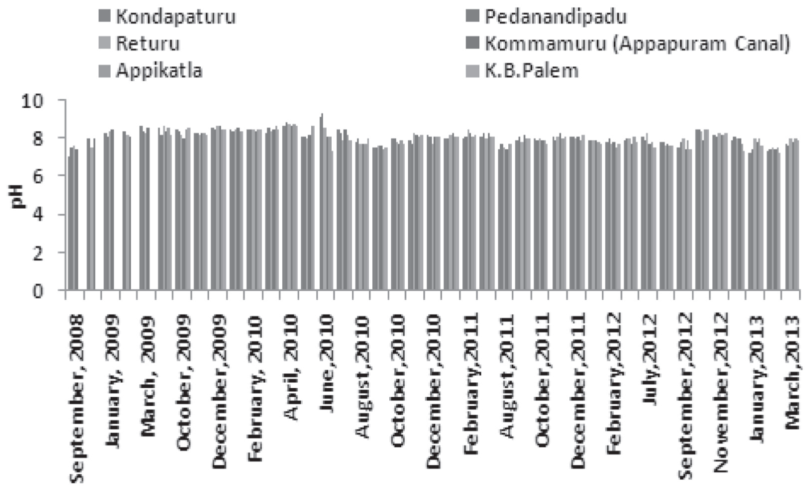

Fig. 6. pH of the Nallamada drain water from 2008-2013

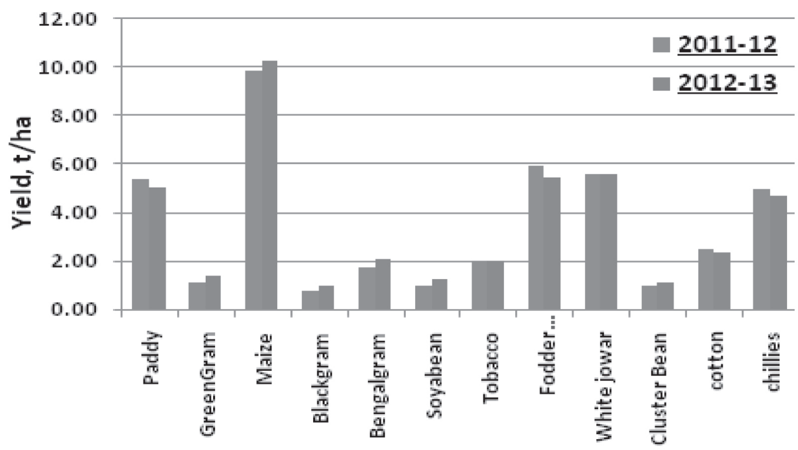

Fig. 7. Stable crop yields in Nallamada command area during 2010-13

Conclusions

The above study on quantitative and qualitative water management in Nallamada drain revealed that the drain water flows during cropping season remains between 1 to 2 dS/m, which can be used for salinity tolerant varities of crops. The adverse affects of vagaries of monsoon resulting in floods and back water flows from the sea, can be avoided by upper catchment treatment using soil and water conservation measures like percolation tanks, farm ponds, checkdams etc. for in-situ water harvesting and avoiding siltation of the nallamada drain. The quality analysis of Nallamada water and nearby canal (Kommamuru Canal) revealed that they can be planned for conjunctive use for getting assured irrigation with better quality throughout the season. The enhanced flows of the Nallamada drain are causing floods and damaging standing crops and nearby habitats, which can be avoided by increasing the existing cross section of the drain and strengthening of the bunds/banks of the drain through dyking or concrete coring. As more water is joining sea, in order to utilize these flows, more number of Lift Irrigation schemes alongside the banks of the drain can be planned. The human causes like using of individual motors to lift drain water on the banks cause's small rills, developing into gullies, later causing breaching of the drain when maximum flood flows occur.

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Effect of Salinity on Genetic Architecture of Fruit Yield and Its Contributing Traits in Tomato (*Lycopersicon esculentum* Mill.)

Jogendra Singh[1*], E.V.D. Sastry[2] and Vijayata Singh[3]

[1]*Central Soil Salinity Research Institute, Karnal-132 001, Haryana, India*
[2]*Rajasthan Agricultural Research Institute Jaipur, SKN Agriculture University, India*
[3]*CCS Haryana Agricultural University, Hisar, Haryana, India*
**Corresponding author E mail: jogendra@cssri.ernet.in; jogendra82@gmail.com*

Abstract

An investigation was conducted using 10 parental lines and their 45 F_1s (generated through diallel mating) of tomato in 2010 at Horticultural Research Farm, Jobner for estimating the effects of salinity on genetic architecture of yield and its contributing traits (days to 50% flowering, days to first fruit, plant height, number of fruits per plant, fruit yield per plant, average fruit weight, fruit volume, leaf area and chlorophyll content at 45 days after sowing) under normal and saline environments. Both additive and dominance gene actions were involved in the genetic control of characters studied. However, relative magnitudes of dominance were higher than additive for most traits (except chlorophyll content, where both are equal). Narrow sense heritability estimates were low (chlorophyll content) to high (fruit yield per plant). For improving salinity tolerance of tomato, breeding should also resort to pyramiding the characteristics since, no described traits alone is likely to produce a tolerant genotype. Threshold limit of salinity for tomato, up to which yield reduces very little or no reduction occur, is 2.5-3.0 dS m^{-1} and after it, every increase of 1.0 dS m^{-1} in EC results in a yield reduction of about 9-10%. Yield reduction at moderate salinity is mainly due to reduction in average fruit weight (while, at higher salinity, yield reduction is due to reduced number of fruit per plant). This in turns is directly proportional to fruit size under normal environment. Hence cultivation of tomato cultivars with small sized fruits or even cherry type tomato should be recommended under saline environment. Both additive and non-additive gene action have to be exploited with trait specific or environment specific breeding by adopting adequate strategies *viz.* bi-parental mating, diallel selective mating, wide crossing and reciprocal recurrent selection.

Key words: Tomato, Additive variance, Salinity tolerant genotypes, Dominance, Combining ability, GCA, SCA

Introduction

There is no separate gene system for yield *per se* as being a complex character and the end product of multiplicative interaction between its components. Number of fruits per plant and average fruit weight are the important contributing attributes of fruit yield and their significance has been reported by number of biometrical studies. The use of diallel analysis has been much helpful in estimating gene action in tomato (*Lycopersicon esculantum* Mill.) which provide the estimates of additive and dominance components so that the fixable component could be exploited by using suitable breeding techniques (Raja *et al.*, 2012; Saeed *et al.*, 2011; Parida and Das, 2005; Bhatt *et al.*, 2004). Keeping in view, these facts, the present study was carried out to investigate genetics of days to 50 % flowering, days to first fruit, plant height, number of fruits per plant, fruit yield per plant, average fruit weight, fruit volume, leaf area and chlorophyll content at 45 days after sowing of 10 parental lines and their 45 F_1s (excluding reciprocals) under normal and saline environments.

*Corresponding author

Material and Methods

Plant material

Material for the present investigation comprised of 10 genetically diverse tomato varieties collected from Division of Vegetable Science, IARI, New Delhi, with varying degree of salt tolerance namely IIVR-Sel-2, ArkaVikas, Sel-7, Azad T-2, PunjabUpma, DARL-64, BSS-368, Himsona, Tom-187 and CO-3.

Development of experimental populations

The parental lines were crossed in all possible combinations (diallel mating) excluding reciprocals to generate 45 F_1s during *Rabi* 2009 at Horticultural Research Farm, Jobner.

Field evaluation and data analysis

All crosses along with parents were evaluated in randomized block design with three replications in each of two environments *viz.* normal (E_1, pH = 7.6 and ECe

2.349 dS/m) and saline (E_2, pH = 8.3 and ECe = 4.329 dS/m) and irrigated with water having pH = 7.7 and ECe 3.679 dS/m at Horticultural Research Farm, Jobner in *Rabi* 2010. The salinity of the saline soil and irrigated water is above the threshold limit (2.5 dS/m) for tomato, hence considered to be saline. Plot size was single row of 3 M long with 50 cm row spacing and 30 cm plant to plant spacing. The observations were recorded on various traits. The data were first subjected to analysis of variance separately for each environment then, estimation of genetic parameters study was done using Hayman's (1954) method. Combining ability analysis was performed following Griffing's (1956) Method II Model I.

Results and Discussion

Analysis of variance

Pooled analysis of variance has shown that the MSS due to environments and genotypes were significant, indicating significant differences among genotypes and the environments on the genotypes. Differential response of genotypes to environments as indicated by significant g x e interaction was significant for all the characters (Table 1).

Genetic components and graphical analysis

The estimation of components of genetic variance was done only for those characters where additive-dominance model was fitted (assumptions of diallel mating design were fulfilled) over the environment (Table 2) and for rest of characters, where additive-dominance model was not fitted (assumptions of diallel mating design were not fulfilled) the inferences were drawn with the help of Wr-Vr graphs in specific environment.

Graphical analysis was carried out as given by Hayman (1954). A total 9 traits were studied in both the environments and W_r-V_r graphs were prepared for each trait. The results revealed that different types of dominance behaviour viz., over dominance, complete dominance and partial dominance (based on regression line intercept behavior) for different characters observes in both the environments. Such variable behaviour may be partly attributed to the partial failure of diallel assumptions. Scattering of parental array points indicated the existence of high genetic diversity among the parents for most of the characters. Relative position of parental array points from origin showed relative proportion of dominant and recessive alleles in the parents. The array points that were located below the regression line indicated complementary gene action.

The intercept being negative indicated over dominance for days to 50% flowering, days to first fruit and chlorophyll content at 45 days after sowing in both the environments, fruit yield per plant in E_2, average fruit weight in E_1 and fruit volume in E_2 environment. Partial

Table 1. Pooled analysis of variance for fruit yield and its contributing characters under normal (E_1) and saline (E_2) environment

Source of variation	D.F.	Characters wise mean sum of squares								
		Days to 50% flowering	Days to first fruit	Plant height	Number of fruits per plant	Fruit yield per plant	Average fruit weight	Fruit volume	Leaf area	Chlorophyll content at 45 days
Environment	1	680.84**	552.51**	3249.90**	1937.46**	1907144.15**	1592.80**	3869.39**	3192.98**	5.81**
Replication/ environment	4	14.95**	14.20	42.69**	10.81	2464.94**	9.49	26.07**	4.85	0.0001
Genotypes	54	22.20**	193.10**	205.93**	20.19**	21424.53**	77.14**	70.25**	127.86**	0.04**
Genotype X environment	54	8.87*	157.21**	168.08**	21.04**	15320.91**	41.80**	44.99**	162.48**	0.05**
Pooled Error	216	5.93	19.54	12.16	2.25	516.33	2.65	2.65	1.94	0.0002

*, **= Significant at 5% and 1% level of significance, respectively.

Table 2. Regression coefficient of Wr on Vr with their standard error and deviation from zero and unity for different characters in F_1 generation under normal (E_1) and saline (E_2) environment

Characters	Environment	b	SE (b)	(b-0) / SE (b)	(1-b) / SE (b)
Days 50% flowering	E_1	0.32	0.35	0.89	1.93
	E_2	0.39	0.14	2.79*	4.35**
Days to first fruit	E_1	-0.01	0.09	-0.13	11.69**
	E_2	0.16	0.07	2.17	11.82**
Plant height	E_1	0.69	0.14	4.93**	2.21
	E_2	-0.10	0.06	-1.77	19.30**
Number of fruits per plant	E_1	-0.24	0.10	-2.40*	12.29**
	E_2	1.37	0.50	-2.74*	-0.74
Fruit yield per plant	E_1	-0.11	0.01	-11.00**	11.10**
	E_2	0.96	0.20	4.80**	0.20
Average fruit weight	E_1	0.17	0.12	1.31	6.38**
	E_2	0.16	0.13	1.25	6.93**
Fruit volume	E_1	-0.08	0.08	-1.01	13.02**
	E_2	0.59	0.19	3.11*	2.15
Leaf area	E_1	0.04	0.03	1.25	31.53**
	E_2	0.18	0.13	1.38	6.71**
Chlorophyll content at 45 days	E_1	0.55	0.23	2.39*	1.96
	E_2	5.09	2.16	2.36*	-1.73

*, **= Significant at 5% and 1% level of significance, respectively.

dominance was evident by positive value of intercept for the characters like plant height in both the environment, number of fruit per plant, fruit yield per plant and fruit volume in E_1 and leaf area in E_2 environment.

Regression line intercepted at origin showed thereby, complete dominance for number of fruits per plant and average fruit weight in E_2 and leaf area in E_1 environment. The results are in agreement with the findings of Saeed *et al*. (2011) and Bhatt *et al*. (2004).

Furthermore, the graphical analysis about location of parental array points from origin revealed that the parents Himsona in E_1; Punjab Upma and DARL-64 in E_2 for days to 50% flowering, IIVR-Sel-2 DARL-64 and BSS -368 in E_1; Azad T-2 in E_2 for days to first fruits, IIVR-Sel-2, Himsona and Tom-187 in E_1; IIVR-Sel-2, Arka Vikas, Azad T-2 and Punjab Upma E_2 for plant height, Arka Vikas in E_1; IIVR Sel-2, Arlka Vikas, Azad T-2, Punjab Upma and CO-3 in E_2 for number of fruits per plant, Arka Vikas in E_1; Azad T-2 and CO-3 in E_2 for fruit yield per plant, DARL-64 in E_1; IIVR-Sel-2 in E-$_2$ for average fruit weight, IIVR Sel-2 and Arka Vikas in E_1; Sel-7 and Punjab Upma in E_2 for fruit volume, Punjab Upma, Tom-187 and CO-3 in E_1; IIVR Sel-2 in E_2 for leaf area and IIVR-Sel-2, DARL-64, BSS-368 and Himsona in E_1; CO-3 in E_2 for chlorophyll content at 45 days, possessed more dominant genes as being nearer to origin. Rest of the parents in respective environment for specific character possessed more recessive genes as being located farther from origin point.

The parental arrays that fall below regression line showed complementary gene action in both the environments were IIVR-Sel-2, Azad T-2 and Punjab Upma for days to 50% flowering, IIVR-Sel-2, DARL-64 and Tom-187 for days to first fruit, Punjab Upma , Tom-187 and CO-3 for plant height, Sel-7 for number of fruits per plant, Sel-7 and DARL-64 for fruit yield per plant, Sel-7 for average fruit weight, BSS-368 and Tom-187 for fruit volume, IIVR-Sel-2 and Tom-187 for leaf area and ArkaVikas and Sel-7 for chlorophyll content at 45 days.

The study of estimation of component of genetic variance and Wr-Vr indicated that both additive and dominance gene actions were involved in the expression of most of the traits under study in normal (E_1) and saline (E_2) environments except for chlorophyll content, where only additive component (D) seemed to be significant (in E_1).

It was only in the case of plant height (E_1), number of fruits per plant (E_2), fruit yield per plant (E_2), fruit volume (E_2) and chlorophyll content (E_1 and E_2), over dominance effect of heterozygous loci (h^2) was found to be significant. Degree of dominance $(H_1/D)^{1/2}$ implies over dominance for all the characters under respective environment. The value of $H_2/4H_1$ indicated that for loci exhibiting dominance, frequency of positive alleles was predominant for all the traits. Positive and significant value of coefficient of co-variance (F) for all the characters except chlorophyll content (E_1), indicated predominance of dominant genes in parents. Further, prevalence of

Table 3. Estimates of components of genetic variance for plant height, number of fruits / plant, fruit volume and chlorophyll content at 45 days under normal (E_1) and saline (E_2) environment

Components	Plant height	Number of fruits per plant	Fruit yield per plant	Fruit volume	Chlorophyll content at 45 days	
	E_1	E_2	E_2	E_2	E_1	E_2
D ± SE	118.04**± 0054	0.51**± 0.0043	171.61**±0.0043	5.60**±0.0043	0.02**±0.0054	0.05**±0.0113
H_1 ± SE	360.14**± 0115	24.11**± 0.0092	20958.18**±0.0092	77.73**±0.0092	0.02±0.0115	0.07**±0.0092
H_2 ± SE	-4486.05** ± 0.0098	-87.32**±0.0079	-17837.75**±00079	-214.22**±0.0079	0.02±0.0098	0.09**±0.0079
h^2 ± SE	-60.09** ± 0.0066	1.97**±0.0053	-13853.79**±0.0053	5.86**±0.0053	0.24**±0.0066	0.08**±0.0053
F ± SE	240.65**± 0.0125	5.31**±0.0100	560.22**±0.0100	20.68**±0.0100	0.01±0.0125	0.03**±0.0100
E ± SE	4.49**± 0.0016	0.45**±0.0013	196.81**±0.0013	0.85**±0.0013	0.00±0.0016	0.00±0.0013
$(H_1 / D)^{1/2}$	1.75	6.90	11.05	3.01	1.16	1.21
$H_2 / 4H_1$	-3.25	-0.91	-0.21	-0.69	0.27	0.32
$\frac{(4DH_1)^{1/2} + F}{(4DH_1)^{1/2} - F}$	1.01	1.24	1.01	1.02	-1.20	-3.09
h^2 / H_2	-0.04	0.02	-0.17	0.02	2.84	0.29
Heritability in narrow sense	1.90	1.67	1.99	1.60	0.02	0.01

*, **= Significant at 5% and 1% level of significance, respectively.

dominant genes for majority of the traits could also be seen from the ratio $(4DH_1)^{1/2}$ +F/ $(4DH_1)^{1/2}$ –F (Table 3).

Effect of environmental variation associated with individual means (E) seemed to be significant for most of the traits except chlorophyll content in both environments. These results showed that both additive and dominance effects were important in controlling various fruit yield contributing traits studies with preponderance of dominance gene actions (Srivastva *et al.*, 1998; Thakur and Joshi, 2000; Roopa *et al.*, 2001; Bhatt *et al.*, 2004). Narrow sense heritability estimates obtained in component analysis ranged from low to high for different traits (Table 3). This was 1.90 for plant height (E_1), 1.67 for number of fruits per plant (E_2), 1.99 for fruit yield per plant (E_2) 1.60 for fruit volume (E_2) and 0.02 and 0.01 for chlorophyll content (E_1 and E_2, respectively). The lower values of heritability for above mentioned character clearly indicated the control of mainly non- additive gene action.

Combining ability: variances and effects

An understanding of the genetic control of the characters is the basic requirement for purposeful management of available genetic variability. The choice of the most suitable breeding method depends mainly on the combining ability behaviour vis-a-vis nature of gene action involved in the control of the traits of interest to the breeder. In the present investigation, the g x e interaction was significant for all the traits; hence combining ability analysis was done for individual environment. Highly significant mean squares due to GCA and SCA in both the environments indicated that all the characters were controlled by both additive and non-additive gene effects (Basihya *et al.*, 2002; Cheema *et al.*, 2003; Bhatt *et al.*, 2004; Raja *et al.*, 2012).

Nature and magnitude of combining ability effects provide an idea about the relative role of fixable and non-fixable gene effects in the inheritance of different characters. Thus, it helps in identifying suitable parents for crossing programme.

An appreciable progress could be achieved through conventional breeding method such as pedigree and bulk method when GCA effects or additive gene action is preponderant. But for the traits where non-additive gene effects are more pronounced, some kind of recurrent selection e.g. diallel selective mating or bi-parental mating in early generations might prove to be effective breeding approach (Akinci *et al.*, 2004; Saeed *et al.*, 2011; Raja *et al.*, 2012; Hamida and Shaddad, 2010).

The analysis of variance for combining ability revealed that GCA as well as SCA effects were highly significant for the characters under study in both the environments, except chlorophyll content. Mostly the magnitude of GCA variance were observed to be higher than SCA variance, that indicated the preponderance of additive gene effects being fixable and thereby heritable, except fruit volume and chlorophyll content, where, non additive gene effects were in preponderance (Table 4).

The success of any plant breeding programme primarily depends upon the choice of parent for initiating a meaningful hybridization programme. The common approaches of selecting the parent on the *per se*

Table 4. Analysis of variance for combining ability of different characters under normal (E_1) and saline (E_2) environment

Characters	Environment	Mean sum of squares			
		GCA (9)	SCA (45)	Error (108)	σ^2_{GCA}: σ^2_{SCA}
Days 50% flowering	E_1	4.39**	2.51**	0.02	0.013
	E_2	8.19**	4.70**	0.02	0.062
Days to first fruit	E_1	25.88**	25.60**	0.08	0.001
	E_2	201.89**	68.97**	0.05	0.160
Plant height	E_1	93.14**	80.35**	0.04	0.013
	E_2	67.09**	37.20**	0.03	0.067
Number of fruits per plant	E_1	15.25**	7.42**	0.01	0.085
	E_2	8.05*	4.42**	0.1	0.066
Fruit yield per plant	E_1	8825.40**	6684.51**	1.37	0.026
	E_2	8319.77**	4584.64**	1.82	0.065
Average fruit weight	E_1	23.80**	21.96**	0.01	0.007
	E_2	23.43**	16.17**	0.01	0.036
Fruit volume	E_1	10.91**	24.56**	0.01	0.045
	E_2	14.18**	16.52**	0.01	0.012
Leaf area	E_1	124.99**	73.44**	0.01	0.056
	E_2	17.79**	14.14**	0.0013	0.021
Chlorophyll content at 45 days	E_1	0.0060	0.0068	0.00	0.009
	E_2	0.0227	0.0256	0.00	0.008

*, **= Significant at 5% and 1% level of significance, respectively.

performance and local adaptation does not necessarily lead to the much gainful results, because the ability of parents to continue well, depends upon the complex interactions among genes, genotype x environment interaction and stability of yield attributes. In general, the GCA estimates of the parents were inconsistence for some characters in both the environments in the present investigation. This might be attributed to the presence of GCA x environment interaction. Thus, it is suggested that breeding for above said characters would be effective only when material is tested over a wide range of environments and selection practiced in target environment. However, some parents showed consistent desirable GCA estimates for some characters in both the environments.

In normal environment Sel-7, Azad T-2, Tom-187 and DARL-64 found to be better and desirable general combiners for fruit yield per plant. Similarly, Sel-7, BSS-368, Himsona and Tom-187 were found to be better and desirable general combiners for fruit yield in saline environment. These above mentioned parents attributed additive and additive x additive gene action which suggested that they have good potentiality for fruit yield and contributing traits in prospective environment and may be used in synthesizing lines having more of favourable genes. Sel-7 was also found to be a better general combiner for days to first, average fruit weight and fruit volume in normal environment, but only for average fruit weight besides fruit yield in saline environment. Azad T-2 and Tom-187 were found to be desirable general combiners for number of fruits per plant chlorophyll content and average fruit weight (in case of Azad T-2) and fruit volume (in case of Tom-187). BSS-368 and Himsona were found desirable general combiners for number of fruits per plant, average fruit weight, fruit volume, leaf area as well as for days to first fruit, plant height and chlorophyll content in case of Himsona in saline environment. Either desirable parents were DARL-64 in normal (for days to 50% flowering, days to first fruit, plant height and number of fruits per plant) and Tom-187 in saline (for plant height, average fruit weight, fruit volume and leaf area) (Table 5).

Since GCA effects are attributed to additive and additive x additive gene effects, the above mentioned parents have good potential for the improvement of yield and contributing traits in respective environment and may be used in a multiple crossing programme to synthesis a dynamic population with most of favourable genes accumulation (Roopa *et al.*, 2001; Chadha *et al.*, 2002; Sharma *et al.* ,2002; Bhatt *et al.*, 2004).

In self pollinated crops SCA effects are generally of less relevance except where commercial exploitation of heterosis is feasible, as SCA effects are primarily governed by dominances gene effects and cannot be fixed in the end product *i.e.* pure line. However, if a cross combination has high SCA effects along with *per se* performances with at least one good general combiner parent for a particular trait, it is expected that this cross combination may provide desirable transgressive segregants in later generations. In present investigation, there was no consistency over environment for the ranks of crosses with high SCA effects. Further more, a number of crosses exhibited changes in the magnitude and direction of SCA effects in

Table 5. Estimates of general combining ability effects for different characters under normal (E_1) and saline (E_2) environment

Progenies	Days to 50% flowering		Days to first fruit		Plant height	
	E_1	E_2	E_1	E_2	E_1	E_2
GCA effects						
IIVR-Sel-2	0.178	0.672	-0.939	7.550**	3.668**	2.649**
Arka Vikas	0.872*	1.700**	1.172	5.106**	-2.412**	-1.151
Sel.-7	0.872*	-0.356	-1.883*	-1.728*	-4.718**	-4.937**
Azad T-2	-0.156	-0.633	0.839	-5.978**	0.882	-1.817**
Punjab Upma	-0.433	0.061	-0.606	-0.033	3.368**	0.016
DARL-64	-0.878*	-0.967*	-2.356**	-2.839**	1.771**	0.436
BSS-368	0.567	-0.717	1.978*	-1.228	1.577*	1.074
Himsona	-0.544	-0.606	-0.411	-3.283**	0.418	3.202**
Tom-187	-0.128	0.200	0.617	-0.561	-2.384**	1.397*
CO-3	-0.350	0.644	1.589	2.994**	-2.171**	-0.870
SE (gi)	0.397	0.407	0.813	0.636	0.606	0.544
Progenies	**No. of fruits / plant**		**Fruit yield / plant**		**Average fruit weight**	
	E_1	E_2	E_1	E_2	E_1	E_2
GCA effects						
IIVR-Sel-2	-0.271	-1.073**	-13.183**	-29.367**	-2.167**	0.528
Arka Vikas	-2.071**	-0.346	-49.656**	-21.033**	-1.167**	-0.917**
Sel.-7	-0.349	0.321	14.678**	29.856**	2.361**	2.722**
Azad T-2	1.512**	-0.784**	40.872**	-24.756**	1.028**	-1.250**
Punjab Upma	-0.532	-0.623*	-12.656**	-15.783**	0.556	0.083
DARL-64	1.129**	0.104	14.067**	-8.311*	-1.167**	-1.528**
BSS-368	0.068	1.593**	4.122	44.744**	0.917**	0.667*
Himsona	0.668*	0.893**	7.456*	24.300**	0.111	0.667*
Tom-187	1.073**	0.349	25.844**	16.300**	0.889**	0.889**
CO-3	-1.227**	-0.434	-31.544**	-15.950**	-1.361**	-1.861**
SE (gi)	0.293	0.192	3.473	4.013	0.291	0.244
Progenies	**Fruit volume**		**Leaf area**		**Chlorophyll content at 45 days**	
	E_1	E_2	E_1	E_2	E_1	E_2
GCA effects						
IIVR-Sel-2	-0.978**	0.217	7.247**	-0.878**	-0.007**	-0.005**
Arka Vikas	0.161	-0.561*	1.883**	-1.978**	0.004**	-0.020**
Sel.-7	0.772**	-0.033	-1.320**	-1.304**	0.019**	-0.026**
Azad T-2	-0.561*	-1.978**	0.445	-0.593	0.021**	-0.060**
Punjab Upma	-0.006	-0.339	-4.529**	-0.097	0.023**	-0.025**
DARL-64	-1.033**	-0.006	-0.364	0.415	-0.043**	0.038**
BSS-368	-0.728**	0.717**	1.210**	2.124**	-0.018**	0.003**
Himsona	0.356	2.161**	0.560	0.991**	0.005**	0.039**
Tom-187	2.133**	0.633*	-2.829**	0.838**	0.019**	-0.032**
CO-3	-0.117	-0.811**	-2.305**	0.481	-0.024**	0.088**
SE (gi)	0.273	0.264	0.308	0.105	0.000	0.000

*, **= Significant at 5% and 1% level of significance, respectively.

different environments, which might be consequence of high SCA x environment interaction (Roopa *et al.*, 2001; Chadha *et al.*, 2002; Sharma *et al.*, 2002; Dhaliwal *et al.*, 2003; Saeed *et al.*, 2011; Raja *et al.*, 2012; Hamida and Shaddad, 2010).

Sel-7 x Himsona exhibited significant SCA effects in the desired direction for fruit yield per plant in the normal environment. This cross also had significant SCA effects in the desired direction for days to first fruit, plant height and average fruit weight. Similarly Azad T-2 x CO-3 also had positive significant SCA effect for fruit yield besides days to first fruit and number of fruits per plant. Crosses worth mentioning are IIVR-Sel-2 x BSS-368 for days to 50% flowering, number of fruits per plant and leaf area, ArkaVikas x PunjabUpma for number of fruits per plant, average fruit weight and fruit volume. In the saline environment, Sel-7 x BSS-368, DARL-64 x BSS-368 and Himsona x Tom-187 which had high significant and positive SCA effects for fruit yield. Among these Sel-7 x BSS-368 also exhibited significant SCA effects for number of fruit per plant and average fruit weight; Himsona x Tom-187 and DARL-64 x BSS-368 for plant height and number of fruit per plant (Table 6).

Table 6. Estimates of specific combining ability effects for for different characters under normal (E_1) and saline (E_2) environment

Progenies	Days to 50% flowering		Days to first fruit		Plant height	
	E_1	E_2	E_1	E_2	E_1	E_2
SCA effects						
IIVR-Sel-2 x Arka Vikas	-5.008**	-3.457**	0.136	-9.207**	10.046**	-0.921
IIVR-Sel-2 x Sel.-7	-3.341**	-1.068	-0.475	1.626	6.751**	4.665**
IIVR-Sel-2 x Azad T-2	-0.313	-1.124	1.136	-3.124	4.285**	5.079**
IIVR-Sel-2 x Punjab Upma	-1.369	0.848	3.581	2.265	-4.335**	-1.454
IIVR-Sel-2 x DARL-64	3.076**	-2.124	-0.003	-15.596**	-2.604	3.693**
IIVR-Sel-2 x BSS-368	-3.369**	-2.040	-0.003	6.126**	3.857	0.854
IIVR-Sel-2 x Himsona	2.409	2.182	3.386	3.848	-4.585**	-2.140
IIVR-Sel-2 x Tom-187	-1.008	1.710	-3.975	6.126**	-1.715	4.865**
IIVR-Sel-2 x CO-3	4.881**	1.265	3.053	2.571	-10.029**	3.732**
Arka Vikas x Sel.-7	2.631**	1.237	5.747**	15.404**	-4.968**	11.532**
Arka Vikas x Azad T-2	2.326	3.848**	11.359**	0.654	2.365	2.846
Arka Vikas x Punjab Upma	-0.063	-0.179	-1.197	-4.624**	-2.654	2.979
Arka Vikas x DARL-64	0.715	-1.152	-5.447**	-4.818**	-3.857	2.960
Arka Vikas x BSS-368	-0.063	0.598	-0.780	13.237**	-13.463**	-2.746
Arka Vikas x Himsona	-0.285	0.821	-6.391**	14.960**	-1.838	-3.607**
Arka Vikas x Tom-187	0.631	-3.318**	-4.419	-11.096**	-2.768	-9.335**
Arka Vikas x CO-3	-0.146	-1.429	-1.725	9.015**	-10.182**	-6.135**
Sel.-7 x Azad T-2	-2.008	-1.763	-6.253**	-0.513	-3.463	1.199
Sel.-7 x Punjab Upma	-2.396	-0.790	-0.808	-5.790**	-9.082**	-4.168**
Sel.-7 x DARL-64	0.381	-0.763	-2.058	-2.318	-6.818**	-6.454**
Sel.-7 x BSS-368	-0.396	-0.346	-2.725	-3.929	-8.290**	-9.093**
Sel.-7 x Himsona	-3.285**	-2.124	-8.003**	-9.540**	8.668**	1.246
Sel.-7 x Tom-187	2.965**	0.071	1.303	3.404	-1.196	0.385
Sel.-7 x CO-3	-0.480	0.960	2.997	-2.818	7.990**	-8.882**
Azad T-2 x Punjab Upma	3.298**	0.487	3.803	3.460	-10.349**	-3.287
Azad T-2 x DARL-64	1.076	0.515	7.553**	2.932	-7.552**	-7.107**
Azad T-2 x BSS-368	-1.035	-0.735	3.553	0.987	0.376	-1.146
Azad T-2 x Himsona	-0.924	3.154**	3.942	3.710	-2.132	-4.740**
Azad T-2 x Tom-187	1.326	-1.652	2.247	-2.013	-3.263	1.465
Azad T-2 x CO-3	-2.452	-3.763**	-10.058**	-8.235**	-2.277	6.465**
Punjab Upma x DARL-64	-1.313	-0.846	-2.003	7.987**	-6.304**	2.793
Punjab Upma x BSS-368	3.576**	4.237**	-0.669	2.376	-7.977**	2.954
Punjab Upma x Himsona	1.354	-0.874	0.720	4.432**	-3.518	-0.707
Punjab Upma x Tom-187	-0.730	0.654	-2.641	16.376**	-0.015	-1.301
Punjab Upma x CO-3	-0.174	-2.457	2.720	-6.179**	-2.496	0.965
DARL-64 x BSS-368	3.020**	1.265	-0.919	-1.485	-7.913**	10.135**
DARL-64 x Himsona	-0.869	-1.179	-0.864	-5.429**	-7.088**	-1.860
DARL-64 x Tom-187	-2.619**	1.682	0.442	-4.485**	-1.952	0.546
DARL-64 x CO-3	-2.396	-2.429	-0.864	-11.707**	-4.899**	8.946**
BSS-368 x Himsona	-0.646	0.571	-0.864	-7.040**	1.707	-1.632
BSS-368 x Tom-187	0.604	-2.568	4.775	3.571	-1.490	0.440
BSS-368 x CO-3	1.159	-1.013	-1.197	-4.318**	0.762	-0.226
Himsona x Tom-187	1.381	0.321	2.831	-2.374	4.068**	19.446**
Himsona x CO-3	0.604	-2.457	12.192**	-5.263**	-7.946**	7.113**
Tom-187 x CO-3	2.854**	5.404**	9.164**	7.348**	-1.943	-6.215**
SE (Sij)	1.2789	1.3104	2.6179	2.0496	1.9516	1.7528

Progenies	No. of fruits / plant		Fruit yield / plant		Average fruit weight	
	E_1	E_2	E_1	E_2	E_1	E_2
SCA effects						
IIVR-Sel-2 x Arka Vikas	0.186	0.509	21.427	30.364**	1.788	2.904**
IIVR-Sel-2 x Sel.-7	2.397**	-0.758	44.093**	-46.525**	-2.073**	-5.068**
IIVR-Sel-2 x Azad T-2	-3.731**	1.547**	-110.768**	32.086**	-6.407**	1.237
IIVR-Sel-2 x Punjab Upma	-1.220	0.453	-78.573**	7.780	-6.268**	-1.429
IIVR-Sel-2 x DARL-64	1.253	0.992	3.705	27.308**	0.121	2.515**
IIVR-Sel-2 x BSS-368	4.780**	-2.097**	146.316**	-58.747**	3.038**	-3.013**
IIVR-Sel-2 x Himsona	-2.753**	-1.330**	-84.018**	-19.970	-3.490**	3.321**
IIVR-Sel-2 x Tom-187	3.708**	-0.853	150.927**	-21.303	1.732	0.765
IIVR-Sel-2 x CO-3	-2.725**	0.131	-65.018**	16.947	-0.684	3.848**
Arka Vikas x Sel.-7	0.197	-0.753	8.566	-29.192**	1.593	1.043
Arka Vikas x Azad T-2	-0.864	0.686	-44.295**	41.753**	-6.740**	6.348**
Arka Vikas x Punjab Upma	3.780**	0.792	126.566**	30.114**	6.399**	3.015**
Arka Vikas x DARL-64	0.319	0.264	-37.490**	3.975	-3.879**	-1.374
Arka Vikas x BSS-368	-0.820	-1.491**	-25.212**	-56.747**	-1.629	-3.902**
Arka Vikas x Himsona	0.047	-0.658	45.121**	-34.970**	6.177**	-4.568**
Arka Vikas x Tom-187	-2.559**	-0.647	-55.934**	-26.636**	1.066	-2.457**
Arka Vikas x CO-3	-0.659	0.670	-44.545**	5.947	-5.018**	-3.707**
Sel.-7 x Azad T-2	-2.453**	0.220	-8.295	-37.136**	-1.934**	-6.957**
Sel.-7 x Punjab Upma	0.725	-1.075	14.899	-35.775**	2.205**	-1.957**
Sel.-7 x DARL-64	1.597	-1.736**	-25.823**	-60.914**	-4.073**	-1.679**
Sel.-7 x BSS-368	-1.209	6.842**	40.455**	314.364**	7.843**	11.460**
Sel.-7 x Himsona	3.391**	2.675**	173.121**	56.475**	10.982**	0.793
Sel.-7 x Tom-187	0.453	-1.114	-12.934	-11.859**	-1.462	0.904
Sel.-7 x CO-3	-0.447	-1.064	-1.212	-31.275**	3.455**	-0.013
Azad T-2 x Punjab Upma	-5.136**	0.564	-122.962**	28.169**	-3.462**	5.015**
Azad T-2 x DARL-64	0.469	-0.630	69.649**	0.364	3.593**	-0.374
Azad T-2 x BSS-368	1.730	-2.253**	-27.407**	-64.359**	-2.157**	-5.235**
Azad T-2 x Himsona	2.197**	-1.153	-22.073	-37.581**	-1.351	-4.235**
Azad T-2 x Tom-187	2.325**	-1.208	-2.462	-40.914**	-0.795	-7.457**
Azad T-2 x CO-3	9.425**	1.575**	241.593**	21.336	3.788**	-1.707**
Punjab Upma x DARL-64	2.647**	-0.525	64.843**	-23.609	-0.601	-7.040**
Punjab Upma x BSS-368	-3.225**	-2.080**	-56.212**	-33.331**	2.649**	4.098**
Punjab Upma x Himsona	0.108	-0.580	-66.212**	-20.220	-7.879**	-2.235**
Punjab Upma x Tom-187	0.436	-0.769	-45.601**	-12.553	-3.323**	-0.457
Punjab Upma x CO-3	-1.264	1.081	-22.545**	35.030**	-1.073	2.960**
DARL-64 x BSS-368	-3.553**	4.459**	-87.934**	77.530**	-2.295**	1.043
DARL-64 x Himsona	-0.486	-1.241**	40.399**	9.641	1.510	4.043**
DARL-64 x Tom-187	-1.292	-0.830	-2.657	-10.692	2.066**	1.154
DARL-64 x CO-3	-2.525**	-0.380	-34.268**	11.891	1.316	3.237**
BSS-368 x Himsona	0.575	-2.664**	-73.657**	-57.414**	-8.240**	1.182
BSS-368 x Tom-187	2.836**	3.347**	123.621**	71.253**	5.316**	3.293**
BSS-368 x CO-3	1.069	-0.803	44.677**	-11.497	2.232**	0.710
Himsona x Tom-187	-2.764**	6.981**	-33.379**	181.697**	0.788	3.626**
Himsona x CO-3	-2.664**	0.431	-53.990**	-1.720	-1.629	-2.290**
Tom-187 x CO-3	-2.003**	-0.891	-84.045**	-13.053	-4.740**	-1.513
SE (Sij)	0.9422	0.6177	11.1838	12.9225	0.9372	0.7872

Progenies	Fruit volume		Leaf area		Chlorophyll content at 45 days	
	E_1	E_2	E_1	E_2	E_1	E_2
SCA effects						
IIVR-Sel-2 x Arka Vikas	3.811**	1.187	-12.311**	3.980**	-0.050**	-0.116**
IIVR-Sel-2 x Sel.-7	-2.134**	-4.674**	-7.484**	1.173**	0.037**	0.108**
IIVR-Sel-2 x Azad T-2	-1.134	0.937	-1.336	2.685**	-0.025**	-0.065**
IIVR-Sel-2 x Punjab Upma	-2.689**	-0.702	-7.686**	-1.404**	-0.019**	-0.188**
IIVR-Sel-2 x DARL-64	-0.662	3.631**	10.936**	0.617	0.011**	-0.128**
IIVR-Sel-2 x BSS-368	0.366	-2.424**	28.122**	-1.385**	0.020**	0.131**
IIVR-Sel-2 x Himsona	-1.384	-4.202**	17.835**	1.448**	-0.011**	0.057**
IIVR-Sel-2 x Tom-187	-1.495	5.992**	-7.882**	-3.629**	0.037**	0.115**
IIVR-Sel-2 x CO-3	4.088**	4.104**	-15.219**	-1.079**	-0.015**	-0.026**
Arka Vikas x Sel.-7	-2.606**	0.770	-4.047**	4.232**	0.030**	-0.351**
Arka Vikas x Azad T-2	3.727**	3.048**	5.048**	-2.719**	-0.008**	0.315**
Arka Vikas x Punjab Upma	6.838**	5.076**	2.365**	-1.178**	-0.042**	0.261**
Arka Vikas x DARL-64	-1.467	-4.591**	-0.870	-1.593**	-0.009**	-0.001**
Arka Vikas x BSS-368	-0.106	1.354	-4.914**	-5.482**	-0.060**	0.072**
Arka Vikas x Himsona	-3.189**	0.909	17.829**	-1.689**	0.014**	-0.093**
Arka Vikas x Tom-187	1.033	-7.563**	4.655**	4.621**	0.076**	-0.179**
Arka Vikas x CO-3	-2.051**	-0.119	-5.882**	0.048	0.121**	-0.074**
Sel.-7 x Azad T-2	3.783**	4.187* *	6.451**	-0.010	-0.026**	0.184**
Sel.-7 x Punjab Upma	4.894**	1.215	-0.329	-4.989**	-0.025**	0.061**
Sel.-7 x DARL-64	0.255	3.215**	-6.377**	-2.101**	-0.004**	-0.084**
Sel.-7 x BSS-368	-5.051**	2.159**	-0.774	5.270**	-0.029**	-0.027**
Sel.-7 x Himsona	6.533**	2.381**	0.886	6.613**	-0.045**	-0.098**
Sel.-7 x Tom-187	-5.912**	-0.758	-9.532**	-1.730**	0.061**	-0.122**
Sel.-7 x CO-3	-3.328**	-2.313**	4.894**	-4.360**	0.105**	0.139**
Azad T-2 x Punjab Upma	-0.773	2.826**	-2.934**	1.666**	0.143**	0.051**
Azad T-2 x DARL-64	-5.412**	-4.508**	-7.009**	1.504**	-0.016**	-0.129**
Azad T-2 x BSS-368	-1.717	-2.896**	-5.410**	-0.198	0.047**	-0.106**
Azad T-2 x Himsona	1.199	0.992	-5.006**	0.909**	-0.040**	-0.013**
Azad T-2 x Tom-187	3.755**	-5.480**	-0.994	1.979**	-0.037**	0.159**
Azad T-2 x CO-3	-7.662**	-3.369**	2.712**	3.319**	0.019**	0.121**
Punjab Upma x DARL-64	-3.967**	-2.813**	1.622	0.295	0.009**	0.029**
Punjab Upma x BSS-368	3.727**	3.465**	-5.946**	2.526**	0.019**	0.206**
Punjab Upma x Himsona	-1.023	-3.980**	-2.112**	0.293	-0.037**	0.057**
Punjab Upma x Tom-187	-1.134	-1.785**	-1.316	0.976**	-0.029**	-0.029**
Punjab Upma x CO-3	-4.551**	-0.341	2.410**	4.146**	0.188**	0.172**
DARL-64 x BSS-368	-7.578**	-3.869**	-9.890**	4.381**	0.033**	0.005**
DARL-64 x Himsona	2.338**	3.020**	-4.040**	-2.319**	0.004**	0.002**
DARL-64 x Tom-187	6.561**	3.215**	3.585**	0.694**	-0.074**	0.106**
DARL-64 x CO-3	-2.856**	12.326**	-0.258	7.848**	0.054**	-0.165**
BSS-368 x Himsona	-6.634**	4.631**	-0.218	-5.578**	-0.003**	-0.338**
BSS-368 x Tom-187	3.922**	5.826**	6.291**	6.645**	-0.030**	0.101**
BSS-368 x CO-3	15.505**	0.937	-5.759**	0.382	0.008**	-0.115**
Himsona x Tom-187	-5.162**	-0.285	-5.975**	5.225**	-0.045**	0.053**
Himsona x CO-3	-3.245**	-5.841**	-7.069**	2.885**	-0.018**	0.058**
Tom-187 x CO-3	-8.356**	-0.980	-1.067	-4.005**	0.193**	0.074**
SE (Sij)	0.8801	0.8511	0.9911	0.3396	0.0003	0.0003

*, **= Significant at 5% and 1% level of significance, respectively.

Conclusions and Future Prospects

It may be concluded that for improving tomato for salinity tolerance, tomato breeding should also resort to pyramiding the characteristics since, no described traits alone is likely to produce a tolerant genotype. Threshold limit of salinity for tomato, up to which yield reduces very little or no reduction occur, is 2.5-3.0 dS m^{-1} and after it, every increase of 1.0 dS m^{-1} in EC results in a yield reduction of about 9-10%. The upper limit of salinity tomato crop improvement is 6.0 dSm^{-1}. Beyond this, breeding programmes are not feasible because yield loss surpass than 50%.

Yield reduction at moderate salinity is mainly due to reduction in average fruit weight (while, at higher salinity, yield reduction is due to reduced number of fruit per plant). This in turns is directly proportional to fruit size under normal environment. Hence cultivation of tomato cultivars with small sized fruits or even cherry type tomato should be recommended under saline environment. Both additive and non-additive gene action have to be exploited with trait specific or environment specific breeding by adopting adequate strategies *viz.* bi-parental mating, diallel selective mating, wide crossing and reciprocal recurrent selection.

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Performance of Fennel (*Foeniculum vulgare* Mill.) as Influenced by Saline Water Irrigation and Organic Input Management in Semi-arid Conditions

R.L. Meena*, S.K. Ambast, S.K. Gupta, Anil R. Chinchmalatpure and D.K. Sharma

Central Soil Salinity Research Institute, Karnal-132 001, Haryana, India
**Email: rlmeena69@gmail.com*

Abstract

Irrigation water is one of the scarcest but critical resources for agricultural production and most of the arid and semi-arid regions are usually underlain by aquifers of poor quality. A field experiment was conducted for four years during *rabi* season to assess the impact of saline water irrigation and organic input management options for sustaining productivity of high value spice crop fennel (var. Hisar Swarup HF-33). Saline water of low (EC_{iw}, 2 dS m^{-1}) and high (EC_{iw} 8.6 dS m^{-1}) salinity were used for irrigation. These types of waters are commonly encountered in arid and semi-arid regions. Eight inorganic and organic input options were used to verify the hypothesis whether the adverse effect of saline water irrigations can be mitigated through organic inputs. Surprisingly the average seed yield of fennel with low and high saline water use was almost at par (1.56 ± 0.02 t ha^{-1}) showing its suitability for saline irrigation. Average seed yield of fennel under inorganic and organic input treatments ranged from 1.4 to 1.7 t ha^{-1}. The trend in yield over the years reveals that application of organic inputs in various combinations can play an important role in sustaining the yield through improvement in fertility of salt-affected soils especially when irrigated with poor quality waters. Amongst all the combinations, farmyard manure + vermi-compost (50:50 ratios for equivalent N) produced economically remunerative and sustainable yield over the years with a net income of about Rs 124 thousand per ha.

Key words: Farm yard manure, Fennel, Neem manure, Organic inputs, Saline water, Seed yield, Vermi-compost, *Foeniculum vulgare*

Introduction

India is a leading producer of spices and condiments; and the seed spices have unique position being the commodity of economic importance. In India, seed spice fennel (*Foeniculum vulgare* Mill.) is grown in Gujarat, Rajasthan, Madhya Pradesh, Haryana and Uttar Pradesh covering an area of about 100 thousand ha with production of 143 thousand tones in the year 2012-13 (Indian Horticulture Database, 2013). Since the crop is widely grown in arid and semi-arid regions where soil and water often contain high concentration of salts, farmers resort to irrigate it with saline groundwater (Ashraf and Akhtar, 2004; Qasim *et al.*, 2003). Though the farmers use saline water for irrigation but no systematic information is available on irrigation water salinity tolerance limits of this crop particularly when organic and inorganic inputs are used. In addition to this, there is growing concern about the adverse impacts of pesticides and chemical fertilizers on the environment, quality of food and safety of human and animal populations. As the people are becoming more quality conscious, the demand for organically grown spices is increasing in the global market. Although the benefits of organic fertilizers are widely documented (Enwall *et al.*, 2005; Lal, 2004; Fliessbach *et al.*, 2009; Pimental *et al.*, 2005), but simultaneously it has also emerged that application of organic inputs may be at the cost of yield-loss over short periods (Mader *et al.*, 2002). However, Mbagwu (1992) advocated that use of organic fertilizers can be as effective as chemical fertilizers over longer periods of time. At present; there is limited information available on cultivation of seed spices using saline water; and role of organic fertilizers in mitigating the adverse effects of saline water. Therefore, the present study was planned with the objectives (i) to assess the effect of saline water irrigations on the yield of fennel and (ii) to investigate the mitigation of adverse impacts of saline water through appropriate combinations of organic inputs under irrigation using low and high saline water for sustainable production of the crop.

Materials and Methods

A field experiment was initiated during *kharif* season of 2008 with sesame-fennel crop rotation, fennel being cultivated during the *rabi* season at Bir Forest Farm, Hisar (29^o 10' N latitude and 75^o 44'E longitude at an altitude

*Corresponding author

of 220 m above mean sea level). The study site is categorized as semi-arid with an average annual rainfall of about 450 mm. The total average annual rainfall received during four years (2008-09 to 2011-12) varied from 399.2 mm to 918.8 mm, of which 75% was received during July to September. Only 10 to 15% of the total annual rainfall was received during the *rabi* seasons (Table 1). The pan evaporation ranged from 1.2-10.3 mm day^{-1} during November 2008 to May 2012. The low temperatures in the area during December and January adversely affected the growth of the fennel but crop growth resumed afterwards with the rise in temperature. The soil of the experimental site is highly calcareous (Ustic Haplocambids) sandy loam with EC_e 0.80 – 0.86 dS m^{-1}, pH_s 8.2 – 8.5 and organic carbon 0.26%. The water quality of two tube wells available at the farm was analyzed at different intervals following standard methods (Jackson, 1973) to keep track of the temporal changes in the water quality. The average EC_{iw} of two tube wells was 1.9 dS m^{-1} and 8.6 dS m^{-1} and designated as low saline and high saline water, respectively. Periodic EC_{iw}, pH, RSC and SAR of low saline water were 2.0 dS m^{-1}, 8.4, 4.8 meq l^{-1} and 12.9 m mol l^{-1}; and of high saline water these values were 8.6 dS m^{-1} , 7.7, nil and 18.5 mmol l^{-1}, respectively (Fig. 1).

The crop was sown in first week of November every year and harvested in last week of April to 3rd week of May of the next respective years in 3-4 plucking. Irrigations were applied commonly to all the treatments but depending upon the climatic conditions, numbers of irrigations varied from 5 – 7 during the four years of study. The fennel variety Hisar Swarup (HF-33) was cultivated for all the four seasons. The treatments composed of irrigations with two water qualities of water in main plots. In sub plots, 8 different treatments comprised of inorganic fertilizer in the recommended dose (60 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}); inorganic fertilizer and organic manures in combination; and 6 combinations of organic inputs, viz., farmyard manure, vermin-compost and non-edible Neem manure as shown in the following treatments:

T_1 : 100% inorganic fertilizer which includes 60 kg N ha^{-1} through urea and 30 kg P_2O_5 ha^{-1} through single super phosphate;

T_2 : 50% N through urea and P through SSP (inorganic) + 50% using organic inputs, for initial three years. This treatment was fully converted to organic inputs in the 4th year applied through FYM+VC+NM @ 8 t, 1.74 t and 1.60 t ha^{-1}, respectively;

T_3 : 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + vermi-compost @ 1.3 t ha^{-1};

T_4 : 50% of N equivalent each using farmyard manure @ 6 t ha^{-1} + non-edible Neem manure @ 1.2 t/ha;

T_5 : 33.3% of N equivalent each using farmyard manure @ 4 t + vermi-compost @ 0.87 t + non-edible Neem manure @ 0.8 t ha^{-1};

T_6 : 100% N equivalent (200% of treatments 3) each using farmyard manure @ 12 t + vermin-compost @ 2.6 t ha^{-1};

T_7 : 100% N equivalent (200% of treatments 4) each using farmyard manure @ 12 t + non-edible Neem manure @ 2.4 t ha^{-1};

T_8 : 66.6% N equivalent (200% of treatments 5) each using farmyard manure @ 8 t + vermi-compost @ 1.74 t + non-edible Neem manure @ 1.60 t ha^{-1}.

Table 1. Rainfall, evaporation and temperature during crop growth period (Nov. 2008-May 2012)

Climatic parameters	Years	Months						
		Nov.	Dec.	Jan.	Feb.	March	April	May
Rainfall (mm)	2008-09	3.2	0.8	10.3	6.1	4.1	24.9	38.2
	2009-10	0.0	0.0	11.5	7.6	2.5	0.0	1.9
	2010-11	0.0	43.6	0.0	34.8	12.5	35.2	84.9
	2011-12	0.0	0.0	14.4	0.0	0.0	33.3	29.8
Evaporation (mm/day)	2008-09	2.3	1.5	1.4	2.1	3.7	7.4	9.3
	2009-10	2.1	1.6	0.9	2.3	4.2	8.1	10.3
	2010-11	2.2	1.4	1.2	1.9	3.0	5.5	9.1
	2011-12	2.6	1.4	1.4	2.2	3.8	5.6	8.7
Temperature (^{0}C) (maximum)	2008-09	28.9	23.5	20.1	24.1	29.4	35.8	40.8
	2009-10	27.1	23.1	17.3	25.8	34.9	41.1	42.9
	2010-11	27.7	21.3	16.9	22.7	28.6	34.4	40.1
	2011-12	29.4	22.9	18.4	21.0	28.5	34.2	39.9
Temperature (^{0}C)(minimum)	2008-09	10.6	6.8	5.8	7.3	11.8	17.3	23.7
	2009-10	9.9	4.9	5.9	7.4	16.7	20.4	24.4
	2010-11	11.5	4.6	4.2	8.1	11.4	16.7	23.9
	2011-12	11.0	5.2	4.8	5.3	10.3	18.0	22.3

The treatments were replicated three times. The crop was sown at row to row spacing of 50 cm in 2 m x 3 m plots. The chemical fertilizers; full dose of phosphorous was applied as basal while nitrogen was applied in two splits, half as basal and half at 30 days after sowing. All the organic inputs were applied before sowing the crop and mixed well into the soil. Observations on plant height, number of umbels per plant, number of umbellets per umbel and seed weight per umbel were recorded on randomly selected and tagged 5 plants per plot. Plucked umbels were kept in shade for drying and seed yield (kg per plot) was recorded after threshing of dried umbels. Soil samples (0-30 cm depth) were collected at the time of harvesting every year and analyzed for EC_e, pH_s, organic carbon, available nitrogen and phosphorous content after each season. Statistical analysis was performed for judging the significance of difference among different treatments at 0.95 level of probability with the help of a statistical package (OPSTAT online). An account of the expenses made under each treatment was maintained for detailed economic analysis.

Results and Discussion

Effects of use of saline water irrigation and organic fertilizer inputs on growth and yield attributes of the fennel crop are discussed in the following sections.

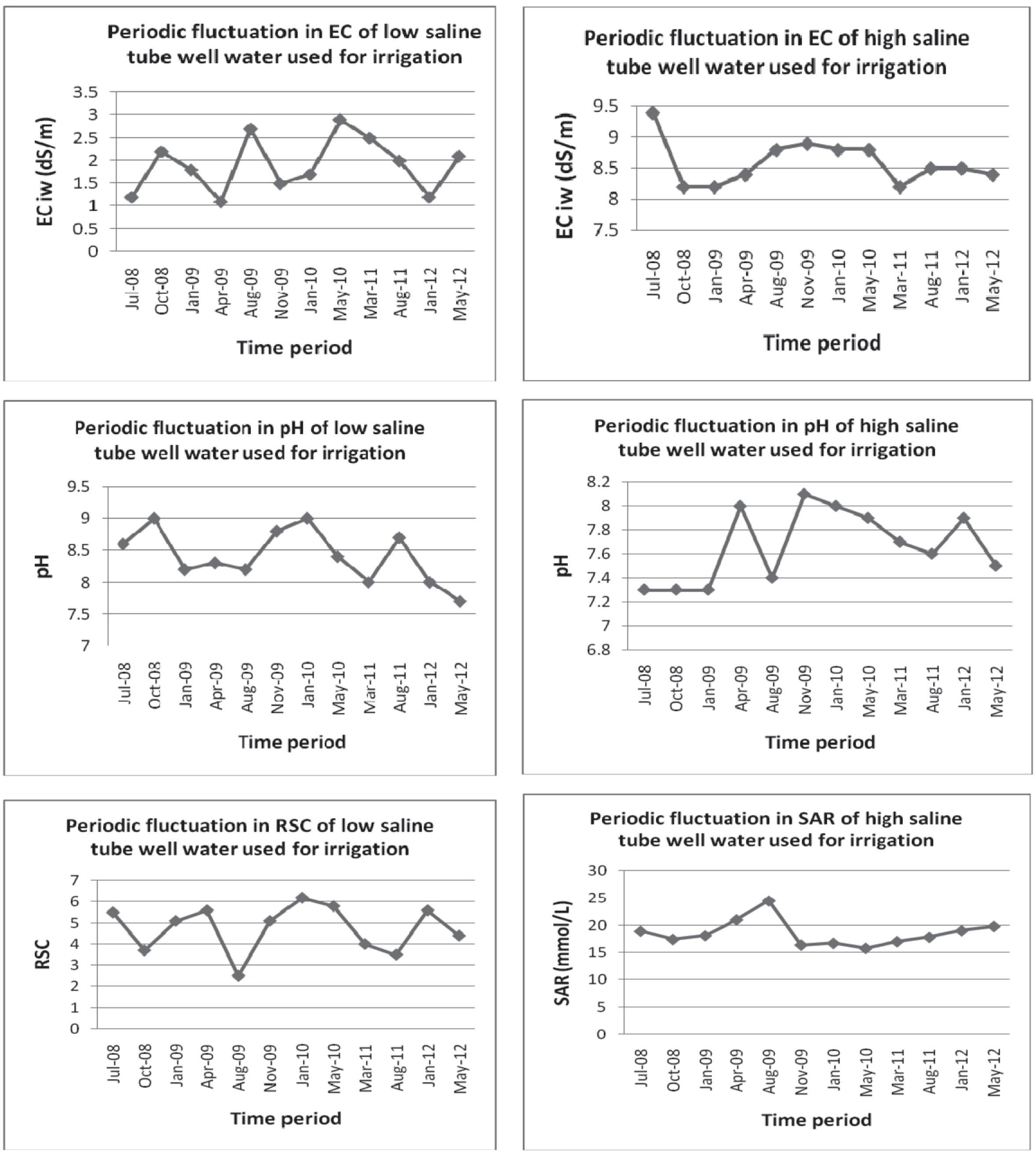

Fig. 1. Periodic water quality measurement of tube well used for irrigation (2008-2012)

Effect of saline water irrigation on growth parameters

Perusal of data on plant height showed that the average plant height (136.4 cm) was highest under low saline irrigation although it was not significantly different to high saline water during 2008-09 and 2010-11 (Table 2). The data show that fennel was able to tolerate high salinity to a great extent without much reduction in plant height. Number of umbels per plant ranged from 20.1 to 28.2 with an average of 23.2 with low saline and 22.7 with high saline water. No significant difference in number of umbels/plant was observed, however, the highest number (30.1) of umbels/plant were recorded during first year under high saline water irrigation. Number of umbellets/umbel decreased from 21 to 19.2 during first three years although maximum (28.3) were recorded during fourth year under low saline water irrigation. Number of umbellets/umbels increased from 18 in first year to 27 in the fourth year under high saline water irrigation. It could be attributed to improved physical condition of soil under various organic inputs over the years. Significant difference in number of umbellets was observed during first and third years with higher average number of umbellets (22.4) recorded in low saline water irrigation (Table 2). Similar results have been reported by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Effect of saline water irrigation on yield and yield attributes

Seed weight per umbel varied from 1.16-4.04 g and 1.27-3.81 g with low and high saline water, respectively with an average of 2.30 and 2.25 g, respectively (Table 3). Contrary to the expectation of large differences, only the small differences were recorded between two salinities of irrigation water. This might be due to several reasons, possibly higher RSC in low saline water and mitigation of the adverse effect of saline water irrigation by application of different organic inputs. Seed weight of 100 seeds did not differ significantly during the initial three years while significant differences were observed only in fourth year. Averaged data showed that maximum 100 seed weight was recorded under high saline water, may be due to presence of RSC in low saline irrigation water which might have adversely affected the development of seeds as compared to high saline water. Similarly, seed yield of fennel showed decreasing trend initially which got reversed during third and fourth years. Averaged seed yield showed that the higher yield of 1.57 t ha^{-1} was obtained under low saline water which was not much different than 1.56 t ha^{-1} with high saline water irrigation (Table 3). The reasons for such minor differences have been discussed previously in this section. Similar results were obtained by Mangal *et al.* (1986) and Abou El-Magd *et al.* (2008).

Effect of organic manures on growth parameters

Application of organic inputs had significant effect on plant height of fennel during all the years. Application of inorganic fertilizers resulted in significantly lower plant heights of 114.3, 100 and 137.5 cm during first, second and fourth year, respectively. Among the treatments, application of farmyard manure, vermi-compost and neem manure (*Neem shakti*) in different combinations (T_3-T_8) resulted in increased plant height as compared to inorganic fertilizer alone (T_1) or combination of inorganic fertilizer + organic manures (T_2). Results also showed that effect of organic manures was quite discernible during the fourth year probably because of the fact that few years are required to improve and rejuvenate the soil fertility. Average plant height was 122.4 cm with application of inorganic fertilizer alone while higher values were obtained in all other treatments. The year-to-year variations in plant height might be due to climate variability, rainfall, impact of saline water irrigation and role of organic manures in mitigating its adverse effects. The role of organic manures in mitigating the adverse effect resulted in overall good plant growth. Average number of umbels/plant under organic manures application ranged from 21.1 to 24.1. There was no significant difference in umbels per plant under different organic manures as compared to inorganic fertilizer alone or their combination (T_2). The maximum number of umbels per plant ranging from 24.3 to 33.3 were recorded during first year and there was general decline in later years. Number of umbellets/umbel has significant variation only in the first year while remaining non-significant in the following years. Maximum umbellets were recorded during fourth year with average number of umbellets per umbel ranging from 19.8 to 23.5 (Table 2). Similar findings in plant height and yield of capsicum spice crop were also reported by Gopinath *et al*. (2008); Jaipaul *et al*. (2011).

Effect of organic input application on yield and yield attributes

Perusal of the data presented in Table 3 showed that seed weight per umbel and seed yield with different organic input management options varied significantly during first year. Average seed weight per umbel ranged from 2.0 g with inorganic treatment to 2.6 g with organic manure treatment T_8. Highest seed weight per umbel was recorded during fourth year which ranged from 3.40 to 4.40 g. Data on 100 seed weight showed that it differed non-significantly during all the years averaging 0.74 to 0.77 g under different treatments.

In first year, the lowest seed yield (1.17 t ha^{-1}) of fennel was obtained with the application of inorganic + organic input combination in the ratio of 50:50 while highest 1.63 t $ha^{-1}$was obtained under treatment T_8 which was at par with the seed yield (1.44 t ha^{-1}) obtained in treatment T_3. The results of lower yield in treatment T_2 (50% inorganic+50% organic) are in line with the results available in literature on several crops, since the availability of nutrients applied through organic inputs needs time to

Table 2. Growth and growth parameters of fennel under saline water and organic input application during 2008-09 to 2011-12

Treatments	Plant height (cm)					Umbels/plant					Umbellets/umbel				
	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.
Salinity of irrigation water															
Low saline	131.2	121.0	143.3	149.9	136.4	28.2	21.7	20.1	22.9	23.2	21.0	20.9	19.2	28.3	22.4
High saline	120.5	98.5	140.3	143.3	125.7	30.1	18.6	21.6	20.3	22.7	18.0	18.5	20.4	27.0	21.0
LSD (p=0.05)	NS	22.2	NS	5.1	-	NS	NS	NS	NS	-	1.8	NS	0.8	NS	-
Organic input options															
T_1	114.3	100.1	137.7	137.5	122.4	28.5	21.1	21.5	21.5	23.2	19.8	18.0	18.2	25.0	20.3
T_2	115.6	100.6	134.3	147.5	124.5	24.3	16.8	20.8	22.5	21.1	17.3	18.5	20.0	23.5	19.8
T_3	120.5	110.4	139.7	141.6	128.1	27.3	19.6	23.8	22.8	23.4	20.0	18.2	18.8	28.3	21.3
T_4	124.7	106.2	140.5	146.3	129.4	28.0	19.7	22.2	21.3	22.8	17.8	18.2	21.0	27.0	21.0
T_5	133.0	105.0	139.7	143.2	130.2	29.8	19.8	19.7	20.5	22.5	20.3	20.5	20.0	28.7	22.4
T_6	132.8	113.9	138.9	146.7	133.1	32.8	22.5	20.8	20.3	24.1	20.2	21.6	20.2	31.8	23.5
T_7	131.8	119.0	152.1	157.1	140.0	29.0	20.0	18.7	21.7	22.4	20.2	21.0	20.5	27.2	22.2
T_8	134.0	122.7	151.3	153.0	140.3	33.3	21.7	19.2	22.0	24.1	20.7	21.5	20.0	29.5	22.9
LSD (p=0.05)	10.9	14.4	11.1	9.2	-	NS	NS	NS	NS	-	2.0	NS	NS	NS	-

(T_1:100% Inorganic fertilizer T_2: Inorganic + organic inputs (50:50)-fully organic after 3 years, T_3: Farmyard manure+ Vermi-compost (50:50), T_4: Farmyard manure + Non-edible Neem manure (50:50), T_5: Farmyard manure + Vermi-compost + Non-edible Neem manure (33.3:33.3:33.3), T_6: Farmyard manure + Vermi-compost (100: 100), T_7: Farmyard+Non-edible Neem manure (100:100), T_8: Farmyard manure+Vermi-compost+Non-edible Neem manure (66.6:66.6:66.6).

Table 3. Seed yield and yield parameters of fennel under saline water and organic input application during 2008-09 to 2011-12

Treatments	Seed weight/umbel (g)					100 seed weight (g)					Seed yield (t/ha)				
	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.	08-09	09-10	10-11	11-12	Av.
Salinity of irrigation water															
Low saline	2.46	1.54	1.16	4.04	2.30	0.90	0.55	0.72	0.79	0.74	1.50	1.26	1.50	2.03	1.57
High saline	2.26	1.64	1.27	3.81	2.25	0.90	0.63	0.77	0.76	0.77	1.40	0.85	1.87	2.13	1.56
LSD (p=0.05)	0.07	NS	NS	0.14	-	NS	NS	NS	0.01	-	NS	0.41	0.06	NS	-
Organic input options															
T_1	2.20	1.31	1.10	3.40	2.00	0.90	0.54	0.75	0.79	0.75	1.37	0.97	1.53	1.78	1.41
T_2	1.95	1.45	1.27	3.37	2.01	0.89	0.56	0.71	0.79	0.74	1.17	1.01	1.55	2.16	1.47
T_3	2.32	1.59	0.94	3.92	2.19	0.87	0.62	0.74	0.78	0.75	1.44	1.20	1.65	2.10	1.60
T_4	2.20	1.53	1.32	4.02	2.27	0.88	0.64	0.78	0.76	0.77	1.34	1.11	1.61	2.17	1.56
T_5	2.23	1.58	1.25	4.11	2.29	0.85	0.60	0.75	0.77	0.74	1.55	1.17	1.63	2.01	1.59
T_6	2.55	1.84	1.25	4.09	2.43	0.90	0.57	0.74	0.75	0.74	1.44	0.88	1.97	1.97	1.57
T_7	2.47	1.69	1.29	4.06	2.38	0.93	0.57	0.74	0.78	0.76	1.60	1.05	1.56	2.17	1.60
T_8	2.95	1.74	1.29	4.40	2.60	0.97	0.60	0.75	0.77	0.77	1.63	1.03	1.98	2.21	1.71
LSD (p=0.05)	0.41	NS	NS	NS	-	NS	NS	NS	NS	-	0.03	NS	NS	NS	-

Depictions for treatments are as in Table 2.

build-up for its availability to the plants. As expected under field conditions, there are year to year variations in crop yield varying from 0.88 to 2.21t ha^{-1}. These can be attributed to initial soil conditions as salinity build-up take time within the season or over the years, variations in quality of irrigation water and rainfall and its distribution during the crop growth period.

Averaged seed yield of fennel (ranged from 1.47 to 1.71 t ha^{-1}) in various treatments, the highest being in treatment T8 with 200% application on N basis. Most economical combination over the four years period however, was T_3, where farmyard manure + vermin-compost was used in 50:50 ratio on N basis with an average seed yield of 1.60 t ha^{-1}. It could fetch a net income of Rs. 123980 per ha. According to Edwards (1998), vermin-compost contains most of the plant nutrients such as; nitrate, phosphates, exchangeable calcium, soluble potassium, and microelements. Thus, application of vermin-compost helps in improving plant growth and development and is responsible for increased qualitative and quantitative yield of many crops (Atiyeh *et al*., 2002; Roy *et al*., 2010). A cursory look at the results of four years revealed that saline water up to 8.5 dS m^{-1} can be used for irrigation of fennel with application of organic manures. Later helps in mitigating the adverse effect of saline water application and sustaining the productivity of high value crop as compared to application of inorganic fertilizers alone. It can be attributed to improved soil physical state especially in low saline RSC water and sustained release of macro and micro nutrients. Similar results were also reported by several workers (Bahadur *et al*., 2006; Gopinath *et al*., 2008; Bahadur *et al*., 2009; Jaipaul *et al*., 2011; Upadhyay *et al*., 2012). Results obtained by Phogat *et al.* (2010) also show that synergy of chemical amendments and organic inputs sustained vegetable production irrigated with high RSC waters. The results presented in this paper are of great importance in managing saline water in arid and semi-arid regions for cultivation of seed spices in general and fennel in particular.

Conclusion

Groundwater of poor quality is a general character of arid and semi-arid ecology where fennel crop is cultivated. Results of four years study reveal that cultivation of high value seed spices in general and fennel in particular is possible using saline water up to EC 8.5 dS m^{-1} without much yield reduction. The long-term adverse effect of saline water if any can be mitigated by application of organic inputs (farmyard manure, vermin-compost and neem manure. The organic inputs in various combinations help in improving the soil physico-chemical properties that mitigates the adverse effect of saline water including RSC, which is known to cause adverse effects on soil physical properties. Considering the cost and quality of organic inputs, a combination of 6 t ha^{-1} farmyard manure and 1.3 t ha^{-1} vermi-compost seems to be a good combination to achieve the sustainable production of fennel crop in saline environment and fetching net income of Rs 124 thousand per ha.

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Impact of FYM and Potassium Interactions on Potato Yield Cultivated on Moderate Saline Soils

Sharif Ahamad[1]*, J.C. Dagar[1] and D. Mani[2]

[1]*Central Soil Salinity Research Institite, Zarifa Farm, Kachhwa Road, Karnal-132 001, Haryana, India*
[2]*Sheila Dhar Institute of Soil Science, Department of Chemistry, Central University of Allahabad, Allahabad-211 001, Uttar Pradesh, India*
**Email: sharif.singhra@gmail.com*

Abstract

Potato is very important food crop of India and needs attention to increase its production. One experiment was conducted to evaluate the effect of farm yard manure (FYM) in interaction with and without potassium fertilizer application on potato (*Solanum tuberosum*) yield. The yield improved with addition of K fertilizer along with FYM and it was highest at 100 kg K_2O ha^{-1} when applied along with 30 t ha^{-1} of FYM. Application of both FYM and K fertilizer resulted significantly increase in above ground and tuber yield as compared to control. The yield increased by 19 % over control with application of 100 kg ha^{-1} potash alone and the same increased by 56 and 87 % when FYM was applied at the rate of 15 and 30 t ha^{-1} with 100 kg K_2O ha^{-1}. Potassium balance was positive only when FYM was applied. The aboveground biomass of the plant was found significantly (p=0.01) correlated with tuber production and in turn the later (due to application of K) was found significantly (p=0.01) correlated with K accumulation in tubers. These studies suggest that it is advantageous to apply FYM in combination with K as it improves tuber yield significantly by way of improving soil physical properties and also maintaining a positive nutrient balance and also helps in keeping quality of the tubers.

Key words: Farm yard manure (FYM), Nutrient management, Potassium, Potato yield, Above ground biomass (AGB), *Solanum tuberosum*

Introduction

Potato is one of the most important crops worldwide and ranks fourth in annual production (Fernie and Willmitzer, 2001). In India, it is cultivated on 1.84 m ha area with a production of 36.6 m tones at the rate of about 20 t ha^{-1} (Mo A, 2011). More than 80 per cent of the potato crop in India is cultivated on the Indo-Gangetic plains during the winter season. The three major states of the country producing potato are Uttar Pradesh, West Bengal and Bihar contributing almost 68 per cent of the total area and 78 per cent of the production (Trehan *et al.*, 2009; Mo A, 2011). High efficiency in nutrient management of the potato crop, therefore, assumes special significance. As compared with other crops, potato has shallow root system which limits its foraging capacity in the soil. On the other hand, uptake of fertilizer nutrients (NPK) by potato per unit area and time is quite high because of the rapid rate of early growth and tuber bulking (Singh and Trehan, 1997). A healthy crop of potato removes about 170-230 kg K_2O ha^{-1} indicating higher requirement for K as compared to cereals. As such potato invariably responds to potassium application in the various kinds of soils and agro-climatic conditions in which it is grown.

Organic and mineral fertilizations improve physical properties of light-textured soils and also water and warmth regime. Systematic fertilization not only increases potato yield but also alters its quality, and results in the higher build up of nutrients in the yield (Bagdoniene *et al.*, 1998). It has been found that nutrients present in mineral fertilizers are more effective than the equivalent amount of these nutrients present in FYM (Bagdoniene *et al.*, 1998), therefore, mineral fertilizer efficacy for potatoes was noticeably higher than that of organic fertilizer (Antanaitis and Svedas, 2000). Depending on the mineral fertilizer forms, rates and nutrient ratios, the contents of dry matter, starch, protein and other substances may either increase or decrease. Excessive nitrogen fertilization reduces starch, dry matter and sugar contents in tubers of potato, which lead to get spoiled more rapidly during storage (Simanaviciene *et al.*, 1996). Dry matter content is affected by various factors, among which the most significant include: tuber maturity, growth character, plant nutrient and water uptake (Haris, 1992). As the fertilizers both organic and inorganic play important role in potato cultivation, but little information is available on interaction of FYM and potassium therefore, the present experiment was conducted to observe the impact of FYM and potassium on yield and quality of potato tubers.

*Corresponding author

Table 1. Physical and chemical characteristics of soil of experimental site

S.N.	Parameters	Content
1	Texture class	sandy clay loam
2	Sand (%)	56
3	Silt (%)	20
4	Clay (%)	24
5	Sesquioxide (%)	0.11
6	CaO (%)	0.02
7	MgO (%)	0.02
8	pH (1:2)	7.20
9	CEC (c mol (p+) kg^{-1})	25.9
10	EC_e (dS m^{-1})	12.6
11	Organic Carbon (%)	0.86
12	Organic matter (%)	1.48
13	Nitrogen (kg^{-1})	480
14	Phosphorus (kg^{-1})	72
15	Potassium (kg^{-1})	144

Material and Methods

The field study was carried out at the experimental farm of Sheila Dhar Institute of Soil Science (SDISS), Allahabad ($25^0$45'N and $81^0$84'E with altitude of 98 m above MSL) in Uttar Pradesh State of India. The climate at the experimental site is humid, sub-tropical monsoon type with an average annual rainfall of 1000 mm. The temperature of the region varied from 5 – 17 ^{0}C during winter and 30 – 42 ^{0}C in summer season. The coldest months are December and January and the hottest months are May and June.

The experiment was conducted on an alluvial sandy clay loam soil having moderate salinity to standardize agronomic practices of potato cultivation through application of FYM and potassium fertilizer with random block design having three replications. The soil samples were initially collected randomly from the study plots before experiment. After grinding the air-dried soil samples, the soil was passed through a 2 mm sieve and analyzed to deduct the electrical conductivity (ECe) of saturated extract using a digital EC meter and pH of soil in water suspension (1:2) by digital pH meter as described by Richards (1954). The mechanical analysis of initial soil samples was done using the pipette method (Piper, 1966). Other physical and chemical parameters were analysed using standard methods (Jackson, 1967). Potash content was observed as described by Jackson (1967). The physical and chemical characteristics of the soil are given in Table 1.

The experiment consisted of combination of nine treatments comprising 3 levels of FYM, i.e. 0, 15 and 30 t ha^{-1} and 3 levels of K i.e. 0, 50 and 100 kg ha^{-1}. Seeds of potato (*Solanum tuberosum* Linn. cv. Sinduri Khupri) were collected from local market, Allahabad, Uttar Pradesh. The tuber seeds were sown on the ridges (of 10 cm height) with ridge to ridge distance of 15 cm in plot size of 4 m x 4 m. In order to preparation the land for cultivation, the field was deep ploughed twice. The fertilizer doses were applied before placing the seed tubers. Half of the nitrogen (60 kg ha^{-1}) and entire dose of P (80 kg ha^{-1}) were applied at the time of sowing and remaining half nitrogen (60 kg ha^{-1}) was applied after 45 days of seed sowing. The FYM was applied at time of ploughing and potassium along with half nitrogen and phosphorus as basal doses. The irrigation and weeding were made on requirement basis. The initial germination was observed for 15 days when tubers started sprouting. The tuber yield was observed at the end of experiment after harvest.

Results and Discussion

It was observed that maximum tuber seed germination/sprouting (78 %) was observed when FYM (30 t ha^{-1}) applied with 100 kg K_2O ha^{-1}. The increase in seed germination was 9 % as compared to control. The germination was lower in other treatments (Fig 1). The data on tuber yield under different treatments are depicted in Table 2.

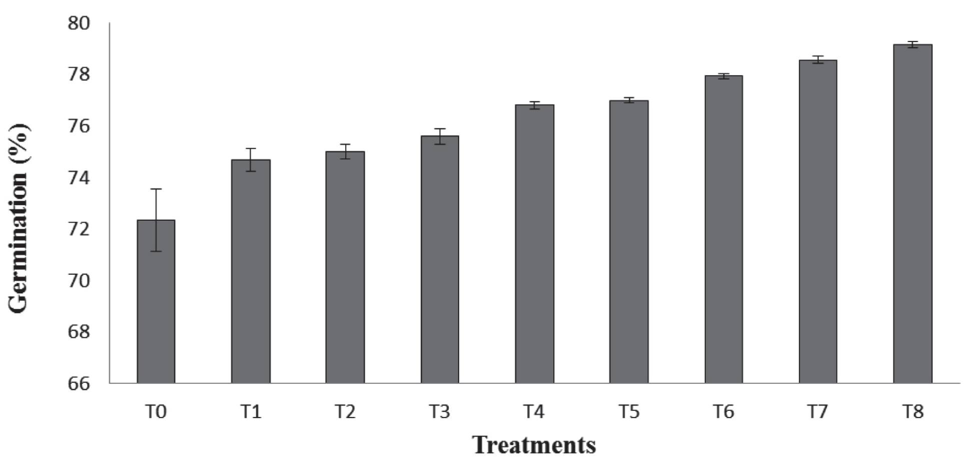

Fig. 1. Tuber seed germination (sprouting) under different treatments of fertilizer (Treatment depiction as in Table 2)

Table 2. Effect of different levels of FYM and potassium treatments on potato yield parameters and K accumulation in tubers

Treatments	Tuber yield ($t\ ha^{-1}$)	Above ground biomass ($t\ ha^{-1}$)	K content in tuber (%)
T_0	25[f]	15[cb]	0.70[d]
T_1	29[e]	15[cb]	0.75[dc]
T_2	30[e]	15[c]	0.78[cb]
T_3	35[d]	17[cba]	0.78[cb]
T_4	38[c]	16[cba]	0.79[cb]
T_5	39[c]	17[cba]	0.79[cba]
T_6	40[c]	17[cba]	0.82[ba]
T_7	43[b]	18[ba]	0.84[ba]
T_8	47[a]	19[a]	0.87[a]
LSD (p=0.05)	2.04	2.90	0.06

Depiction: T_0 (FYM 0 + K 0), T_1 (FYM 0 + K 50), T_2 (FYM 0 + K 100), T_3 (FYM 15 + K 0), T_4(FYM 15 + K 50), T_5 (FYM 15 + K 100), T_6 (FYM 30 + K 0), T_7 (FYM 30 + K 50), T_8 (FYM 30 + K 100) and (FYM values in tones ha^{-1} and K in kg ha^{-1}). The same superscripts in a column are statistically not significant.

The results of variance analysis of fresh potato tuber yield were consistent and statistically significant ($p<0.05$) among the different combination of FYM and K fertilization treatments. Under all the treatment combinations the yield increased significantly over control. The highest mean potato tuber yield (47 t ha^{-1}) was achieved at treatment T_8 (30 t ha^{-1} FYM and 100 kg K_2O ha^{-1}) followed by T_7 (30 t ha^{-1} FYM and 50 kg K_2O ha^{-1}). Application of K alone had significant effect on yield increase. The increase was 16 and 20 % when potassium alone was applied at the rate of 50 and 100 kg ha^{-1}, respectively. When FYM at the rate of 15 t ha^{-1} alone was applied the increase in yield was 40 % over control. The same increased to 52 and 56 % over control when K was applied at the rate of 50 and 100 kg h^{-1} respectively with 15 kg ha^{-1} FYM but there was no significant increase between treatment T_4 and T_5 i.e. 50 and 100 kg ha^{-1} application of K with 15 t ha^{-1} FYM. At the same time the impact of K at the rate of 50 and 100 kg ha^{-1} with application of FYM (15 t ha^{-1}) was only 9 and 3 %, respectively. Combined application of 30 t ha^{-1} FYM with K (50 and 100 kg ha^{-1}) significantly increased the tuber yield as compared to the application of organic or inorganic fertilizers when applied alone. The application of 30 t ha^{-1} FYM alone increased the yield to 60 % over control and the same also increased to 72 and 88 % over the control with combination of K at the rate of 50 and 100 kg ha^{-1}, respectively. The higher benefits from combined applications might be attributed, in part, to enhanced fertilizer recovery (increased uptake) due to increased soil physical and chemical properties as a result of increased soil organic matter. Besides increasing soil physical and chemical properties, by providing macro and micronutrient organic manure improved crop production. The results are in partial agreement with reports of Bereez *et al.* (2005); Alam *et al*. (2007); Daniel *et al.* (2008); and Johnston (2008), who reported higher yields of potato from manure application along with inorganic fertilizers. Exclusion of K from either inorganic or from combined inorganic-organic treatments significantly decreased the tuber yield, suggesting K as a major yield limiting factor for optimum production of potatoes. These results are in line with reports of several workers mentioned above, who suggested the balanced management of inorganic fertilizers in production of potato and other different crops. Significantly higher tuber yield by application of K along with 30 t FYM was probably due to nutrients supply of manure and releasing of already bonded P from the soil due to the release of acids by decomposition of FYM. However, Rutunga and Neel (2006), reported that application of high rate of nutrient rich farmyard manure (35 t ha^{-1}) alone was sufficient to increase potato yield and no supplemental P and lime were required after four regular seasonal applications in Alisols of Mata, Rwanda. From laboratory incubation results of 40 g animal manure kg^{-1} soil, Whalen *et al*. (2000), observed highly significant pH increase and high concentration of available P and K in labile forms. Moreover, from the present investigations it is clear that besides application of FYM and nitrogen and phosphorus, potassium plays as a limiting factor for enhancing tuber yield.

Above ground biomass (AGB) production

The observations clearly showed that the plant above ground biomass was higher (19 t ha^{-1}) in T_8 (30 t FYM + 100 kg K_2O ha^{-1}) treatment followed by T_7 (30 t FYM + 50 kg K_2O ha^{-1}). However, the application of FYM alone at the rate of both 15 and 30 t ha^{-1} significantly increased the AGB to 13 % over the control. The increase was 16 and 20 % when potassium was applied at the rate of 50 and 100 kg ha^{-1}, respectively. Usually the growth of above ground foliage is indicator of tuber yield also as the photosynthetic biomass helps in tuber growth and the carbohydrates accumulated in foliage are translocated in tubers. This is evident from Figure 2 where tuber yield is significantly correlated ($p=0.01$) with AGB (Fig. 2). Trehan *et al*. (2001) also reported almost similar results.

K content in potato tuber

K application had showed the statistically significant ($p = 0.05$) among the different combinations of FYM and K fertilizer treatments in respect of K content in potato tuber. It is observed that the K content significantly increased to 7 and 11 % over the control with increasing dose of 50 and 100 kg ha^{-1} K fertilizer alone, respectively. However, FYM alone also increased the K content in tuber to 11 and 17 % with application of 15 and 30t ha^{-1},

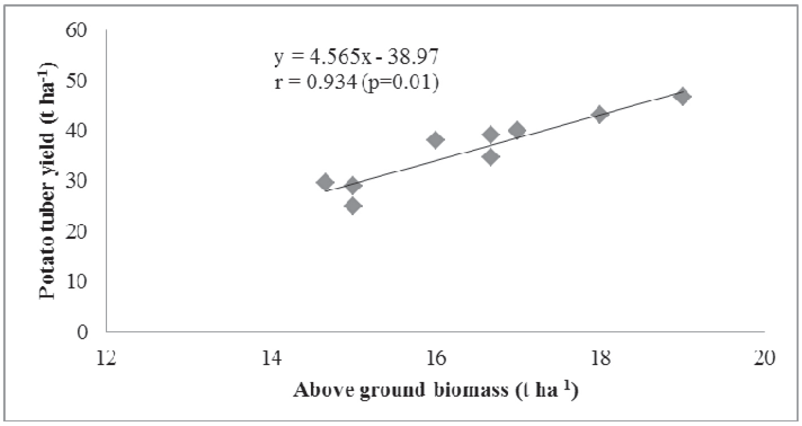

Fig. 2. Correlation between above ground biomass and tuber yield

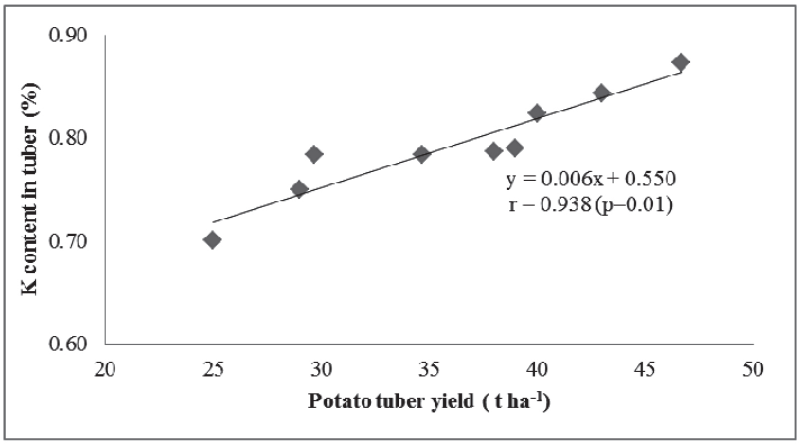

Fig. 3. Correlation between potato tuber yield and K accumulation in tuber

respectively. Although, the FYM at the dose of 30 t ha^{-1} expressed the significant higher K content to 6 % in tuber when applied with 100 kg K ha^{-1}. The interaction of FYM and K application helps in increase of tuber yield, which in turn is significantly correlated (p=0.01) with K accumulation in tuber (Fig. 3).

This has significance because K in tubers helps in keeping quality as well as frost tolerance during winter. Application of K increases plant height, crop vigour and imparts resistance against drought, frost and diseases. Potassium increases leaf expansion particularly at early stages of growth and extends leaf area duration by delaying leaf shedding near maturity. It increases both the rate and duration of tuber bulking. Its application activates a number of enzymes involved in photosynthesis, carbohydrate and protein metabolism; and assists in the translocation of carbohydrates from leaves to tubers. It is observed that potassium increases the size but not the total number of tubers (Grewal and Singh, 1980; Trehan *et al.*, 2001). Potassium application thus increases yield by the formation of larger size tubers. In the north-western plain, potassium plays an active role in protecting this rather sensitive crop to frost damage. In the north-western hills, under long day and rainfed conditions, K application prevents the crop suffering from moisture stress during the early stages of growth (Trehan *et al.*, 2009).

Wilkerso and Grunes (2000) reported that under high K availability, increasing N supply will increase K concentration and uptake, whereas without K application K concentration decrease in high rates because of growth dilution. This suggested that continuous application of NP without K depletes soil K and may pose problem in crop production.

Conclusion

The results of the present study indicate that it is advantageous to apply FYM along with K application as it increases potato yield by way of improving soil physical properties. FYM also supplies macro and micro nutrients and maintains healthy positive nutrient balance besides being a source of organic matter; and further it emphasizes the need for integrated and balance nutrient management in potato in irrigated alluvial sandy loam moderate saline soils. It is concluded that application of 30 tones FYM and 100 kg K ha^{-1} is sufficient to meet the crop requirements of potato cultivars. Further, application of potassium also helps in reducing the frost injury and also in the keeping quality of the tubers for longer period.

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Distribution and Characteristics of Salt-affected Soils of Morena District of Madhya Pradesh

Y.P. Singh[1], S.K. Verma[2], S.K. Dubey[3] and S.C. Tiwari[4]

[1]*RVS Krishi Viswa Vidyalaya, Zonal Agricultural Research Station, Morena-476 001, Madhya Pradesh, India*
[2]*College of Agriculture, RVS Krishi Viswa Vidyalaya, Gwalior, Madhya Pradesh, India*
[3]*Regional Research Station, CSWCRTI, Chhalesar, Agra, Uttar Pradesh*
[4]*AICRP on Management of Salt Affected Soils and Use of Saline Water in Agriculture, Indore, Madhya Pradesh, India*

Abstract

Soil samples were identified using RS software on digital satellite data and analyzed for different physico-chemical properties and characterized for different classes of salinity and alkalinity. Three types of texture of surface soils *i.e.* sandy loam, sandy clay loam and clayey were observed. Soil colour varies from brownish yellow to yellowish brown and light yellowish brown. All soil samples were neutral to alkaline in reaction and their mean values of pH of saturation paste (pHs) and electrical conductivity of saturation extract (ECe) were 8.55 and 3.93 dS m^{-1}, respectively. The average values of infiltration rate, saturation percentage and bulk density were 5.4 mm hr^{-1}, 30.95 and 1.51 Mg m^{-3}, respectively. These salt-affected soils were non-calcareous in nature with 97% deficient in organic carbon (OC) content. Similarly the mean values of cation exchange capacity (CEC) in cmol (p+) kg^{-1} and exchangeable sodium percentage (ESP) were found to be 34.5 and 38.4, respectively. The mean values of cations and anions in cmol (p^+) kg^{-1} of saturation extract were containing 21.1 of calcium, 13.25 of sodium, 0.27 of potassium and 0.63 of carbonate, 14.71 of bicarbonate, 23.64 of chloride and 2.45 of sulphate, respectively. Saturation extract analysis revealed that the cations and anions followed decreasing order calcium > sodium > potassium and chloride > bicarbonate > sulphate > carbonate, respectively. The values of sodium adsorption ratio (SAR) were ranged from 2.2 to 5.8, with mean value of SAR was 3.87. It was observed that, out of total 782 villages of Morena District, 167 villages are having saline and alkaline nature of soil. Out of total cultivated area of the district, 8.59% area was affected either by salinity or alkalinity. A map sowing distribution of salt -affected soils of Morena district was also generated.

Key words: Anions, Cations, Cation exchange capacity, Exchangeable sodium percentage (ESP), Salt-affected soils, Sodium adsorption ratio (SAR)

Introduction

Out of an estimated area of 173.64 million hectare (M ha) of total degraded land approximately 7 M ha are affected by soil salinity/sodicity in India (Abrol and Bhumbla, 1971). During the last decade several agencies have given divergent estimates of extent of salt-affected soils. For example, the National Commission of Agriculture indicated the extent as 7.16 M ha, the National Remote Sensing Agency as 3.9 M ha, the National Wasteland Development Board as 1.5 M ha and the National Bureau of Soil Survey and Land Use Planning as 6.02 M ha. Singh (1992) estimated the extent of these soils to be 9.8 M ha. The data from various sources were critically evaluated at Central Soil Salinity Research Institute, Karnal (Haryana) and figure has now been updated to 6.7 M ha. An area of more than 2.5 lakh ha affected by salinity and alkalinity is estimated to be existing in the Chambal Command area of Madhya Pradesh. These soils extent in 23 districts spreading over two soil regions *i.e.* black soil region and the alluvial soil region in Chambal Command area (Raghuwanshi, 2011). High water table in irrigation commands like Chambal, Kunwari, Asan, Sankh, Tawa and Barna had inflicted a wide spread secondary salinization. Soil salinity and alkalinity problems in Chambal division occur primarily due to use of poor quality waters for irrigation, over-irrigation in canal command area, imbalanced use of nutrients coupled with limited use of organic manures, less recycling and burning of crop residues in soil, soil erosion, undulated topography, water logging in canal command area, improper drainage, and presence of natural salt in sub surface, etc. The distribution of water quality in Madhya Pradesh state was observed as 75% good, 10% marginal and 15% poor quality underground water (Yadav and Kumar, 1995). Keeping above points in view, the present study was undertaken to determine the detail information about quality of soil and its properties with respect to their suitability for crops and management of soil for sustainable production system.

*Corresponding author

Material and Methods

The present investigation was carried out in different blocks in Morena district which is situated in the northern part of Madhya Pradesh and the agro-ecological region of investigation area is N8D2 (Sehgal, 1996). The study area is located in between 23° 15' to 26° 45' N – latitude and 70° 30' E – longitude with an altitude ranging from 150 to 240 m. The agro-climatic region of Madhya Pradesh state of India is under Central Plateau and Hills Region and state is further divided into 11 sub agro-climatic zone. The Morena district falls under Gird Agro-climatic zone. The climate of this zone is characterized as semi-arid and extremely hot during May-June (up to 49°C) and extremely cold during end of December to January (up to 0°C). Only 90 % of the rainfall is received from south-west monsoon during July to September and rest in winter. The mean annual rainfall of the district is less than 700 mm. Total geographical area of Morena district is 5.67 lakh ha. Out of this total area 2.39 lakh is under cultivation consisting of alluvial and 0.24 lakh ha medium black soils (Tomar *et al.,* 1995). Their texture is variable ranging from very coarse to fine. However the soils of the area are deep, alluvium derived soils with medium AWC (available water retention capacity). The major crops of the area of investigation are paddy, sesame, pearl millet and sorghum in *Kharif,* whereas mustard and wheat in *Rabi.*

A salt affected soils map was prepared using data of soil analysis; features identified showing salinity/sodicity problem on digital satellite data of Resourcesat-1 LISS-III through visual interpretation of the digital image using Remote Sensing Software (ERDAS IMAGINE 8.7) and geographical position of the identified points of salinity/sodicity. Digital satellite data were procured from the NRSA, Hyderabad. Geographical position of the identified points was recorded using RS software and soil samples were collected from these identified points. During the traversing of the area, soil samples were also collected from locations other than identified one, showing problem of salinity/sodicity. The morphological features of the area studied and were described in the field as per soil survey manual of USDA (Soil Survey Staff, 1998). The collected soil profile samples were analyzed for different physico-chemical properties in the laboratory as per standard methods of Richards (1954). On the basis of degree of salinity and sodicity, the soils were classified and map of the district was generated. According to salinity and sodicity hazards, the soil was classified in to three different categories viz, for salinity [Slight (ECe 4-8 dS m^{-1}), Moderate (ECe 8-15 dS m^{-1}) and High (ECe > 15 dS m^{-1})] and for alkalinity [Slight (ESP 15-25), Moderate (ESP 25-40) and High, (ESP > 40)] as suggested by Verma *et al*. (2014).

Results and Discussion

Physico-chemical properties of soil

The soil textures of surface soils were sandy loam, sandy clay loam and clayey (Table 1). The colour varied from brownish yellow to yellowish brown and light yellowish brown. Soils were slight to highly erodible, well drained and infiltration rate ranged from 2.8 to 7.9 mm hr^{-1} with mean value of 5.4 mm hr^{-1}. The saturation percentages of soils were from 24.7 to 42.7 and with mean value 30.95. The bulk density ranged from 1.48 to 1.56 Mg m^{-3} with mean value of 1.51 Mg m^{-3}. The calcium carbonate ($CaCO_3$) content varied from 0.63 to 2.3% with mean value of 0.83%. As per rating limit proposed by FAO (1973), none of the soil samples were found in calcareous ($CaCO_3$ content <5%). Organic carbon contents ranged from 0.22 to 0.51% having an average value 0.35%.

According to Muhr *et al.* (1965) rating limit, 97% soil samples were found in low carbon content (<0.50 %) whereas, 3% were medium (0.50 to 0.75 %) in range and none of the soil samples were found in high (>0.75 %) in organic carbon content. All soil samples were found neutral to alkaline in reaction and pH values of saturation paste varied from 8.0 to 9.1 having mean value of 8.55. The higher value of pH could be due to increase in accumulation of bicarbonate, sodium and calcium carbonate in soil. The electrical conductivity of saturation paste ranged from 2.50 to 8.62 dS m^{-1} with the mean values of 3.93 dS m^{-1}. Cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) ranged from 19.2 to 46.2 cmol (p^+) kg^{-1} and 18.1 to 56.2%, respectively and mean of CEC and ESP values were 34.5 and 38.4, respectively. In most of the soil samples ESP was observed greater than 15, and pH values were also higher than 8.5 indicating severe alkaline conditions in soil.

The calcium content of saturation extract was 9.1 to 46.2 cmol (p^+) kg^{-1} and recorded mean value 21.1 cmol (p^+) kg^{-1} of calcium (Table 1). The sodium content of saturation extract ranged from 8.4 to 18.8 cmol (p^+) kg^{-1} and with mean value of 13.25 cmol (p^+) kg^{-1}. The potassium content of saturation extract ranged from 0.10 to 1.25 cmol (p^+) kg^{-1} with mean value 0.27 cmol (p^+) kg^{-1}. Saturation extract analysis of cations revealed that the dominating cations was calcium followed by sodium and potassium, respectively.

The anion content of saturation extract varied from 0.40 to 0.80 cmol (p^+) kg^{-1} with mean value 0.63 cmol (p^+) kg^{-1} of carbonate (Table 1). The values of bicarbonate content of saturation extract ranged from 4.5 to 38.1 cmol (p^+) kg^{-1}, with mean value of 14.71 cmol (p^+) kg^{-1}. The chloride content of saturation extract was 14.4 to 48.5 cmol (p^+) kg^{-1} with mean value 23.64 cmol (p^+) kg^{-1}. The sulphate contents in saturation extract ranged from 1.2 to 3.1 cmol (p^+) kg^{-1} with mean value of 2.45 cmol (p^+)

Table 1. Physico-chemical characteristics of soils

Soil Characteristics	Range	Mean
Sand (%)	52.40 to 80.24	60.53
Silt (%)	14.10 to 25.72	20.15
Clay (%)	6.56 to 32.95	19.63
Soil texture	Sandy loam, Sandy clay loam and Clay	
Dry soil colour (Munsell)	10YR 6/8M, 5 5/4M, 6/4D	
Soil colour	Brownish yellow, Yellowish brown, Light yellowish brown	
Erosion	Slight to severe	
Drainage	Well drained	
IR (mm hr^{-1})	2.8-7.9	5.4
Saturation (%)	24.7 to 42.7	30.95
BD (Mg m^{-3})	1.48-1.56	1.51
$CaCO_3$ (%)	0.61-2.3	0.83
Organic Carbon (%)	0. 20 – 0. 31	0. 27
pHs	8.0 to 9.1	8.55
ECe (dS m^{-1})	2.50 to 8.62	3.93
ESP (%)	18.1 to 56.2	38.4
CEC [cmol (p+) kg^{-1}]	19.2 to 46.2	34.5
Cations of saturation extract		
Ca [cmol(p+) kg^{-1}]	9.1 to 46.2	21.1
Na [cmol(p+) kg^{-1}]	8.4 to 18.8	13.3
K [cmol(p+) kg^{-1}]	0.10 to 1.25	0.27
Anions of saturation extract		
CO_3 [cmol(p+) kg^{-1}]	0.40 to 0.80	0.63
HCO_3 [cmol(p+) kg^{-1}]	4.5 to 38.1	14.71
Cl [cmol(p+) kg^{-1}]	14.4 to 48.5	23.64
SO_4 [cmol(p+) kg^{-1}]	1.2 to 3.1	2.45
SAR ($mmol^{1/2}$ $L^{-1/2}$)	2.2 to 5.8	3.87

IR-infiltration rate, BD-bulk density, pHs-pH of saturation paste, ECe-electrical conductivity of saturation extract, ESP-exchangeable sodium percentage. CEC-cation exchange capacity, SAR-sodium adsorption ratio

Table 2. Area of salt affected soils in different categories of Morena district

Category	Area (ha)
Slight salinity and slight alkalinity (EC 4-8 dS m^{-1} and ESP 15-25)	9920
Slight salinity and Moderate alkalinity (EC 4-8 dS m^{-1} and ESP 25-40)	1263
Slight salinity and High alkalinity (EC 4-8 dS m^{-1} and ESP > 40)	1647
Moderate salinity and slight alkalinity (EC 8-15 dS m^{-1} and ESP 15-25)	5548
Moderate salinity and Moderate alkalinity (EC 8-15 dS m^{-1} and ESP 25-40)	4106
Moderate salinity and High alkalinity (EC 8-15 dS m^{-1} and ESP > 40)	108
High salinity and slight alkalinity (EC > 15 dS m^{-1} and ESP 15-25)	-
High salinity and Moderate alkalinity (EC > 15 dS m^{-1} and ESP 25- 40)	-
High salinity and High alkalinity (EC > 15 dS m^{-1} and ESP > 40)	-
Total	22592

kg^{-1}. Saturation extract analysis reveals that the dominating anions was chloride followed by bicarbonate, sulphate and carbonate, respectively. The values of sodium adsorption ratio (SAR) ranged from 2.2 to 5.8 $mmol^{1/2}$ $L^{-1/2}$ with mean value of SAR 3.87 $mmol^{1/2}$ $L^{-1/2}$.

Extent of salt affected soils

According to salinity and sodicity hazards, the soil was classified in to three different categories as suggested by Verma *et al.,* (2014). Out of the total cultivated area (262.7 thousand ha) of Morena district, salt-affected soils are distributed in 22.59 thousand ha (Table. 2) with about 8.6 % of total cultivated area of the district. The maximum area of the salt-affected soils of Morena district falls under the categories of slight salinity and slight alkalinity (9920 ha) followed by moderate salinity and slight alkalinity (5548 ha), moderate salinity and moderate alkalinity (4106 ha), slight salinity and high alkalinity (1647 ha), slight

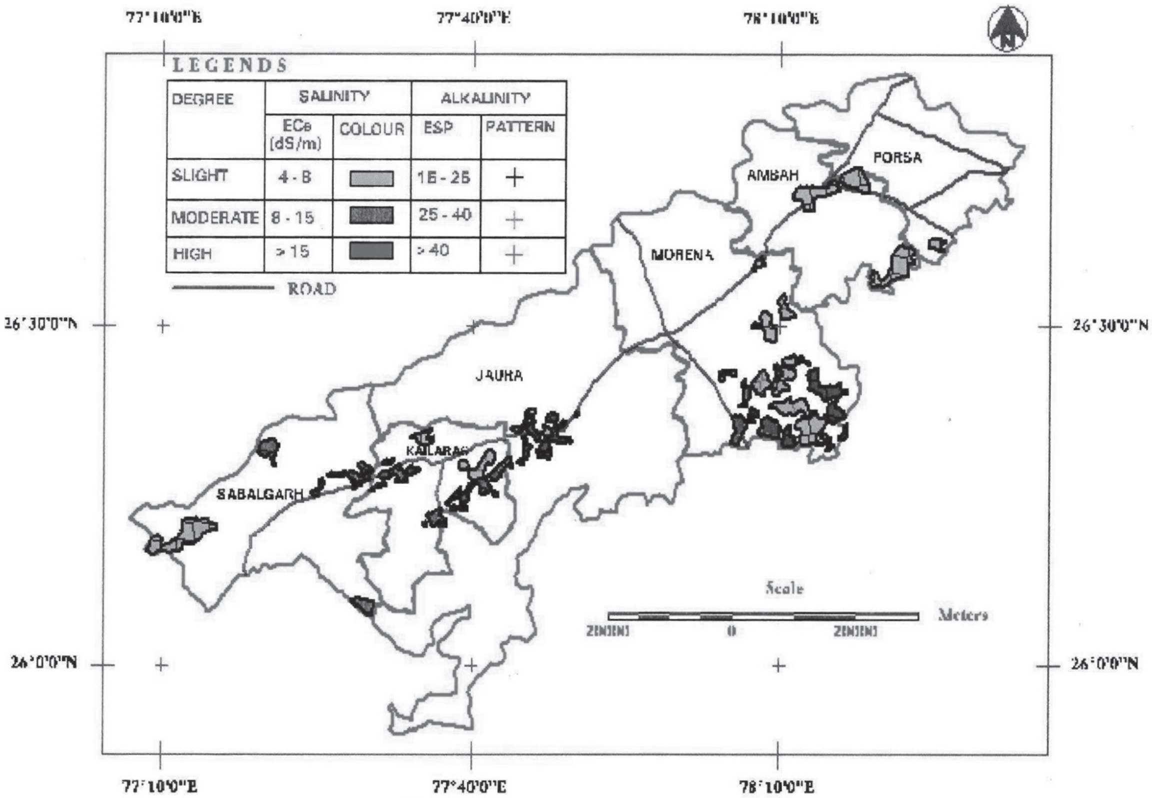

Fig. 1. Distribution of salt affected soils in Morena District of Madhya Pradesh

Table 3. Distribution of salt affected soils in different villages of Morena district

Category	Villages
Morena Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Navali, Badagaon, Karari, Kheria Kalan, Herang, Nawla, Getwal, Biseda, Indurkha, Shanipur, Basapur, Urhan, Banpura
Slight salinity and high alkalinity(ECe 4-8 dS m^{-1} and ESP > 40)	Bijolipura, Dawar, Dogarpur Lodhi, Khadagpur, Bharrad, Khuti, Endraj, Gaupura
Slight salinity and moderate alkalinity(ECe 4-8 dS m^{-1} and ESP 25-40)	Padawali, Paroli, Bhatera, Manjar, Churola, Barenda
Moderate salinity and high alkalinity(ECe 8-15 dS m^{-1} and ESP > 40)	Usretha
Moderate salinity and Moderate alkalinity (ECe 8-15 dS m^{-1} and ESP 25-40)	Karola, Godhara, Kankata pura, Nayagaon, Mahtoli, Jhulap, Bharard, Khuti, Jaynagar, Nurabad, Gawra, Jireshwar, Tikri, Mavai, Bhidrad, Vijayath, Lakheta pura, Jaipur, Bager
Moderate salinity and slight alkalinity(ECe 8-15 dS m^{-1} and ESP 15-25)	Basapur, Badwari, Mavai, Ritarak
Joura Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Bhopatpur, Sakra, Kemra, Bachoura, Bisnouri, Simroda, Niwas, Jounara, Sikroda
Moderate salinity and Slight alkalinity(ECe 8-15 dS m^{-1} and ESP 15-25)	Parsoda, Narholi, Dhadore, Gajra, Jaura, Akbarpur-Nidhan, Manpur Balla, Amroutha, Gapra
Moderate salinity and Moderate alkalinity (ECe 8-15 dS m^{-1} and ESP 25-40)	Dhadore, Gajra, Barawali
Kailaras Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Mahema, Uchad, Bhilampur, Saipura, Haripura, Kirawali Jadid, Kheda Kala, Kheda Taur, Toda
Slight salinity and High alkalinity(ECe 4-8 dS m^{-1} and ESP > 40)	Madhopur, Piparraua, Chamargawa, Kheda Mangarh, Mali Bajna, Baman Bajna, Pandoli, Gastoli, Risoni, Bastoli, Dogarpur Mangarh

Moderate salinity and Slight alkalinity(ECe 8-15 dS m^{-1} and ESP 15-25)	Samai, Uchad, Hirawali, Rahadpur, Etora, Galpura, Butrawali, Pancholi, Suhas, Kiraich, Damezer, Fuloda, Chak-Sirwanda, Birawali, Padoli, Baman Bajna, Kirawali, Bhangarh, Kemra Cham, Pipronia, Kisloli
Moderate salinity and Moderate alkalinity (ECe 8-15 dS m^{-1} and ESP 25-40)	Badroli, Auroda, Baman Bajna, Damezer, Tilojari, Sahri, Kodera, Chodera, Sigachouli, Jillowa, Devkachcha, Sagoriya
Sabalgarh Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Bitchpuri, Niwadi, Kemara Kala, Konara, Gadula, Chawadi Pura, Shivlalpur, Itawa
Slight salinity and Moderate alkalinity(ECe 4-8 dS m^{-1} and ESP 25-40)	Dubhra, Kurawali
Moderate salinity and Slight alkalinity (ECe 8-15 dS m^{-1} and ESP 15-25)	Bewarkhedi, Palri, Ganjikhera, Rahuka Gaon, Sunhera, Sabalgarh, Bhurwai, Kurawali
Moderate salinity and Moderate alkalinity (ECe 8-15 dS m^{-1} and ESP 25-40)	Kurawali, Murwai
Ambah Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Bareh, Madkar, Banakpur, Ambah, Inanki, Thara, Jalkandara, Pali, Tiktoli, Manpur Rajputi, Arusi, Sangoli, Lepa, Bhidosa, Kolaua, Ranipura, Swargpura
Porsa Tehsil	
Slight salinity and slight alkalinity(ECe 4-8 dS m^{-1} and ESP 15-25)	Mihroda, Budhara

salinity and moderate alkalinity (1263 ha) and moderate salinity and high alkalinity (108 ha).

Distribution of salt affected soils

Out of total 782 villages of Morena District, 167 were having the problem of salinity and alkalinity (Table 3). On the basis of degree of salinity and sodicity, the soil map of the district was generated (Fig. 1).

Fifty two villages of Morena Tehsil of the district were affected by slight salinity to moderate salinity and slight alkalinity to high alkalinity. Similarly in Joura Tehsil of Morena District, 21 villages were affected by slight salinity to moderate salinity and slight alkalinity to moderate alkalinity and 56 villages of Kailarash Tehsil of Morena District were having slight salinity to moderate salinity and slight alkalinity to high alkalinity problems. In Sabalgarh Tehsil, total 20 villages were having slight salinity to moderate salinity and slight alkalinity to moderate alkalinity problematic soils; whereas 16 villages of Ambah Tehsil were having slight salinity and slight alkalinity and in Porsa Tehsil of the District only 2 villages were affected with slight salinity and slight alkalinity problem. The salinity and alkalinity affected maximum villages in Kailarash followed by Morena, Joura, Sabalgarh, Ambah and Porsa Tehsil of the District, respectively.

Conclusions

Major factors of soil salinity and alkalinity problems were found due to irrigation with poor quality waters, over-irrigation in canal command area, undulated topography, water logging in canal command area, and improper drainage. The survey indicated that 21.36% villages representing 8.6% cultivated area were affected by salinity or alkalinity problem. In rest of the area crops such as pearlmillet, sesame, green gram, black gram, cluster bean, pigeon pea, chick pea, mustard, and wheat can be cultivated safely. The slight or moderate saline or alkali soils can be recommended to grow *Sesbania*, mustard and barley in area of coarse textured soil; whereas paddy and wheat can be grown in heavy textured soil under good quality irrigation water management. For effectively management of high alkali soils, these must be reclaimed before cultivation of crops through application of gypsum or pyrite as per requirement and use of *Sesbania* as green manure crop.

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

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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}

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