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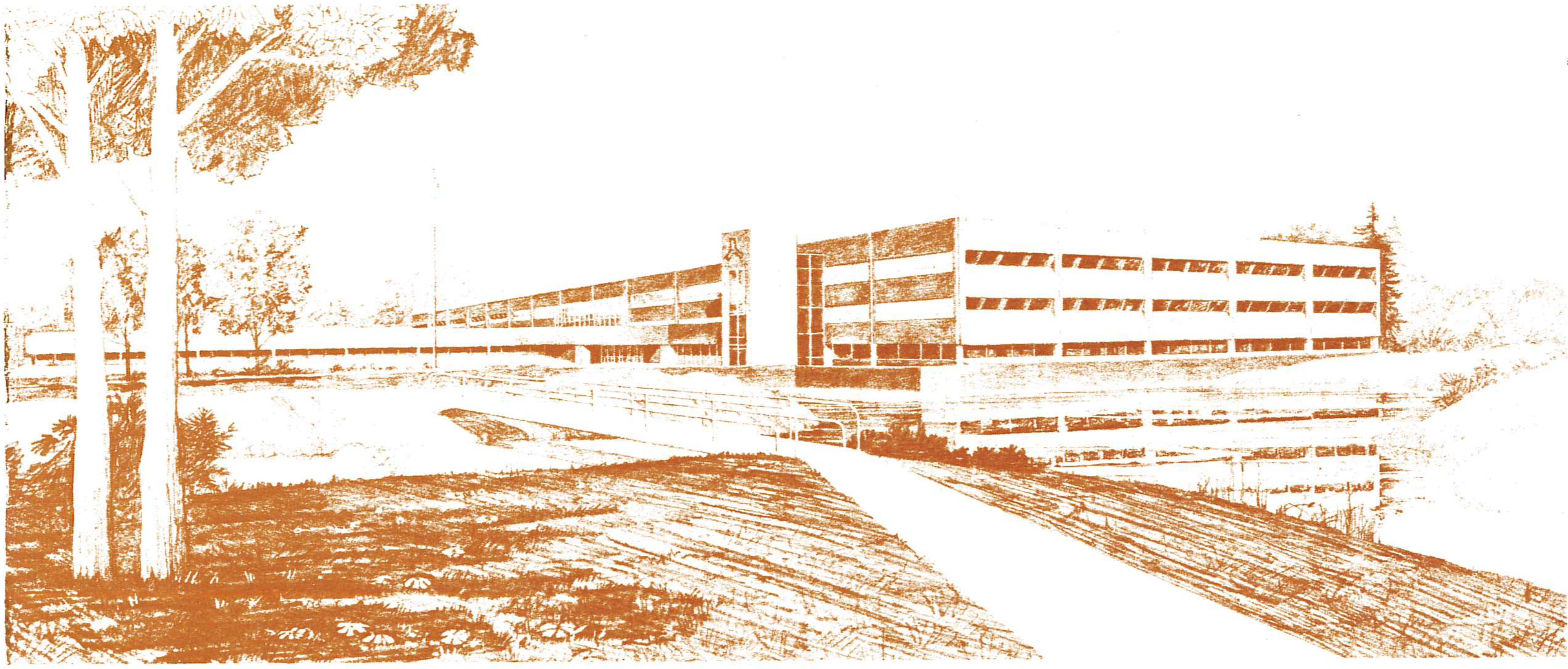

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Effects of Irrigation on Crops and Soils with Raft River Geothermal Water

Norman E. Stanley
Richard C. Schmitt

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ABSTRACT

The Raft River Irrigation Experiment investigated the suitability of using energy-expended geothermal water for irrigation of selected field-grown crops. Crop and soil behavior on plots sprinkled or surface irrigated with geothermal water was compared to crop and soil behavior on plots receiving water from shallow irrigation wells and the Raft River. In addition, selected crops were produced, using both geothermal irrigation water and special management techniques. Crops irrigated with geothermal water exhibited growth rates, yields, and nutritional values similar to comparison crops. Cereal grains and surface-irrigated forage crops did not exhibit elevated fluoride levels or accumulations of heavy metals. However, forage crops sprinkled with geothermal water did accumulate fluorides, and leaching experiments indicate that new soils receiving geothermal water may experience increased salinity, exchangeable sodium, and decreased permeability. Soil productivity may be maintained by leaching irrigations.

FOREWORD

The Raft River Geothermal Test Site in south-central Idaho is operated as part of the Idaho National Engineering Laboratory, sponsored by the Department of Energy. EG&G Idaho is the prime contractor. The experimental work conducted at the site is part of a national program designed to investigate the practical use of moderate-temperature geothermal energy for electric power production and for substitution for fossil fuels in direct heat applications. The work in this report examines the benefits of fluid disposal by irrigation using geothermal fluids quite similar to those expected following a primary energy extraction power generation or direct application step.

ACKNOWLEDGMENTS

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EFFECTS OF IRRIGATION ON CROPS AND SOILS WITH RAFT RIVER GEOTHERMAL WATER

INTRODUCTION

Geothermal energy projects in the planning and development stage today generally plan to follow the practice of injecting the geothermal brine into the aquifer after extracting heat from it. The theory is that injection will (a) dispose of an unuseful brine while guarding against possible environmental disruption, (b) maintain reservoir pressures, (c) reduce possible subsidence or seismicity, and (d) augment extraction of thermal water from reservoir rocks in areas of poor aquifer recharge. However, actual experience with injection is limited, and drilling and operating injection wells are costly. In fact, the high cost of injection, if a requirement, may well prohibit the development of geothermal energy for many small users. Alternate, environmentally acceptable methods of disposal are needed, particularly if disposal can be coupled to a beneficial use of the water.

Heretofore, beneficial uses for heat-expanded geothermal water, such as crop irrigation, aquaculture, and industrial washing operations, have been given little consideration. But as the use of geothermal energy advances, large quantities of these waters will become available for such purposes. Also, many known geothermal resource areas coincide with areas of chronic water shortage, and geothermal water may be a valuable additional source for agriculture on currently unproductive lands. Understanding the environmental effects that will result when soils, plants, and animals are exposed to geothermal waters is important for these reasons and for geothermal energy development in general. The irrigation experiment at the Raft River Geothermal Test Site encompasses 3 years of field trials designed to evaluate the feasibility of using geothermal water for irrigated crop production, thus contributing to the information needed to evaluate total use concepts for geothermal fluids.

Problem Statement

The suitability of geothermal water for agricultural irrigation is determined by the amount and kind of salts present, and upon the characteristics of the receiving crops and soils. Raft River geothermal irrigation water is classified as exhibiting medium to very high salinity and sodium hazards that will likely lead to the development of soil or cropping problems unless special management practices are implemented to maintain suitable crop productivity.

The potential problems surrounding the use of Raft River geothermal water for irrigation vary, depending upon the water characteristics (water quality varies among production-well locations), soil characteristics, and crop variety. The problems are explained below.

Salinity

Irrigation-related salinity usually occurs on poorly drained soils, or soils above high water tables. When geothermal water containing approximately 1.5 kg salts/m^3 (typical of Raft River geothermal water) is applied to soils at an annual rate of 6000 to 14 000 m^3/ha, considerable quantities of salts are added to the soils over a few years. On poorly drained soils, much of the water is lost through evapotranspiration, leaving the salts in the root zone. If irrigations cause the water table to rise to within 1 to 2 m of the soil surface, ground water moves upward by capillary action into the root zone and soil surface. Under this condition, ground water, as well as irrigation water, may contribute to salinity. High salinity in soils may impair crop production by increasing the osmotic pressure of the soil solution and increasing soil-moisture tension as the soil dries, thus reducing the availability of water to plants.

Increased quantities of salts in the soil solution may also hinder the entrance of nutrient ions into root hairs, resulting in nutritional imbalances in the crop.

Permeability

Geothermal water with a high sodium-adsorption ratio will increase the amount of exchangeable sodium in most soils. As sodium ions are adsorbed, deflocculation of soil colloids may occur, resulting in a breakdown of the structural units of the soil. This condition causes the soil to become less pervious to water, reducing the water supply to crop roots. In fine-textured soils, deflocculation may also impede root penetration and reduce aeration, restricting root respiration and setting up anaerobic conditions that may produce toxic compounds.

Toxicity

Toxicity occurs within a crop as a result of the uptake and accumulation of certain constituents from the irrigation water. The constituents of major concern in Raft River geothermal water are sodium, chloride, and fluoride. Crop plants exhibit a wide range of sensitivity to these elements. Water containing these ions is absorbed by the plants, and much of the water is transpired from the leaves leaving the ions behind. Damage occurs when the sodium, chloride, and fluoride ions accumulate to concentrations which exceed the tolerance of the crop. Characteristic symptoms usually include leaf burn, drying, and necrosis of the tissue beginning at the outer edges and tip of the leaf. As severity increases, the burning progresses inward, between leaf veins and toward the center. The damage may reduce both the quantity and quality of the crop.

High levels of fluorides that accumulate in feed and food crops may also contribute to fluoride toxicity in consuming organisms. Signs of excessive fluoride ingestion in livestock usually include dental and osseous lesions, and lameness.

Experiment Phases

The experiment was initiated with the 1976 (Phase-1) growing season, and continued through the 1977 (Phase-2) and 1978 (Phase-3) seasons. Previous reports[1,2] provide detailed descriptions of Phases-1 and -2 activities and results, and contain appendixes of plot soil descriptions and guidelines for quality ratings of irrigation water.

EXPERIMENT DESCRIPTION

In addition to the overall objectives of the experiment regarding the feasibility of irrigation as a beneficial use for low-salinity geothermal fluid, and to understanding some of the environmental implications of this application, further objectives are

1. To provide a field experiment of sufficient scale for meaningful data on geothermal-fluid effects on field crops
2. To examine plant behavior, tolerance, yield, and uptake of heavy metals and fluorides, when irrigated wholly or partially with geothermal waters in surface and sprinkler irrigation
3. To examine changes in root-zone soils following soil irrigation with geothermal waters
4. To accumulate a data base on problems that might be encountered during geothermal crop raising.

Plot Description

The experiments were conducted on a 13.2-ha tract of land located near the Raft River Geothermal Test Site in south-central Idaho (see Figure 1). The land was divided into three plots and several subplots to facilitate the tests performed during each experiment phase. Figure 2 shows the layout of the plots and subplots for each experiment phase, indicating the source of irrigation water, mode of application, and crops cultured.

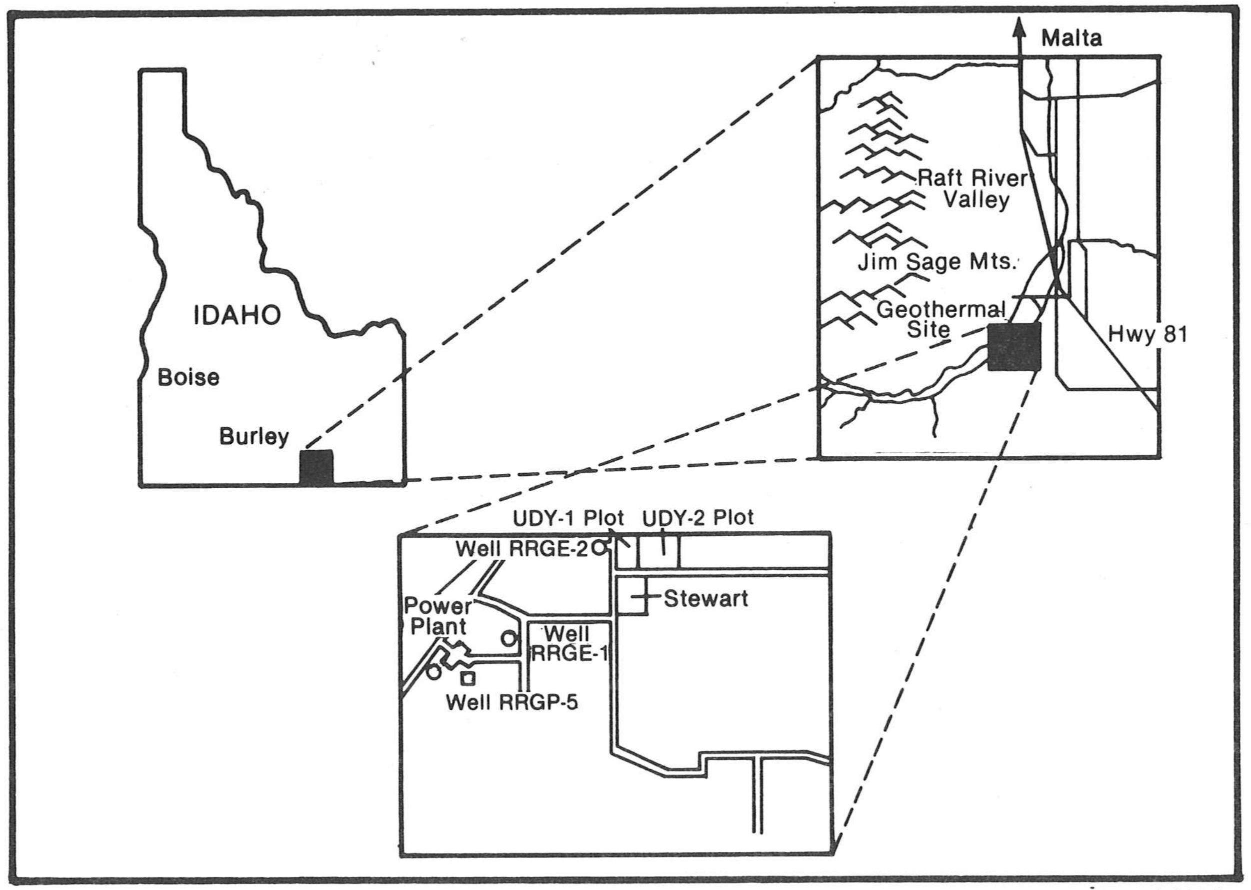

Figure 1. Location of the Raft River Geothermal Site, wells, and irrigation experiment plots.

The 2.8-ha Stewart plot was located on Sweetzer silt-loam soil, characterized by a 33-cm silt-loam surface layer overlying a stratified substratum. This plot, used only during Phase 1 (1976) of the experiment, had a history of cultivation with the principal source of water being an existing shallow aquifer well.

The Udy-1 and -2 plots were untilled and supported sagebrush-community vegetation prior to these tests. Udy 1 was first tilled during Phase 1 and was used during all three experiment phases. Udy 2 was first tilled during Phase 2 and was used again during Phase 3. The Udy plots were located predominately on Bram, silt-loam soil, typically composed of a 10-cm thick, silt-loam surface layer underlain by silty clay loam to a depth of 150 cm. The soil is strong-to-very-strong alkaline and calcareous with a concentration of lime between 10 and 75 cm. Permeability on these soils is moderately slow.

A narrow strip of Ayses-Hiko Peak-Complex soil characterized by a 15-cm surface loam, underlain by gravel and sand loams, was located along the north margin of the Udy-1 and -2 plots. This soil is calcareous, alkaline, saline, and excessively drained.

The experiment plots were selected primarily for availability and proximity to water sources. At the time of plot selection, no soil survey information was available. The plot soils are highly variable, which has required random collection of crop samples from all subplots. Data of crop yields from geothermal-irrigated plots are compared only to the area average. No yield comparisons between plots or subplots were attempted.

Irrigation water for the geothermal-irrigated subplots was obtained from two 1500-m deep

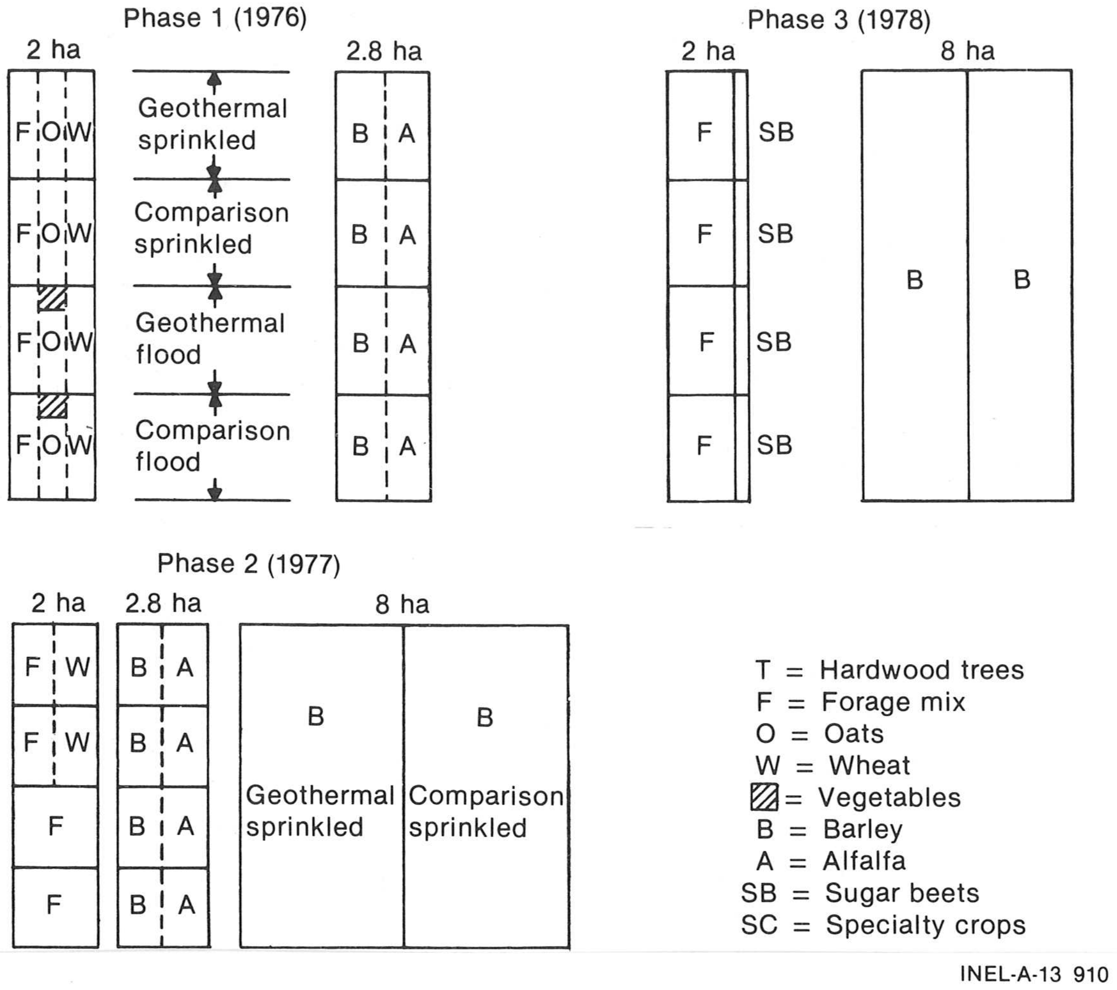

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Figure 2. Plot layout by phase of the Raft River Geothermal Irrigation Experiment.

geothermal wells, identified as RRGE 1 and RRGE 2 on Figure 1. The comparison water was obtained from the Raft River during Phase 1 and from existing, shallow irrigation wells during Phases 2 and 3. Drought conditions experienced during the latter two experiment phases eliminated the availability of Raft River water and necessitated the change.

Crops Selected

In selecting crops to evaluate the effects of geothermal irrigation, consideration was given to the nature of the local soils, climate, water characteristics, local farming practices, and possible alternatives. The growing season in the Raft River Valley is short, having an average, frost-free growing period of only about 120 days. Also, many of the local soils and irrigation waters are saline. These adverse conditions limit the productivity of many crop varieties. Consequently, most of the crops cultured in the area are hardy and salt tolerant. The crops selected for this study are adapted to the local climate and, for sampling purposes, represent a range of salt tolerance. Figure 2 shows the crop distribution on the plots for each experiment phase. Table 1 lists the crop species grown, and their relative salt tolerance.

Crop management and timing were in keeping with recommendations from Utah State University Irrigation Engineering Department and University of Idaho Agricultural Extension Service consultants. Local farmers were contracted to perform crop production activities requiring mechanized equipment, e.g., tilling, seeding, cultivating, and harvesting.

TABLE 1. FIELD, VEGETABLE, AND TREE SPECIES CULTURED IN THE RAFT RIVER IRRIGATION EXPERIMENT PLOTS[a]

Field Crops	Variety or Cultivar	Salinity ECe
Barley *Hordeum vulgare*	Steptoe	18
Sugar Beets *Beta vulgaris*	Great Western	15
Wheat *Tritium vulgare*	Twin	13
Alfalfa *Medicago sativa*	Ranger	8.8
Oats *Avena sativa*	Oakland	8.5
Forage Grass		
Brome *Bromus inermis*	Manchar	11
Fescue *Festuca arundinacea*	Alta	9
Orchard *Dactylis glomerata*	Pomar	7
Vegetables		
Beet *Beta vulgaris*	Ruby queen	9.6
Potato *Solanum tuberosum*	Northland Russet	5.9
Lettuce *Lactuca sativa*	Simpson	5.2
Radish *Raphanus sativas*	Cherry Belle	5
Carrot *Daucus carota*	Chantenay	4.6
Squash *Cucurbita maxima*	Bush Acorn	4.1
Turnip *Brassica rapa*	Purple Top Globe	
Swiss Chard *Beta vulgaris*	Luculius	
Trees		
Hybrid Poplar *Populus spp*		
Ash *Fraxinus pennsylvanicia*		
Willow *Salix viminalis*		
Elm *Ulmus pumila*		

---

[a] The species are listed in decreasing tolerance to salinity as expressed in mmho/cm (ECe) of soil extract. The ECe numbers are the electrical conductivity values of the soil saturation extract in mmho/cm at 25°C associated with a 50% decrease in crop yield.

Irrigation System and Scheduling

The irrigation systems consisted of 15.2-cm aluminum main lines and 7.6-cm lateral lines on sprinkled subplots, and 15.2-cm gated, surface-pipe laterals on the surface flood sections. The lateral lines were spaced 15.4 m on center, with sprinkler heads 9.2 m apart. Full circle impact sprinkler heads with 0.36-cm nozzles were placed on 91-cm risers. Each lateral line (sprinkler and gated pipe) was controlled with a valve. At the top of each surface-irrigated plot, only one lateral line was required. The pipe gates were 76 cm apart, on center. Water was supplied to the plots via pumps located near the Raft River, RRGE-2 geothermal well, and the L. Udy farm. The water application rate was about 0.6 cm/ha of water per hour.

During Phase 1, extensive meteorological data were collected and analyzed; evapotranspiration potentials were calculated; and irrigations scheduled in an attempt to provide the consumptive irrigation requirements to plot crops. However, this approach met with some difficulty due to variability in the individual crop requirements across the plots, nonuniformity of leaching requirements for the soil types present, irregular water supply availability, and pumping system failures.

Subplot design for Phases-2 and -3 experiments was changed to achieve crop water requirement compatibility across the plots. Irrigation scheduling was based upon classic, consumptive irrigation requirements for Strevell, Idaho,[3] a weather monitoring station located approximately 24 km northeast of the experiment plots. In general, plots were irrigated every 10 days from mid-May through mid-September, with approximately 8 cm of water applied per irrigation.

SAMPLES, ANALYSES, AND RESULTS

An extensive sampling and analysis program was employed to characterize irrigation waters and to evaluate their effects upon soils and crops. The sample analysis program included thorough baseline characterizations during Phase 1, and follow-up analyses during Phases 2 and 3, concentrating on fluoride accumulation in crops- and salt-related problems in soils.

Water

Water from the two geothermal wells, the Raft River, and comparison irrigation wells was sampled and analyzed periodically during the irrigation seasons by technicians from EG&G and the State of Idaho Department of Water Resources. The Phase-1 analysis provided a thorough characterization of the water constituents, whereas Phases-2 and -3 analyses concentrated on conductivity (ECw), SAR, pH, fluoride, chloride, total hardness, and silica. Results of the water analyses are shown in Table 2.

The most important quality characteristics of an irrigation are (a) total concentration of soluble salts, (b) relative proportion of sodium to other cations, and (c) concentration of toxic elements, such as fluoride or boron. (The effects of high salinity, sodium, and fluoride were briefly discussed in the Problem Statement of the Introduction.) Figure 3 shows a diagram for determining the quality rating of an irrigation water from its electrical conductivity and sodium adsorption ratio, with symbols indicating the classifications of waters compared in this experiment.

Soils

A general preexperiment evaluation of the salinity of plot soils was obtained by collecting random 0- to 25-cm deep soil samples across each plot, and compositing them for analysis. The results of these initial analyses were compared with data from subsequent tests, which included a laboratory leaching experiment, a single irrigation field test, and 3 years of geothermal irrigations on the Udy-1 plots. The results of the initial soil analyses are found in Table 3.

The short-term effects of geothermal water on new soils was determined in the field on a small plot of uncultivated, sagebrush-community soil. A portion of the soil was irrigated with geothermal water for 24 hours. Following the irrigation, soil samples were collected from the irrigated and adjacent nonirrigated soils, analyzed, and compared for soil salinity. The results of these analyses are shown in Table 4.

In the laboratory, a composite-bulk soil sample, collected from the 0- to 15-cm depth of Udy 1, was placed in a column and leached with 3 m of geothermal water. The soil was subsequently analyzed and the results compared to the initial evaluation soil data. The results of these soil analyses and the chemistry of the leaching waters are shown in Tables 5 and 6.

The long-term effects of geothermal irrigation were investigated by sampling and analyzing Udy-1 plot soils at two locations on each subplot, following the three seasons of water application. The samples were analyzed individually to provide an index of the variation that may be encountered across the plot. Table 7 shows the results of the 3-year soil analyses.

Crops

The geothermal water contained a high level of fluoride and traces of other potentially toxic elements. A major concern regarding the use of this water for irrigation was that crop productivity, nutritional value, or edibility might be impaired if plants accumulated toxic substances from the water. During Phase 1, samples of mature oats, wheat, barley, grasses, alfalfa, and potatoes were irrigated with geothermal and comparison waters, collected, and analyzed for total constituents [using chemical- and neutron-activation (NAA) techniques] and for nutritional values. The geothermal-irrigated crops were compared to control-plot crops and to composition data from the literature. The Phase-1 comparisons indicated no significant differences in growth, yields, or nutritional values between crops irrigated with geothermal and comparison waters. Geothermal-sprinkled crops exhibited elevated levels of fluoride, but were otherwise similar in elemental composition to comparison and reference-data crops. On the following pages, the constituents of barley (Table 8) and alfalfa (Table 9) are listed, as well as the analyses of the various constituents by both chemical- and neutron-activation methods.

TABLE 2. WATER CHEMISTRY OF IRRIGATION WATERS (Season Averages, Values in ppm)

	Phase 1			Phase 2		Phase 3	
	Geothermal	Raft River	Comparison Well	Geothermal	Comparison Well	Geothermal	Comparison Well
ECw	2850	1160	2480	3100	2500	2800	2480
SAR	21.1	2.6		17.9	9		9
pH	8.3	8.2	7.7	8	7.5	8.2	7.6
B	0.19	0.10	0.1				
Ca	53	82	97				
Fe		0.15	<0.1				
K	39	7.1	16.5				
Li	1.6	<0.1	1.2				
Mg	0.57	19	10				
Na	564	72	536				
Ni	0.01						
P	<0.1	2.5	0.01				
Si	70						
SiO_2	180	38	58	180	50	182	42
Sr	1.4						
Cl^-	936	133	895	936	664	837	686
CO_3	14.2						
F^-	9.4	0.61	3.6	9.4	2	10.4	2
HCO_3	26.8	248	169	124	199	150	202
NH_4	0.1						
SO_4		54	74				

Yields

Estimates indicate essentially no difference in yields between crops receiving geothermal or comparison waters. Yields also compared favorably with crops grown in the surrounding farm area. For example, the barley grown on the newly tilled Udy-2 plot during Phase 2 yielded 2581 kg/ha, which was lower than the area average (∿3657 kg/ha), but not uncommon for first-year production on new soil. During Phase 3, the Udy-2 plot barley yielded ∿5273 kg/ha, which was greater than average yields in the area.[7]

Fluoride Analyses

Since geothermal water often contains soluble salts, traces of heavy metals, and fluoride (6 to 10 ppm at Raft River), an objective of the Raft River Experiment was to evaluate crop constituents after exposure to geothermal fluids. Analyses of crop constituents during Phase 1 indicated that geothermal-irrigated crops do not accumulate excessive heavy metals or minerals. But the cereal grains exhibited elevated fluoride concentrations, primarily as adsorbed surface contamination. The fluoride levels prompted concern over possible high-fluoride concentration in livestock forage crops. Plants and animals exhibit varying degrees of fluoride sensitivity. Accumulation of fluorides in sensitive plants can result in changes in their metabolism, production of foliar lesions, and alterations in growth, development, and yield. Their sensitivity is usually to gaseous

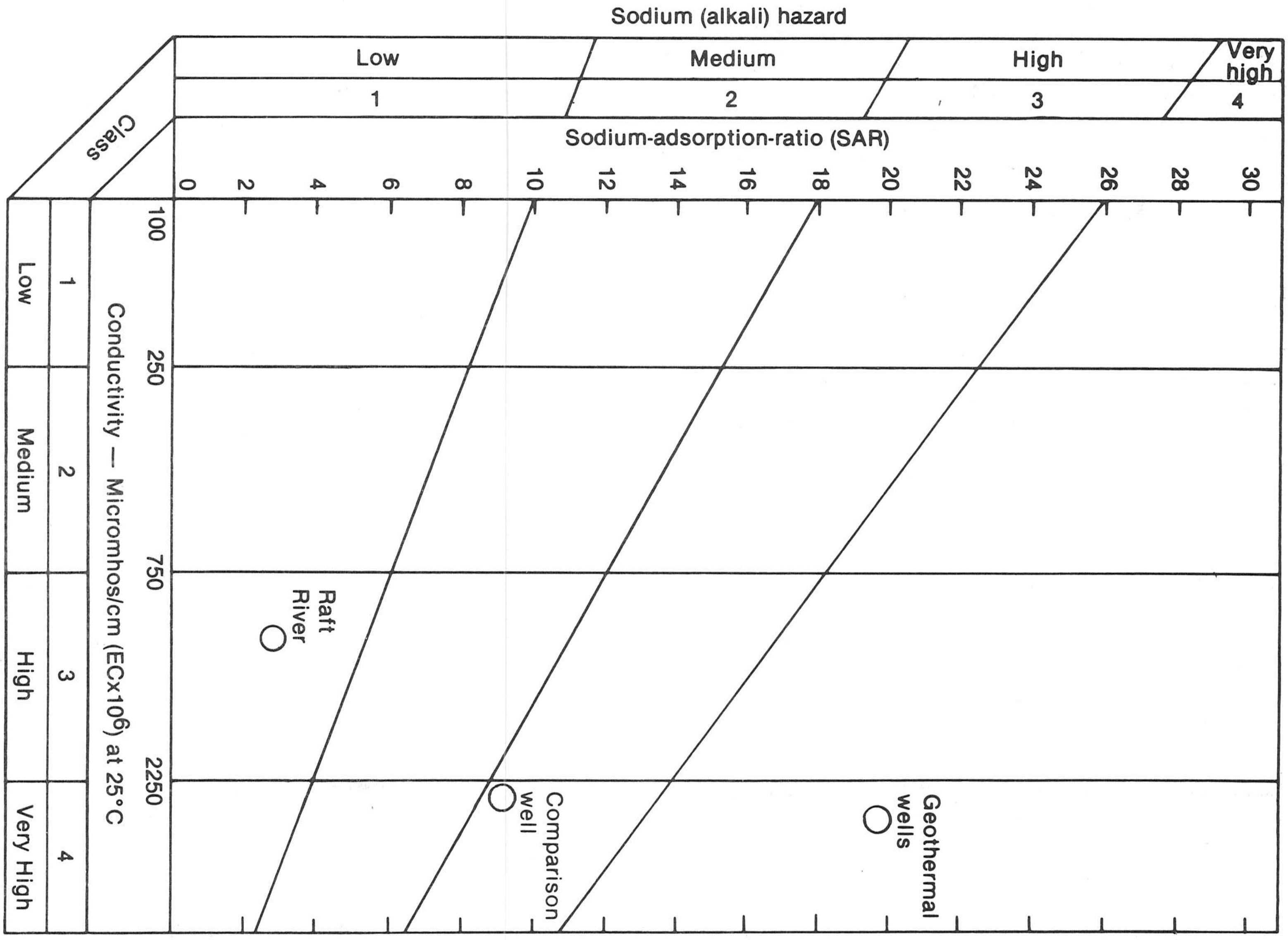

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Figure 3. Diagram for classifying irrigation waters.[4]

TABLE 3. ANALYTICAL DATA ON SOIL FROM THE UDY-1, UDY-2, AND STEWART TRIAL AREAS

Sample	Depth (in.)	pH	EC_e [a] (mmho/cm)	CEC [b]	Water-Soluble Na [c] (me/100 g)	Saturation (%)	Extractable Na (me/100 g)	Exchangeable Na (%)
Udy 1	0 to 6	8.2	1.5	18.9	0.4	39.7	2.2	9.5
Stewart	0 to 6	8	2.9	25	1.2	57.8	5.4	16.9
Udy 2	0 to 6	8.6	3		3.7		9.4	

---

a EC_e = Specific Electrical Conductance.

b CEC = Cation Exchange Capacity; a measure of the quality of the soil (CEC = me/100 g of sample).

c me = Mili-equivalents [ml x normality = me; mg/l ÷ formula weight = me/l].

TABLE 4. SALT EXCHANGE CAPACITY AND EXCHANGEABLE SODIUM CONTENT OF BRUSH SOIL NEAR RRGE 2, WITH AND WITHOUT GEOTHERMAL WATER

Soil	Sample Number	Depth (in.)	Treatment	pH	ECe (mmho/cm)	CEC	Water-Soluble Na (me/100 g)	Saturation (%)	Extractable Na (me/100 g)	Exchangeable Na (%)
104	1	0 to 10	No water	8.3	1.9	20.5	0.5	36	3.9	16.4
104	2	0 to 10		8.2	5.8	16.8	1.3	37	5.5	24.8

NOTE: ECe, CEC, and me are defined in Table 3.

TABLE 5. SALINITY AND ALKALINITY OF UDY-1 SOILS, BEFORE AND AFTER LEACHING WITH GEOTHERMAL WATER

	NH_4OAc (me/100 g)	H_2O-Sol (me/100 g)					
Sample	CEC	Na	Na	ESP	SP	pH	ECe (mmho/cm)
Initial sample	18.9	2.2	0.4	9.5	39	8.2	1.5
After leaching	18.1	4.2	1.2	17	39	8.3	3.8

TABLE 6. QUALITY OF GEOTHERMAL LEACHING WATERS

Sample	Ca (me/l)	Mg (me/l)	Na (me/l)	ECe (mmho/cm)	SAR
RRGE 1 and 2	3.2	0.1	23	3160	17.96

forms of fluoride, such as hydrogen fluoride. The ingestion of excessive fluorides by animals may result in lesions on developing teeth, osseous lesions, lameness, and impairment of appetite—with related decreases in growth and milk yield.[8] Consequently, Phases-2 and -3 evaluations were designed to further evaluate crop composition with particular emphasis on accumulations of fluoride in forage crops.

Thus, samples of alfalfa, spring and fall barley, brome, fescue, and orchard grasses, sugar-beet tops, and wheat were collected and analyzed for composition (including fluoride) and nutritional value during the next two growing seasons. Samples of leaves and crowns of sugar beets collected from the Udy-1 subplots were included in the evaluations because they are commonly used as animal feed. The results of the fluoride determinations are shown in Table 10.

These data show that geothermal waters containing fluoride can be used for surface irrigation without greatly increasing the fluoride content of the forage being grown, but that fluorides are apparently absorbed by forage crops receiving sprinkled water. There is no indication that the seeds of cereal crops accumulate excessive amounts of fluoride when sprinkled with geothermal water.

OBSERVATIONS AND DISCUSSIONS

Soils

The Raft River soils are typically saline. This may be the result of a combination of factors, including salt constituents in the ground water and primary soil minerals, low rainfall, and poor surface drainage. Drainage of salt-bearing waters from the higher elevations may periodically raise the ground-water level to near the soil surface in the valley floor. Subsequent evaporation leaves behind dissolved salts, resulting in salinization of the soils. The presence of excessive salt in the soil increases soil-moisture tension and osmotic pressure of the soil solution, reducing water availability to plant roots and restricting growth. Some Raft River soils, called Saline-Alkali soils, contain appreciable quantities of exchangeable sodium, in addition to salt. The sodium-saturated clay materials in these soils are highly dispersed and may become transported downward through the soil, accumulating at lower levels in the soil profile where they develop a dense layer of low permeability.

When these soils are used for irrigated agriculture, leaching irrigations are required to

TABLE 7. ANALYSES DATA OF THE SOIL SAMPLES FROM THE UDY-1 IRRIGATION PLOTS, FOLLOWING 3 YEARS OF IRRIGATION

		NH_4OAc [a] (meg/100 g)			Water soluble (meg/100 g)				Exchangeable [a] (meg/100 g)					
Sample	Identity	CEC	Na	K	Na	K	Ca	Mg	Na	K	ESP	SP	pH	ECe (mmho/cm)
1	Geothermal flood, southwest corner	18.3	4	5.9	1.2	0.1	0.2	0.1	2.8	5.8	15	41	7.9	4
2	Comparison well sprinkled, plot center	16.6	3.1	4.3	0.8	0.1	0.2	0.1	2.3	4.2	14	41	8	2.6
3	Comparison well flood, southwest corner	20.5	3.9	6	1.2	0.1	0.3	0.1	2.7	5.9	13	42	7.9	4.5
4	Comparison well sprinkled, southeast corner	17.6	3.2	4.7	1.1	0.1	0.3	0.1	2.1	4.6	12	43	7.8	3.8
5	Comparison well flood, southeast corner	19.4	5.2	7	1.6	0.2	0.5	0.1	3.6	6.8	19	44	7.5	5.7
6	Geothermal flood, center east	18.7	5.7	4.7	2	0.2	0.5	0.2	3.7	4.5	20	47	7.8	6.2
7	Geothermal sprinkled, northeast corner	18.7	4.9	4.7	0.7	0.1	0.1	0.1	4.2	4.6	23	41	8	2
8	Geothermal sprinkled, southwest corner	17.6	4.3	4.5	0.7	0.1	0.1	0.1	3.6	4.4	21	44	8	1.9

a. In the presence of lime, the exchangeable Ca and Mg cannot be accurately determined.

TABLE 8. COMPOSITION OF PHASE-1 BARLEY, ACCORDING TO THE SOURCE AND APPLICATION OF THEIR IRRIGATION WATER

	Geothermal-Sprinkled Irrigation		Comparison-Sprinkled Irrigation		Geothermal-Flood Irrigation		Comparison-Flood Irrigation		
Constituent	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Reference Source^{5,6}
Crude Protein %	9.9		10		9.2		9.9		9 to 15.9
Crude Fat %	1.4		1.3		1.3		1.1		1.5
Crude Fiber %	10.6		10.7		12		12		4.8 to 10.2
Ash %	5.5		6.3		8.1		7.2		2.5 to 3.9
NFE %	72.6		71.7		69.4		69.8		67.6 to 81.9
TDN %	83.1		82.2		80.2		80.7		
Dry Matter %	98.9		99.1		98.7		98.8		
Phosphorus	1100		1100		1200		1300	3650	3300 to 5100
Potassium	3000	3350	3000	3750	3000	3350	4000		5000 to 6800
Calcium	1900		1800		1900		2000		500 to 1300
Magnesium	1300		1400		1400		1600		100 to 1700
Sulphur	650		720		560		800		100 to 600
Sodium	300	575	400	300	400	170	400	220	1200 to 2200
Fluorine	13		12		8.4		0.2		
Zinc	28		27		25		26		9 to 29
Iron	44	84	44	56	42	99	32	105	40 to 100
Manganese	31	28	28	27	28	24	25	22	2 to 30
Copper	4		3		4		5		4 to 38
Boron	2		2		2		2		
Arsenic	<0.5		<0.5		<0.5		<0.5		
Selenium	<0.1		<0.1		<0.1		<0.1		
Lead	4		3		3		3		
Mercury	0.2		0.1		0.1				
Aluminum		100		56		90		95	
Chlorine		1610		1380		1035		1140	1200
Chromium		2.8		–		2.4		1	
Cobalt		1.7		0.1		1.2		1.1	0.1
Bromine		2.6		1.9		1.7		1.7	

TABLE 9. COMPOSITION OF PHASE-1 ALFALFA, ACCORDING TO THE SOURCE AND APPLICATION OF IRRIGATION WATER

	Geothermal-Sprinkled Irrigation		Comparison-Sprinkled Irrigation		Geothermal-Flood Irrigation		Comparison-Flood Irrigation		
Constituent	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Chemical Technique	NAA Technique	Reference Source^{5,6}
Crude Protein %	25.5		24.6		27.1		23.2		9.3 to 24.7
Crude Fat %	1.4		1.5		1.7		1.7		
Crude Fiber %	17.6		18		16.9		17.3		15.9 to 42.4
Ash %	11		10.5		11		12.2		6.7 to 15.3
NFE %	44.5		45.4		43.7		45.8		36.7 to 49.1
TDN %	62.7		62.6		62.8		61.6		
Dry Matter %	94.6		94.4		94.4		94.5		
Phosphorus	2 600		2 500		2 600		2 500		1 600 to 4 300
Potassium	20 000	9 350	21 000	12 300	19 000	9 700	21 000	13 200	4 300 to 27 400
Calcium	19 000		16 000		20 000		19 000		7 600 to 29 800
Magnesium	2 100		2 300		1 900		3 000		300 to 8 400
Sulphur	1 200		900		1 700		600		2 000 to 7 300
Sodium	1 100	570	900	140	1 200	350	1 500	320	100 to 3 300
Fluorine									
Zinc	33	8	33	10	28	5	16	10	10 to 29
Iron	190	195	150	130	220	140	120	180	40 to 1 640
Manganese	76	36	70	34	79	27	75	24	8 to 100
Copper	11		10		10		6		4 to 38
Boron	29		40		44		36		
Arsenic									
Selenium									
Lead									
Mercury									
Aluminum		315		165		195		210	
Chlorine		4 900		4 300		3 500		3 600	600 to 5 400
Chromium		2.2		2.5		0.6		2.5	
Cobalt		0.8		0.8		0.3		0.6	0.2 to 0.31
Bromine		16		15		14		21	

TABLE 10. FLUORIDE CONTENT OF CROP SAMPLES

Crop	Phase 1 (1976) Geothermal Sprinkle (9.4 ppm)	Phase 1 (1976) Comparison Sprinkle (2 ppm)	Phase 1 (1976) Geothermal Flood (9.4 ppm)	Phase 1 (1976) Comparison Flood (2 ppm)	Phase 2 (1977) Geothermal Sprinkle (9.4 ppm)	Phase 2 (1977) Comparison Sprinkle (2 ppm)	Phase 3 (1978) Geothermal Sprinkle (10.4 ppm)	Phase 3 (1978) Comparison Sprinkle (2 ppm)	Phase 3 (1978) Geothermal Flood (10.4 ppm)	Phase 3 (1978) Comparison Flood (2 ppm)
Alfalfa					113	38	113	38	15	15
Barley										
Spring	13	12	8.4	0.2[a]			2.5	1.8		
Fall							8.3			
Grasses										
Brome					93	37	379	60		
Fescue							242	44		
Orchard					118	38	81	37		
Oats	13	12								
Sugar-beet tops							50	12		
Wheat	14	7	19		74[b]	31[b]				

a. Apparent analytical error.

b. Immature samples included leaves, tillers, and heads of grain.

dissolve and transport soluable salts downward through the soil. Farmers using irrigation water to leach salts from the soil must consider water quality, irrigation management, leaching, and drainage to obtain maximum efficiency.

Water Quality

Upon evaluating geothermal water for irrigation and soil leaching, it was apparent that reduction of yield would occur unless salt tolerant crops were grown and special management practices maintained a favorable soil-salt balance. Laboratory leaching experiments indicate that new soils may experience increased salinity and decreased permeability when irrigated with geothermal water. Comparisons of soil analysis data from the Udy-1 plot, following 3 years of geothermal irrigation, confirm that soil salinity and exchangeable sodium levels were increased through geothermal-water application. However, satisfactory crops were produced on plot soils using geothermal water, and the salts did not cause significant yield reductions of tolerant crops.

Irrigation Management

The best methods for applying geothermal irrigation water depend upon crop variety, soil type, topography, water availability, and water quality. The three principal means of irrigation used during this experiment were flood, furrow, and sprinkler.

The surface-flood and furrow methods appear to offer advantages in irrigating salt-sensitive crop varieties. For example, a row of hardwood trees planted along one border of the Udy-1 plot, exhibited satisfactory establishment and growth on the surface-irrigated subplots; whereas the trees planted on the sprinkled subplots experienced severe foliar damage, which resulted in nearly 100% mortality following foliar exposure to the saline waters.

Flood irrigation offers advantages over furrow irrigation for applying saline water to forage and cereal crops. If the hazard of soil erosion is low, and the topography suitable for uniformly applied flood irrigations over the soil surface, the crop consumptive use and soil leaching requirements may be fully satisfied. In addition, foliar damage will be minimal, and a soil salt balance can be maintained. Furrow irrigation is less desirable than flooding for non-row crops because salts tend to accumulate in the ridges between furrows. Refer back to Table 7 for an indication of the efficiency of sprinkler and furrow irrigation in maintaining soil salt balances, using geothermal and comparison waters. During Phase 3, the surface-flood subplots were corrugated to provide more efficient irrigation water distribution to high spots. The flood plots were thus changed from flood to furrow, but the subplot title remained unchanged for the sake of uniformity. The higher salinity (ECe) values shown for flood-irrigated subplots indicate that less effective leaching occurred. Under the furrow system, the saline water moved into the ridges between furrows by capillary action; the water evaporated; and the dissolved salts remained in the soil ridges.

Irrigation by sprinkling, although more costly than surface irrigation, allows for uniform water distribution and close control over the amount of water applied. Sprinkling is often used on steep slopes or where the topography is too rough for surface methods. However, there is a general tendency to apply an insufficient amount of water to satisfy the leaching requirements under sprinkler systems, and special effort must be made to maintain a favorable soil salt balance. If geothermal water delivered to the field is hot, sprinkling offers a means of cooling prior to plant contact.

Leaching Requirement

Field crops derive most of their moisture from the upper portions (top 15 cm) of the root zone. Although plants can consume water from anywhere in the root zone, normally about 40% is obtained from the upper quarter, 30% from the second quarter, 20% from the third quarter, and 10% from the lowest quarter.[9] Thus, the salinity of the lower root zone is considered to be of less importance as long as the crop is relatively well supplied with moisture in the upper, more active root zone. If water in excess of crop requirements is uniformly applied, each irrigation will leach the upper soil area and maintain it at a relatively low salinity. Except for salt crusts, salinity will usually increase with depth and be greatest in the lower part of the rooting area.

Since the geothermal fluids used in this experiment contained appreciable quantities of salts ($\sim$1.5 kg/m^3), periodic leaching irrigations were required to remove salts which accumulated as a result of evapotranspiration from root-zone soils. The leaching requirement is defined as the fraction of the irrigation water that must pass through the root zone to prevent the soil salinity from exceeding a specified value.[9] Assuming steady-state, water-flow rates, uniform application of irrigation water, no rainfall, no removal of salt in the harvested crop, and no precipitation of soluable constituents in the soil, the leaching requirement is simply the ratio of the equivalent depth of the drainage water to the depth of irrigation water (Ddw/Diw), and may be expressed as a fraction or percent. This ratio is equal to the inverse ratio of the corresponding electrical conductivities, that is,

$$LR = \frac{Ddw}{Diw} = \frac{ECiw}{ECdw}\,^{9}. \qquad (1)$$

Tolerant crops, such as beets and barley, are capable of producing good yields where the salt concentration of the soil solution may reach ECe values as high as 8 mmho/cm.

Drainage

Drainage in agriculture is the process of removing the excess water and salts from the soil to maintain high crop productivity. The irrigation, soil management, and leaching practices employed with high-salinity geothermal water, establish the drainage requirements. The minimum requirement must be adequate to remove a depth of water equivalent to that which must be passed through the soil root zone to maintain a favorable salt balance.

The Raft River plots currently exhibit sufficient natural, internal drainage to accommodate the excess waters applied. However, if large land areas are irrigated with the required leaching fraction, the local water table may rise, leading to complications in salinity control; the ground water may be impacted by leachates; and drainage problems may result.

Continuing phases of this experiment will concentrate on determining and applying the proper leaching irrigations to plot soils, characterizing the resultant soil profiles, and determining the quality of the leachates which reenter the natural aquifer system.

Crops

Growth and Yields

During Phase 2, barley growth patterns on the Udy-2 plot were variable, a result of uneven leaching of soil salts. Figures 4 and 5 show a comparison to two areas on the barley plot where one received adequate and the other inadequate leaching. The crop quality did not appear to be affected by the irrigation water source. Figure 6 shows typical cereal grains irrigated with geothermal and comparison waters. The growth and yields of barley and sugar beets irrigated with geothermal water were not restricted by the soil and water salinity, as evidenced by yield comparisons with the surrounding area farms.

The forage crops planted on the subplots included monoculture alfalfa and a forage mixture consisting of alfalfa, smooth brome, alta fescue, and orchard grass. The alfalfa on all of the sprinkled subplots exhibited varying degrees of leaf curl and tip burn. Moisture stress associated with the saline soils and water and other factors such as nutrient deficiencies may have prompted this reponse. However, none of these symptoms appear to severely retard total growth and yields. The forage grasses exhibited satisfactory establishment, growth, and productivity on each of the subplots. Figures 7 and 8 show the relative growth of forage on geothermal- and comparison-water sprinkled subplots. Figure 7 shows a portion of the subplot located on Ayses-Hiko Peak-Complex soil, which is not well suited for irrigated agriculture, and is therefore inherently less productive than the Bram, silt-loam soil on the remainder of the plot.

Fluoride

Fluoride is present in various amounts in all soils and natural waters. All vegetation contains some fluoride that has been taken up from soils, absorbed through the leaves from the air, or sprinkled by irrigation water.

There is little detailed information available on the amount or mechanism of fluoride uptake from irrigation water by plants. Investigators have reported that fluorides can be absorbed from the soil solution or directly through the leaves.[10,11] Rand and Schmidt[12] reported elevated fluoride content of forage grown with irrigation water containing 6.2 ppm fluoride.

Figure 4. Barley plot sprinkled by geothermal water, showing good growth near sprinkler lines where soils were leached effectively.

The natural concentration of fluoride in the foliage of most plants is in the range of 2 to 20 ppm.[8] The fluoride concentrations of 107 samples of alfalfa from different U.S. areas that are assumed to be free of industrial pollution, ranges from 0.8 to 36.5 ppm, with a mean of 3.6 ppm.[13]

Results from the experiment indicate that cereal grains sprinkled with geothermal water may exhibit high fluoride contents on their surfaces, but that fluorides are apparently not translocated from the roots, leaves, and tillers to the grain. Therefore, there is little likelihood of having high fluoride in the grain, even when sprinkled with high fluoride water.

There is strong evidence, however, that fluorides are absorbed by forage crops when sprinkled with water containing fluorides. Nonetheless, further evidence indicates that geothermal water containing fluoride can be used for surface irrigation without greatly increasing the fluoride content of the forage being grown.

From our observations, it seems likely that frequent sprinkler applications of irrigation water at low rates of application during hot weather and low humidity are all conducive to high absorption of fluoride by the foliage of crops. In contrast, high water volumes applied infrequently during the cool of the night are conducive to lower fluoride adsorption. Further, there is little likelihood of having high levels of fluoride in the forage or grain crops when the waters are applied by surface irrigation.

The fluoride levels exhibited by forage crops sprinkled by geothermal water may be high enough to produce toxic effects in consuming

Figure 5. Barley plot sprinkled by geothermal water, showing poor growth midway between sprinkler lines where soils were not leached effectively.

livestock, if fed as the major source over a prolonged period of time, or if the water supply available to the consuming animals also contains fluorides. Livestock feeders using geothermal-sprinkled forage as a feed source should take steps to blend high and low fluoride feeds and provide low fluoride water to the animals during the feeding program.

CONCLUSIONS AND RECOMMENDATIONS

Agricultural irrigation offers a potential alternative to dispose of energy-expended, Raft River geothermal water. Such irrigation may reduce reinjection costs and provide an additional water source to the arid Raft River region. Soils receiving geothermal water may experience increased salinity and decreased permeability, such that leaching irrigations must be applied to maintain a favorable soil salt balance. Barley, forage, and sugar-beet crops produced satisfactory growth and yields, with no apparent reduction in nutritional value from exposure to geothermal water. Cereal grains and surface-irrigated forage crops did not absorb and translocate appreciable quantities of fluoride; but geothermal-sprinkled forage crops exhibited abnormally high fluoride levels.

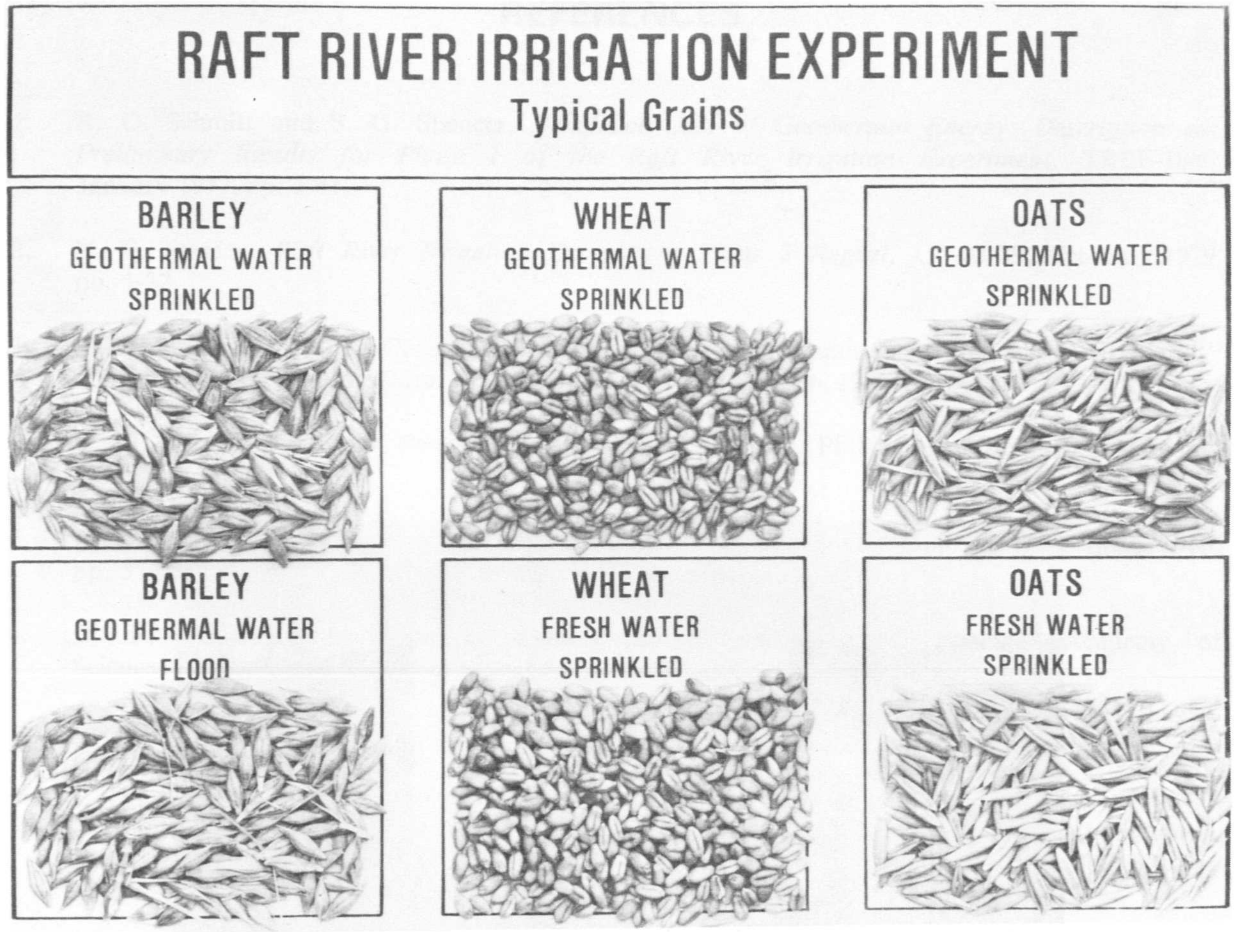

Figure 6. Typical threshed grains from experiment.

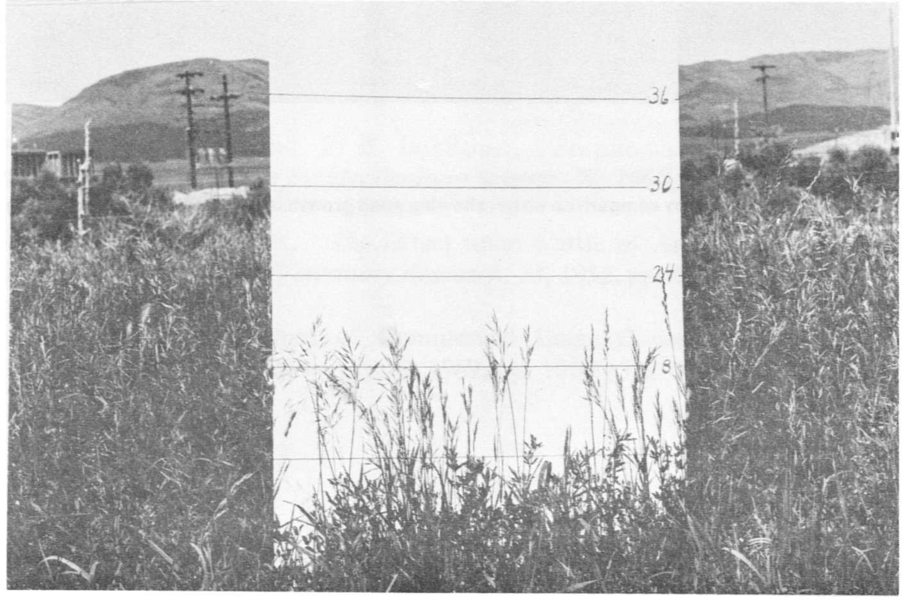

Figure 7. Forage subplot sprinkled by geothermal water on soil at Ayses-Hiko Peak Complex.

Figure 8. Forage subplot sprinkled by comparison water, showing good growth of alfalfa and grasses on Bram, silt-loam soil.

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