Pakistan Journal of Applied Sciences 2(3): 351-354, 2002

Water Depletion Effects on Water Infiltration Rate, Salt Behavior, and Leaching Requirements in Saline Soil

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Abstract: The field experiment was laid-down in farmers' saline fields near Sindh Agriculture University, Tandojam campus, to determine the effects water depletion on water infiltration rate, salt behavior, and leaching requirements in saline soil. The experiment consisted three soil moisture depletion (SMD) levels of 30, 50, and 80% on available soil moisture. The pre-project soil physical and chemical properties were examined which showed that the soil had clay loam texture for 0-90 cm depth. The bulk density of the soil was 1.25 g/c^3 with permanent wilting point 13.5 percent soil moisture. The composite profile sampling for p^H ranged between 8.0 to 8.5, ECe 5.7 to 5.9 m.mhos/cm, SAR 9 to 11 and ESP 10.8 to 13.2. The results of the experiment showed that the infiltration rate initially was higher in all the fields, but it decreased sharply and became constant after few hours. However, 80 percent SMD having dry soil due to water stress condition produced cracks and recorded maximum infiltration rate during first 20 minutes then gradually decreased and became constant after 2-3 hours. This trend of infiltration rate was also observed for the other moisture depletion levels as well. In this study the total amount of water applied under 30, 50, and 80 percent soil moisture depletions was 822, 644 and 529 mm and salts leached were 25 and 15.30 meq/l under excess (30 percent SMD) and adequate (50 percent SMD) levels respectively. It is recommended that saline soils should be irrigated at the rate of 50% SMD. But, for the quick and satisfactory salt leaching the water should be incorporated at the rate of 30% SMD. For satisfactory salt leaching practice it may take four months or greater period.

Key Words: Saline Soils, Salt Behavior, Leaching Requirements, Water Depletion

Introduction

Soil salinity changes with application of irrigation. Since more frequent irrigation maintains better water availability in the active root zone that result in dilution of salts, which are then leached down, ultimately optimize the crop production. The under irrigation results in salt accumulation in the root zone. In contrast, over irrigation increases the ground levels that cause upward movement of salts (Rashid, 1994). However, frequent application of irrigation leaches the salts from the root zone and provide better environment for crop growth (Oad *et al.*, 2001a). Thus, irrigation must be adequate over the long term to prevent harmful accumulation of salts in the root zone. To prevent high water table, which often contribute to salt accumulation at the soil surface, irrigation applications must not be excessive. Infiltrated depths of water must be relatively uniform to meet the crop's needs and leach salts adequately without excessive surface run-off or deep percolation. To meet such depth and uniformity, irrigation systems must be suited to the site, well designed, and well managed (Kruse, 1990). Recent studies on varying water depletions applied to saline soil showed that value of soil chemical properties viz. pH, ECe, SAR and ESP increase with the water deficit (70-90% soil moisture depletion SMD), however adequate irrigation application at 50% SMD or frequent irrigation leaches the salts downward from the surface. Salinity prominently becomes high in the water stress conditions (Oad *et al.*, 2001b). Some times soil salinity develops in spite of good quality irrigation water and good irrigation practices (Michael, 1978). Since the high concentration of salts acts adversely on the physical, chemical and biological properties of the soil. The accumulation of salts usually takes place during germination upto harvesting period in the crop root zone and was reported in less or non economic productivity of crop. It is due to improper drainage, soil, cultural practices, and unsuitable cropping sequences. The physical properties of soil may be improved or deteriorate despite the presence of salts depending upon the nature and amount of salts, soil amendments, and the initial physical and chemical conditions of the soil. The main physical properties influencing the air-water relationships in irrigated agriculture are markedly influenced by the nature and amount of exchangeable cations and swelling characteristics of the soil (Kovada, 1960). Cultural and drainage practices were also considered to be effective in the amelioration of the problem soils. These soils if brought under cultivation can contributed a tidy sum to total agriculture production of the country. Looking the above facts this study was set to observe the salt behavior and leaching requirements under different soil moisture depletions in saline soil, which can assist the appropriate water application rate.

Materials and Methods

The field experiments were conducted in saline field, near Sindh Agriculture University TandoJam. The experiment was conducted to identify the water depletion effects on the behavior of salts. For this purpose the land was prepared by deep plowing followed by leveling for uniform distribution of irrigation. The experimental treatments were laid-out in Randomized Complete Block Design, replicated three times, having net plot size of 3m x 5 m. The Water treatments applied were as: 30, 50 and 80 % Soil Moisture Depletions (DSM).

Irrigation: Irrigation was applied to the plots on the basis of water depletion levels.

Identifying soil moisture depletions: It involved determining the current water content of the soil. The Gravimetric sampling method was used. The moisture content (%) on dry weight basis was computed by:

$$\theta_w = W_w - W_d / W_d \times 100$$

Where: θ_w = Moisture content on dry weight basis (%), W_w = Wet weight of soil (g), and W_d = Oven dry weight of soil (g)

Amount of Irrigation Water

$d = FC\text{-}SMC \times A_s \times d_r / 100$

Where: d = Depth of water applied (cm), FC = Field capacity (%) = 27, SMC = Soil moisture content before irrigation (%), A_s = Apparent specific gravity of soil (1.25), d_r = Depth of root zone (cm) (Constant for 90 cm).

How Long to Irrigate: It involved cut-throat flume for discharge flow, fixed in the middle of the channel.

$Qt = a.d$

Where: Qt = discharge (m^3/sec), a = Area (hectare), and d = Depth of applied water (mm).

Soil Chemical Analysis: Salinity of the soil was determined by measuring the electrical conductivity using EC meter. p^H meter determined p^H of the soil. Samples were air dried and sieved (? = 2mm). ESP and SAR were determined by the following formula:

$ESP = 100 (-0.0126 + 0.01475 SAR) / 1 + (-0.0126 + 0.01475 SAR)$

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

Where: SAR= Sodium adsorption ratio, ESP= Exchangeable sodium percentage

Results and Discussion

Infiltration Rate: The infiltration rate of clay loam texture, having 1.25 bulk density was observed at first and last irrigation applications. The average infiltration rate was 13.21 mm/hr, at first irrigation. The last irrigation according to moisture depletion levels, recorded different values of the infiltration rate. The maximum infiltration was exhibited in the plots receiving 80 percent SMD, which was 11.28 mm/hr, followed by 50 and 30 percent SMD having the rate of 9.99 and 7.91 mm/hr, respectively (Table 1). The drier soil had more initial infiltration due to thirst of the soil and preferential flow through soil cracks.

The infiltration rate initially was higher in all the plots, but decreased sharply and became constant after few hours. However, 80 percent SMD having dry soil due to water stress condition which produced cracks recorded maximum infiltration rate during first 20 minutes then gradually decreased and became constant after 2 to 3 hours. This trend of infiltration rate was also observed for the other two moisture depletion levels.

The infiltration rate of the soil is influenced by various factors depending on the condition of the soil surface, its chemical and physical characteristics, and distribution of water (U. S. Salinity Laboratory Staff, 1954). The results of the experiment were in agreement with the earlier findings of Stern (1980) who reported that the rate of entry of water was greatest when the soil was dry at the start of watering, but, it decreased as the topsoil became saturated. FAO (1988) also reported similar findings and expressed that the infiltration rate takes place most rapidly when the water is first applied to the soil, but as the topsoil becomes saturated, the swelling of the clay is caused and hence, the infiltration gradually becomes constant (Donen and Westcot, 1988; McNeal, 1973). The decrease in infiltration rate with time is mainly due to the depth of wetted zone. The metric potential gradient tends to zero and steady at the approximate hydraulic conductivity of the soil (Hillel, 1971). However, cracks developed in dry soil are closed by swelling of clay particles and the volume of water passing through decreases sharply with time because of filling of the cracks (Kosmas and Moustakes, 1991). Oster (1999) reported that, in order to grow crops, farmers must maintain adequate physical properties by using various combinations of crop, soil, water, and tillage practices. The primary properties of concern are water and air movement into and through soil, and the ability to prepare seed beds with a tilth that fasters seed germination, a critical step in crop growth. Furthermore, hydraulic conductivity must be adequate so that salts can be removed from the root zone through leaching. Soil physical conditions, such as slow re-distribution, compaction and poor aeration, and trafficability are often the consequences of low hydraulic conductivity. The conditions can occur quickly in the salt affected soil when the salinity is too low to compensate for the effects of exchangeable sodium on soil properties. Oster and Jayawardane (1998) reported that infiltration rates, hydraulic conductivities, and soil tilth decrease with decreased soil salinity and with increasing exchangeable sodium. At the soil surface, infiltration rates and soil tilth are particularly sensitive to salt and exchangeable sodium levels. The mechanical impact and stirring action of the irrigation water, or rain, combined with the freedom for soil particle movement at the soil surface can result in low infiltration rate when the soil is wet, and cause hard, dense soil crusts when the soil is dry. Crusts can block the emergence of seedlings. Tillage of crusted soil can result in hard soil clods that are particularly difficult to reduce in size when the clod is dry. Extensive tillage can be required to prepare a seed bed with sufficient tilth to assure adequate seed contact with soil for seed germination. Morin and Benyamini (1977) suggested that when water is applied to the soil surface at a rate exceeding infiltration rate, whether through rainfall or by irrigation, some enters the soil, while the remainder either accumulates on the surface or is carried as runoff. Generally, infiltration rate is high during the initial stage of soil wetting but decreases exponentially with time to approach a constant rate. Two main factors are responsible for this decrease: (1) a decrease in the matric potential gradient, which occurs as infiltration proceeds, and (2) the formation of a seal or crust at the soil surface. In soils in semi-arid and arid regions, where the organic matter content is usually low, soil structure is unstable, and sealing is major factor determining the steady-state infiltration rate.

Salt Balance: The relationship between the quantity of soluble salts brought into an area by the irrigation water and the salts already present in the irrigated soil and the quantity of salts removed from the soil by the drainage water has been termed as salt balance of the soil. Therefore, in an irrigated area, a favorable salt balance, a condition wherein the output of salts equals or exceeds the input of salts. The maintenance of a favorable salt balance in the soil requires proper water management practices. Kruse (1990) reported that the salt loading is caused by canal and lateral seepage and deep percolating irrigation water. Management of salt affected soils centered on the maintenance of salt balance of the soil through water management, which is expected to reduce annual salt loading to less than half the present values in agricultural lands. Laboratory estimated soil water limits were used for absolute accuracy in water balance calculations, while accurate evaluation of soil water availability is vital for an accurate computation of water balance. Soluble salts increase or decease in the root zone depending on whether the net downward movement of salt is lower or greater than the net salt input from irrigation water and other sources. Robbins (1986) reported that maintaining acceptable soil physical properties on soil with high salt and exchangeable sodium levels, saline/sodic soils require an understanding not only of the adverse impacts of salinity/sodicity on soil properties, but also of the consequent effects on root zone conditions for crop growth. Both water and air entry and its subsequent redistribution within the soil are essential for root and crop growth. Vigorous root growth can play a key role in maintaining good soil physical properties below the soil surface.

The results of the experiment (Table 2) indicate that after the completion of leaching process, a favorable salt balance was achieved in the soil profile. The salt balance in the soil profile after leaching process by applying different soil moisture depletion levels showed that maximum salts leached down by applying 30 percent soil moisture depletion followed by 50 percent SMD. However, deficit irrigation treatment of 80 percent soil moisture depletion developed the water stress effect and capillary rise of salts, which did not leach the salts from the observed soil profile. Thus, it was concluded that satisfactory salt leaching process could be achieved through the excess and adequate (30 and 50%SMD) irrigation application, respectively.

Leaching requirement: The staff of the U.S. salinity Laboratory has formulated the amount of water, which must be leached through the root zone to keep a favorable salt balance. Leaching requirement is the fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level. The amount of water required to leach a saline soil is always additional water to irrigation requirement that carries with it salt downward. It is usually essential that large depths of water be applied to saline and alkali lands and be made to percolate through the soil in order to leach-out excess salts. The leaching requirement represents, therefore, necessary water for a permanent irrigated agriculture. Shalhevet (1994) also suggested that the key to salinity control and irrigation sustainability is leaching, a net downward movement of soil water and salt through the root zone. It controls salt accumulation in the soil and generates drainage water. The greater the salinity of the irrigation water, the greater the leaching and drainage required to maintain acceptable salinity levels for crop production. Devrajani (1998) and Oad *et al.* (2001c) suggested that frequent irrigation application at more depth leached-down the soluble salts to lower horizons. Kruse (1990) reported that irrigation water cannot be applied with total uniformity, some water percolates below the root zone. If the amount of deep percolation is less than the natural drainage capacity of the soil, the water table will remain low and the net movement of salt in the profile will be downward. If deep percolation exceeds the natural drainage capacity of the soil, the water table will rise. When the water table is too close to the soil surface in an arid region, water and salt will be carried upward by capillary action and the upper soil profile and surface may become salinized as the water evaporates. Annually, if enough irrigation water is applied for net downward movement of water through the profile, a favorable salt balance can exist, even in the presence of a high water table. The shallower the water table, the more care needs to be taken with water applications to assure a net downward movement. Further, He observed that if the natural drainage capacity is so limited that normal deep percolation of irrigation water causes the water table to rise close to the soil surface, drains must be installed. Kruse (1990) has also confirmed the present results by reporting that irrigation must be adequate over the long term to prevent harmful accumulation of salts in the root zone. To prevent high water table, which often contribute to salt accumulation at the soil surface, irrigation applications must be relatively uniform to meet the crop needs and leach salts adequately without excessive surface runoff or deep percolation. To meet such depth and uniformity, irrigation systems must be suited to the site, well designed, and well managed. Recent studies of Oad *et al.* (2001c) on varying water depletions applied to saline soil shows that salinity prominently becomes high in the water stress conditions. Jensen *et al.* (1970) and Burman *et al.* (1980) concluded that scheduling each irrigation application amount allows the depth of leaching water to be accurately determined and prevents excessive deep percolation. Limiting irrigation applications to amount necessary for replacement of root zone water and leaching also helps to minimize deep percolation and buildup of the water table.

In this study the total amount of water applied under 30, 50, and 80 percent soil moisture depletions was 822, 644, and 529 mm and salts leached were 25 and 15.30 meq/l under excess (30%SMD) and adequate (50%SMD) levels, respectively (Table 2 & 3). However, deficit irrigation treatment of 80 percent soil moisture depletion developed the water stress effect and capillary rise of salts, which did not leach the salts from the observed soil profile.

Table 1: Average Water Infiltration Rate (Mm/hr.) of Clay Loam Saline Soil

Soil Moisture Depletion Levels	Test No.	Infiltrationrate (mm/hr.)	Average (mm/hr.)
At first irrigation	1	13.17	
	2	12.82	13.21
	3	13.64	
At last irrigation			
30%SMD	1	8.94	
	2	7.76	7.91
	3	7.05	
50%SM			
	1	9.99	
	2	10.23	9.99
	3	9.76	
80%SMD			
	1	11.52	
	2	11.76	11.28
	3	10.58	

Table 2: Salt Balance in the Soil Profile under Different Soil Moisture Depletion (Smd) Levels

Treatments	Salt concentration (meq/l)
30%SMD	
Pre-project salts	79.91
Salts available in the soil	54.91
Salts leached-down	25.00
50%SMD	
Pre-project salts	79.91
Salts available in the soil	64.61
Salts leached-down	15.30
80%SMD	
Pre-project salts	79.91
Salts available in the soil	79.91
Salts leached-down	-

Table 3: Irrigation Scheduling and Total Amount of Water Used to Required Soil Moisture Depletion Levels for 90 Cm Soil Profile Depth

Month & Date	30% SMD		Month & Date	50%SMD		Month & Data	80% SMD	
	Depth of water applied (mm)	Interval (days)		Depth of Water applied (mm)	Intervale (days)		Depth of Water applied (mm)	Interval (days)
June, 01	110	Soaking Dose	June, 01	110	Soaking Dose	June, 01	110	Soaking Dose
June, 08	54	7	June, 18	83	17	June, 27	106	26
June, 15	55	7	July 03	86	15	July, 31	102	34
June, 23	50	8	July, 20	65*	17	Aug., 28	107	28
July, 02	53	9	Aug., 08	87	19	Sep., 30	104	34
July, 11	65*	9	Aug., 25	87	17			
July, 20	*	9	Sep., 10	80	16			
July, 29	53	9	Sep., 30	86	20			
Aug., 06	52	8						
Aug., 15	54	9						
Aug., 23	55	9						
Aug., 31	53	8						
Sep., 09	55	9						
Sep., 19	56	10						
Sep., 30	57	11						
Total Water		822		644			529	

* = Rain fall

Suggestions

- The three soil moisture depletion levels of 30, 50 and 80 percent were ranked as excess, adequate and deficit irrigations, respectively.
- The excess water application at the rate of 30 percent SMD had its positive effect in terms of decreasing soil salinity parameter values as compared to pre-project values, followed by 50 percent SMD. However, minimum or no decrease in soil salinity values was observed with the application of deficit irrigation at the rate of 80 percent SMD.
- Soil p^H, ECe, SAR and ESP values obtained from interaction of different soil profile depths and duration showed a gradual decrease in the soil salinity from 1st month to 4th month, however, during 4th month the maximum decrease in values was exhibited, whereas slight decrease or no change in the soil salinity parameter values was found at 60-90 cm soil profile depth.
- The maximum infiltration rate was recorded at 80 percent SMD, due to dry stress condition which produced cracks, followed by 50 and 30 percent SMD (9.99 and 7.91 mm/hr, respectively). The infiltration rate was higher initially, but decreased sharply and became constant after few hours.
- The result of this research concludes that frequent irrigation application at more depth of water leached down the soluble salts to lower horizons. Thus, it is suggested that saline soils should be irrigated at the rate of 50 percent soil moisture depletion, but, for the quick salt leaching the water should be applied at the rate of 30 percent SMD. For satisfactory salt leaching it may take four months or greater period.

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