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THE IMPACT OF IRRIGATION ON GROUND WATER QUALITY

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Abstract

Most soils in arid regions contain significant quantities of water soluble salts. When these soils are brought under irrigation, soluble salts are leached into the ground water. The salt leaching rate and the annual salt outflow depends upon the quantity of water applied in excess of evapotranspiration each irrigation season. The total quantity of salt leached from a Portneuf silt loam, 5 m deep, was 70 metric tons/ha. The first 14 cm of water passing out the bottom of the soil carried 38 metric tons of soluble salt/ha of soil into the ground water. Essentially all of the residual soluble salt was leached into the ground water after 30 cm of water/m of soil depth had passed from the soil as leachate, regardless of the number of irrigation seasons required for that amount of leaching. After the residual salts were removed, the salt concentration in the newly irrigated soil was the same as in Portneuf silt loam that had been irrigated for 70 years with a high leaching fraction. Subsequent salt outflow from the soil into the groundwater was directly related to the quantity of water leaching through the soil, indicating that more minerals dissolved with more leaching, but the salt concentration in the soil did not change significantly with the leaching fraction. Salt outflows from both newly irrigated and old irrigated lands can be predicted based upon prevailing land conditions and given irrigation practices. The impact of these outflows upon ground water quality can be estimated.

Introduction

Water passing through soils dissolves soluble salts and transports them through the soil to ground water. Large quantities of soluble salt are leached from many arid region soils brought under irrigation (3). These salt outflows can have an important negative impact on the receiving water quality. In addition, water entering the soil replaces soil solution that has been equilibrating with soil minerals and compounds, forcing the soil solution deeper into, and finally through the soil to the ground water. This soil solution generally contains more ions or total salt than the water replacing it because of small amounts of mineral dissolving during the equilibrating process. The water entering the soil becomes the new soil solution, and the equilibrating process begins again. Each subsequent replacement of the soil solution sends some additional salt toward the ground water. The quantity of

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salt dissolved from soil minerals depends upon several factors, including: (a) soil mineral solubility, (b) the ionic and total salt concentration of the entering water, (c) the replacement frequency of the soil solution or the amount of leaching, and other factors. Under some conditions, slightly soluble compounds are actually precipitated from the irrigation water into the soil.

Several papers have been published on the salinity of drainage waters and on factors influencing both salt concentration and total salt outflow in these waters (2, 4, 6, 10, 11, 12). Most of these papers have concerned lands that have been irrigated for many years. New management techiques to reduce salt outflows from irrigated lands by minimizing leaching (11) and to manage irrigation so that much of the soluble salt remains in the lower soil depths below the crop root zone (1, 14) have been shown to be effective. The overall impact of irrigation on the ground water quality must concern both newly irrigated lands and older irrigated lands as well as irrigation management. Studies of this kind are few. McNeal and Starr (9) reported the potential salinity hazard of irrigating new lands in the Horse Heaven Hills area of Washington, and Carter and Robbins (3) have recently reported salt outflows from new and old irrigated lands. This paper reports the impacts of irrigating both new and old lands on ground water quality.

Experimental Methods

One experimental site was located on land that had never been irrigated. This site was similar to millions of hectares of land in the western U.S.A. and in other countries that could be irrigated, if water were available. This site will hereafter be referred to as the N-site, representing newly irrigated land. Another site was selected on the same soil series in an area that had been irrigated since 1905, or about 70 years, with Snake River water. Snake River water has an electrical conductivity (EC) averaging about 500 μmhos/cm, and the following ionic composition in meq/liter: $Ca^{++} = 2.54$, $Mg^{++} = 1.23$, $Na^{+} = 0.90$, $K^{+} = 0.12$, $Cl^{-} = 0.66$, $HCO_3^{-} = 3.38$, and $SO_4^{=} = 0.88$. The following nutrient ion concentrations in ppb were: NO_3-N = 120 and PO_4-P = 66 (4, 6). This site will hereafter be referred to as the O-site, representing old irrigated land.

The two sites were on Portneuf silt loam soil and were 5 and 4 m deep over fractured basalt, respectively. Average annual precipitation is 22 cm. Actual precipitation during the two year study period was measured at an official weather station located near the O-site.

The experimental layout at both sites consisted of 12, 15-m square, leveled and bordered plots, 6 m apart, arranged in a completely randomed design. Furrows about 70 cm apart and about 15 cm deep were formed on the plot surfaces. Three water application treatments, each replicated four times, were applied in 2, 4, and 8, 20-cm applications, totaling 40, 80, and 160 cm of Snake River water each season for two seasons. Water applications were distributed at about equal time intervals for each treatment throughout the 5-month season. These treatments will hereafter be referred to as low, medium, and high water application treatments, respectively. A water meter was used for measuring the amount of water applied.

The plots were not cropped and were kept weed-free to avoid a transpiration component in calculating the quantity of water passing through the soil. Evaporation from the soil surface after each irrigation was calculated from the relationship:

$$E = 8.5 \exp(-0.139t)$$

where E is evaporation in mm/day, and t is time in days. After 20 days following irrigation, evaporation was assumed to remain constant at 0.5 mm/day (3). Evaporation during the noncropping season was measured using weighing lysimeters near the O-site.

Soils at both sites were sampled at 30.5-cm increments to the fractured basalt bedrock before initiating irrigation treatments and at the end of each irrigation season. Undisturbed core samples were collected initially for bulk density determinations (7). Field water content was determined gravimetrically on all samples. By measuring the amount of water applied, calculating evaporation, and determining the quantity of water in the soil, the quantities of water passing through the soil during each season were calculated. Saturated extracts of the soil samples were prepared and analyzed for electrical conductivity (EC) as a measure of total soluble salts. Quantities of total salt in the soil were calculated by converting values obtained from the saturated extract analyses to a field moisture basis. By this means, the total quantities of salt in the soil initially and at the end of each season were determined, and the quantities of total salt leached from the soil were calculated from the difference. The quantity of salt added in the irrigation water was also included in the calculations.

Initial soil water and salinity data were obtained by averaging results from four samplings by auger or core equipment to bedrock at each site. Subsequent data at the end of each irrigation season were averages of eight auger samplings per treatment, comprised of two samplings per plot. Differences between treatments were great, and no statistical analyses were felt necessary.

The salt removal from the N-site soil and the quantity of water required to remove it was compared to the salt removed from the O-site soil. The quantity of water required to remove residual salt from the O-site soil per unit depth of soil was calculated. The expected salt removal from soils at both sites was calculated based upon irrigation management to provide different leaching fractions.

Results and Discussion

Soil at the N-site was initially quite dry, containing only 60 cm of water in the 5-m soil depth, whereas soil at the O-site contained 108 cm of water in the 4-m depth. Therefore, considerably more water was required to wet the soil at the N-site than at the O-site.

Water passed through the soil only with the high water application treatment at the N-site the first season, but with both medium and high treatments at the O-site (Table 1). Water applied by the low and medium water applications increased the soil water content at the O-site to depths of 260 and 450 cm respectively, the first season. Water passed through the entire depth at both sites the second season, except the low water application treatment at the N-site, where the soil water content was increased over the entire depth. Possibly a small amount of water passed through.

Table 1. Water Balances and Salt Removed by the Low, Medium, and High Water Application Treatments at the Two Sites.

	N-Site			O-Site		
	Low	Med	High	Low	Med	High
1st Season						
Water content - initial	60	60	60	108	108	108
Applied	40	80	160	40	80	160
Rainfall	4	4	4	4	4	4
Water content - end	85	123	166	137	138	156
Evaporation	19	28	44	19	28	44
Leachate	0	-7	14	0	26	72
			metric tons/ha			
Net salt outflow	0	0	38	-4	1.3	3.4
2nd Season						
Water content - initial	85	123	166	137	138	156
Applied	40	80	160	40	80	160
Rainfall	2	2	2	2	2	2
Water content - end	115	145	153	141	142	140
Evaporation	18	28	47	18	28	47
Leachate	-6	32	128	20	50	131
			metric tons/ha			
Net salt outflow	0	50	35	6.2	2.4	6.2
Total leachate	0	32	142	20	76	203
Total net salt outflow	0	50	73	0.2	3.7	9.6

The water balance did not unequivocally account for all water in all cases, indicating some errors. For example, the quantity of water in the soil plus evaporation for the medium treatment at the N-site exceeded the water applied plus the initial water content by 7 cm in 1973. This likely represents experimental error because there was no evidence of lateral water movement.

All water application treatments moved salt downward at the N-site the first season, and about 38 metric tons of salt per hectare were leached from the soil by the high water applications (Fig. 1). This large quantity of salt was removed by only 14 cm of leachate. The total quantity of salt remaining in the soil receiving the low and medium water applications was the same as the amount there originally, but it was deeper in the soil.

The second season of the high water application removed essentially all of the residual salt from the N-site soil, and the medium application removed a large portion of it (Fig. 2). The salt content in the N-site soil receiving the high water application was about equal to that in soil irrigated for 70 years. The quantity of salt removed or moved per increment of applied water was nearly the same for the treatments. The salt distribution in the soil after two seasons at the low application treatment was about the same as after one season at the medium application. Similarly, the salt remaining in the soil after two seasons at the medium application was a little less than after one season at the high treatment (Fig. 3). These comparisons represent the same amount of applied water in each case, but a different time period.

Results indicated that after about 150 cm of water had passed through 5 m of soil, the residual soluble salt had been removed, and the salinity content of the soil was then the same as similar soil irrigated for 70 years. The leaching requirement to remove residual salts is about 30 cm of leachate/m depth of soil. The method and timing of leaching affect the rate of salt removal, and intermittent water applications as used in the study are more efficient than continuous ponding (5, 8). Irrigating for crop production would also be intermittent. Hence these results should be indicative of salt leaching under normal irrigation practices. In some areas, materials within and beneath the soil contain larger quantities of soluble salt (12) which would contribute greater salt discharge than measured in this study.

After residual soluble salts are leached, the salt outflow depends upon the leaching fraction which is determined by the irrigation practice. Comparing the low, medium, and high application treatments for the O-site soil for the second season demonstrates that the more often the soil solution is replaced by irrigation water, the greater will be the salt outflow (Table 2). Each time the soil solution is replaced by water lower in concentration of the ions that dissolve from soil minerals, the greater will be the amount dissolved over a given time period. The total salt concentration in the soil solution tends toward the equilibrium value in any given soil, and varies little from that value even over long time periods (3).

Table 2 - Salt Balance for O-site Soils with Three Water Application Treatments for the 2nd Season

	Water application treatment		
	Low	Med	High
	----- metric tons/ha -----		
Total salt in soil after 1st season	8.75	7.87	8.07
Salt added in the applied water	1.17	2.35	4.70
Total salt in soil and applied water	9.92	10.22	12.77
Total salt in soil after 2nd season	9.68	7.84	6.58
Soluble salt leached from the soil	0.24	2.38	6.19

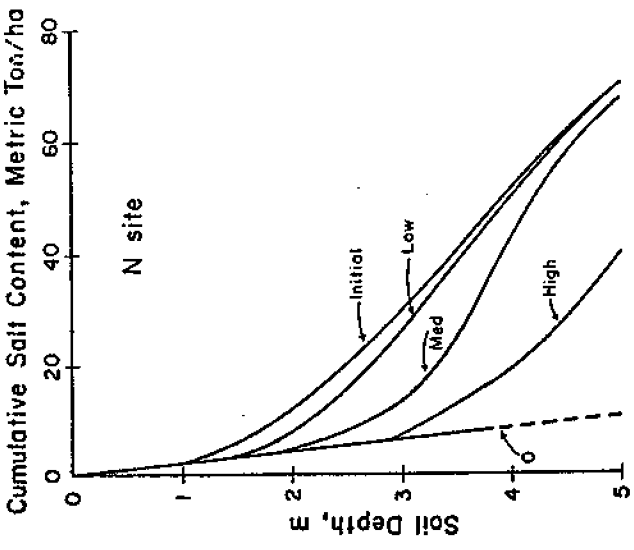


Fig. 1 - Cumulative Salt Content with Depth in the Soil at the N-site after the First Irrigation Season. The Initial Salt Content at the N-site and the O-site (0) are Shown for Comparison.

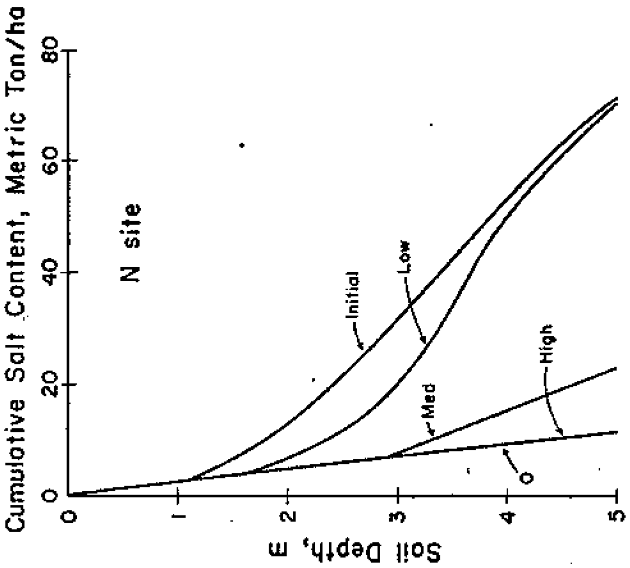
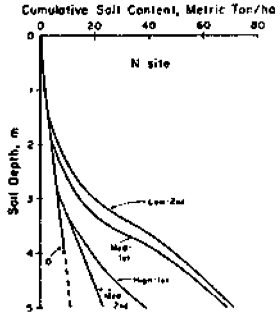


Fig. 2 - Cumulative Salt Content with Depth in the Soil at the N-site after the Second Irrigation Season. The Initial Salt Content at the N-site and the O-site (0) are Shown for Comparison.



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Discussion and conclusions

Results of our field investigations have shown that nonirrigated soils of the Snake River Plain contain large quantities of residual soluble salt that will be discharged into the ground water when these soils are irrigated. The salt-removal rate depends upon the irrigation practices which in turn governs the quantity of leachate passing through the soil. Results indicated that about 30 cm of leachate/m of soil must pass from the soil to remove the residual salts under conditions similar to those used for this study. Similar results might be expected from many thousands of hectares of similar soils in the western U.S.A. and in many other arid regions of the world with silt loam soils similar to those in this research.

Under efficient sprinkle irrigation with a low leaching percentage, several seasons would be required to increase the water content of a soil to the point that water and salt discharge would occur. After that, salt would be discharged at a decreasing rate for years. For example, consider a 5 m deep, previously nonirrigated soil, planted to crops with ET requirements of 70 cm and irrigated by sprinkling with 10% leaching fraction. An annual water application of 78 cm, or 8 cm more than ET, would add the 90 cm of water needed to increase the water content to the point that salt discharge would occur in 12 years. After that, salts would be discharged at a decreasing rate for over 19 additional years. This example, of course, represents an extreme. Doubling the leaching percentage would reduce by half the time required for residual salt removal.

Consider another extreme where the water is applied with a 50% leaching fraction for the same crops as Example 1. The amount of water for leaching would be about 70 cm per season. Some salt would be discharged into the ground water the second irrigation season for soil 5 m deep, and earlier for shallower soils, and essentially all the residual salt would be leached midway through the fourth season. The Twin Falls Tract (4, 6) has a leaching fraction of about 50%. However, this tract is furrow irrigated, and the nonuniformity of leaching under furrow irrigated conditions may translate into a considerably longer leaching period.

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