1-1-1982

Sprinkler Application of SO2 - Treated Groundwater at the Sandarosa Farm, Snowville, Utah

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SPRINKLER APPLICATION OF SO_2-TREATED GROUNDWATER

AT THE SANDAROSA FARM, SNOWVILLE, UTAH

by

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and
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Report to
International Environmental, Inc.
Salt Lake City, Utah

Submitted by
Utah Water Research Laboratory
Utah State University
Logan, Utah 84322
January 1982

INTRODUCTION

Sulfur is recognized as one of the essential elements for plant growth. It has also been used in agriculture for reclamation of saline and sodic soils. During the reclamation process there is the potential benefit of increased availability of phosphorus and certain micronutrients for plant uptake. There is also potential for increased infiltration thus increasing water utilization efficiency.

Sulfur has been applied to soils in a flake or nodule form, by the addition of sulfuric acid and most recently by the application of sulfurous acid. The raw sulfur addition technique is accomplished by spreading raw sulfur on the soil and under the appropriate temperature, soil moisture, pH and aerobic conditions, microorganisms oxidize the sulfur to sulfate. This process is rather slow except under some very limited optimal conditions. Sulfuric acid has been used under a variety of conditions but seems to be limited due to its hazardous nature and corrosive properties. The sulfurous acid technique seems to have the most promising future as the best and most appropriate technique of sulfur addition. Raw sulfur is burned on site and administered into the irrigation water as needed according to the soil, water and crop conditions.

This project was initiated to evaluate the application and beneficial effects of sulfurous acid (using an International Environmental Inc. Model 150 sulfur burner) to an alkaline soil using barley as the test crop.

OBJECTIVES

The principal objectives of the completed study were: (1) to identify changes in water and soil quality due to SO_2 treatment of the irrigation waters being applied to the soil, (2) to evaluate factors that influence the efficient, economical operation of the system, and (3) to determine SO_2-induced changes in crop yield and nutrient value.

PROCEDURES

A test plot and a control plot of barley were planted on May 19, 1981 (Figures 1 and 2). The first irrigation session began June 19, 1981 and continued on a weekly basis through September 9, 1981. In order to monitor the amount of water applied, rain gages were installed near four rainbirds on both plots. In each session, 1 1/2 to 2 inches of water were applied over a 4 to 9 hour period. Samples were periodically taken during the irrigation session to monitor changes in water chemistry with time. All chemical parameters determined in the irrigation waters were analyzed in accordance to Standard Methods (APHA 1980). The volume of applied water was then calculated by the Thiessen Method (Viessman et al. 1977). On August 26, a 60-foot strip to the south of each monitored rainbird was harvested with a combine. Six soil samples were also collected and evaluated for moisture content (see Appendix, Table 19).

The harvest included a large percentage of weeds, as well as wheat stored in the combine from a previous cutting. These contaminants were removed from a weighed representative sample for both plots and the percent barley was calculated. This percentage was used to determine the total yield of barley.

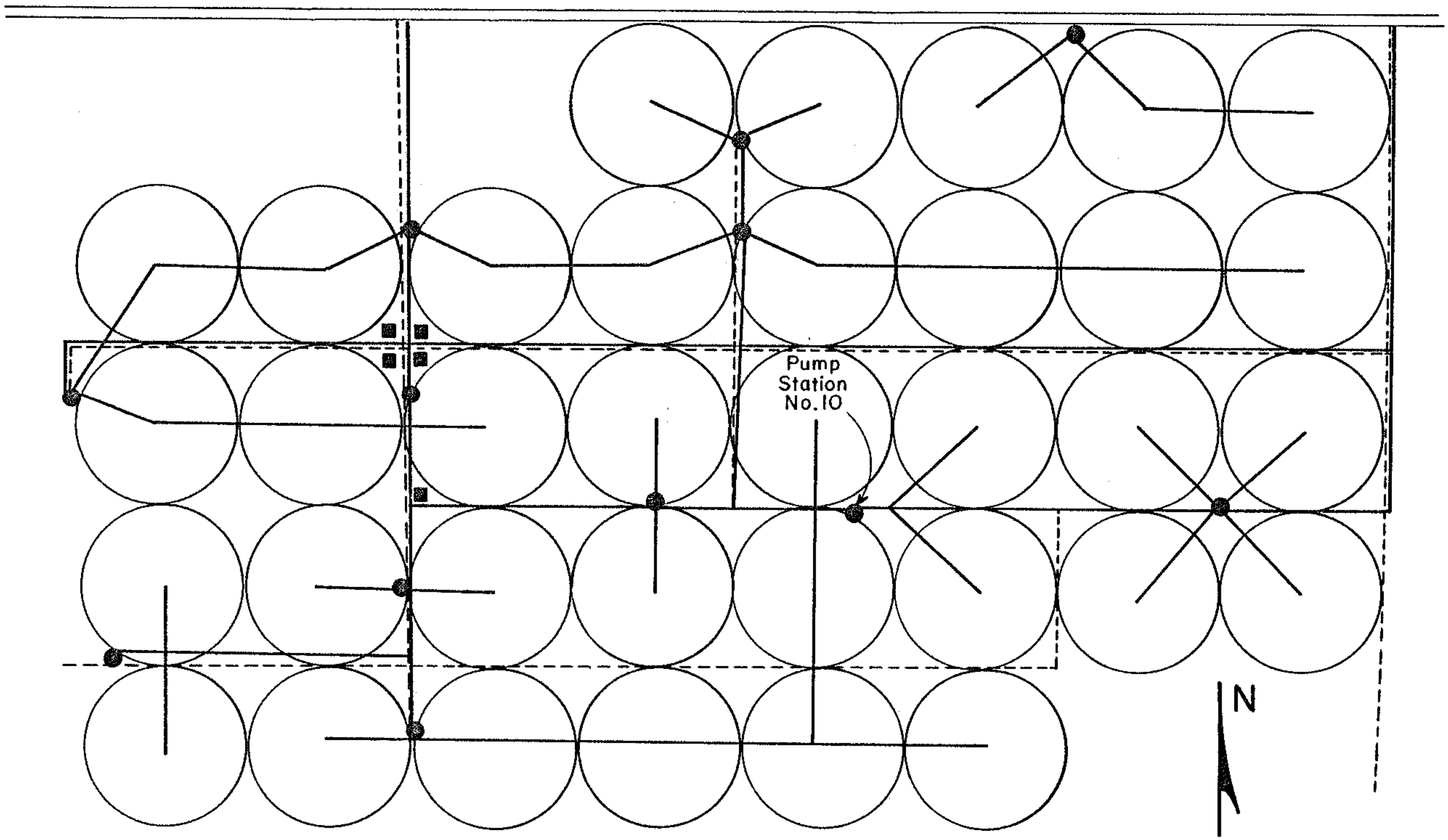

Figure 1. Sandarosa Farms west irrigation system, Snowville, Utah. The test plots were located near station #10 (see Figure 2).

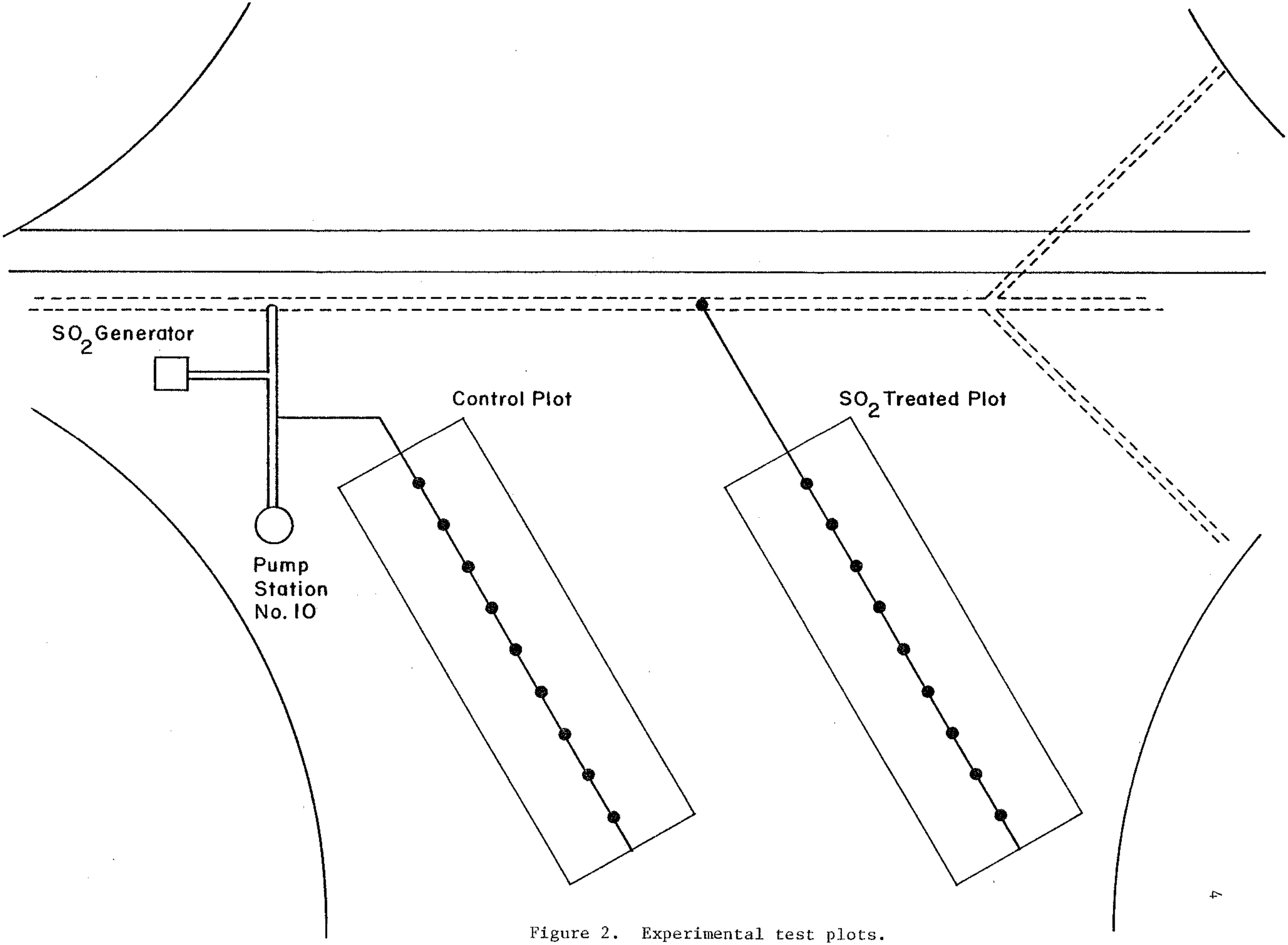

Figure 2. Experimental test plots.

Control and test plot samples of the separated barley were analyzed for protein, percent dry matter, Ca, Mg, Na, K, Cu, Fe, P, Mn, and Zn by the Soil Testing Lab at Utah State University, Logan, Utah.

Following the harvest, two additional irrigation sessions were conducted to permit further treatment of the soil.

Soils samples (12 surface samples from each plot and 12 samples taken at 2 feet for each plot) were collected prior to any irrigation from the control and test plots to evaluate soil conditions. Soil samples were also collected after the irrigation season. Surface samples from before and after irrigation were randomly selected from each monitored rainbird area and submitted to Western Laboratories Inc., Parma, Idaho, for analysis.

RESULTS AND DISCUSSION

Water Quality

pH, alkalinity, and SO_2 were measured on the control and test plot and at other sites throughout the ranch where burners were in operation. Sulfate and total inorganic carbon were also monitored on the control and test plots. Table 1 provides a summary of data for June 30.

As shown in Table 1, a pH increase occurred "in-flight" in both the experimental plots. In addition, alkalinity was 83 percent lower in the test plot as compared to the control plot. These observations indicate that acidity is being lost and bicarbonate is being removed. A reaction sequence that accounts for this phenomenon is provided below:

Table 1. pH, alkalinity, and SO_2 for samples collected 6-30-81.

Site	pH	Alkalinity mg/l as $CaCO_3$	SO_2 mg/l as SO_3
Test Plot			
Nozzle	6.0-6.2	(field data)	
Rain gages	7.2	30	4
Burner	2.1	-	1678
Control Plot			
Nozzle	7.8	165	-
Rain gages	8.4	180	-
Creek Burner	2.3	-	1012
Burner #15	2.4	-	976

(1) $SO_2(g) + H_2O(d) \rightleftarrows (SO_2 \cdot H_2O)_\ell \rightleftarrows HSO_3^- + H^+ \rightleftarrows SO_3^= + 2H^+$

(2) $H^+ + HCO_3^- \rightleftarrows H_2CO_3$

If reaction (2) is open to the atmosphere:

(3) $H_2CO_3 \rightleftarrows CO_2 \uparrow (g) + H_2O$

As indicated by Equations (2) and (3) above, the bicarbonate (alkalinity) under acidic conditions is converted to carbonic acid which disassociates into CO_2 and water in the atmosphere.

To check this reaction sequence, total inorganic carbon (TIC) was measured before and after flight on July 8. Unfortunately, a very low pH was measured at the test plot nozzle. Because of this low pH in the July 8 samples, the same tests were run again on July 15. Data for these two irrigation sessions are provided in Tables 2 and 3.

As shown in Tables 2 and 3, the post-flight total inorganic carbon was generally less than the TIC at the nozzle. Furthermore, TIC in the

Table 2. Chemical parameters for samples collected 7-8-81.

Site	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as $SO_3^=$	$SO_4^=$ mg/l	TIC mg/l
Test Plot					
Nozzle	3.24	-	46	238	10.6
Rain gage	6.25	11.8	4	216	6.0
Post-Flight	3.31	-	24	242	1.8
Control Plot					
Nozzle	7.85	165.8	-	29	44.0
Rain gage	8.41	176.3	-	35	43.5
Test Plot Burner	2.08	-	880	154	22.9

test plot, was substantially less than in the control plot. These observations indicate the escape of CO_2 and support the proposed reaction sequence.

Tables 4-10 summarize water quality data taken from June 22 to September 9. Several trends are evident in all sessions. Initially, pH at the test plot nozzle is near the control plot nozzle pH at 7.8-8.2. As time elapses, however, the pH at the test plot nozzle decreases, finally stabilizing at about pH 3.

Another interesting trend is the conversion of inorganic carbon initially present as bicarbonate in the groundwater to carbonic acid in the burner tank and thence to CO_2 and water upon expulsion into the atmosphere. Table 10 provides evidence that significant CO_2 loss does not occur until the water exits the nozzle as a spray. In this session, the 4:30 p.m. sample was collected using a hose to prevent

Table 3. Chemical parameters for samples collected 7/15/81.

Time	Site	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as $SO_3^{=}$	$SO_4^{=}$ mg/l	TIC mg/l
11:00 AM	Test Plot					
	Nozzle	3.60	-	44	196.8	11.2
	Post-Flight	6.40	18.9	-	189.3	6.1
11:30	Control Plot					
	Nozzle	7.91	164.9	-	32.3	52.7
11:30	Burner	2.20	-	1434	166.4	12.4
12:00	Pivot					
	Nozzle	6.37	32.5	-	141.9	16.6
	Post-Flight	6.70	40.4	-	190.6	14.0
1:30 PM	Test Plot					
	North Nozzle	6.35	26.3	-	146.3	10.9
	South Nozzle	6.36	32.9	-	150.7	15.5
	Post-Flight	7.07	45.2	-	152.5	11.9
1:30	Burner	2.11	-	1512	176.3	12.3
3:45	Test Plot					
	Nozzle	6.09	21.9	-	151.9	16.8
	Post-Flight	6.58	27.6	-	146.9	5.6
	Rain Gage	7.17	28.9	-	166.2	6.4
3:45	Control Plot					
	Nozzle	7.94	161.8	-	34.8	35.0
	Rain gage	8.30	181.1	-	41.8	
3:45	Burner	1.93	-	1676	176.3	23.2

spray formation. As noted in Table 10, the total inorganic carbon (TIC) was high indicating that the carbonic acid had not dissociated. This conclusion is further supported by the low TIC values of post-flight and rain gage samples.

Yet another observation concerns the sulfur dioxide to sulfate oxidation. As shown in Table 10, the sulfate concentration of the

Table 4. Chemical parameters for samples collected 7-22-81.

Site	Time	pH	Alk mg/l as CO_3	SO_2 mg/l as $SO_4^=$	$SO_4^=$ mg/l	TIC mg/l
Burner	10:30	2.14	0	1214	227	18.2
	12:30	2.16	0	1080	171	18.9
	2:30	2.13	0	1126	238	17.4
Test Plot Nozzle	10:45	7.80	147.1	0	22	35.9
	12:30	6.66	41.7	0	133	14.7
	2:30	3.28	0	0	231	9.3
Control Plot Nozzle	10:00	7.99	154.2	0	34	50.8
	12:00	8.02	159.6	0	27	37.7
	2:00	8.07	162.2	0	27	38.7
Test Plot Post Flight	12:30	7.47	47.9	0	149	11.9
	2:30	3.37	0	0	227	0.9
Test Plot Rain Gage		6.37	33.2	0	168	8.0
Control Plot Rain Gage		7.47	173.7	0	36	39.0

Table 5. Chemical parameters for samples collected 7-29-81.

Site	Time	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as SO_3	$SO_4^=$ mg/l	TIC mg/l
Burner	10:15	2.22	0	1460	136	33.5
	11:30	2.22	0	1602	115	21.4
	12:20	2.20	0	1676	207	23.3
	4:15	2.21	0	1448	116	20.7
	5:10	2.15	0	1808	122	20.8
Test Plot Nozzle	10:15	8.06	169.5	0	26	36.2
	11:15	6.44	33.2	0	139	13.7
	12:15	3.21	0	0	213	6.5
	2:15	3.05	0	0	202	6.9
	4:15	3.18	0	0	178	4.4
	5:30	3.97	0	0	178	7.8
Control Plot Nozzle	10:15	8.15	169.5	0	26	38.8
	4:15	8.05	168.6	0	25	37.4
Test Plot Post-Flight	11:15	7.26	44.8	0	144	10.6
	12:15	3.47	0	0	196	1.3
	2:15	3.30	0	0	210	0.7
Test Plot Rain Gage		4.84	0	0	173	1.2
Control Plot Rain Gage		8.41	178.5	0	29	35.2

Table 6. Chemical parameters for samples collected 8-5-81.

Site	Time	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as SO_3	$SO_4^=$ mg/l	TIC* mg/l
Burner	10:00	2.42	0	685	171	41.0
	11:00	2.07	0	1493	121	15.6
	12:00	2.08	0	1507	155	14.8
	2:00	2.01	0	1760	138	6.6
	4:00	2.00	0	1657	134	38.6
Test Plot Nozzle	10:00	8.08	155.6	0	26	38.6
	11:00	7.20	63.8	0	55	32.9
	12:00	5.05	3.9	0	146	17.8
	2:00	3.78	0	0	165	9.7
	4:00	3.13	0	0	184	19.6
Control Plot Nozzle	10:00	8.03	162.3	0	27	44.0
	4:00	8.08	164.3	0	27	43.7
Test Plot Post-Flight	12:00	6.13	5.3	0	134	0.6
	4:00	3.45	0	0	182	<0.5
Test Plot Rain Gage		7.33	25.6	0	138	6.8
Control Plot Rain Gage		8.28	173.9	0	28	46.0

*Samples were run 8-7-81. All others were run 8-6-81.

Table 7. Chemical parameters for samples collected 8-12-81.

Site	Time	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as SO_3	$SO_4^=$ mg/l	TIC mg/l
Burner	11:00	2.22	0	1558	204	18.4
	12:00	2.22	0	1247	168	19.5
	2:00	2.25	0	1298	171	21.5
	4:00	2.18	0	1150	148	19.8
Test Plot Nozzle	11:00	7.97	157.4	0	33	39.8
	12:00	3.18	0	0	252	6.1
	2:00	5.86	9.9	0	152	11.2
	4:00	3.44	0	0	172	7.3
Control Plot Nozzle	11:00	8.06	161.3	0	27	42.0
	4:00	8.18	167.3	0	7	42.6
Test Plot Post Flight	4:00	4.00	0	0	155	<0.5
Test Plot Rain Gage		6.94	19.3	0	147	5.3
Control Plot Rain Gage		8.29	172.2	0	28	43.6

Table 8. Chemical parameters for samples collected 8-19-81.

Site	Time	pH	Alk mg/l $CaCO_3$	TIC mg/l
Burner	10:30	2.06	0	22.5
	11:30	1.89	0	22.0
	1:30	1.84	0	19.3
	3:30	1.85	0	21.1
Test Plot Nozzle	10:30	7.85	168	43.6
	11:30	2.96	0	7.5
	1:30	2.98	0	9.7
	3:30	3.09	0	24.0
Control Plot Nozzle	10:30	8.10	174	40.7
	3:30	7.88	174	43.3
Test Plot Rain Gage		5.69	5	5.0
Control Plot Rain Gage		8.05	199	41.8

Table 9. Chemical parameters for samples collected 9-2-81.

Site	Time	pH	Alk mg/l as $CaCO_3$	SO2 mg/l as SO_3	$SO_4^{=}$ mg/l
Burner	11:00	2.52	0	553	174
	3:00	2.05	0	1702	174
	4:30	1.97	0	2083	167
Test Plot Nozzle	11:00	8.00	166	0	17
	3:00	3.06	0	62	311
	4:30	3.03	0	128	376
Test Plot Rain Gage		3.42	0	21	291
Pivot Nozzle	3:00	8.07	133	0	69
Control Plot Nozzle	11:00	8.17	169	0	36
	4:30	8.24	169	0	37
Control Plot Rain Gage		8.32	176	0	41
#16 Burner	12:00	2.01	0	1705	146
#16 Pivot Nozzle	12:00	6.80	122	0	131

Table 10. Chemical parameters for samples collected 9-9-81.

Site	Time	pH	Alk mg/l as $CaCO_3$	SO_2 mg/l as SO_3	$SO_4^=$ mg/l	TIC mg/l
Burner	11:15	1.97	0	1870	205	19.1
	12:15	1.97	0	2078	154	18.2
	2:15	2.04	0	1510	118	24.8
	4:30	2.04	0	1410	421	18.7
Test Plot Nozzle	11:15	8.44	164	0	26	39.8
	12:15	3.07	0	33	208	12.8
	2:15	2.92	0	145	233	2.0
	4:30	3.05	0	65	206	31.7*
Test Plot Rain Gage		3.27	0	10	210	1.1
Control Plot Nozzle	11:15	8.36	167	0	28	42.6
	12:15	8.35	167	0	29	41.9
	2:15	8.04	165	0	27	41.7
Control Plot Rain Gage		7.88	170	0	29	43.2

*Collected without spray-air contact.

4:30 sample was not significantly decreased by preventing spray formation. This implies that oxidation occurs in-line prior to arrival at the nozzle. The same effect was observed on burner #16 in a sample taken September 2 (Table 9). Essentially all of the sulfur exiting the center pivot fed by burner #16 was present as sulfate.

Several observations suggest that only a small amount of the sulfur exiting the burner was actually applied to the test plot. For instance, using the data from Table 9 for 3:00 p.m., on September 2 1702 mg/l SO_2 and 174 mg/l SO_4 were present in the burner. At the same time, 311 mg/l SO_4 and 62 mg/l SO_2 were present at the test plot nozzles. When these concentrations are converted to moles of sulfur, total sulfur concentration in the burner = 23.1 mmoles/l, and sulfur concentration at the test plot nozzles = 4.0 mmoles/l. Each liter from the burner was therefore dilluted by approximately 4.8 liters from the pump. Since test plot demand is small relative to center pivot demands, and since the sulfur mass flow rate = Q (flow rate of water) x C (concentration of sulfur), the vast majority of the sulfur in the burner was transported west away from the test plot. A sample taken from a center pivot nozzle west of the burner had a sulfate concentration of 69 mg/l, roughly twice the normal background concentration of 25-35 mg/l.

Application rates of water and sulfur for the monitored sections of the test and control plots are provided in Table 11. As shown in Table 11, the sulfur application of the September 2 session was nearly double that of other sessions. A typical application rate was approximately 1.4 lbs S in 3170 gallons. This is equivalent to 1.7 mmoles S/l.

Assuming an average combined flow rate of 30 gpm out of the test plot nozzles and a sulfur concentration of 1.7 mmoles/l, approximately 0.8 pound of sulfur per hour exited the test plot nozzles. This result checks out fairly well with calculations based on measurements of water applied and sulfate concentrations in the rain gages. As shown in Table 11, a total of 17.1 pounds of sulfur was applied in the rain gage monitored sections in 76.84 hours, a rate of 0.22 pound per hour for four rainbirds. For all nine rainbirds the rate becomes 9/4 x 0.22 = 0.50 pound per hour. If 30 percent of the spray overshoots the plot boundaries, then 0.71 pound per hour was leaving the test plot nozzles.

Table 11. Water and sulfur applied to monitored sections of test and control plots.[a]

Date/Site	Duration (hrs)	Volume of Water Applied (gallons)	Water Application Rate (gpm)	Est. Weight of Sulfur Applied (lbs)	Lbs of Sulfur Applied/ per Acre
5-19/Planting					
6-19/Control	2.83	740	4.36	0.06[b]	0.7
Test	2.83	969	5.71	0.40[b]	4.9
6-23,/Control	19.08	7818	6.83	0.66[b]	8.0
24 Test	19.08	8573	7.09	2.15[b,c]	26.0
6-30/Control	5.00	2707	9.02	0.22[b]	2.7
Test	5.00	2574	8.58	1.07[b]	13.0
7-8/Control	4.25	2491	9.77	0.24	2.9
Test	4.18	2136	8.52	1.30	15.7
7-15/Control	4.50	2385	8.83	0.28	3.4
Test	4.75	1938	6.80	0.90	10.8
7-22/Control	6.25	3357	8.95	0.34	4.1
Test	6.25	2973	7.92	1.39	16.8
7-29/Control	5.92	3684	10.37	0.30	3.6
Test	6.00	3474	9.65	1.67	20.3
8-5/Control	9.00	4521	8.37	0.35	4.3
Test	9.00	4432	8.21	1.70	20.6
8-12/Control	5.00	2704	9.01	0.21	2.6
Test	5.00	2704	9.01	1.11	13.4
8-19/Control	4.00	2351	9.80	0.20[b]	2.4
Test	4.00	2281	9.50	0.95[b]	11.5
8-26/Harvest					
9-2/Control	5.50	3616	11.0	0.41	5.0
Test	5.50	3084	9.3	2.71	32.8
9-9/Control	5.25	3121	9.9	0.25	3.0
Test	5.25	2867	9.1	1.77	21.4
Total/Control	76.58	38,495	8.4	3.52	42.7
Test	76.84	38,005	8.2	17.12	207.2

[a]"Monitored Sections" are 30' x 30' square sections on four rainbirds per plot. Water application was determined by the Thiessen Method using five rain gages on each of the four monitored rainbirds.

[b]Assumes sulfur concentrations of 30 mg/l SO_4 in control plot and 150 mg/l SO_4 in test plot rain gages.

[c]Estimated sulfur concentration is reduced 40 percent to account for burner shutdown during the night.

Given that the burner is supplying approximately 40 pounds/hr, then only 1-3 percent of the sulfur in the burner actually reached the test plot area. The remaining sulfur not being applied to the test plot is being distributed to the farm irrigation center-pivots associated with pump station #10.

Crop Yield and Nutrient Value

Table 12 provides a summary of data on grain yield and quality. As shown in Table 12, barley yield was 39 percent greater in the test plot than the control plot (see Appendix, Table 21). It should be recognized, however, that the test plot had 68 percent fewer weeds. This may partially account for the smaller yield in the control plot but SO_2 may have also been the controlling factor regarding fewer weeds in the test plot (Stroehlein 1978).

Table 12 provides data for one analysis per sample of grain and, therefore, can only serve as a preliminary indicator of probable differences. In order to provide a statistically significant difference in grain quality, replicate samples should be analyzed.

Soil Quality

On May 21, 1981, 48 soil samples were collected on the experimental plots from the surface and at 2 feet below the surface using an open faced auger. These samples were dried, sieved through a #10 sieve, and stored for future analysis.

Samples were also collected on September 22, 1981. Twelve soil samples from the surface and 12 soil samples at a 2 foot depth were collected from the control plot and the test plot (total of 48). The samples were dried and sieved through a #10 sieve.

Table 12. Grain quantity and quality 9-26-81.

Parameter	Control	Test	% Difference (from control)
Barley Yield, lbs/acre	479.6	668.4	+39
% Protein	10.0	9.3	
% Dry Matter	84.8	84.6	
% Ca	3.7	3.6	
% Mg	0.057	0.068	
% Na	0.016	0.029	
% K	0.197	0.175	
% P	0.24	0.25	
Cu, ppm	11	32	
Fe, ppm	65	50	
Mn, ppm	23	18	
Zn, ppm	14	16	

Surface soil samples were selected (16 surface samples collected on May 21, 1981, and 16 surface samples collected on September 22, 1981) and sent to Western Laboratories, Inc. for analysis (Appendix, Tables 15-18). A summary of the mean values are presented in Tables 13 and 14. A split quality control sample was also submitted for analysis (Appendix, Table 20).

A t-statistic evaluation (two sample test) was performed on the soils data (Tables 13 and 14). The soils data are somewhat difficult to interpret but it appears that there is a significant decrease in soil pH in the test plot after irrigation with SO_2 treated irrigation water. The data also indicate that there is a significant increase in soluble salts in both the control and test plots; this may indicate that there was insufficient "soil flushing." It also may indicate inefficient infiltration and drainage of both the control and test plot areas.

Lime also decreased significantly in both the control and test plots. Nitrate decreased significantly in the test plot. There is also a very definite significant increase in sulfate in the test plot. A decrease in sodium was not observed as was expected (Messer et al. 1980) but this may be due to inadequate infiltration and drainage of the control and test plots.

Table 13. Summary of the soils analysis control plot data (no SO_2 treatment).

	Mean Surface Soil Data Prior to Irrigation[a]		Mean Surface Soil Data After Irrigation[b]		
	$\bar{x}$[c]	SD[d]	$\bar{x}$[c]	SD[d]	t[e]
pH	8.4	0.1	8.4	0.1	0.181
Sol. Salts mmhos/cm	1.0	0.3	1.3	0.4	1.82
CEC meq/100 g	32	0.4	31	0.9	3.33*
Lime % $CaCO_3$	7.6	1.0	6.1	1.3	2.43**
O.M., %	0.8	0.1	0.7	0.1	2.39**
NO_3-N ppm	16	4	15	3	-0.39
P, ppm	9	4	16	7	-2.73**
K, ppm	1541	200	1671	115	-1.60
Ca, ppm	6907	246	7240	208	-2.92**
Mg, ppm	498	27	544	18	-4.07**
Na, ppm	467	172	492	139	-0.32
Zn, ppm	1.0	0.2	0.8	0.1	2.14
Fe, ppm	7.1	3.6	7.9	1.1	-0.59
Mn, ppm	8.4	0.6	6.5	0.4	8.34*
Cu, ppm	2.8	0.5	2.1	0.2	3.80**
SO_4, ppm	22.5	40	18.9	13.1	0.08
B, ppm	1.2	0.1	1.2	0.1	0.38

[a]Soil samples collected on May 21, 1981, summary data from Appendix, Table 15.

[b]Soil samples collected on September 22, 1981, summary data from Appendix, Table 16.

[c]Mean values for n=8.

[d]SD = Standard Deviation.

[e]t - statistic evaluation (14 degrees of freedom).

*Statistical significance at the 99% level.

**Statistical significance at the 95% level.

Table 14. Summary of the soils analysis test plot data (SO_2 treated).

	Mean Surface Soil Data Prior to Irrigation[a]		Mean Surface Soil Data After SO_2 Irrigation[b]				
	$\bar{x}$[c]	SD[d]	$\bar{x}$[c]	SD[d]	t[e]	t[f]	t[g]
pH	8.4	0.1	8.2	0.2	-2.72**	-3.73*	-3.15*
Sol. Salts mmhos/cm	1.2	0.3	1.8	0.7	2.54**	1.86	2.05
CEC meq/100 g	32	1	31	1	1.78		
Lime % $CaCO_3$	7.6	1.1	5.9	1.3	2.76**	2.11	1.73
O.M., %	0.7	0.1	0.7	0.1	0		
NO_3-N ppm	18	3	10	2	-5.94*	-4.99*	-5.56*
P, ppm	9	3	13	5	1.75		
K, ppm	1572	166	1605	259	0.30		
Ca, ppm	7092	335	7120	273	-0.18		
Mg, ppm	546	34	577	40	1.67		
Na, ppm	576	327	532	320	-0.27	-1.41	-0.51
Zn, ppm	1.0	0.3	1.0	0.2	0.42		
Fe, ppm	6.7	2.5	8.3	3.0	-1.21		
Mn, ppm	8.4	0.7	8.0	3.3	0.51		
Cu, ppm	3.0	1.1	2.2	0.3	-1.86	-1.67	-1.15
SO_4, ppm	9	10	65	39	4.84*	4.78*	4.01*
B, ppm	1.2	0.1	1.2	0.1	-0.88		

[a]Soil samples collected on May 21, 1981, summary data from Appendix, Table 17.

[b]Soil samples collected on September 22, 1981, summary data from Appendix Table 18.

[c]Mean values for n=8.

[d]SD = Standard Deviation.

[e]t - statistic evaluation (14 degrees of freedom).

[f]t - statistic evaluation (not using data from 6-1-S + 6-2-S (May), 12 degrees of freedom).

[g]t - statistic evaluation (not using data from 6-1-S + 6-2-S (May); or 6-1-S + 6-3-S (Sept.), 10 degrees of freedom).

*Statistical significance at the 99% level.

**Statistical significance at the 95% level.

A statistical evaluation was also performed on the data leaving out 6-1-S and 6-2-S (May samples) and 6-1-S and 6-3-S (September samples) due to a drainage valley in the area where these samples were collected. The data are also shown in Table 14. A more sophisticated approach was also used to evaluate all of the soils data (D. Sisson, Personal Communication). The results were similar to those of the previously described statistical evaluation.

CONCLUSIONS

Based on the results of this study the following conclusions can be made.

1) Although there did not appear to be any difference in the protein content of the barley grain crop there was a 39 percent higher yield on the test plot (SO_2 treated) than the control plot (no SO_2 treatment). It should be noted that there were fewer weeds on the test plot but this may have been the results of the SO_2 treatment.
2) Upon SO_2 addition to the irrigation water and sprinkler irrigation application of the water to the soil, 80 to 100 percent of the alkalinity could be removed from the irrigation water depending upon the pH adjustment.
3) Nearly all of the sulfur is in the form of sulfate upon reaching the soil.
4) There was a significant decrease in surface soil pH (8.4 to 8.2) in the test plot receiving SO_2 treated water. No significant surface soil pH change was determined in the control plot.
5) Nitrate (NO_3-N) in the surface soil was significantly reduced in the test plot as compared to the control plot.
6) Sulfate in the surface soil increased significantly in the test plot.

RECOMMENDATIONS FOR FUTURE STUDIES

This initial preliminary study was designed to determine some of the beneficial effects of agriculture soil SO_2 treatment. Some recommendations for further research of a general type are as follows:

1) Evaluate the addition of other nutrients (phosphorus and nitrogen) to the process of SO_2 soil treatment. This may also include controlled application of other essential plant growth elements such as K, Fe, Zn, B, Mn, Co, and Mo.
2) Determine appropriate and optimum pH conditions for irrigation water being applied to soil and crop species.
3) Determine the effects of SO_2 soil application on the chemical and biological characteristics of the soil.
4) Verify increased yields on other appropriate crops and soils (both alkaline and sodic).

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APPENDIX

Table 15. Surface soil analysis data[a] from the control plot prior to irrigation (no SO_2 treatment) (samples collected May 21, 1981).

Analytical Parameter	Sample									
	1-1-S	1-3-S	2-1-S	2-2-S	3-1-S	3-3-S	4-1-S	4-2-S	$\bar{x}$[b]	SD[c]
pH	8.3	8.4	8.5	8.6	8.5	8.3	8.2	8.4	8.40	0.13
Sol. Salts mmhos/cm	0.9	1.4	1.0	0.8	1.2	1.2	0.7	0.7	0.99	0.26
CEC meq/100 g	32	32	32	32	32	32	31	32	31.9	0.35
Lime, % $CaCO_3$	8.5	9.0	8.5	7.5	6.5	6.5	6.5	7.5	7.6	1.0
O.M., %	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8	0.78	0.07
NO_3-N ppm	19	22	20	17	14	12	10	13	15.9	4.3
P, ppm	12	9	4	10	6	5	13	16	9.4	4.2
K, ppm	1250	1530	1805	1300	1635	1545	1480	1780	1541	200
Ca, ppm	7070	6584	7075	7015	6565	6715	7185	7050	6907	246
Mg, ppm	496	497	496	451	503	478	522	540	498	26.7
Na, ppm	322	658	560	602	672	336	252	336	467	172
Zn, ppm	0.9	0.6	1.2	0.8	1.1	1.2	1.1	0.9	0.98	0.2
Fe, ppm	5.5	6.1	5.5	5.8	5.8	5.8	6.1	16.0	7.08	3.6
Mn, ppm	8.1	9.2	9.2	7.6	8.0	8.6	8.4	8.5	8.45	0.56
Cu, ppm	2.9	1.7	3.2	2.8	3.2	3.0	2.6	2.9	2.8	0.48
SO_4, ppm	120	9	9	24	3	6	6	3	22.5	40.0
B, ppm	1.3	1.4	1.2	1.3	1.0	1.1	1.1	1.3	1.21	0.14

[a] Western Laboratories Inc., Parma, Idaho.
[b] Mean value.
[c] SD = Standard Deviation.

Table 16. Surface soil analysis data[a] from the control plot after irrigation (no SO_2 treatment) (samples collected September 22, 1981).

Analytical Parameter	Sample 1-1-S 3822	1-2-S 3821	2-1-S 3847	2-3-S 3846	3-1-S 3853	3-2-S 3854	4-1-S 3862	4-3-S 3852	$\bar{x}$[b]	SD[c]
pH	8.7	8.3	8.5	8.5	8.3	8.4	8.3	8.3	8.41	0.15
Sol. Salts mmhos/cm	1.0	1.4	0.9	0.9	1.8	1.2	1.8	1.2	1.28	0.37
CEC meq/100 g	30	30	30	31	32	32	31	30	30.7	0.89
Lime, % $CaCO_3$	3.5	5.0	6.5	6.0	7.5	6.5	7.5	6.5	6.1	1.3
O.M., %	0.7	0.7	0.6	0.7	0.7	0.8	0.7	0.7	0.70	0.05
NO_3-N ppm	18	17	16	17	14	18	8	13	15.1	3.4
P, ppm	9	8	11	26	20	23	18	24	16.5	7.1
K, ppm	1635	1565	1735	1755	1865	1640	1680	1495	1671	115
Ca, ppm	7110	6960	7205	7035	7355	7525	7225	7505	7240	208
Mg, ppm	538	547	531	556	526	522	572	563	544	18.1
Na, ppm	745	350	450	420	550	445	630	350	492	139
Zn, ppm	0.6	0.8	0.8	0.8	0.9	0.9	0.8	0.8	0.80	0.09
Fe, ppm	6.7	7.5	7.8	9.3	9.3	8.4	6.4	7.5	7.86	1.1
Mn, ppm	6.4	7.1	6.6	6.6	6.3	6.1	6.7	5.9	6.46	0.37
Cu, ppm	1.9	2.0	2.3	2.3	1.9	2.2	2.0	2.2	2.1	0.17
SO_4, ppm	15	9	12	51	24	18	18	24	18.9	13.1
B, ppm	1.1	1.2	1.1	1.0	1.3	1.2	1.4	1.2	1.19	0.12

[a]Western Laboratories Inc., Parma, Idaho.
[b]Mean value.
[c]SD = Standard Deviation.

Table 17. Surface soil analysis data[a] from the test plot prior to irrigation (SO_2) (samples collected May 21, 1981).

Analytical Parameter	Sample 5-1-S	5-3-S	6-1-S	6-2-S	7-1-S	7-3-S	8-1-S	8-2-S	$\bar{x}$[b]	SD[c]
pH	8.4	8.4	8.5	8.6	8.5	8.3	8.2	8.2	8.39	0.146
Sol. Salts mmhos/cm	0.9	1.0	1.4	1.6	1.6	1.0	1.0	0.8	1.16	0.32
CEC meq/100 g	31	30	32	32	31	32	32	32	31.5	0.76
Lime, % $CaCO_3$	8.0	8.5	8.0	8.5	8.0	6.5	7.5	5.5	7.6	1.1
O.M., %	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.8	0.72	0.05
NO_3-N ppm	16	17	14	16	18	20	18	23	17.8	2.8
P, ppm	12	8	5	9	9	13	10	7	9.1	2.6
K, ppm	1790	1450	1460	1800	1530	1510	1355	1685	1572	166
Ca, ppm	6810	7130	6770	6885	7130	7375	6885	7750	7092	335
Mg, ppm	563	563	586	550	494	550	492	566	546	34.3
Na, ppm	448	462	942	1134	756	336	266	266	576	329
Zn, ppm	1.2	0.9	1.1	1.2	0.8	0.6	0.8	1.4	1.0	0.27
Fe, ppm	4.9	6.4	5.2	6.4	5.5	5.5	7.0	12.5	6.68	2.5
Mn, ppm	8.1	7.4	8.0	8.6	7.8	9.1	9.7	8.3	8.38	0.7
Cu, ppm	2.9	2.8	3.3	3.8	2.2	1.7	1.9	5.2	3.0	1.1
SO_4, ppm	3	6	3	6	33	12	6	3	9	10
B, ppm	1.3	1.3	1.3	1.2	1.3	1.1	1.1	1.0	1.2	0.12

[a]Western Laboratories Inc., Parma, Idaho.
[b]Mean value.
[c]SD = Standard Deviation.

Table 18. Surface soil analysis data[a] from the test plot after irrigation (SO_2-treated) (samples collected September 22, 1981).

Analytical Parameter	Sample 5-1-S 3823	5-2-S 3825	6-1-S 3830	6-3-S 3835	7-1-S 3838	7-3-S 3832	8-1-S 3844	8-3-S 3841	$\bar{x}$[b]	SD[c]
pH	8.2	8.1	8.5	8.2	8.1	8.2	8.2	7.9	8.17	0.17
Sol. Salts mmhos/cm	1.1	1.3	2.6	2.0	1.4	1.6	1.6	3.0	1.82	0.66
CEC meq/100 g	31	32	31	31	30	30	31	31	30.9	0.64
Lime, % $CaCO_3$	6.5	5.5	5.5	6.0	6.5	8.5	4.5	4.5	5.9	1.3
O.M., %	0.7	0.8	0.7	0.8	0.7	0.6	0.8	0.7	0.72	0.07
NO_3-N ppm	12	11	8	10	11	8	14	7	10.1	2.4
P, ppm	5	13	5	13	14	16	18	17	12.6	5.0
K, ppm	1595	1615	1660	2195	1470	1340	1500	1465	1605	259
Ca, ppm	7035	7055	6680	6830	7505	7295	7260	7300	7120	273
Mg, ppm	630	607	552	607	605	515	543	556	577	40.4
Na, ppm	325	335	1235	745	295	490	335	500	532	320
Zn, ppm	1.1	0.9	0.8	1.2	1.1	0.6	0.8	1.1	0.95	0.21
Fe, ppm	6.4	15.4	7.5	7.0	7.8	5.8	8.1	8.7	8.34	3.0
Mn, ppm	7.8	7.3	7.2	12.8	7.7	6.4	7.0	7.7	7.99	3.3
Cu, ppm	2.3	1.7	2.3	2.3	2.6	2.2	1.9	2.3	2.20	0.28
SO_4, ppm	15	69	51	66	84	126	75	135	65.1	38.7
B, ppm	1.2	1.2	1.1	1.3	1.2	1.4	1.2	1.4	1.25	0.11

[a]Western Laboratories Inc., Parma, Idaho.
[b]Mean value.
[c]SD = Standard Deviation.

Table 19. Soil samples taken 9-26-81.

	Number	% Moisture	SD
Control Plot	3	5.05	2.22
Test Plot	3	7.28	5.66

Table 20. Analytical parameters of duplicate sample submitted to Western Laboratories Inc.

	9-1-S	9-2-S
pH	8.4	8.4
Sol. Salts (mmhos/cm)	1.2	1.3
CEC (meq/100 g)	31	31
Lime $CaCO_3$ (%)	4.0	6.5
O.M. (%)	0.7	0.6
NO_3-N (ppm)	23	24
P (ppm)	10	8
K (ppm)	1500	1470
Ca (ppm)	7450	6865
Mg (ppm)	517	496
Na (ppm)	602	588
Zn (ppm)	0.9	0.9
Fe (ppm)	7.8	6.7
Mn (ppm)	8.5	9.3
Cu (ppm)	2.6	2.9
SO_4 (ppm)	6	12
B (ppm)	1.2	1.3

Table 21. Grain yield calculations.

	Control Plot	Test Plot
1. Total cut weight	178 lbs	146 lbs
2. Percent grain[a]	74%	90%
3. Weight of grain	132 lbs	131 lbs
4. Percent grain as barley[b]	71%	100%
5. Weight of barley	94 lbs	131 lbs
6. Acreage cut	0.196 Ac	0.196 Ac
7. lbs/acre of barley	479.6	668.4

[a]Percent grain was calculated because of the large amount of weeds: 46.3 lbs of weeds were cut on the control plot and 14.6 lbs of weeds on the test plot. Therefore,

$$\% \text{ control grain} = \frac{178-46.3}{178} \times 100 = 74\%$$

$$\% \text{ test grain} = \frac{146-14.6}{146} \times 100 = 90\%$$

It is possible that the higher yield of grain on the test plot was due to the lesser weed population.

[b]Percent grain as barley was calculated for the control plot because wheat stored in the combine from a previous cutting was mixed with the barley from the control plot.