Journal of AgriSearch, 9 (3): 226-235
An Open Access International Peer Reviewed Quarterly

ISSN : 2348-8808 (Print), 2348-8867 (Online)
https://doi.org/10.21921/jas.v9i03.11007

Salt Dynamics and Budgeting in the Root Zone of Wheat under Irrigated Saline Environment

PARMANAND KUMAR[1]*, A SARANGI[2] AND DK SINGH[3]

ABSTRACT

Plant growth is adversely affected by salt deposition in the root zone and requires judicious irrigation water management for enhancing productivity in an irrigated saline environment. To study the salt deposition and subsequent leaching of salts below the root zone of wheat, an experiment with four wheat cultivars (viz. three salt-tolerant KRL-210 (V_1), KRL-1-4 (V_2), and one salt non-tolerant HD- 2894 (V_4) were taken for the experiment under artificially prepared irrigation water with salinity levels of 4 dS m^{-1} (S_2), 8 dS m^{-1} (S_3) and 12 dS m^{-1} (S_4) besides the varying salinity of the groundwater from 1.45 to 1.7 dS m^{-1}(S_1) during *rabi* seasons of 2009-10 and 2010-11 at the research farm of Indian Agricultural Research Institute (IARI), New Delhi, India. The soil salinity ($EC_{1:2}$) was 0.2 dS m^{-1} before the conduction of the experiment during *rabi* 2009-10 and varied from 0.26 to 0.95 dS m^{-1} during *rabi* 2010-11. The total salt-induced in soil was 70.15 t ha^{-1} and 55.6 t ha^{-1} for *rabi* 2009-10 and 2010-11 respectively by saline irrigation water. The salt deposition in the crop root zone was observed at maximum (i.e., 17.04 and 22.97 t ha^{-1} during *rabi* 2009-10 and 2010-11, respectively) for S_4 treated plots and minimum in S_1 treatment levels. The production functions for wheat varieties were developed and the coefficient of determination (R^2) was 0.98 to 0.99 and 0.94 for salt-tolerant and salt non-tolerant varieties, respectively. Moreover, it was also estimated that the maximum salt was deposited on the top soil layer (15cm) and the leaching of salts from S_1, S_2, S_3 and S_4 treatments levels was 65%, 63%, 52%, and 48% salts, respectively from the root zone. However, this study would assist in the computation of leaching requirements for enhancing productivity in irrigated saline environments.

ARTICLE INFO

Received on	:	04/07/2022
Accepted	:	09/09/2022
Published online	:	30/09/2022

Keywords: Root zone salt dynamics; salt deposition; production functions; leaching

INTRODUCTION

Environmental factors which limit the productivity of crops, soil, and water salinity are considered to be one of the most severe environmental factors. Salinization in agriculture occurs when salts are deposited in the root zone, either due to the soil being naturally saline or due to poor drainage of water from the sub-soil, which is not adequate to prevent the capillary rise of saline water up to the root zone (Pitman and Lauchli, 2002). Food production in irrigation commands has been adversely affected by soil salinity and land degradation caused by water logging. The adoption of a subsurface drainage system can help in the rehabilitation and conservation of irrigated saline lands. The strategy to use poor quality drainage water for irrigation of winter wheat without considerable yield reduction and soil degradation has been suggested by Sharma and Rao, (1998). Saline soils are mostly distributed in arid and semi-arid regions. However, the extent and harshness of salinized areas are observational and estimates show that about 955 million ha of the world are under different categories of salt-affected soils (Qadir *et al.*, 2000). During the monsoon season there would be no long-term build-up of salts due to leaching and also it was established that despite the seasonal build-up of salts and salt transport due to saline water use causing the soil profile was salt-free at the time of sowing of *rabi* crops (Wallender, *et al.*, 2006; Verma *et al.*, 2010, 2012). According to Chhabra (1996) water can be a source of salts leading to the development of soil salinity in coastal areas or in regions where shallow groundwater is used for irrigation.

Water quality related to a salinity problem occurs if the total quantity of the salts in the irrigation water is such that the salt gets accumulated in the root zone and affects plant growth (Li *et al.*, 2015). Moreover, in areas where annual rainfall is less than 250 mm, saline waters with EC exceeding 4 dS m^{-1} will cause salt toxicity in most crops (Manchanda *et al.*, 1993). Also, water up to an EC 16 dS m^{-1} can be utilized for growing some crops (*i.e.* barley, ray and soybean) in areas where annual rainfall exceeds 500 mm.

Experimental data collected from a field experiment with five levels of saline irrigation treatments (*i.e.* 0.5, 6, 9, 12 and 18 to 27 dS m-1) were used by Dutta *et al.* (1998) to estimate crop-water production functions and fitting quadratic, log-log and linear functions. They found that the production function in quadratic form produced the best results. For sustained irrigation with marginal quality water, different practices like the appropriate selection of crops, conjunctive and cyclic water use, frequency and doses of amendments have been recommended (Minhas and Gupta, 1992; Oster,1994; Minhas, 1996; Sharma and Minhas, 2005; Soother *et al.*, 2019). The crop yield increased with an increasing amount of applied water for all irrigation regimes indicating the water production functions of wheat developed by Singh *et al.* (2009) with a single level of alkali water (*i.e.* 3.7 dSm-1) and two levels of

[1]Scientist-D, Forest Research Institute, Dehradun-248006, India
[2]Principal Scientist, WTC, ICAR-IARI, New Delhi-12, India
[3]Principal Scientist and Professor, Division of Agricultural Engineering, ICAR-IARI, New Delhi-12, India
*Corresponding Author E-mail: pkumar@icfre.org

saline irrigation (i.e. groundwater; 3.5 and 9.4 dS m-1). However, maximum yields were obtained with groundwater but were not achieved even with increased quantities of saline water and need to be proper irrigation scheduling (Wang et al., 2016). A crop-water-salinity production function developed by Yang-Ren *et al.* (2007) and coupled with a soil-water-salinity dynamic regression maximize the net return of irrigated wheat crop. They were suggested for wheat and cotton crop, If the salinity concentration was more than 10.9 dS m^{-1} in groundwater, then irrigation was needed with only fresh water and if the salinity was about 7.8 dS m^{-1}, twice irrigation was required with fresh water and once with saline water and if less than 4.7 dS m-1, irrigation could be sole with saline water for getting optimum crop yield.

Water logging and land degradation due to salinity is the largest and least manageable natural resource. Since, the leaching requirement for frequently irrigated wheat, sorghum, and lettuce crops for improving productivity was established by Hoffman, *et al.* (1979) and Zhu *et al.* (2019) developed a salt balance model for long-term soil salt prediction. Once leaching of the salts has happened, it is necessary to keep the salts at a depth that minimises the impact on plant growth. Salt movement was observed by Van Hoorn (1981) and Ayars *et al.* (1993) in a soil profile having sandy loam and silty clay loam texture. Gupta and Abrol (2000) suggested carrying out the regional salt and water balance study in the northwest Indo Gangetic Plain (IGP) for enhancing the productivity of rice-wheat cropping systems.

The salt dynamics were measured through frequent soil sampling from different crop root zone depths and the impact of salinity was studied by Bakker *et al.* (2010). The soil samples up to 100 cm depth with 10 cm intervals were collected seasonally and found substantial seasonal variations in the salt dynamic with groundwater fluctuation (Cullu, *et al.*, 2010). Liu *et al.* (2020) studied the impact of the root system on solute transport and accumulation in the root zone and they found a strong correlation between root location and salt distribution in the soil. To study the salt dynamics and its deposition, an experiment was conducted during the wheat-growing period with three salts tolerant and one salt non-tolerant wheat varieties under different irrigation water salinity regimes. The objective of this study was to quantify the amount of salt build-up or leached down below the root zone and to estimate the amount of salt-induced by the irrigation water during the crop growth period. Further, the depth of rainfall required or fresh irrigation water to eradicate excess salt from the root zone was estimated which would assist in the design of subsurface drainage systems for retrieval of salt-affected lands.

MATERIALS AND METHODS

Descriptions of Experimental Site

A field experiment was conducted during *rabi* 2009-10 and 2010-11 at the experimental farm of Water Technology Centre (WTC), Indian Agricultural Research Institute (IARI), New Delhi, India. The experimental site is located between 28° 37' 22″ to 28° 39' 00″ N and 77° 8' 45'' to 77° 10' 24'' E with an average elevation of 230 m amsl.

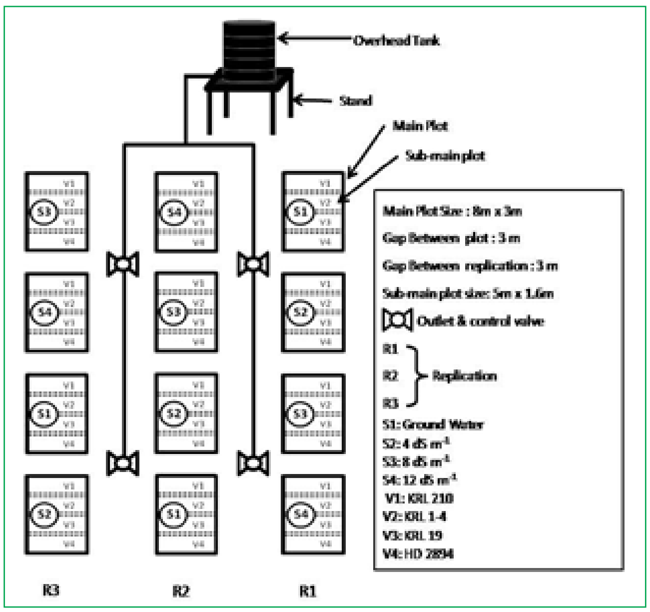


Fig. 1: Layout of the field experiment with different wheat varieties and saline irrigation levels (A) and the infrastructure for providing saline water to different plots of the experiment with standing crop (B)

The soil of the study site was deep, well-drained sandy loam containing 63.05% sand, 20% silt and 16.6% clay for an average of 30 cm soil depth. The saturated hydraulic conductivity of soil was 22.16 cm $d^{-1}$and bulk density 1.75 Mg m^{-3}, respectively (Table 1). For mixing of three salts (*viz*. NaCl, $MgSo_4$, $CaCl_2$) to prepare artificial saline water for irrigating at designed salinity levels of 4 dS m^{-1} (S_2), 8 dS m^{-1} (S_3) and 12 dS m^{-1} (S_4), an overhead tank was installed at 2 m height (Fig. 1). The control plots were irrigated using groundwater with salinity varying from 1.45 to1.7dSm^{-1} during the study period. The study was conducted with four wheat varieties with 3 salt-tolerant varieties (*i.e.* KRL-210, KRL-1-4, KRL-19) and one non-salt-tolerant variety (HD2894).

Table 1: Physical and chemical properties of the soil of the experimental field

Determination	Soil depth				
	0-15	15-30	30-45	45-60	60-90
Sand (%)	62.4	63.7	44	39	39
Silt (%)	21	19	23	25	27
Clay (%)	16.6	17.3	33	36	34
Soil texture	Sandy loam	Sandy loam	Loam	Loam	Clay loam
FC (w/w)	20.45	22.02	30.59	32.8	33
PWP (w/w)	9.5	10.2	13.7	14.7	15
Ks (cm d^{-1})	27.4	26.2	18.6	19.1	19.5
Bd (g cm^{-3})	1.66	1.7	1.88	1.67	1.83
EC (dS m^{-1})	0.2	0.12	0.11	0.13	0.12
pH	7.7	8.1	8.01	8.05	8.5
Organic matter (%)	0.53	0.48	0.40	0.37	0.38
N (ppm)	179	159	130	123	126
P (ppm)	3.3	3.7	129.6	4.3	4.1
K (ppm)	172.4	177.7	182.5	188.1	191.2

† Bd: Bulk Density, Ks: Saturated Hydraulic Conductivity, FC: Field Capacity, PWP: Permanent Wilting Point, EC: Electric Conductivity

Irrigation Scheduling

The soil moisture deficit (SMD) method was applied for irrigation scheduling with periodic monitoring of soil moisture using Frequency Domain Reflectometer (FDR) soil moisture sensors. The maximum allowable moisture deficit criterion (*i.e.* 50% of the moisture between the field capacity (FC) and the permanent wilting point (PWP)) was used to estimate the amount of irrigation water on a volumetric basis and the root zone depth of the crop. The irrigation was applied up to the FC moisture content of the soil. Therefore, adopting the above procedure, the total depth of irrigation was 258 mm and 250 mm applied during *rabi* 2009-10 and 2010-11 respectively (Table 2), whereas the effective rainfall was 14.14 mm and 32.2 mm during *rabi* 2009-10 and 2010-11, respectively.

Table 2: Irrigation schedule during 2009-10 and 2010-11

Irrigation	Days after sowing	
	2009-10	2010-11
1st	24	30
2nd	44	55
3rd	64	86
4th	80	100
5th	97	-

Soil sampling and measurement of soil salinity

Soil samples were collected from five depths at 0-15, 15-30, 30-45, 45-60 and 60-90 cm before and after irrigation to a determination of the soil salinity using the suspension extract ($EC_{1:2}$) method. For measurement of soil salinity, the soil water extract method is easier than the saturation extract method but this method takes more time and also requireslaboratory facilities. The soil: water suspensions (1:2) was prepared by adding 100 ml of distilled water (2 parts) to 50 g of air-dried soil sample. The mixture was shaken for 1 hour (Rhoades, 1982; Rhoades, 1989) in a mechanical shaker. The stirred solution was allowed to settle down and subsequently filtered and then the EC was measured using an EC meter.

Estimation of total salt content in the soil

The salt deposition in soil was estimated by measurement of soil EC measured by suspension extracts (1:2) method. The estimated unit of soil salinity in dS m^{-1} under different salinity levels and also at different root zone depths were converted to t ha^{-1} unit by using Eq. 1. The experiment data were used and subsequent analysis to develop this equation.

$$S_{Di} = \frac{ECi \times D_f \times 640}{10^9} \times BD_i \times V_{si} \quad (1)$$

Where,

S_{Di} = Salt deposited in i^{th} layer, t ha^{-1},

EC_i = Salinity in i^{th} layer, dS m^{-1},

D_f = Dilution factor (*viz.* for $EC_{1:2}$ the D_f will be 2; after multiplying EC1:2 will be converted into ECe and it is an actual representation of salt concentration in the soil)

BD_i= Bulk density in i^{th} layer, kg m^{-3}, and

V_{si} = Volume of soil in i^{th} layer per hectare, m^3 ha^{-1}

Salt induced in the soil during the wheat growing season

Total salt-induced by irrigation water in the study plots was 70.14 t ha^{-1} (*viz.* 5.96, 11.67, 23.30 and 29.22 t ha^{-1} for S_1, S_2, S_3 and S_4 respectively) for *rabi* 2009-10 and 55.60 t ha^{-1} (*viz.* 4.05, 8.66, 17.18 and 25.71 t ha^{-1} for S_1, S_2, S_3 and S_4 respectively) for *rabi* 2010-11 and the saline water prepared artificially for irrigation with EC of 4 dS m^{-1}, 8 dS m^{-1} and 12 dS m^{-1}obtained by mixing of 3 salts (*viz.*NaCl, $MgSo_4$, $CaCl_2$) in the ratio of 2.5:1.5:1 is given in Table 3.

Table 3: Salt induced in soil by irrigation water in different treatments.

Salinity levels	Salt Induced (t ha^{-1})	
	2009-10	2010-11
S_1	5.96 (8.5%)	4.05 (8.1%)
S_2	11.67 (16.6%)	8.66 (15.6%)
S_3	23.30 (33.2%)	17.18 (30.9%)
S_4	29.22 (41.7%)	25.71 (45.4%)
Total	**70.14**	**55.60**

Table 4: $EC_{1:2}$ of the soil before and after crop seasons

Soil Depth	Salinity gradient	$EC_{1:2}$ of the soil before sowing ($dS\ m^{-1}$)		$EC_{1:2}$ of soil after harvesting ($dS\ m^{-1}$)	
		2009-10	2010-11	2009-10	2010-11
0-15	S1	0.2	0.39	0.58	0.42
	S2	0.2	0.58	1.39	0.48
	S3	0.2	0.74	1.97	2.77
	S4	0.2	0.95	2.15	4.00
15-30	S1	0.12	0.31	0.41	0.69
	S2	0.12	0.56	0.82	0.80
	S3	0.12	0.47	1.17	1.27
	S4	0.12	0.26	1.15	2.02
30-45	S1	0.11	0.36	0.36	0.29
	S2	0.11	0.43	0.65	0.35
	S3	0.11	0.54	0.85	0.37
	S4	0.11	0.53	0.90	1.78
45-60	S1	0.13	0.53	0.33	0.29
	S2	0.13	0.89	0.56	0.37
	S3	0.13	0.43	0.68	0.38
	S4	0.13	0.68	0.88	1.60
60-90	S1	0.12	0.77	0.33	0.19
	S2	0.12	0.89	0.51	1.03
	S3	0.12	0.67	0.54	0.33
	S4	0.12	0.77	0.74	0.98

Salt Budgeting

The soil samples were collected from different experimental plots for measurement of $EC_{1:2}$ in $dS\ m^{-1}$ and it was converted to $t\ ha^{-1}$ by using Eq.1 and shown in Table 5. It was observed from Table 5 that the salt content in soil was 2.26 $t\ ha^{-1}$ during *rabi* 2009-10 before execution of the experiment for all the salinity levels. However, the salt content before sowing during *rabi* 2010-11 in different treatments varied with the highest salt content of 11.54 $t\ ha^{-1}$ occurring in S_2 level and the lowest of 8.01 $t\ ha^{-1}$ in S_1 level. Such variation under different salinity treatment plots can be attributed to rainfall and saline irrigation water applied for growing maize crops during the *kharif* 2010. Moreover, the analysis of soil samples from different plots after the harvest of wheat showed that the minimum salt deposition was 4.43 $t\ ha^{-1}$ in the crop root zone for S_1 level during *rabi* 2009-10 whereas, the salt deposition in the same salinity level was -1.8 $t\ ha^{-1}$ (the negative sign indicated that the salt was leached out from the root zone) during *rabi* 2010-11. The maximum salt deposition, 17.04 and 22.97 $t\ ha^{-1}$ were observed during *rabi* 2009-10 and 2010-11, respectively in S_4 level plots. The total salt in soil was observed to be maximum *i.e.* 31.48 $t\ ha^{-1}$ during 2009-10 whereas; it was 37.09 during *rabi* 2010-11 in S_4 level (Table 5). It was also observed from Table 5 that the leaching of salt was maximum (*i.e.* 12 $t\ ha^{-1}$) under S_4 level during *rabi* 2009-10, whereas the maximum leaching (*i.e.* 9.99 $t\ ha^{-1}$) was observed during *rabi* 2010-11in S_2 and S_3 salinity levels. The leaching of salt to be 19%, 6%, 32%, and 39% were observed during 2009-10 and 48%, 49%, 36%, and 7% during 2010-11 from S_1, S_2, S_3, and S_4 levels, respectively. However, the more leaching percentage during *rabi* 2010-11 might be due to higher rainfall during the crop growing season (*i.e.* 128% more during *rabi* 2010-11 than during *rabi* 2009-10).

The salinity of soil samples from different treatments was measured after harvesting of *rabi*2009-10 wheat during April 2010 and also during November 2010 before sowing of wheat for *rabi* 2010-11to estimate the leaching of salt from the root zone. The quantity of leached salt 2.22, 9.10 and 8.16 $t\ ha^{-1}$ were observed in S_2, S_3 and S_4 salinity levels, respectively. However, the leaching from the plots under the control treatment (Groundwater; S_1) was not observed during the two years of the experiment. On average, it was estimated that rainfall depth of 14.5 cm could remove about one ton of salt from the root zone from all salinity levels. Moreover, the salt deposition was highest at S_4 level due to maximum salt-induced in the same treatment during both *rabi* seasons of 2009-10 and 2010-11. The salt-induced, salt before sowing, salt after harvesting and salt deposition in the root zone of all wheat varieties in

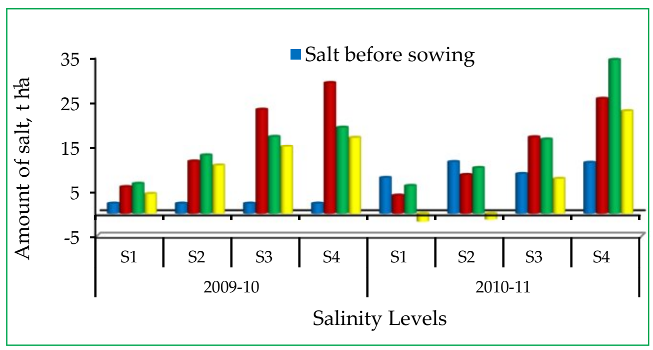


Fig. 2: Salt deposition in the root zone during *rabi* 2009-10 and 2010-11

Table 5: Salt budgeting in soil profile within the crop root zone

Year	Salinity levels	Salt before sowing ($t\ ha^{-1}$)	Salt induced ($t\ ha^{-1}$)	Salt after harvesting ($t\ ha^{-1}$)	Salt deposition ($t\ ha^{-1}$)	Total salt in soil	Total leached out
		(a)	(b)	(c)		(a+b)	(a+b)-c
2009-10	S1	2.26	5.96	6.69	4.43	8.23	1.54
	S2	2.26	11.67	13.04	10.77	13.93	0.90
	S3	2.26	23.30	17.26	15.00	25.56	8.30
	S4	2.26	29.22	19.31	17.05	31.48	12.17
2010-11	S1	8.01	4.05	6.22	-1.80	12.07	5.85
	S2	11.54	8.66	10.21	-1.33	20.20	9.99
	S3	8.88	17.18	16.69	7.80	26.06	9.38
	S4	11.37	25.71	34.35	22.97	37.09	2.74

different treatments during both seasons of the experiment is shown in Fig. 2. It was observed from Fig. 2 that there was no salt deposition in the crop root zone during *rabi* 2010-11 under S_1 and S_2 treatments.

Root Growth under Saline Environment

The rooting depth of different wheat cultivars was observed to vary from 70 cm to 90 cm (Fig. 3). Root depth of different cultivars was observed to be more during rabi 2010-11 as compared to *rabi* 2009-10. This may be attributable to more rainfall and leaching of salts from the root zone during *rabi* 2010-11 than *rabi* 2009-10. Maximum root depth of 88.2 cm and 90 cm for the salt-tolerant cultivar KRL-210 was observed during *rabi* 2009-10 and 2010-11, respectively under saline water treatment of 8 dSm^{-1}. Minimum root zone depth, 71.2 cm and 73.3 cm for the salt non-tolerant cultivar HD-2894 were observed under salinity level 4 dSm^{-1} during *rabi* 2009-10 and 2010-11, respectively. It was also observed from Fig. 3 that the higher rooting depth (*i.e.* 81 cm and 84 cm for years 2009-10 and 2010-11, respectively) for salt non-tolerant wheat variety HD-2894 at higher salinity levels (8 $dS\ m^{-1}$), and it was more than the rooting depth of other varieties at same salinity levels.

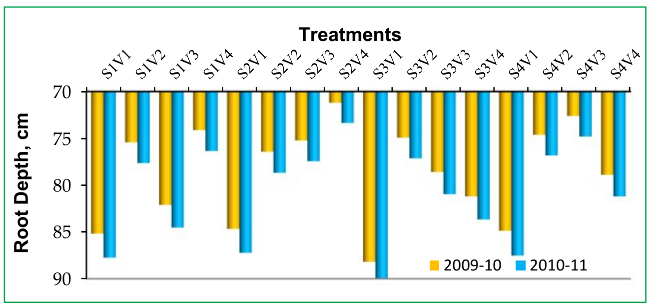


Fig. 3: Depth of root under different treatments of salinity for *rabi* 2009-10 and 2010-11

Development of Regression Equations on Salt Deposition

(2)An effort was made in this study to develop a regression equation relating to salt deposition using the data taken from field experiments conducted during *rabi* 2009-10 and 2010-11. Relationships were established between observed data of salt-induced by irrigation water, the salt concentration in the soil before sowing of seed, depth of irrigation, salt deposition in the root zone and depth of rainfall during the growing season (Eq. 2). The standard error of the developed regression equation and coefficient of determination (R^2) were observed at 4.76% and 0.87 respectively, and the correlation coefficient was 0.93. The regression equation is developed with a mention of the range of different parameters used for the development of the model. The model can be used for the prediction of salt deposition in the root zone and for the experimental environment similar to that of the reported study region using four input parameters. The developed equation was:

$$S_D = 0.51S_{bs} + 1.03S_I + 4.731_I - 24R_I - 13.42$$

Where,

S_D = Salt deposition ($t\ ha^{-1}$)

S_{bs} = Salt before sowing ($t\ ha^{-1}$) Range: $2.26 \leq S_{bs} \geq 11.54$

S_I = Salt induced ($t\ ha^{-1}$) Range: $4.05 \leq S_I \geq 29.22$

I_I = Irrigation Index (ratio of irrigation, cm and salt-induced, $t\ ha^{-1}$) Range: $0.07 \leq I_I \geq 1.13$

R_I = Rainfall index (ratio of rainfall, m and salt induced, $t\ ha^{-1}$) Range: $0.88 \leq R_I \geq 6.17$

Development of Crop-Water Production Function

The productivity of wheat is highly influenced by the quantity and quality of the irrigation water and initial soil salinity. Other factors that might have affected the productivity of the wheat crop and its quality were considered to be constant while developing the crop-water production function. The relationships between the yield of wheat and other parameters used in the production function can be presented as (Eq. 3):

$$Y = f(G_c, Y_a, S_i, D_i, D_r) \quad (3)$$

Where,

Y = crop yield per unit of area

G_c = crop growth parameters

Y_a = yield attributes

S_i = salt induced in soil by irrigation water

D_i = depth of irrigation water

D_r = depth of rainfall during growing season

The governing parameters such as yield, soil salinity, irrigation water and rainfall depths acquired from the experiment were used to develop the production functions of different wheat varieties. The yield attributes and crop growth parameters were spikes per m^2, thousand kernel weight and maximum plant height. The rainfall depth representing the rainfall that occurred during the growing season besides salt-induced during the growing season was representative of the soil salinity and saline irrigation water depth. Developed equations for four different wheat varieties relating to these parameters are presented in Eq. 4 to 7.

The coefficient of determination (R^2) of these regression equations were 0.99, 0.98 and 0.98 for varieties V_1, V_2 and V_3 (salt-tolerant) verities, respectively. Moreover, the standard errors (SE) of these equations were observed to be 1.9%, 10% and 7% for V_1, V_2 and V_3 varieties, respectively. Prediction error statistics of developed equations showed that the salt-tolerant varieties performed better in a saline environment and these production functions will be useful for the irrigated saline environment with maximum salinity of 12 dSm^{-1}. However, the production functions developed for salt non-tolerant variety may not be useful for salinity exceeding 4 dSm^{-1} beside the higher value of SE could be an indicator reflecting poor performance of salt non-tolerant variety in an irrigated saline environment. The results were in line with the findings reported by Dutta *et al.,* 1998. The crop-water production functions developed using the experimental data of the study area were:

(4)<u>KRL-210 (V_1)</u>

$$Y = -0.00015P_{hmax} + 0.73T_{kw} - 0.0015S_{psm} + 0.21R_i - 0.24I_i - 18.77 \quad (4)$$

$R^2 = 0.99$; SE = 1.9%

<u>KRL-1-4 (V_2)</u>

$$(5) Y = 0.037P_{hmax} - 0.05T_{kw} + 0.008S_{psm} + 0.21Ri - 0.24I_i - 18.77 \quad (5)$$

$R^2 = 0.98$; SE = 10%

<u>KRL-19 (V_3)</u>

$$Y = 0.037P_{hmax} - 0.05T_{kw} + 0.008S_{psm} + 0.21Ri - 0.24I_i - 18.77 \quad (7)$$

$R^2 = 0.98$; SE = 7%

<u>HD2894 (V_4)</u>

$$Y = 0.07P_{hmax} - 5.62T_{kw} + 0.4S_{psm} + 0.016Ri + 1.13I_i + 54.8 \quad (8)$$

$R^2 = 0.94$; SE = 30%

Where,

Y = grain yield ($t\ ha^{-1}$)

P_{hmax} = Maximum plant height (cm) Range: $45 \leq P_{hmax} \geq 83$

T_{kw} = Thousand kernel weight (g) Range: $25 \leq T_{kw} \geq 38$

S_{psm} = Spikes per m^2 Range: $230 \leq S_{psm} \geq 390$
I_I = Irrigation Index (ratio of irrigation in cm and salt-induced in t ha^{-1}) Range: $0.05 \leq I_I \geq 1.5$
R_I = Rainfall index (ratio of rainfall in cm and salt-induced int ha^{-1}) Range: $0.5 \leq R_I \geq 6.5$

The soil samples before and after irrigation were analysed from all treatments and salt dynamics observed in the root zone during *rabi* 2009-10 and 2010-11 (Figs. 4 to 7). The salt deposition was observed to be maximum in the upper layer (15 cm) which varied from 0.5 dS m^{-1} to 0.74 dS m^{-1},

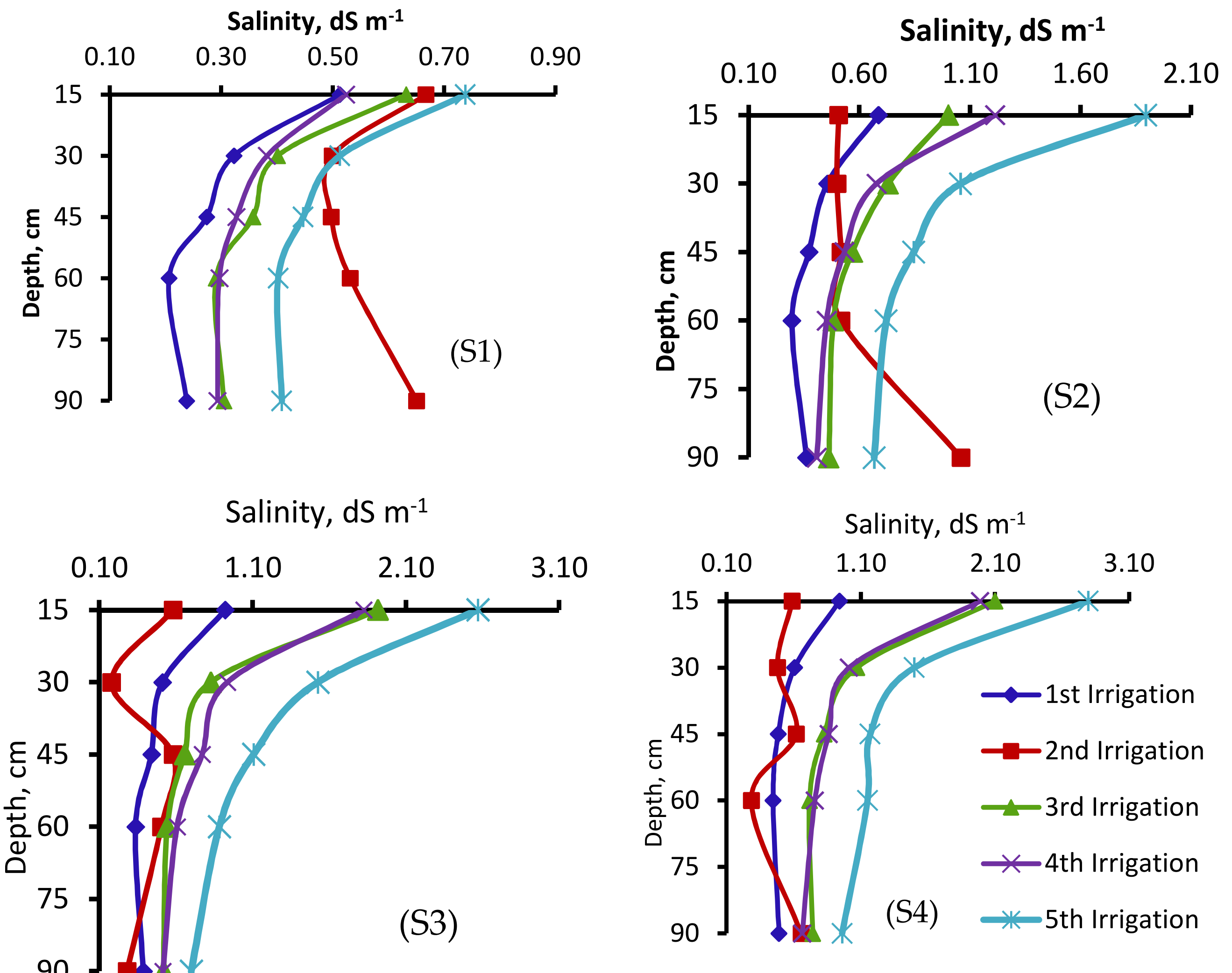
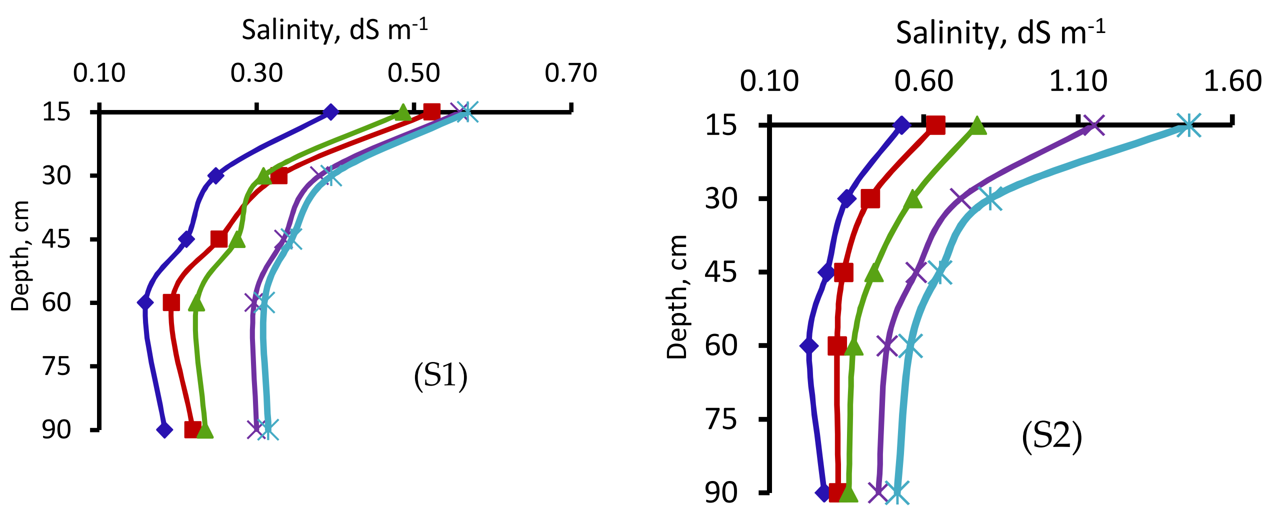


Fig. 4: Salt dynamics before each irrigation during rabi 2009-10.



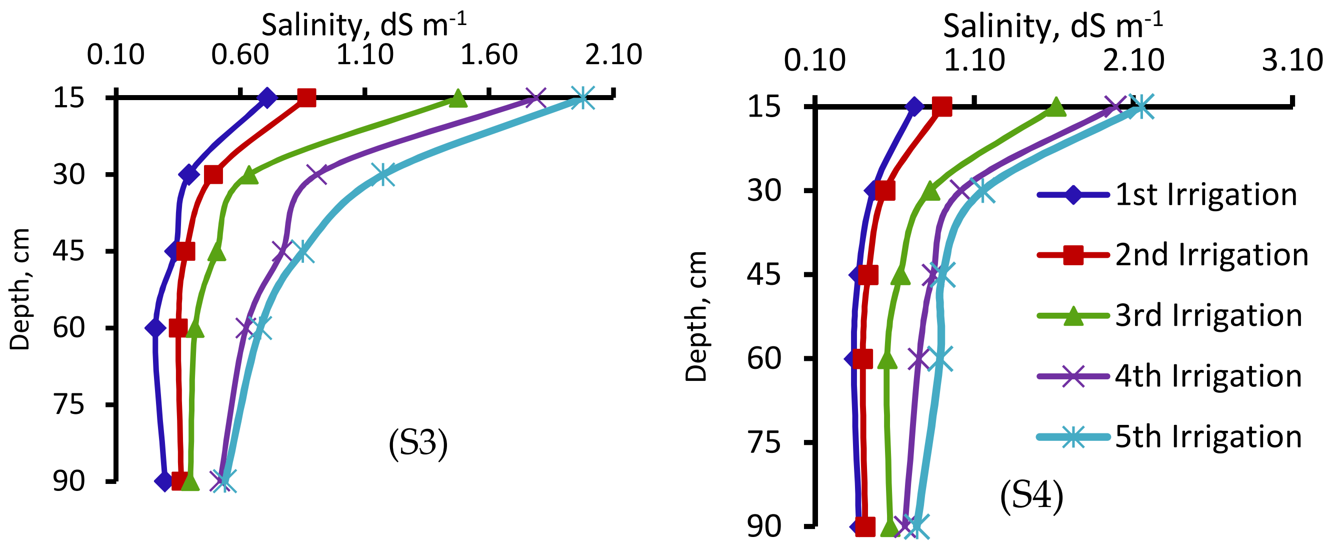


Fig. 5: Salt dynamics after each irrigation during *rabi* 2009-10.

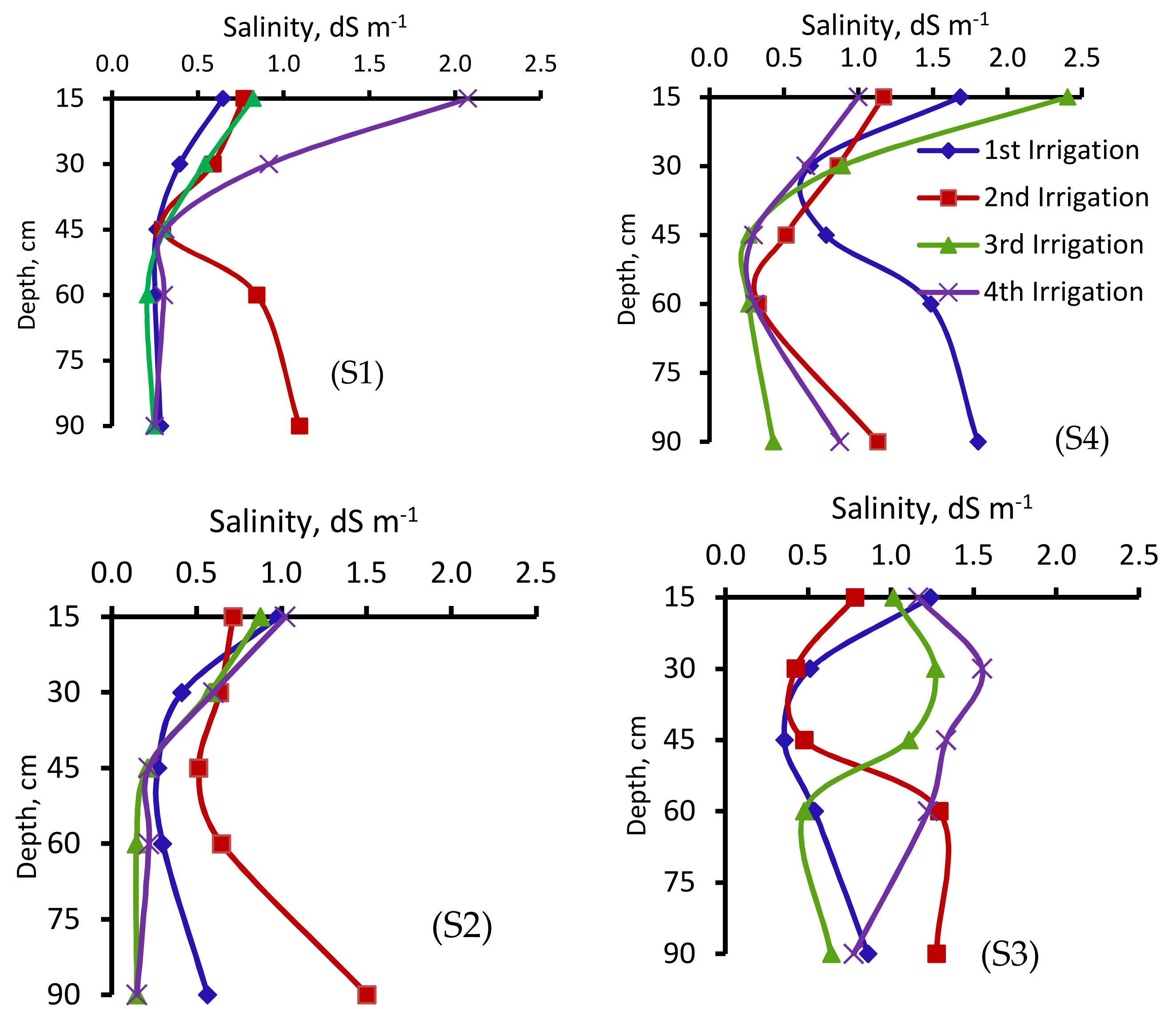


Fig. 6: Salt dynamics before each irrigation during rabi 2010-11.

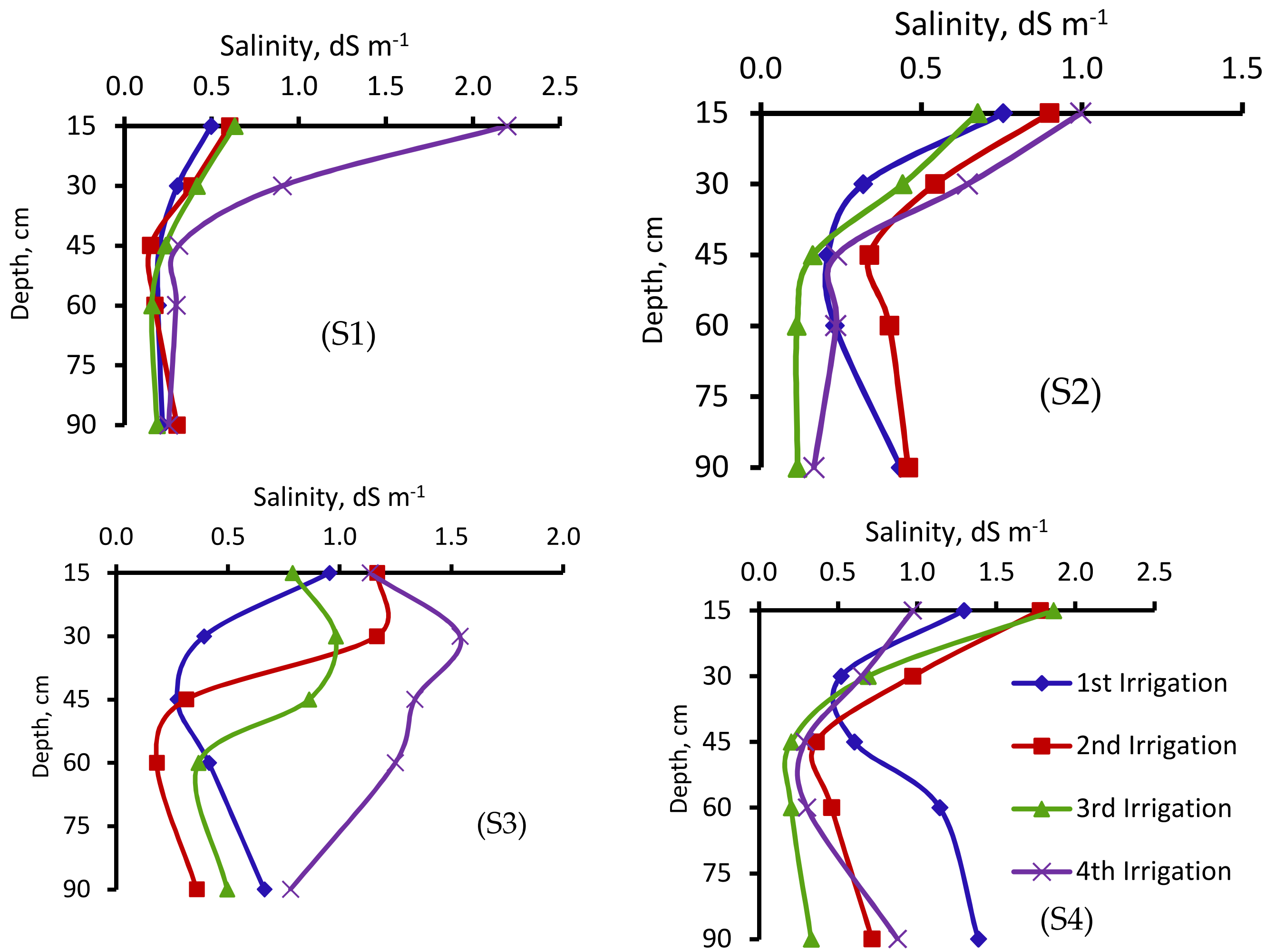


Fig. 7: Salt dynamics after each irrigation during rabi 2010-11.

before and after all irrigations during *rabi* 2009-10 at different salinity levels. Moreover, the soil salinity did not follow any specific trend and the soil salinity decreased with increased depth of root zone at a soil depth of 90 cm for S_1 and S_2 salinity levels in which before 2nd irrigation the salinity was observed to be more than the upper layer. The soil salinity was almost the same for S_3 and S_4 salinity levels at 90 cm depth before each irrigation. The trend of variation in root zone soil salinity up to 90cm depth was observed to be similar for all salinity levels (Fig. 4). The trend of salt deposition was observed to follow the uniform pattern for all salinity levels after each irrigation. The soil $EC_{1:2}$ was found at maximum (*i.e.* 0.39 to 2.15 dS m^{-1}) and minimum (*i.e.* 0.18 to 0.74 dS m^{-1}) in the upper soil layer up to 15cm depth and at lower soil depths at 60 to 90cm, respectively, for different observations recorded after each irrigation for all salinity treatments (Fig. 5).

The salt dynamics were observed during the year 2010-11 after and before irrigation and four irrigations were applied during the entire cropping season. The maximum salt deposition before irrigation was observed in the upper layer (15 cm) of the soil and the minimum was found in the lower layer (90 cm) of soil depth. However, the salt deposition was observed more (*i.e.* 0.91 dS m^{-1}) in 90 cm soil depth as compared to the salt deposited on the upper layer. The minimum (*i.e.* 0.58 dS m^{-1}) salt deposition was observed for S_1 salinity level before the first irrigation and maximum (*i.e.*2.40 dS m^{-1}) for S_4 salinity level before the third irrigation. Based on the data collected, a trend was observed in the S_1, S_2 and S_4 salinity levels before each irrigation whereas no such trend was observed for S_3 salinity levels (Fig. 6).

The salt deposition and salt dynamics after each irrigation during *rabi* 2010-11 showed that the deposition in the upper soil depths was more than in the lower soil depths. The soil salinity after each irrigation exhibited that there were no significant differences in the salinity for S_1 and S_2 treatment, whereas, for S_3 treatment, the salinity values were close to each other in lower and upper soil depths. Moreover, higher salinity at upper and less salinity at lower root zone depths were observed in most of the treatments. However, the variation in salinity values at different depths and before and after each irrigation did not follow any specific trend and was unpredictable to infer any significant conclusion. The randomness of such data was more prominent during 2010-11 as compared to 2009-10 and this could be due to the higher rainfall during 2010-11 which might have triggered erratic leaching and salts deposition from one layer to the other. Hence, the application of irrigation water at different salinity levels caused variation in soil salinity at different soil depths which did not show any definite trend (Fig. 7).

Table 6: Leaching of salt from root zone for all treatments.

Treatments	Root zone depth (cm)	Amount of salt (t ha^{-1}) before rainfall	Amount of salt (t ha^{-1}) after rainfall	Leaching of salt (kg) by per m^3 of rainfall	Leaching out (%)
	0-15	1.67	1.01	4.69	61
S1	15-30	1.05	0.76	2.02	73
	0-15	2.03	1.00	7.38	49
S2	15-30	1.36	0.56	5.73	41
	0-15	2.83	1.59	8.86	56
S3	15-30	1.61	0.69	6.51	43
	0-15	2.93	1.14	12.78	39
S4	15-30	1.76	1.10	4.73	62

Leaching Requirement

An experiment was conducted to estimate the leaching requirement to remove salt from root zone depth (up to 30 cm) using the observed soil salinity before and after rainfall of 14 mm during *rabi* 2009-10. The quantity of average salt deposition varied from 1.67 to 2.93 t ha^{-1}before rainfall in the upper layer (0-15 cm) whereas, in the lower layer (15-30 cm) the salinity variation was 1.05 to 1.76 t ha^{-1} for all treatments. Likewise, the amount of salt deposition in the upper layer was observed to be more after rainfall than in the lower layers for all treatments (Table 6). Subsequently, the average $EC_{1:2}$ of these two layers were observed1.09 dS m^{-1} and 0.59 dS m^{-1} and the reduction of salinity was due to the leaching of salt from the upper and lower layer of soil profile after rainfall, respectively. From Table 6 it was observed that the leaching of salt was maximum from the upper layer (0-15 cm) of the root zone and minimum from the lower layer (15-30 cm) of the root zone concerning per unit rainfall depth. The average leaching of salt from the upper layer was assessed to be 8.4 kg of salt per m^3 of rainfall from all treatments, whereas the same amount of rainfall could remove average salt of 4.7 kg from the lower layer of the root zone. Therefore, higher leaching (73%) was observed for S_1 treatment from 15-30 cm soil profile and minimum salt leaching (39%) was observed for S_4 treatment from 0-15 cm (upper) soil profile. These results indicated that the depth of rainfall required for leaching salt from the root zone is essentially dependent on the soil texture and hydraulic properties of cropped fields.

CONCLUSIONS

Soil salinity is one of the restraining factors of agricultural production. It is essential to the determination of soil salinity timely and reliable for subsequent water management for enhancing agricultural productivity in an irrigated saline environment. Root zone salt dynamics in the wheat crop under irrigated saline environment exhibited that the soil salinity was more in the upper 15cm depth of soil profile as compared to the lower profiles during both cropping seasons before sowing and after harvesting of the crop. The maximum leaching of salt was also observed at higher salinity levels (*i.e.* 8 and 12 dSm^{-1}) during both experimentation years as compared to lower irrigation water salinity treatments. Also, the root length of salt non-tolerant variety HD-2894 was observed more as compared to the salt-tolerant varieties at higher salinity levels. Yield production functions for different varieties and regression equations for salt deposition in the crop root zone were developed using the most causative parameters governing the salt movement, its deposition and subsequent crop yield data acquired from the different treatments of the experiment. It was also observed that the factor associated with the rainfall index in the regression equation was negative, which exhibited the importance of rainfall amount in the leaching of salt and subsequent deposition in the root zone profiles. These equations would assist in the prediction of the crop yield and estimate the leaching requirement in regions similar to the study area under irrigated saline environment. Besides this, the protocols standardized and independent variables used in this study for the development of salt deposition and production functions can be replicated in other similar regions. Overall, it can be inferred from the study that a more realistic computation of leaching requirement and selection of appropriate crop varieties pertaining to different irrigation water salinity levels for enhancing productivity from irrigated saline environments could be assisted by the salt dynamics in the crop root zone.

REFERENCES

Ayars JE, Hutmacher RB, Schoneman RA, Vail SS, and Pflaum T.1993. Long term use of saline water for irrigation. *Irrigation Science* **14**: 27-34.

Bakker DM, Hamilton GJ, Hetherington R and Spann C. 2010. Salinity dynamics and the potential for improvement of waterlogged and saline land in a Mediterranean climate using permanent raised beds. *Soil & Tillage Research* **110** (1):8-24.

Chhabra R. 1996. Soil salinity and water quality. A.A. Balkema publishers, VT, USA. 284 pp.

Cullu MAC, Aydemir S, Qadir M, Almaca A, Ozturkmen AR, Bilgic A and Agca N. 2010. Implication of groundwater fluctuation on the seasonal salt dynamic in the Harran plain, South-Eastern Turkey. *Irrigation and Drainage* **59**: 465–476.

Dutta KK, Sharma VP and Sharma DP.1998. Estimation of a production function for wheat under saline conditions. *Agricultural Water Management* **36**: 85–94.

Gupta RK and Abrol IP. 2000. Salinity build up and changes in the rice wheat system of the Indo Gangetic Plain. *Experimental Agriculture* **36**(02): 273-284.

Hoffman GJ, Rawlins SL, Oster JD, Jobes JA and Merrill SD. 1979. Leaching requirement for salinity control I. Wheat, sorghum, and lettuce. *Agricultural Water Management* **2**(2): 177-192.

Li H, Yi J, Zhang J, Zhao Y, Si B, Hill R L, Cui L and Liu X. 2015. Modeling of soil water and salt dynamics and its effects on root water uptake in Heihe arid wetland, Gansu, China. *Water* **7**:2382-2401.

Liua A, Qua Z and Nachshonb U. 2020. On the potential impact of root system size and density on salt distribution in the root zone. *Agricultural Water Management* **234**: 106118.

Manchanda HR, Karwasra SPS and Sharma HC. 1993. Salinity research at HAU. In: Manchanda, H. R., Karwasra, S. P. S., Sharma, H. C. (Eds.), CSC Haryana Agricultural University, 109 pp.

Minhas P S.1996. Saline water management for irrigation in India. *Agricultural Water Management* **30**: 1-24.

Minhas PS and Gupta RK.1992. Conjunctive use of saline and non-saline waters. III Validation and applications of a transient model for wheat. *Agricultural Water Management* **23**: 149–160.

Oster JD. 1994. Irrigation with poor quality water. *Agricultural Water Management*. **25**: 271–297.

Pitman M and Lauchli A. 2002. Global impacts of salinity and agricultural ecosystems. In: Lauchli, A., Luttge, U. (Eds.), Salinity: Environment–Plants–Molecules. Kluwer Academics, 3–20.

Qadir M, Ghafoor A and Murtaza G. 2000. Amelioration strategies for saline soils. *Land Degradation and Development* **11**: 501–521.

Rhoades JD, Nahid A, Manteghi PJ, Shouse PJ and Alves WJ. 1989. Estimating soil salinity from saturated soil paste electrical conductivity. *Soil Sci. Soc. Am. J.* **53**(4), 28-33.

Rhoades JD.1982. Soluble Salts. In: A.L. Page (ed.) Methods of soil analysis, Part 2 Chemical and microbiological properties, 2nd edition. *Agronomy* **9**:149-157.

Sharma BR and Minhas PS. 2005. Strategies for managing saline/alkali waters for sustainable agricultural production in South Asia. *Agricultural Water Management* **78**: 136 –151.

Sharma DP and Rao KVGK.1998. Strategy for long term use of saline drainage water for irrigation in semi-arid regions. *Soil and Tillage Research* **48**: 287-295.

Singh RB; Chauhan CPS; Minhas PS. 2009. Water production functions of wheat (Triticum aestivum L.) irrigated with saline and alkali waters using double-line source sprinkler system. *Agricultural Water Management* **96**:736–744.

Soothar RK, Zhang W, Liu B, Tankari M, Wang C, Li L, Xing H, Gong D, and Wang Y. 2019. Sustaining yield of winter wheat under alternate irrigation using saline water at different growth stages: A case study in the North China Plain. *Sustainability* **11**:45-64.

Sun G, Zhu Y, Ye M, Yang J, Qu Z, Mao W and Wu J. 2019. Development and application of long-term root zone salt balance model for predicting soil salinity in arid shallow water table area. *Agricultural Water Management* **213**: 486–498.

Van Hoorn JW. 1981. Salt movement, leaching efficiency and leaching requirement. *Agricultural Water Management* **4**(4): 409-428.

Verma AK, Gupta SK and Isaac RK. 2010. Long-term Use of Saline Drainage Waters for Irrigation in Subsurface Drained Lands: Simulation Modelling with SWAP. *Journal of Agricultural Engineering* **47** (3): 15-23.

Wallender W, Tanji K, Gilley JR, Hill RW, Lord JM, Moore CV, Robinson R and Stegman EC. 2006. Water Flow and Salt Transport in Cracking Clay Soils of the Imperial Valley, California. *Irrigation and Drainage Systems* **20**(4): 361-387.

Wang Q, Huo Z, Zhang L, Wang J and Zhao Y. 2016. Impact of saline water irrigation on water use efficiency and soil salt accumulation for spring maize in arid regions of China. *Agricultural Water Management* **163**:125–138.

Yang-Ren W, Shao-Zhongli K, Fu-Sheng L, Lu Z and Jian-Hua Z. 2007. Saline Water Irrigation Scheduling Through a Crop-Water-Salinity Production Function and a Soil-Water-Salinity Dynamic Model. *Pedosphere* **17**(3): 303-317.

Citation:

Kumar P, Sarangi A and Singh D K.2022. Salt dynamics and budgeting in the root zone of wheat under irrigated saline environment. *Journal of AgriSearch* **9**(3): 226-235