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Salt Outflows from New and Old Irrigated Lands

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ABSTRACT

Three water application treatments with low salt water were applied to previously nonirrigated soil and to a similar soil which had been irrigated for 67 years. The total soluble salt content of these soils initially, and after one and two seasons of treatment, was measured to determine salt outflow. Residual soluble salts were essentially removed from the previously nonirrigated soil after 30 cm of water/m depth of soil had passed from the soil as leachate, regardless of the number of seasons required for that amount of leaching. The total quantity of residual salt removed from soil 5 m deep was 70 metric tons/ha, with about 38 metric tons/ha being leached out by the first 14 cm of leachate. After the residual salt was removed, the salt content of the newly irrigated soil was the same as that of the soil which had been irrigated for 67 years. Subsequent salt outflow from the soil was directly related to the quantity of water leaching through the soil, indicating that more minerals dissolved with more leaching. Soils irrigated for many years and then not irrigated for up to 10 years had no measurable reaccumulation of soluble salts during the period of nonirrigation. Results of these investigations provide a basis for estimating salt outflows from newly developed and old irrigated lands, and for assessing the impact of these salts on surface and groundwater supplies.

Additional Index Words: **Salt leaching, residual soluble salts, drainage water quality, leaching percentage.**

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NEW LAND AREAS are irrigated each year as water resources are located and developed. Irrigating new lands has certain environmental impacts. One of these is the impact of soluble salts in subsurface drainage waters. Many 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, 3, 5, 9, 10, 11). Most of these papers have concerned lands that have been irrigated for many years. New management techniques to minimize leaching, to reduce total salt outflows from irrigated lands (10) and to manage irrigation so that much of the soluble salt remains in the lower soil depths below the crop root zone (1, 13) have been developed and shown to be effective. McNeal and Starr (8) reported the potential salinity hazard of irrigating new lands in the Horse Heaven Hills area of Washington. Except for this latter report, however, little published information is available on expected salt outflows from newly irrigated land areas. Also, little is known about the quantity of leaching water required to leach residual salts from newly irrigated lands and the time required for the leaching process.

As new lands are developed for irrigation, potential environmental impacts should be assessed and management alternatives developed to prevent the accumulation of leached salts in low-lying areas or to minimize their impact on ground water and irrigation return flows. To assess these environmental impacts, information is needed on the quantities of residual salt that will be leached from newly irrigated land, the time required for residual salt removal, the amounts and concentrations of salts that will enter streams used for irrigation, or for other purposes that could be detrimentally affected by salinity, and practices to minimize salt damage.

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This paper reports the quantities of salt leached from a typical silt loam soil, previously nonirrigated that was brought under irrigation on the Snake River Plains, the amount of water required to leach residual salts from the soil, the effect of the leaching fraction on the salt-removal rate, and the quantity of salt expected in drainage water on a yearly basis after residual salts have been removed. Various alternatives for managing the discharge of residual salts are discussed. Field data for this previously nonirrigated soil are compared with data from a similar soil that had been irrigated for 67 years.

METHODS AND MATERIALS

One experimental site was located on land where native vegetation had been removed and range grass seeded a few years earlier. This area had never been irrigated and resembled many thousands of hectares of land in the western U.S.A. that could be irrigated, if water were available. This site will hereafter be referred to as the D-site. The second site was located on land that had been irrigated since about 1905, or for 67 years before initiating this study. Irrigation water is diverted from the Snake River, and applied in furrows. Snake River water has an electrical conductivity (EC) averaging about 500 μmhos/cm, and the following ionic composition in meq/liter: Ca^{2+}= 2.54, Mg^{2+} = 1.23, Na^{+} = 0.90, K = 0.12, Cl^{-} = 0.66, HCO_3^{+} = 3.38, and SO_4^{2-} = 0.88. The following nutrient ion concentration in ppb were: NO_3-N = 120 and PO_4-P = 66 (3, 5). The site was located on land operated by the Snake River Conservation Research Center for research purposes, and will hereafter be referred to as the SRC-site.

The two sites were located on the same soil series, Portneuf silt loam, a coarse silty, mixed, mesic, Xerollic Calciorthid. The layer-silicate minerals are mostly micas, with small amounts of montmorillonite. Soil depths were about 5 and 4 m at the D- and SRC-sites, respectively. The underlying material of the entire area is highly fractured basalt (3, 5). Average annual precipitation is about 22 cm. Actual precipitation during the 2-year study period was measured at an official weather station located near the SRC-site.

The experimental layout at both sites consisted of 12, 15-m square, leveled and bordered plots, 6 m apart, arranged in a completely randomized 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 with herbicides and machine and hand weeding 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. (Personal communication, M. E. Jensen and J. L. Wright, Snake River Conservation Research Center, Kimberly, Idaho). Evaporation during the noncropping season was measured using weighing lysimeters near the SRC-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 (6). 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 (ECe) 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. This approach to determining the quantity of salt leached assumes little or no contribution of soluble salts from soil mineral or from dissolving slightly soluble salts. Because of the relatively high soluble salt concentration in the previously nonirrigated soils, little if any such dissolving would be expected. If such dissolving did contribute soluble salts to the total quantity in the soil, the quantity of salt leached out could be greater than calculated. However, for the soils irrigated for many years, a significant portion of the salt leached would be from dissolving of soil minerals and slightly soluble salts. The quantities of salt from this source for the three water applications for 1974 were calculated.

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/treatment, comprised of two samplings/plot. Differences between treatments were great, and no statistical analyses were felt necessary.

Results from the D-site were compared with those from the SRC-site to determine the removal rate of residual salts from previously nonirrigated soil, the amount of leaching water required, and the time necessary for newly irrigated lands to reach the same salinity status as the soil that had been irrigated for many years. Expected salt discharges from new and old irrigated lands were estimated based upon the quantity of leaching water or the leaching fraction.

The salinity status of soils irrigated for many years and then no longer irrigated for periods of up to 10 years was examined to determine if the salinity of such soils would increase during an intervening period without irrigation because of mineral weathering processes. To accomplish this, soils were sampled to the underlying basalt at several sites meeting these criteria, and then analyzed for water and total salt contents.

RESULTS AND DISCUSSION

Soil at the D-site was initially quite dry, containing only 60 cm of water in the 5-m soil depth. The water content of the 30.5-cm sampling increments ranged from 2.8 to 5.3 cm, with the 5.3-cm water content found at the 61- to 91.5-cm depth increment. This depth increment is composed mostly of a cemented layer, and had the highest water content at both sites for all treatments. The soil at the SRC-site, which had been cropped and irrigated the previous season, contained 108 cm of water in the 4-m soil depth.

Water passed through the total soil depth only with the high water application treatment at the D-site in 1973, but with both the medium and high water application treatments at the SRC-site (Table 1). At the D-site, applied water increased the soil water content during the 1973 season to a depth of about 260 cm for the low, and to a depth of about 450 cm for the medium, water application treatments. Soil-water content was increased to a depth of about 370 cm at the SRC-site by the low water application treatment. Water passed through the entire soil depth for all treatments at both sites during 1974, except the low

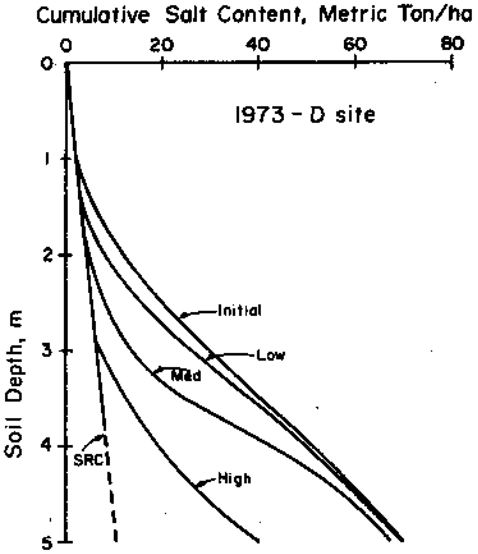

Fig. 1—Cumulative salt content with depth in the soil at the D-site after the first season of water application treatments. The initial salt content at the D-site and for the low water application treatment at the SRC-site are shown for comparison.

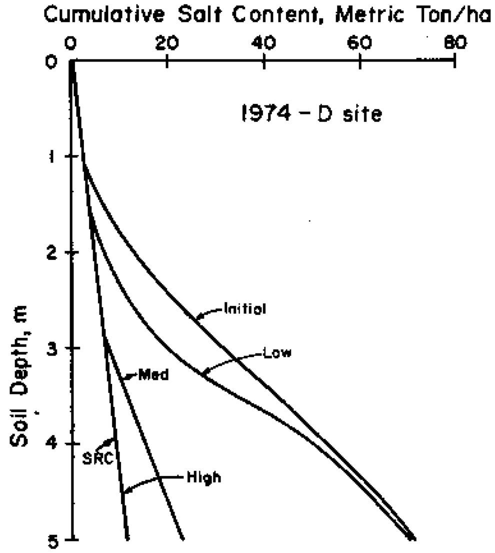

Fig. 2—Cumulative salt content with depth in the soil at the D-site after the second season of water application treatments. The initial salt content at the D-site and for the low water application treatment at the SRC-site are shown for comparison.

treatment at the D-site. A small amount of water could have passed through as a result of the low treatment at the D-site, because the soil water content was increased throughout the 5-m soil depth.

The water balance (Table 1) did not unequivocally account for all of the water in all cases, indicating some errors. For example, the quantity of water in the soil plus evaporation for the medium treatment at the D-site exceeded the water applied plus the initial soil water content by 7 cm in 1973. There was no evidence of lateral movement, so these differences likely resulted from errors in measurement or in the methods used to calculate evaporation. These errors were small. Therefore, the water balance data could be used to estimate salt movement per unit of water movement with reasonable accuracy.

Data from the nearby weighing lysimeter indicated that the precipitation and evaporation from the fall of 1973 to the spring of 1974 were essentially equal. Precipitation was in small amounts during the period, and leaching from precipitation was not likely. The cumulative quantities of salt in the soils initially and after water application treatments are illustrated in Fig. 1, 2, and 3. Soil at the D-site initially contained 70 metric tons/ha in the 5-m soil depth, whereas soil at the SRC-site contained only about 10 metric tons/ha in the 4-m soil depth. All water application treatments moved salt downward at the D-site the first season, and about 38 metric tons of salt/ha were leached from the soil by the high water treatment (Fig. 1). This large quantity of salt was removed by only 14 cm of

Table 1—Water balances for low, medium, and high water application treatments at the two experimental sites.

	D-Site			SRC-Site		
	Low	Med	High	Low	Med	High
	cm					
Initial water content in total soil depths	60	60	60	108	108	108
Applied in 1973 season	40	80	160	40	80	160
Rainfall during 1973 season	4	4	4	4	4	4
Measured in the soil at the end of the 1973 season	85	123	166	137	138	156
Evaporation, 1973	19	28	44	19	28	44
Leachate, by fall 1973	0	−7	14	−4	26	72
In soil, fall 1973	85	123	166	137	138	156
Applied in 1974 season	40	80	160	40	80	160
Rainfall during 1974 season	2	2	2	2	2	2
Measured in the soil at the end of the 1974 season	115	145	153	141	142	140
Evaporation, 1974	18	28	47	18	28	47
Leachate, fall 1973 to fall 1974	−6	32	128	20	50	131
Total leachate, two seasons	0	32	142	20	76	203

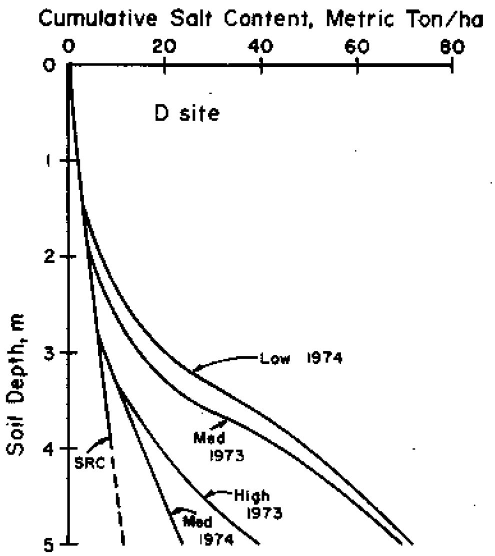

Fig. 3—Comparison of the cumulative salt content with depth in the soil at the D-site for low water application treatment after two seasons (1974) and the medium water application treatment after one season (1973), and for the medium water application treatment after two seasons (1974) and the high water application treatment after one season (1973). The low water application treatment at the SRC-site is shown for comparison.

Table 2—Salt balance for SRC site soils with three water application treatments for the 1974 season.

	Water application treatment		
	Low	Med	High
	metric tons/ha		
Total salt in soil after 1973 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 1974 season	9.68	7.84	6.58
Soluble salt leached from the soil	0.24	2.38	6.19

leachate (Table 1). The 4.7 metric tons of salt added in the applied water during the 1973 season were included in the calculations. The data indicated that small quantities of salt were leached out of the soil by the low and medium water application treatments also, even though the water balance indicated that no water had passed through the soil with these treatments. These differences were small and likely within the range of experimental error. The salt content of the soil at the SRC-site did not change with water application treatment, suggesting that the salt content of the soil solution remains virtually unchanged after residual salts are removed. Some salt is of course discharged as irrigation water passes through, depending upon the leaching fraction (3, 5).

The salt content at the D-site shifted towards that of the SRC-site for all water application treatments. The cumulative salt content with depth for the high treatment at the D-site coincided with the low treatment at the SRC-site to the 300-cm depth, indicating that residual soluble salts were removed to this depth by this treatment during the first season (1973).

The high water application treatment removed almost all of the residual soluble salts from the D-site soil by the end of the 1974 season (Fig. 2). The medium treatment had removed more salt by the end of the 1974 season than had the high treatment by the end of 1973 (Fig. 3), because more water had passed through the soil in 2 years of the medium water treatment (Table 1). The low water application treatment also moved salt downward in two seasons as much as the medium treatment had during the first season (Fig. 3). The same quantity of water was applied over two seasons by the low treatment as during the first season by the medium treatment, with about the same effects on salt movement. The results established that the amount of water passing through the soil controls salt outflow under these conditions, with the time period of the leaching not being a critical controlling factor.

These results suggest that when about 150 cm of water have leached through 5-m of soil under these irrigation conditions, nearly all of the residual salt will be removed from the soil. This is equivalent to 30 cm leachate/m of soil. The method and timing of leaching affect the rate of salt removal and intermittent water applications, as used in this study, are more efficient than continuous ponding for leaching (4, 7). With irrigation for crop production, the water would be applied intermittently, and, hence these results should be indicative of leaching under normal irrigation practices. In some areas the materials within and beneath the soil contain large quantities of soluble salt (11), which will contribute greater salt discharge than that measured in these studies.

Table 3—Quantity of salt per 30.5-cm sampling depth in soils irrigated for many years and then not irrigated for a number of years, in soil at the SRC-site, and in soil at the D-site initially and after two seasons at the high water application treatment.

	Salt present in the 30-cm depth							
	Years after terminating irrigation							
Depth	3	5	7	9	10	SRC site	D-site leached	D-site *before* leaching
cm	kg/ha							
0 - 30.5	407	631	485	574	714	595	524	529
30.5- 61.0	217	2,698	697	698	835	448	402	590
61.0- 91.5	342	370	1,580	1,822	726	407	506	1,040
91.5-122.0	774	368	488	365	606	394	449	2,050
122.5-152.5	802	398	444	435	571	438	459	3,390
152.5-183.0	544	365	430	398	533	399	596	4,230
183.0-213.5	482	409	–	441	565	424	689	4,740
213.5-244.0	–	480	–	467	517	484	691	5,960
244.0-274.5	–	–	–	484	676	514	766	6,080

Differences in the salt content of the soil solution at the SRC-site were small and the low water application treatment data were used in Fig. 1, 2, and 3 for comparison with data from the D-site. In Fig. 1 and 3 the dashed line below the 4-m depth is an extension of the linear relationship for comparison purposes only. In Fig. 2, the data for the high water application treatment followed the same linear relationship.

Data from the SRC-site suggest that the quantity of salt leached from soils, after residual salts have been removed, depends upon the quantity of leachate passing from the soil (Table 2). The quantity of salt added in the irrigation water during the 1974 season plus the quantity in the soil solution at the beginning of the season represent the total quantity of soluble salt in the soil by the end of the 1974 season. The difference between that total quantity and the quantity measured in the soil solution after the 1974 season for each treatment represents the quantity of salt leached under the conditions of this study. As soil solution containing dissolved minerals and slightly soluble salts is replaced by irrigation water, more dissolving occurs because the irrigation water contains lower mineral concentrations than does equilibrated soil solution.

The data in Table 3 illustrate that once residual salts are removed by irrigation, there is no rapid salt accumulation to high concentrations from dissolving minerals, when lands are no longer irrigated. The salt content per sampling increment for those sites no longer irrigated resembled those for leached SRC-site and for high water application treatment at the D-site soils after the second irrigation season. The salt content for the D-site before irrigation is shown for comparison, to a 275-cm depth. Some of the soils sampled contained more soluble salt in the hardpan layer than for other sampling increments, and the equilibrium concentration is likely higher in this layer when it occurs. In no cases did the salt contents of the previously irrigated soils approach those of the D-site soil before irrigation.

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 leached 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. Data reported by McNeal and Starr (8) indicate that rather large quantities of residual salts could be expected in irrigation return flows from irrigating the Horse Heaven Hills in Washington.

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 to reach 30 cm of leachate/m of soil 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/season. Some salt would be discharged 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 (3, 5) 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.

The latter example could add large quantities of salt to a river or stream receiving subsurface drainage water from the new irrigated tract, but the impact may last only about three seasons. The first example would add much less salt per season, but the addition of salt would continue for many seasons. Actually, the water supplies planned for most newly irrigated tracts in the western U.S.A. provide a leaching fraction about midway between these two examples.

Our results provide an improved basis for estimating the environmental impact of residual soluble salt outflows from newly irrigated tracts. These results can be used to evaluate alternative practices. For example, some leaching might be done in the fall after cropping, when the impact of salinity on downstream uses may not be as important as during the cropping season. Or leaching might be accomplished when stream flows are high and dilution of subsurface return flow is greater. Furthermore, results can be used to estimate the time period that salts can be stored in very deep soils and the impact that may result once these salts begin to be discharged into surface or groundwaters. The time required for drainage water to travel from the bottom of the soil to the surface stream also needs to be considered.

As residual salts are leached from newly irrigated soils, the salt content remaining in the soil eventually attains a distribution that changes little with time. The salt distribution and total salt content of soil from which residual salts were recently leached were the same as in similar soils irrigated for nearly 70 years with the same irrigation water (Table 3). The quantity of salt outflow from soils, after residual salts are removed, depends almost entirely upon the amount of leaching water passing through the soil. With less water passing through the soil, smaller quantities of salt dissolved from soil minerals and slightly soluble salts will be removed by leaching water. These results agree well with those from other laboratory and lysimeter studies (1, 2, 3, 5, 9, 10, 12, 13). All of these investigations recommend lower leaching fractions for most irrigated lands.

The salt distribution in soils irrigated for 50 years or more and then no longer cropped and irrigated were the same as that in soils under irrigation as well as newly irrigated soils from which residual salts have been removed. There was no measurable salt buildup in soils from mineral dissolving for at least 10 years after irrigation was terminated. There was no salt outflow from these soils because no leaching took place, nor was there much input, because the only water received was from the annual precipitation of about 22 cm, which contained very little salt. Sufficient dissolving of minerals and slightly soluble salts evidently takes place to produce 300 to 800 kg soluble salt/ha in each 30.5-cm depth each time the soil solution is replaced by irrigation water. Apparently, minerals and slightly soluble salts do not dissolve further with time. Hence, the premise that soluble salts might accumulate to high concentrations at a constant rate seems without basis.

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