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Salt Movement and Forage Crop Establishment in a Saline-Alkali Soil as Influenced by Ridges and Furrows, Sprinkler Irrigation, and Soil Amendments

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SALT MOVEMENT AND FORAGE CROP ESTABLISHMENT IN A SALINE-ALKALI SOIL AS INFLUENCED BY RIDGES AND FURROWS, SPRINKLER IRRIGATION, AND SOIL AMENDMENTS

by

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INTRODUCTION

An estimated two to four million acres of irrigable saline and alkali soils of the United States return very little income to land owners (17, 19). Increased needs for forage crops, and the relatively high salt and alkali tolerance of some improved forage species, once established, suggests a way of increasing revenue from some of these lands without costly reclamation.

Lower salt and alkali tolerance during the germination and seedling period has limited the use of these crops. High salinity and alkalinity reduces the nitrifying power of soils, thus reducing productivity (3, 5, 6, 7, 10).

Water line or shoulder planting on sides of furrow-irrigated ridges or raised beds has been found to increase stands of truck crops on saline and alkali soils (23). Stands of sugar beets on a saline-alkali soil in Yakima Valley have been materially improved by rill irrigation adjacent to seed at seeding time (18).

Furrow or rill irrigation has characterized all previous work on salt movement studies on ridges and furrows. No comparisons of crop stand have been made between ridge top and furrow bottom plantings. No reports were found where sprinkler irrigation was used to reduce the salt content in the area of seed germination.

A field experiment was conducted to determine the effectiveness of ridge top and furrow bottom plantings, sprinkler irrigation, and soil treatments in establishing forage crops on an extremely saline-alkali soil. (Saline-alkali soil as defined by Regional Salinity Laboratory at Riverside, California, is a soil having a conductivity of the saturated extract in excess of 4 millimhos per cm., and an exchangeable sodium percentage greater than 15).

A laboratory experiment was conducted to determine the nitrifying power of this soil to see if it is a factor contributing to low productivity of these soils.

In the evaluation of ridge and furrow plantings, sprinkler irrigation, and soil treatments of sulfuric acid, gypsum, manure, sawdust, Krilium, straw and PR78, answers to the following specific questions were sought:

1. Can sprinkler irrigation be used to apply water in small quantities so as not to establish capillary connection with a water table located at 15 to 18 inches? Will these light water applications be sufficient to move salt away from the germinating seedlings?

2. What is the effect of ridges and furrows on salt movement and crop establishment under sprinkler irrigation?

3. What is the effect of ridge top and furrow bottom plantings on forage crop establishment under soil treatments of gypsum, sulfuric acid, manure, sawdust, straw, Krilium and PR78 and sprinkler irrigation?

4. Is the pH of soil affected by ridges and furrows and soil treatments of gypsum, sulfuric acid, manure, sawdust, straw, Krilium, PR78 and sprinkler irrigation?

5. Is a low nitrate fertility level contributing to the non-productivity of this soil?

REVIEW OF LITERATURE

The literature on saline and alkali soils is voluminous. Recent work is adding materially to the knowledge in this field.

The literature reviewed in this thesis is confined to the recent articles dealing with salt and alkali tolerance of grasses, salt movement in irrigated soils, effect of grasses on saline and alkali soils, crop establishment on these soils, and the effect of salts and pH on nitrifying power of soils.

Grass is one of our most salt tolerant crops. Work by Scofield and Kearney (29) indicates that up to two per cent salt can be tolerated by certain grass species. Brown and Bernstien (8) have demonstrated the varying salt tolerance of several grasses. Listed in the order of decreasing salt tolerance are the varieties tested: tall wheatgrass, tall fescue, wild-rye, perennial ryegrass, Hardinggrass, orchardgrass and meadow foxtail. At high levels of salt, tall wheatgrass, tall fescue and ryegrass showed good survival.

Brown and Bernstien (8), Ayers (1), and Ayers and Hayward (2) have shown that osmotic effects of salts have more influence on yield than does the toxicity of specific ions of Na, Ca, Cl, SO_4, and that moisture in saline soils must be maintained near field moisture capacity if plants are to obtain water at high salt concentrations (above 1/2 per cent salt). Grasses can be grown on and used in the reclamation of saline and alkali soils. Extensive root systems of the grasses open up the soil and hasten reclamation by improving water penetration rate and aeration (21).

Marshal and Palmer (22) found that over a 20-year period there was twice as much salt leached downward under perennial crops as under cultivated crops and cereals. Gardner (14) has also shown the increased permeability of soils planted to perennial crops. Under good drainage and adequate irrigation, soluble salts can be leached to lower depths in the soil profile or removed with drainage water; however, evaporation from the surface and capillary action of water will reverse this movement (12, 22, 29).

Several workers have shown that under poor drainage, inadequate irrigation, or poor quality irrigation water, salts accumulate in the surface soil (14).

Many crops, particularly grasses and sugar beets, are highly salt tolerant once they get past the germination and seedling stages (1, 2, 8, 18, 28, 30). Ayers (1), Ayers and Hayward (2) and Heald, et al. (18) found that losses at the germination and seedling stage could be reduced by lowering salinity in the immediate area of germinating seedlings and maintaining moisture near field moisture capacity.

Work in Washington by Heald, et al. (18) on saline and alkali soils of the Yakima Valley demonstrated the possibility of moving salts laterally and vertically away from the germinating seeds by rill irrigation. Stands were increased over 100 per cent by this method.

McGeorge and Wharton (23) found that in lettuce and truck crop beds in Arizona there was considerable salt movement from furrow to ridge where raised beds and furrow irrigation were used.

Wadleigh and Fireman (30) planted cotton on ridges and furrow-irrigated. They found that salts moved from the furrows into the ridges. Moisture studies in the same experiment demonstrated that the cotton plants took most of their water from the non-saline area under the furrow.

The power of a saline or alkali soil to convert organic material, or nitrogen salts (ammonium compounds) to nitrates, is very limited. Greaves (15) and later Greaves and Jones(16) demonstrated that even slight amounts of alkali salts cause accumulation of ammonia in soils by decreasing the nitrifying power of the nitrate-formers.

Bollen and Ahi (3) used an alkali soil from eastern Oregon, and an acid soil from the Willamette Valley, Oregon. They added various salts to the two soils and got decreases in ammonification and nitrification.

Caster, Martin and Buehrer (10) working in Arizona, established a threshold pH value of 7.7 ±.1 for nitrification. In their experiment no nitrification occurred above this level. Accumulation of nitrites occurred at pH slightly above 7.7 ±.1, but no nitrates were formed until pH was reduced to 7.7 ± .1. The high pH of the soil in this experiment raised the question of low nitrate fertility and low nitrifying power as factors contributing to the low productivity of this soil.

Earlier work done by Meyerhof (25) and Olsen (26) as reported by Caster, Martin and Buehrer (10) set an optimum pH level of 8.3 for nitrification and a maximum of 8.8. Meyerhof (25) and Olsen (26) worked with solution cultures. Caster, Martin and Buehrer (10) used soil cultures.

Breazeale and McGeorge (6) working at this same station (Arizona) established that above pH 7.6, plants cannot absorb nitrates. These workers found that carbon dioxide evolution by roots, reduced pH at the soil root interface below 7.6, permitting nitrate absorption by plants in alkali soils. They also demonstrated that carbon dioxide, released during decomposition of manure, reduces soil pH and as a result, nitrates are increased.

The soil used in this experiment is waterlogged the greater part of the year. During the period of this experiment, the water table remained at from 15 to 18 inches below the soil surface.

Soils with high water tables and submerged soils were studied for nitrifying power by Breazeale and McGeorge (7), and Kelley (20) (as reported by Breazeale and McGeorge (7)). Oxygen was shown to be one of the limiting factors in action of soil microorganisms.

Kelley (21), as reported by Breazeale and McGeorge (7), working with rice on submerged soils, found that active ammonification occurred under these conditions, but that nitrates were reduced to ammonia. There was no nitrogen loss in this experiment as the ammonia was fixed in the soil.

Breazeale and McGeorge (7) worked with ammonium sulfate on normal and puddled soils. On well aerated, calcareous alkaline soils all the ammonia had been converted to nitrates in 18 days. In these same soils in a puddled or waterlogged condition, nitrification ceased and denitrification set in. At the end of 18 days, 50 per cent of the nitrogen added in ammonium sulfate had been lost. They also found that manure and chemical amendments increased nitrification, which, upon incorporation with the soil, resulted in improved aeration (7).

PROCEDURE

Field Experiment

The effect of ridge and furrow plantings, sprinkler irrigation and soil treatments on stand establishment of 11 forage crop varieties, was determined on a highly saline-alkali soil on the D. E. Williams farm at Spanish Fork, Utah, in 1952.

Four sites were sampled in the plot area prior to ridging or application of treatments. Analysis of these samples is used to characterize the soil as shown in table 1.

Table 1. Some characteristics of the soil prior to treatment (averages of four sampling sites in experimental area)

Depth of samples	Cation exchange capacity	Sodium saturation	Potassium saturation	pH of soil paste	Conductivity of saturation extract
inches	m.eq./100	per cent	per cent		millimhos/cm.
0 - 2	14.9	81.82	13.6	10.1	98.8
2 - 4	14.5	55.8	12.8	10.0	46.8
4 - 8	16.0	56.47	10.6	10.1	25.4
8 -12	15.1	56.8	10.2	10.1	19.0

The soil contains 21 per cent calcium carbonate and no calcium sulfate to a depth of one foot. The soil is tentatively classified as a Kirkham loam. The surface soil has a good granular structure. Horizontal layering is found in the 2 to 8 inch depth; below this is an amorphous layer; at 12 to 15 inches a compacted layer is found. The color changes from a dark brown at the surface to a light tan at about 12 inches. High salt and alkali has caused the land, on which these plots were located, to be abandoned. Vegetation was made up of a few small greasewood (Sarcobatus vermiculatus) plants scattered patches of saltgrass (Distichlis stricta) and some whitetop (Cardaria draba).

The water table remained at 15 to 18 inches throughout the experiment except during the late winter and early spring when water was standing on the soil surface. Factors which maintain this high water level are drainage of excess irrigation waters from the south and the west, a high terraplane irrigation ditch on the east, and a built-up road on the north which prevents surface drainage.

The experiment was designed as a completely randomized block with uniform moisture treatment on the entire area. Individual plots were 25 feet by 22 feet. There were eight soil treatments replicated four times. Eleven forage crop varieties were planted in each plot. The plots were ridged (about four inches high) every 22 inches, and a seeding of each forage variety made on a ridge and in the adjacent furrow.

The treatments used in the field experiment in this thesis were selected for one of three reasons: (1) proven value in reclaiming saline and alkali soils; (2) value as a mulch to reduce evaporation and keep moisture high near seeds; (3) possible value as suggested by previous work or by manufacturer. No experiment has been conducted using these materials in the manner employed in this experiment.

Soil treatments of gypsum, one ton per acre; sulfuric acid, one ton per acre; and Krilium, one thousand pounds per acre, were made prior to seeding. They were applied in narrow bands on tops of ridges and in bottoms of furrows, and incorporated into the soil with a hoe.

Manure, 10 tons per acre; sawdust, 5 tons per acre; straw, 2 tons per acre, and PR78 (wetting agent sold by Atlantic Refininy Company), 40 pounds per acre; were applied after seeding over the entire area of plots receiving these treatments.

The following forage crop varieties were planted in each plot: biennial yellow sweetclover (Melilotus officinalis), reed canarygrass (Phalaris arundinacea), Russian wild-rye (Elymus junceus), alta fescue (Festuca elatior var. arundinacea), tall oatgrass (Arrhenatherum elatius), biennial white sweetclover (Melilotus alba), tall wheatgrass (Agropyron elongatum), Tualatin oatgrass (Arrahenatherum elatius), birdsfoot trefoil (Lotus corniculatus), pubescent wheatgrass (Agropyron trichophorum), mountain brome (Bromus marginatus).

All treatments and seedings were made on August 27, 1952. Frequent light irrigations were made with a portable sprinkler irrigation system to keep soil surface moist, and soil near seeds at, or near, field moisture capacity. The irrigation schedule for the experiment is given in table 2.

Table 2. Irrigation schedule for forage crop plots on E. D. Williams farm, 1952

Date	Time (hrs.)	Pressure (p.s.i.)	Amount (inches)
Sept. 4	3	45	1.35
Sept. 8	1.5	45	0.67
Sept. 10	2	45	0.9
Sept. 12	1.5	40	0.6
Sept. 16	1.5	40	0.6
Sept. 23	1	40	0.4
Sept. 27	1.75	40	0.7
Oct. 4	1	45	0.45

Note: Spacing 40' x 40'; nozzle, Rainbird Model 40, 11/64" x 3/32"

One hundred pounds of ammonium sulfate was applied (September 8th) to the plots through the irrigation system.

Plant counts were made on October 11, 1952, and on May 8, 1953. Soil samples were taken four times during the experiment. The dates of sampling were September 8, September 23, October 11, in 1952, and May 8 in 1953. Samples were taken near the center of each plot on the ridge and in the furrow at the following depths: 0 - 2 inches, 2 - 4 inches, 4 - 8 inches, and 8 - 12 inches. Samples were placed in plastic bags. They were later air dried, ground to pass a 2 mm. seive, and replaced in the plastic bags for storage.

The following determinations were made: conductivity of the saturation extract (28, 9); pH (28); exchangeable cation analysis on some samples not reported in this thesis (4, 11).

Laboratory Experiment

The pH level was considerably above the threshold pH value for nitrification as determined by Caster, Martin and Buehrer (10), or by Meyerhof (25), or Olsen (26) as reported by Caster, et al. (10). The soil used in this experiment had a pH of 10. The water table is at 15 to 18 inches in the field. During the winter months a large portion of the field is flooded.

On October 11 a bulk sample was taken from the field to the one foot depth. This sample was taken adjacent to the experimental area in what appeared to be the better part of the field as judged by plant growth. It was air dried and stored until April 24 when the nitrification study was started.

One hundred-gram samples of air dry soil were measured into 250 ml. Erlenmeyer flasks. One gram of alfalfa, one gram of dried cow manure, one gram of straw, one-tenth gram of ammonium sulfate and one-tenth gram of ammonium nitrate were added to appropriate flasks and mixed thoroughly. Four replicates of each treatment and control were established. Distilled water was added to bring the soil to the one-third atmosphere moisture percentage. The weights of the individual flasks were then recorded. Flasks were maintained at this weight by daily weighing and adding distilled water. The samples were held at room temperature (approximately 20° C.) and the one-third atmosphere moisture percentage for 34 days.

Nitrate content of incubated samples, and of manure, alfalfa, straw, ammonium sulfate and ammonium nitrate were determined (31).

RESULTS

Forage plants were established on several plots in this experiment. Table 3 shows the number of plants of each variety that had become established by October 11, 1952. The number of plants that had survived until the following spring are shown in table 4.

No plants were established on the control or on the plots receiving PR78. Only a few plants were established on the straw-treated plots. Manure, sawdust, Krilium, gypsum and sulfuric acid all showed greater plant establishment than the control in three out of four replicates on October 11, 1952. (See tables 3 and 4).

On May 8, 1953, alta fescue and tall wheatgrass still survived on many of the plots. Replicate number 1 showed several varieties surviving and some yellow sweetclover had appeared in replicate number 3 of the Krilium treated plots. The germination of hard seeds accounts for the plants found on May 8, where none were found on October 11.

With one or two exceptions, all plants established were found in the furrows. Their establishment is associated with reduction in salt content around the germinating seeds (figures 1, 2, 3, 4), or low initial salt content as in replicate number 1 of the manure treated plots (tables 3 and 4).

Under the gypsum and sulfuric acid treatments reduction of salt content in the furrows was equal to the reduction of salt in furrows of control during the germination period in the fall (figure 4). Preliminary investigations not reported in this thesis indicate that under gypsum and sulfuric acid there is a high replacement of exchangeable sodium by calcium in this soil and that pH is materially reduced by sulfuric acid (table 5

Table 3. October 11 plant count showing number of plants of each variety established per row for individual replicates of different treatments on ridges (R) and in furrows (F)

Plants	Treatments															
	Control				Gypsum				Manure				Sawdust			
	Replicates				Replicates				Replicates				Replicates			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Yellow sweetclover	-	-	-	-	-	-	-	-	150R	-	-	-	-	-	-	-
Reed canarygrass	-	-	-	-	100F	10F	-	-	300R 100F	-	-	50F	-	25F	-	8F
Russian wild-rye	-	-	-	-	55F	12F	-	-	150R 200F	-	-	20F	-	-	-	-
Alta fescue	-	-	-	-	40F	25R 25F	50F	60F	200R 50F	8F	10F	160F	-	50F	10F	6F
Tall oatgrass	-	-	-	-	21F	35F	-	-	275R 200F	-	-	8F	-	-	-	-
White sweetclover	-	-	-	-	4F	-	-	-	50F	-	-	-	-	-	-	-
Tall wheatgrass	-	-	-	-	20F	10R 50F	12F	45F	260R 225F	7F	10F	50F	25F	35F	25F	60F
Tualatin oatgrass	-	-	-	-	12F	-	-	-	75R 50F	-	-	-	-	-	-	-
Birdsfoot trefoil	-	-	-	-	-	-	-	-	-	-	-	10F	-	-	-	-
Pubescent wheatgrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mountain brome	-	-	-	-	12F	-	-	-	40R 20F	-	-	-	-	-	-	-

Table 3 (cont'd).

Plants	Treatments															
	Straw				Krilium				P.R.78				Sulfuric acid			
	Replicates				Replicates				Replicates				Replicates			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Yellow sweetclover	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Reed canarygrass	25F	-	-	60F	-	100F	150F	-	-	-	-	-	26F	6F	-	-
Russian wild-rye	-	-	-	-	-	-	25F	-	-	-	-	-	60F	4F	-	-
Alta fescue	25F	-	-	10F	15F	10F	127F	-	-	-	-	-	68F	50F	25F	-
Tall oatgrass	-	-	-	10F	10F	-	30F	-	-	-	-	-	27F	20F	-	-
White sweetcover	-	-	-	-	-	-	-	-	-	-	-	-	5F	-	8F	-
Tall wheatgrass	50F	-	-	30F	60F	70F	150F	-	-	-	-	-	37F	60F	35F	-
Tualatin oatgrass	-	-	-	-	-	-	10F	-	-	-	-	-	13F	-	-	-
Birdsfoot trefoil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pubescent wheatgrass	-	-	-	-	3F	-	-	-	-	-	-	-	-	-	-	-
Mountain brome	-	-	-	-	5F	-	75F	-	-	-	-	-	-	-	-	-

Table 4. May 8 plant count showing number of plants of each variety established per row for individual replicates of different treatments on ridges (R) and in furrows (F)

Plants	Treatments															
	Control				Gypsum				Manure				Sawdust			
	Replicates				Replicates				Replicates				Replicates			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Yellow sweetclover	-	-	-	-	-	-	-	-	150R	-	-	-	-	-	-	-
Reed canarygrass	-	-	-	-	-	-	-	-	300R 100F	-	-	-	-	-	-	-
Russian wild-rye	-	-	-	-	-	-	-	-	150R 200F	-	-	-	-	-	-	-
Alta fescue	-	-	-	-	-	-	-	-	200R 50F	-	-	25F	-	-	-	4F
Tall oatgrass	-	-	-	-	-	-	-	-	275R 200F	-	-	-	-	-	-	-
White sweetclover	-	-	-	-	-	-	-	-	50F	-	-	-	-	-	-	-
Tall wheatgrass	-	-	-	-	-	15F	-	4F	260R 225F	-	-	50F	13F	-	17F	26F
Tualatin oatgrass	-	-	-	-	-	-	-	-	75R 50F	-	-	-	-	-	-	-
Birdsfoot trefoil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pubescent wheatgrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mountain brome	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4 (cont'd).

	Treatments															
	Straw Replicates				Krilium Replicates				P.R.78 Replicates				Sulfuric acid Replicates			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Yellow sweetclover	-	-	-	-	-	-	200F	-	-	-	-	-	-	-	-	-
Reed canarygrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Russian wild-rye	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Alta fescue	-	-	-	-	-	-	45F	-	-	-	-	-	1F	-	-	-
Tall oatgrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
White sweetclover	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tall wheatgrass	12F	-	-	12F	12F	-	100F	-	-	-	-	-	5F	11F	-	-
Tualatin oatgrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Birdsfoot trefoil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pubescent wheatgrass	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mountain brome	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

and figure 4).

Good stands of forage crops were established on many plots in the fall. The extreme variation in salt content and plant growth between replicates of the same treatments make presentation of some data on an individual plot basis necessary (tables 3, 4, and 5). This is associated with low salt concentration. The high mortality from fall to spring resulted from extremely high increases in salt concentration as shown in tables 5 and 7, and figure 1.

Tables 6 and 7 and figure 1 show the reduction of salt in the furrow and increase in the ridges.

Changes in salt concentration in the upper one foot of soil can be seen in table 7. In the gypsum and sulfuric acid plots there was considerable reduction in salt concentration in the furrows as compared with original salt content of the soil (figure 4). This reduction was not as great as in the control.

There was a slight reduction in salt in the top foot of soil under all soil amendments except gypsum and sulfuric acid from September 8, 1952, to October 11, 1952. By May 8, 1953, all treatments of soil amendments showed increases in salt in the upper foot of soil. There was considerable movement of salt from the furrows to the ridges. This movement occurred very rapidly after soil amendments were applied and irrigation started. (See tables 6 and 7 and figures 1, 2, 3, and 4).

The salt movement from furrows to ridges was confined mostly to the upper four inches of soil with slight changes at 4 - 8 inches as shown in tables 6 and 7, and figures 1, 2, 4, 5, 6 and 7.

The high increase in salt under all treatments in the 0 - 2 inch depth during the winter and spring (table 7 and figures 2, 4, 5, 6 and 7), as well as the over-all increase in salt concentration in the upper one foot of soil (table 7 and figures 1, 2, 3, 4, 5, 6 and 7) during this same period, resulted in death of all crops except alta fescue and tall wheatgrass and there was also high mortality in these two varieties as can be seen by comparing counts given in tables 3 and 4.

The high plant establishment on the manure, sawdust and Krilium treated plots is associated with a highly significant reduction in salt concentration, as is shown in the statistical analysis of this data. These materials all showed low salt concentration at all dates (figures 3, 4 and 5). There were no significant changes (variance tables in Appendix) in salt concentration at the 4 - 8, and 8 - 12 inch depths on any date under any treatment or between ridges and furrows (figures 1, 2, 4, 5, 6 and 7).

There was high establishment on the gypsum and sulfuric acid plots. The low salt concentration in the furrow shown in this experiment, and the lower sodium saturation indicated by some preliminary work, results in good stand establishment.

The pH level at all depths and dates was extremely high at values near pH 10. Changes in pH resulting from treatments were not as great as differences in pH existing between individual plots. The one exception to this was the sulfuric acid treatment on September 8 at the 0 - 2 inch depth. This change in pH had disappeared by September 23. Appendix table 12 gives a summary of pH determinations. (Appendix tables give the combined statistical analysis of pH data).

The laboratory experiment showed that slight increases in nitrates were found in the manure and alfalfa treatments (table 8). There was a loss of nitrate in the ammonium nitrate, ammonium sulfate and straw tests. Table 8 gives the result of this experiment.

Table 5. Alta fescue and tall wheatgrass established in furrows (number of plants per 25 feet of row) on individual plots with salt concentration measured in millimhos per cm. and pH for fall and spring data

Treatment and date	Plot no.	Alta fescue established in 25 ft. of furrow	Tall wheatgrass established in 25 ft. of furrow	pH of saturation paste	Conductivity of saturation extract in millimhos per cm. in 0-2" depth
Control					
Oct. 11	3	-	-	9.9	15.0
	14	-	-	9.3	4.5
	24	-	-	9.3	9.0
	32	-	-	9.3	6.1
May 8	3	-	-	9.6	210.0
	14	-	-	10.1	82.0
	24	-	-	10.0	90.0
	32	-	-	10.0	50.0
Gypsum					
Oct. 11	2	40	20	9.9	22.0
	12	25	50	9.7	45.0
	17	50	12	10.0	60.0
	28	60	45	9.9	40.0
May 8	2	-	-	9.8	140.0
	12	-	15	9.8	216.0
	17	-	-	9.8	240.0
	28	-	4	9.8	210.0
Manure					
Oct. 11	8	50	225	9.0	6.5
	13	8	7	9.8	21.0
	19	10	10	9.9	90.0
	30	160	50	9.2	7.3
May 8	8	50	225	9.2	13.0
	13	-	-	10.0	136.0
	19	-	-	9.8	232.5
	30	-	50	9.8	45.0
Sawdust					
Oct. 11	1	-	25	9.9	19.5
	16	50	35	9.7	12.0
	22	10	25	9.6	22.0
	31	6	60	9.9	4.6
May 8	1	-	13	10.0	21.0
	16	-	-	10.2	90.0
	22	-	17	9.9	126.0
	31	4	26	9.1	20.0

Table 5. (cont'd.)

Treatment and date	Plot no.	Alta fescue established in 25 ft. of furrow	Tall wheat-grass established in 25 ft. of furrow	pH of saturation paste	Conductivity of saturation extract in millimhos per cm. in 0-2" depth
<u>Straw</u>					
Oct. 11	6	25	50	10.0	17.5
	9	-	-	9.5	13.0
	20	-	-	10.0	19.0
	29	10	30	9.0	7.0
May 8	6	-	12	10.0	68.0
	9	-	12	9.5	237.0
	20	-	-	10.0	122.0
	29	-	-	10.1	130.0
<u>Krilium</u>					
Oct. 11	5	15	60	9.9	9.0
	10	10	70	9.5	7.5
	23	127	150	? 9. 4.0	9.1
	29	-	-	10.0	60.0
May 8	5	-	12	9.9	70.0
	10	-	-	9.8	140.0
	23	45	100	9.8	32.0
	29	-	-	9.9	135.0
<u>P.R. 78</u>					
Oct. 11	7	-	-	9.7	17.0
	15	-	-	9.7	12.5
	18	-	-	9.7	150.0
	26	-	-	9.2	16.0
May 8	7	-	-	9.9	79.0
	15	-	-	10.1	140.0
	18	-	-	9.6	255.0
	26	-	-	9.7	170.0
<u>H_2SO_4</u>					
Oct. 11	4	68	37	8.9	40.0
	11	50	60	9.9	120.0
	21	25	35	8.7	50.0
	27	-	-	8.5	20.0
May 8	4	1	5	9.8	156.0
	11	-	11	9.7	210.0
	21	-	-	9.7	240.0
	27	-	-	9.9	225.0

Table 6. Comparison of average salt concentration in ridge and furrow for each depth (all dates and treatments combined); salt concentration given in conductivity of saturation extract in millimhos per centimeter

Location of samples	Sample depths in inches			
	0 - 2 in.	2 - 4 in.	4 - 8 in.	8 - 12 in.
Ridge	102.9	48.3	26.3	20.0
Furrow	61.0	25.9	21.7	19.6
original area.	99	47	25	19

Table 7. Relation of soil treatment to changes in salt concentration in ridges (R) and furrows (F) in the upper foot of soil with average salt concentration in the upper foot of soil under each treatment; salt concentration given in millimhos per centimeter; Ed Williams farm, 1952-53

Date	Control		Gypsum		Manure		Sawdust		Straw		Krilium		P.R.78		H_2SO_4	
	R	F	R	F	R	F	R	F	R	F	R	F	R	F	R	F
Sept.8	144	109	335	98	271	69	127	54	209	83	136	72	184	81	177	122
Average	126		217		170		91		146		104		133		150	
Sept.23	206	109	177	139	182	103	111	161	228	135	119	69	162	141	316	155
Average	158		158		143		136		181		94		151		235	
Oct. 11	174	58	290	103	83	80	90	45	155	50	81	58	236	111	243	118
Average	116		196		81		67		102		70		173		180	
May 8	273	190	362	324	141	125	180	125	286	238	201	159	271	275	363	327
Average	231		343		133		152		262		180		273		345	

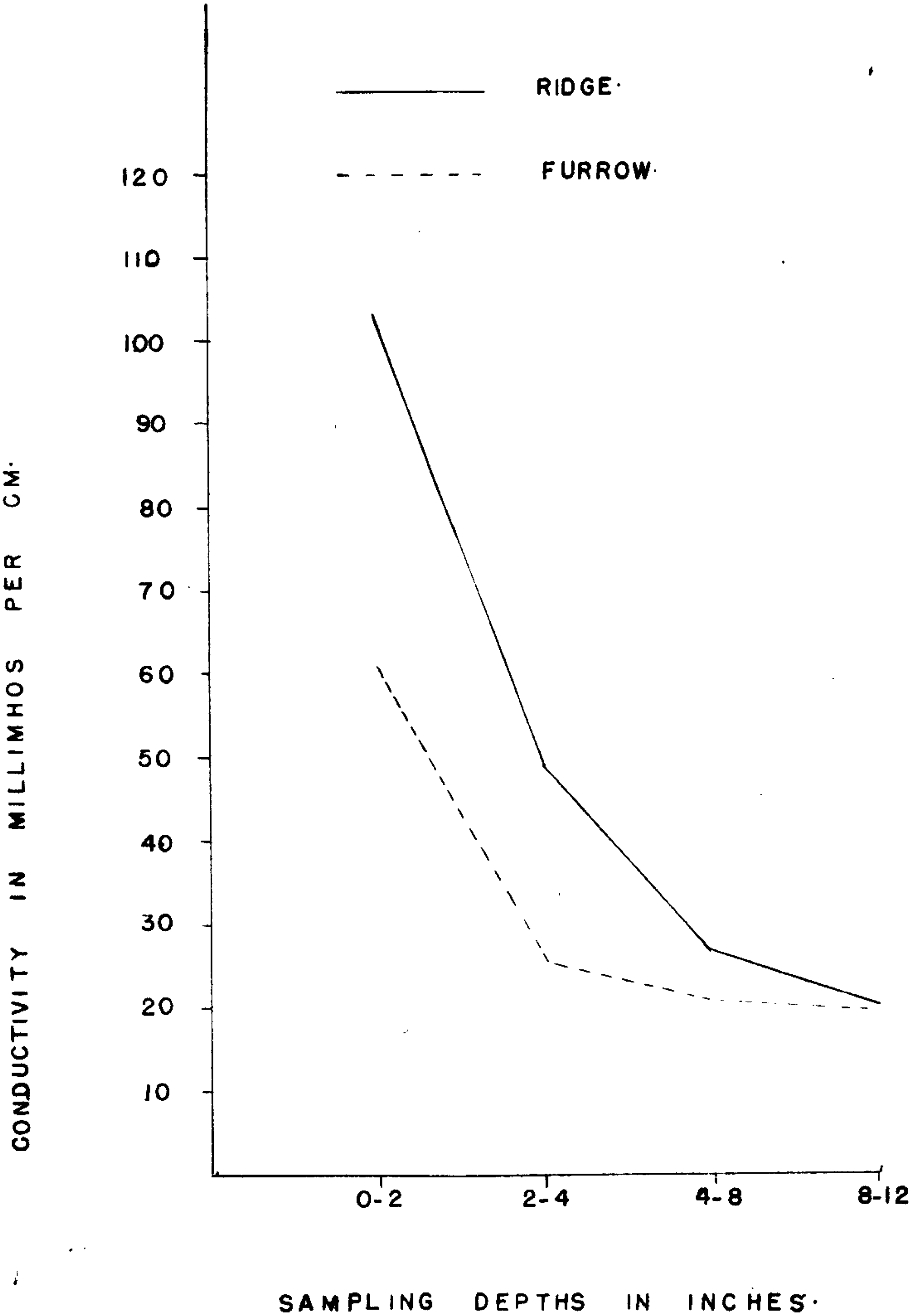

Figure 1. Average salt concentration in ridge and furrow samples at four inch depth as indicated by conductivity of saturation extracts. (All dates and all treatments combined.) Ed William's farm, 1952-53.

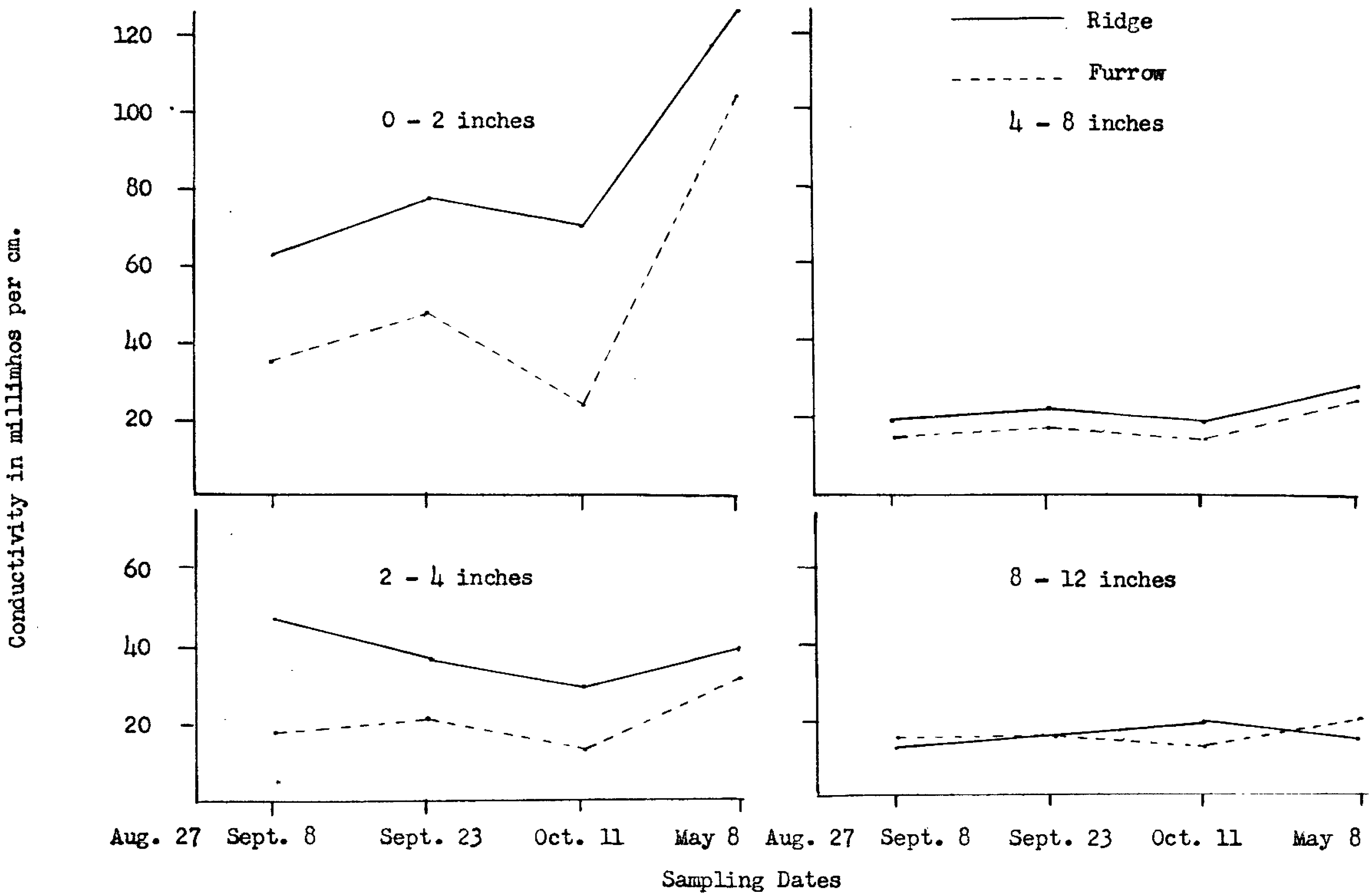

Figure 2. Shows changes in salt concentration in ridges and furrows for each sampling depth on four sampling dates. (All treatments combined.) Ed William's farm, 1952-53.

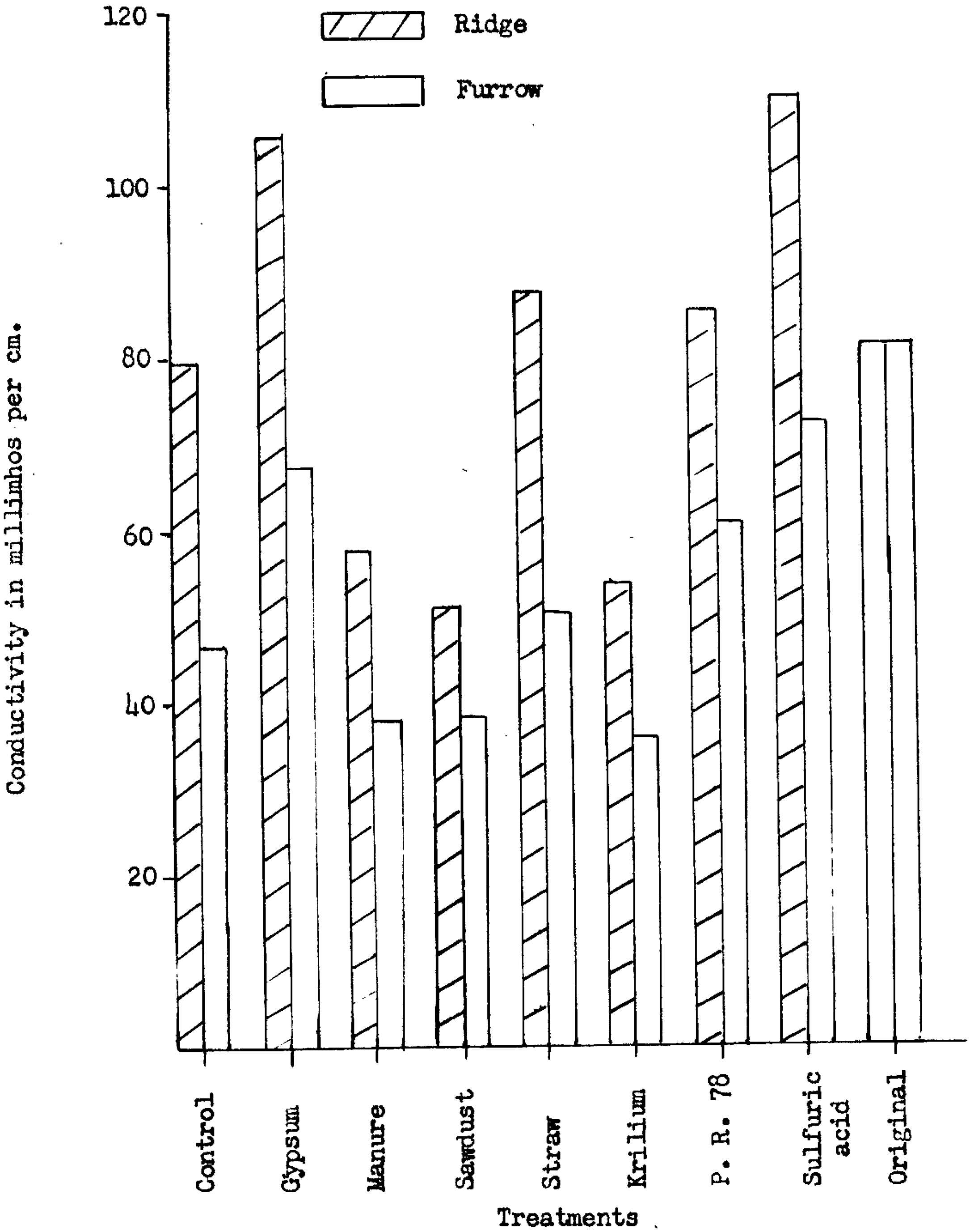

Figure 3. Relation of soil treatment to changes in salt concentration in the upper one foot of soil for ridge and furrow samples. Ed William's farm, 1952-53.
(Original - approximate salt concentration before experiment.)

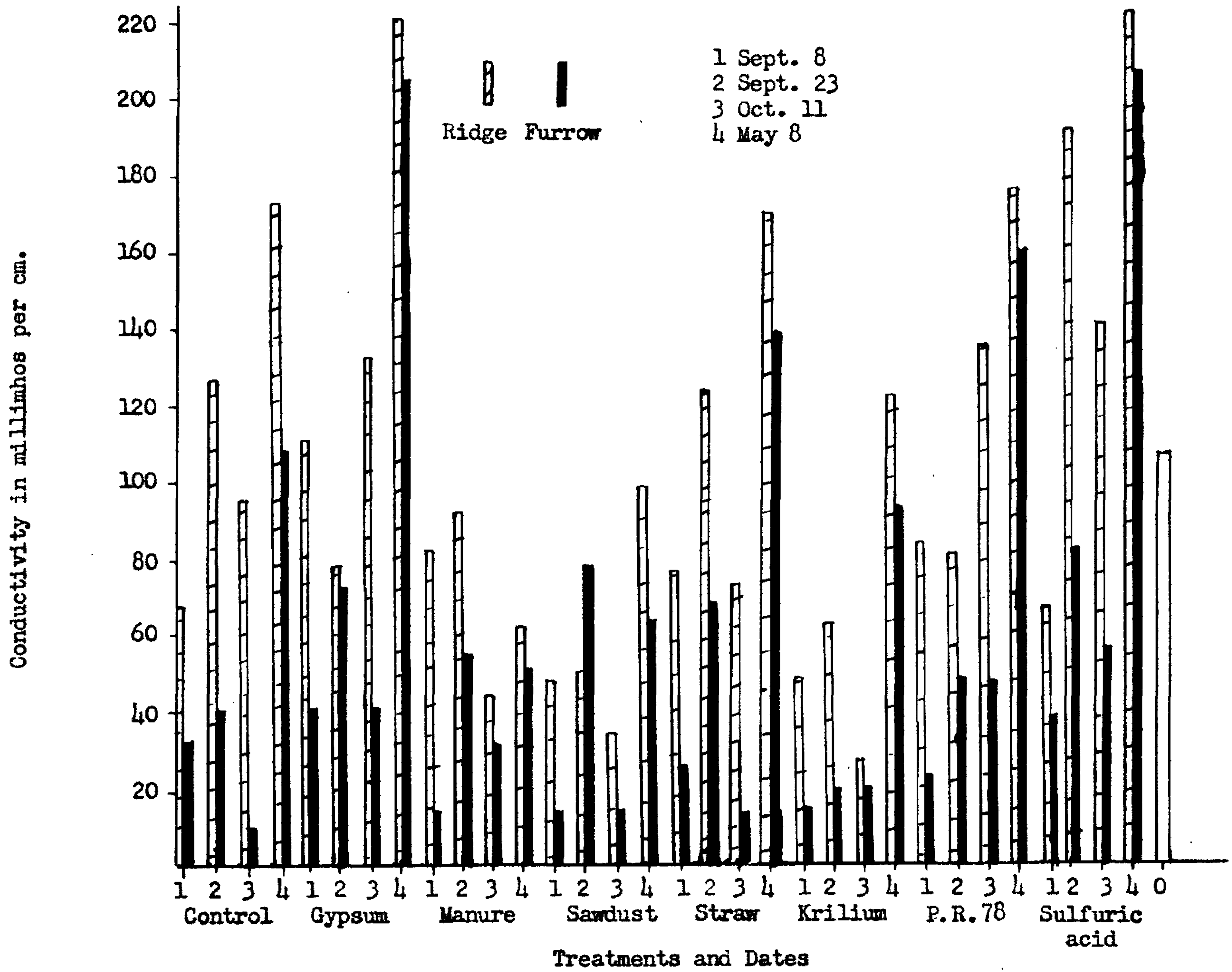

Figure 4. Relation of salt concentration in ridge and furrow samples (0 - 2 inch depth) to soil treatment. (0 - approximate salt concentration at 0 - 2 inch depth before experiment.)

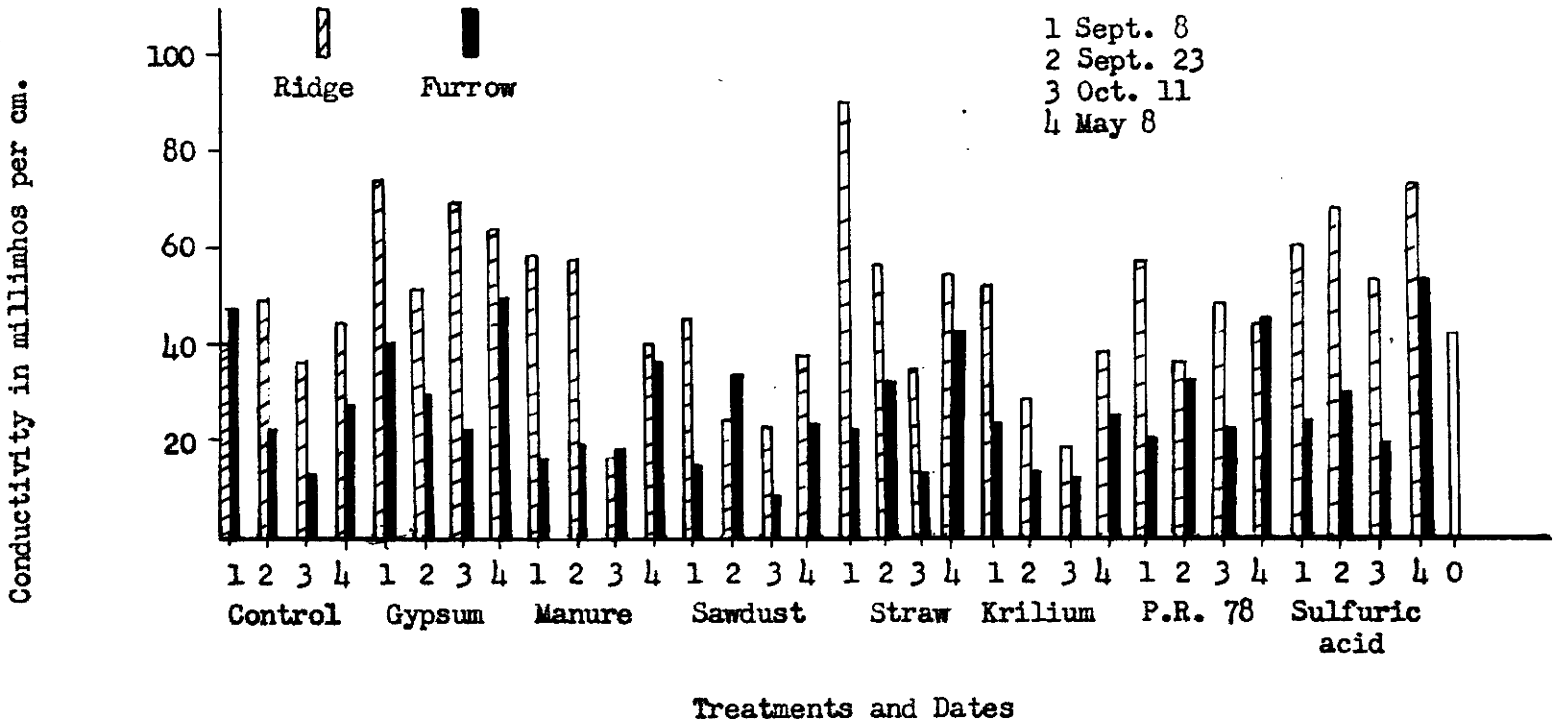

Figure 5. Relation of salt concentration in ridge and furrow samples (2 - 4 inch depth) to soil treatment. (0 - approximate salt concentration at 2 - 4 inch depth before experiment.) Ed William's farm, 1952-53.

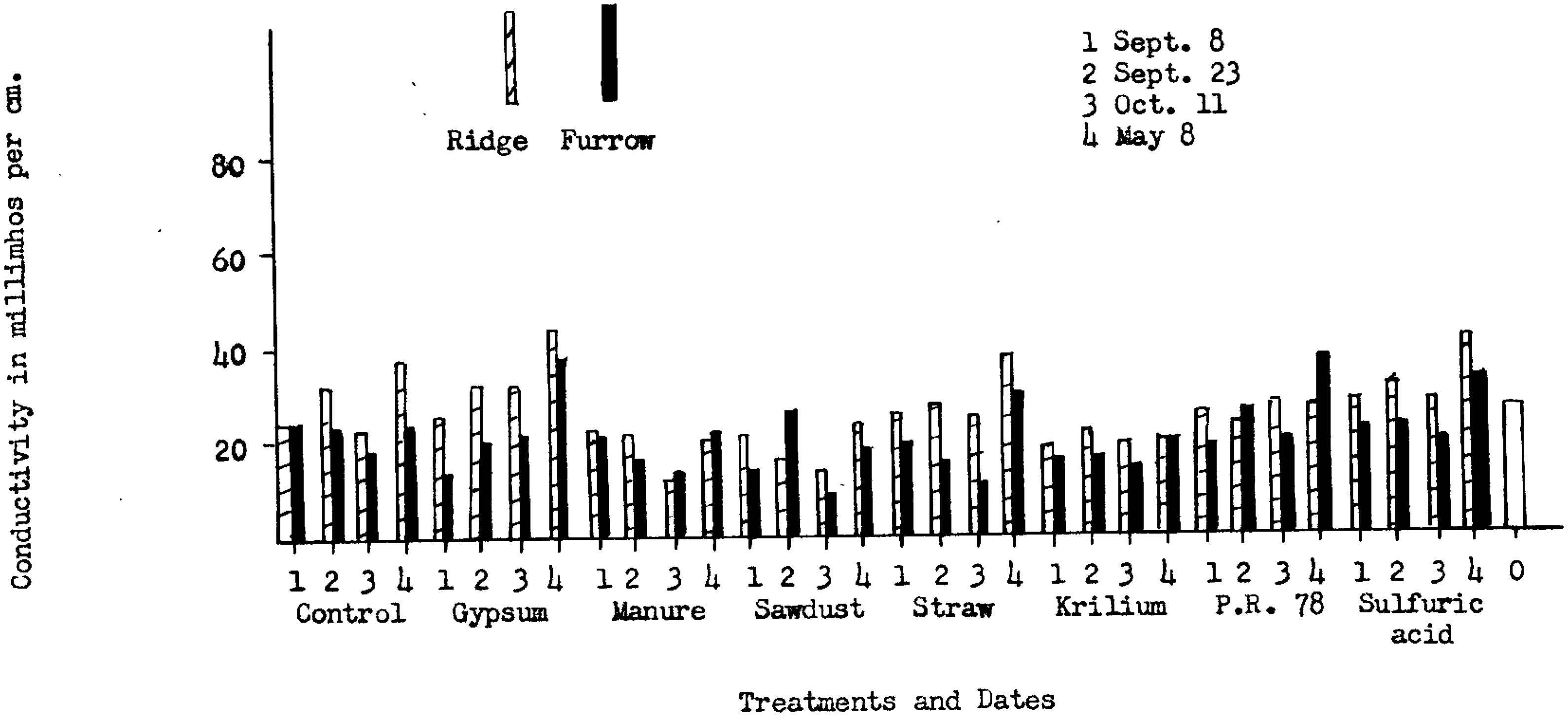

Figure 6. Relation of salt concentration in ridge and furrow samples (4 - 8 inch depth) to soil treatment. (0 - approximate salt concentration at 4 - 8 inch depth before experiment.) Ed William's farm, 1952-53.

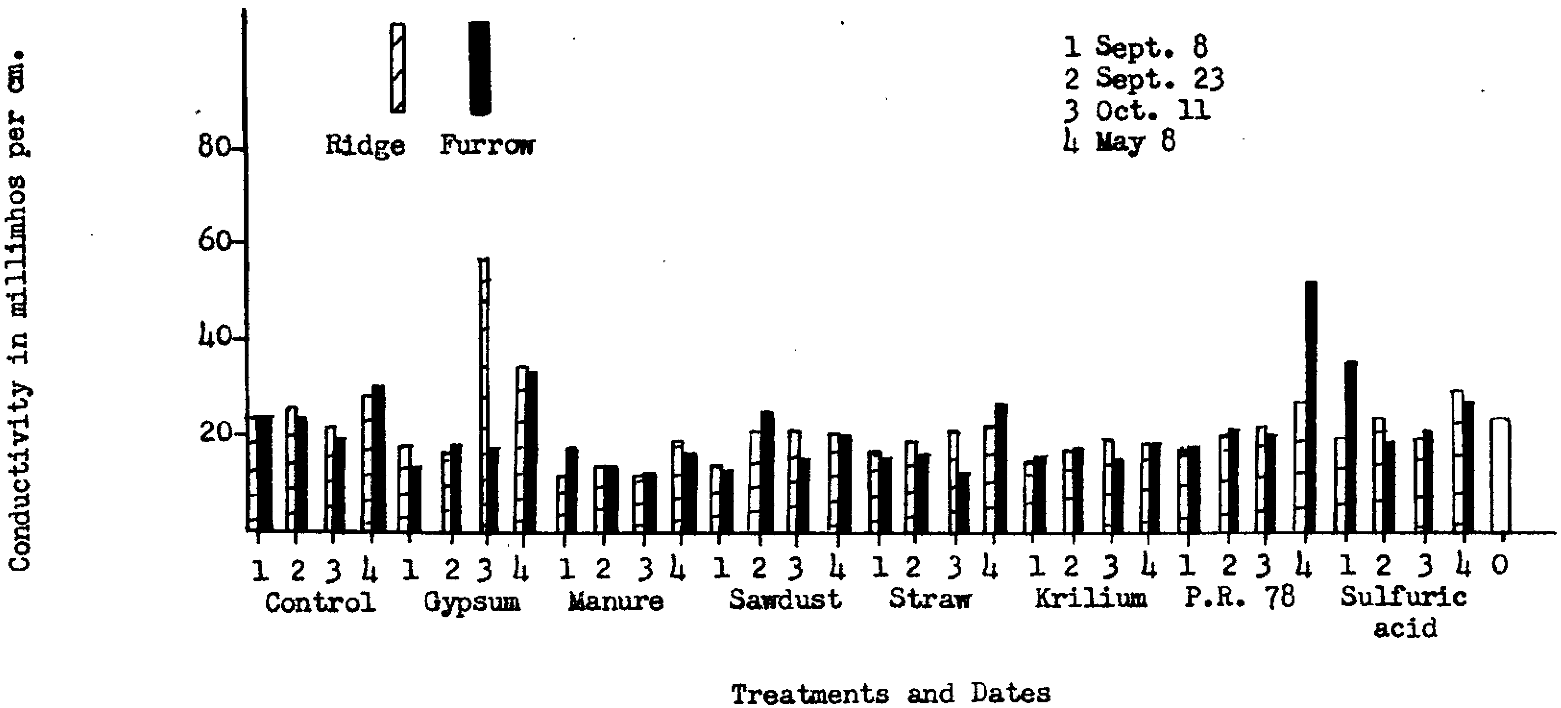

Figure 7. Relation of salt concentration in ridge and furrow samples (8 - 12 inch depth) to soil treatment. (0 - approximate salt concentration at 8 - 12 inch depth before experiment.) Ed William's farm, 1952-53.

Table 8. Nitrifying power of a saline-alkali soil as indicated by increases or decreases in nitrate content of 100-gram samples incubated for 34 days with different materials added

Soil treatment	NO_3 as N	NO_3 as N in material plus soil	Increase or decrease
	ppm	ppm	ppm
Control	3.0	3.0	0.0
Alfalfa (1 gm.)	5.2	9.6	+ 1.4
Manure (1 gm.)	3.4	7.8	+ 1.4
Straw (1 gm.)	0.0	0.5	- 2.5
Ammonium sulfate (1/10 gm.)	0.0	1.0	- 2.0
Ammonium nitrate (1/10 gm.)	170.0	58.0	-112.0

DISCUSSION

Results from this experiment indicate that sprinkler irrigation can be effectively used with furrow plantings and limited soil treatments of manure, sawdust, Krilium, gypsum and sulfuric acid to establish forage crops on saline-alkali soils. Furrow planting of salt tolerant alta fescue and tall wheatgrass (8) using soil treatments of manure, sawdust, Krilium, gypsum and sulfuric acid, gave highly significant increases in crop establishment with sprinkler irrigation.

The high plant establishment under the manure, sawdust and Krilium treatments are associated with reduction in salt concentration. These treatments did not prevent salt increases in the spring.

Reduced evaporation on the manure and sawdust plots increases the effective leaching of the water applied, and maintains high moisture around the germinating seeds.

The high increases in plant establishment under the sulfuric acid and gypsum treatments is due to a lowering of the salt concentration in the furrows during germination period and a lowering of the sodium saturation percentage. (The latter is indicated by preliminary work done by the author and is not reported in this thesis).

The extreme variation in the plots and the varying plant response under the different treatments or on various parts of the same plot indicate that a more exact means of sampling soil should be developed. The soil samples were taken near the center of each plot so may not necessarily represent the conditions around plant roots on that plot.

Soil samples should be taken under plants that grew in order to know the actual condition that stimulated plant establishment.

There was considerable variation in salt concentration on ridges and furrows under different treatments on the four sampling dates. Plots were ridged, treated and planted on August 27, 1952, and received 1.35 inches of irrigation water on September 4. By September 8 big differences in salt concentration between ridges and furrows had developed. The movement of salts from furrows to ridges under furrow irrigation has been well demonstrated by Heald, et al. (18), McGeorge and Wharton (23), and Wadleigh and Fireman (30). These same workers as well as Ayers (1) and Ayers and Hayward (2) have demonstrated the possibility of utilizing this salt movement phenomenon to improve plant establishment on the sides or shoulders of ridges or beds.

It was found in this experiment that planting in the bottom of the furrow, under sprinkler irrigation and manure, sawdust, Krilium, gypsum or sulfuric acid soil treatments, is very effective in establishing highly salt tolerant forage crops on extremely saline-alkali soils.

The pattern of salt concentration established by September 8, remained about the same throughout the fall (tables 2, 4, 5, 6 and 7). The extent of salt movement from furrows to ridges can be increased or decreased with various soil treatments (table 7 and figures 3, 4, 5, 6 and 7).

Highly significant changes in pH (variance tables in Appendix) were affected by the treatments of ridges and furrows and soil amendments under sprinkler irrigation, but the magnitude of these changes was so small and the resulting pH level so high, that it had little effect on plant growth.

The laboratory experiment on nitrate fertility and nitrifying power of this soil showed increased nitrates in the manure and alfalfa treatments. The explanation given by Breazeale and McGeorge (6) for the increased nitrates results from:

(a) the reduced pH of the soil which follows the carbon dioxide evolution on the decomposition of organic materials;

(b) the improved aeration of the soil affected by the alfalfa and manure.

Straw and ammonium sulfate showed slight losses of nitrate. Ammonium nitrate showed a high loss of nitrate. One hundred seventy p.p.m. of nitrate as nitrogen was added in the ammonium nitrate treatment. Only 58 p.p.m. of nitrate as nitrogen was recovered. This is in agreement with the results of others (3, 6, 10, 16).

The results indicate that this soil is low in nitrate content and restricted growth may in part result from inadequate amounts of nitrogen for plant growth. (It should be remembered that the soil from which sample was taken was from area where plants grew, and does not represent poorest areas).

SUMMARY

1. Two experiments were conducted on an extremely saline-alkali soil:

(a) a field study to determine the possibility of establishing known salt tolerant forage crops with sprinkler irrigation by planting them in furrows under limited treatments of gypsum, sulfuric acid, manure, sawdust, straw, Krilium and PR78.

(b) a laboratory study to determine the nitrifying power of the soil.

2. Salt movement from ridges to furrows under the soil treatments and sprinkler irrigation showed manure, sawdust and Krilium to be effective treatments for reducing salt concentration, and to be very effective in improving tall wheatgrass and alta fescue establishment on this soil. The gypsum and sulfuric acid treatments resulted in high plant establishment, lowered salt content in furrows and lower sodium saturation under these treatments (as indicated by preliminary work not reported here) are factors contributing to success of these treatments. They gave only very limited increase in plant establishment and were not effective in changing salt concentration. PR78 and the control gave almost identical results. No plants were established and the amount of salt movement from furrow to ridges was the same.

3. Nitrifying power of this soil was determined on a bulk sample taken from the better part of the field. It was found that manure and alfalfa were possibly of some value in increasing nitrate content of the soil. Ammonium sulfate and ammonium nitrate both showed denitrification.

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APPENDIX

Table 1. Average salt concentration as measured by conductivity of saturation extract in millimhos per centimeter on ridges (R) and in furrows (F), under the various treatments for each depth sample, and on the four sampling dates, with L.S.D.'s where appropriate

Depth	Date	Control R	Control F	Gypsum R	Gypsum F	Manure R	Manure F	Sawdust R	Sawdust F	Straw R	Straw F	Krilium R	Krilium F	PR78 R	PR78 F	Sulfuric acid R	Sulfuric acid F
0 - 2"	Sept. 8	62	33	110	40	82	15	48	15	77	26	49	16	84	24	67	40
	Sept.23	101	40	77	72	91	56	51	78	125	70	53	21	82	59	192	84
	Oct. 11	95	9	132	42	45	31	34	14	74	14	28	20	137	49	142	58
	May 8	171	108	221	204	62	51	100	64	172	139	123	94	177	161	223	208

L.S.D.'s	R vs. F .05	R vs. F .01	Treatments .05	Treatments .01
Sept. 8	17	22	-	-
Sept.23	30	-	-	-
Oct. 11	19	25	38	51
May 8	-	-	56	75

Depth	Date	Control R	Control F	Gypsum R	Gypsum F	Manure R	Manure F	Sawdust R	Sawdust F	Straw R	Straw F	Krilium R	Krilium F	PR78 R	PR78 F	Sulfuric acid R	Sulfuric acid F
2 - 4"	Sept. 8	40	28	74	32	59	16	45	14	90	22	53	23	57	20	61	23
	Sept.23	49	23	51	29	57	20	24	33	56	32	28	13	36	33	68	29
	Oct. 11	36	12	69	22	16	19	22	8	35	13	18	12	48	22	53	20
	May 8	45	27	63	49	41	36	37	24	55	42	38	25	45	45	73	58

L.S.D.'s	R vs. F .05	R vs. F .01	Treatments .05	Treatments .01
Sept. 8	11	15	-	-
Sept.23	13	17	-	-
Oct. 11	9	11	17	23
May 8	9	-	18	24

Table 1. (cont'd.)

Depth	Date	Control R	Control F	Gypsum R	Gypsum F	Manure R	Manure F	Sawdust R	Sawdust F	Straw R	Straw F	Krilium R	Krilium F	PR78 R	PR78 F	Sulfuric acid R	Sulfuric acid F
4 - 8"	Sept. 8	24	24	25	13	22	21	22	14	26	19	20	18	27	20	30	25
	Sept.23	31	23	32	20	21	16	17	27	29	17	22	18	24	28	33	24
	Oct. 11	22	18	32	22	12	19	14	10	25	11	16	12	29	20	28	20
	May 8	37	24	45	38	21	23	25	20	38	31	22	21	28	38	42	34

L.S.D's	R vs. F .05	R vs. F .01	Treatments .05	Treatments .01
Sept. 8	-	-	-	-
Sept.23	-	-	-	-
Oct. 11	6	-	-	-
May 8	-	-	13	-

Depth	Date	Control R	Control F	Gypsum R	Gypsum F	Manure R	Manure F	Sawdust R	Sawdust F	Straw R	Straw F	Krilium R	Krilium F	PR78 R	PR78 F	Sulfuric acid R	Sulfuric acid F
8 - 12"	Sept. 8	18	23	17	13	10	17	12	12	16	16	15	16	16	18	20	35
	Sept.23	25	23	17	18	13	13	19	23	18	17	16	17	20	21	23	19
	Oct. 11	21	20	57	18	10	12	20	13	20	12	19	14	23	20	19	21
	May 8	20	30	34	33	18	16	19	18	21	26	19	18	22	31	24	27

L.S.D's	R vs. F .05	R vs. F .01	Treatments .05	Treatments .01
Sept. 8	-	-	-	-
Sept. 23	-	-	-	-
Oct. 11	-	-	-	-
May 8	-	-	11	-

Table 2. Average salt concentrations as measured in millimhos per centimeter under ridges (R) and furrows (F) at four sampling depths on four sampling dates, all treatments combined

Date	Depth in inches							
	0 - 2		2 - 4		4 - 8		8 - 12	
	R	F	R	F	R	F	R	F
Sept. 8	79	45	60	22	24	19	15	17
Sept. 23	97	60	46	26	26	21	19	19
Oct. 11	86	29	37	16	22	17	24	16
May 8	156	129	50	43	32	29	22	25

Table 3. Average salt concentration in each of the four replicates expressed as conductivity in millimhos per centimeter with least significant differences

Reps.	Conductivity in millimhos per cm. (average)
1	26.28
2	42.04
3	49.47
4	45.78

L.S.D. .05 = 4.92 .01 = 6.48

Table 4. Average salt concentration under eight soil treatments expressed as conductivity in millimhos per centimeter with least significant differences

Treatments	Conductivity in millimhos per cm. (average)
Control	40.81
Gypsum	53.83
Manure	29.89
Sawdust	28.03
Straw	43.31
Krilium	28.26
P.R. 78	45.78
Sulfuric acid	57.23

L.S.D. .05 = 6.97 .01 = 9.16

Note: Tables 3 to 13, inclusive, are the analysis of variance tables of conductivity data for the replicates, treatments, depths, dates and locations, and their interactions with L.S.D!s at the .05 and .01 per cent levels where appropriate.

Table 5. Average salt concentrations at four sampling depths expressed as conductivity in millimhos per centimeter with least significant differences

Depths	Conductivity in millimhos per cm. (average)
0 - 2"	82.39
2 - 4"	37.13
4 - 8"	23.99
8 - 12"	2.07

L.S.D. .05 = 4.92 .01 = 6.48

Table 6. Average salt concentration on four sampling dates expressed as conductivity in millimhos per centimeter with least significant differences

Date	Conductivity in millimhos per cm. (average)
Sept. 8	32.50
Sept. 23	39.78
Oct. 11	30.99
May 8	60.30

L.S.D. .05 = 4.92 .01 = 6.48

Table 7. Average salt concentration under ridges (R) and furrows (F) expressed as conductivity in millimhos per cm. with least significant differences

Location	Conductivity in millimhos per cm. (average)
R	49.75
F	32.03

L.S.D. .05 = 3.47 .01 = 4.57

Table 8. **Average salt concentration under eight soil treatments at four sampling depths, expressed as conductivity in millimhos per centimeter with least significant differences**

Depth in inches	Treatments							
	Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
0 - 2"	81.20	112.30	53.98	50.64	87.08	50.59	96.60	126.77
2 - 4"	32.65	48.95	33.02	25.99	43.21	26.49	38.42	48.33
4 - 8"	25.72	28.32	19.04	18.65	24.73	19.16	26.75	29.53
8 - 12"	23.67	25.76	13.54	16.85	18.24	16.80	21.38	24.30

L.S.D. .05 = 13.91 .01 = 18.30

Table 9. **Average salt concentration under eight treatments on four sampling dates, expressed as conductivity in millimhos per centimeter with least significant differences**

Date	Treatments							
	Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
Sept. 8	32.40	40.70	30.37	22.84	36.60	26.25	33.28	37.55
Sept. 23	42.67	39.55	35.82	34.08	45.49	23.60	38.00	59.09
Oct. 11	29.21	49.25	20.00	17.01	25.67	18.06	43.50	45.23
May 8	58.97	85.82	33.40	38.20	65.48	45.12	68.38	87.04

L.S.D. .05 = 13.91 .01 = 18.30

Table 10. **Average salt concentration in ridges (R) and furrows (F) under eight soil treatments, expressed as conductivity in millimhos per centimeter with least significant differences**

Location	Treatments							
	Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
R	52.36	66.05	36.34	31.85	54.89	34.00	53.42	69.13
F	29.26	41.61	23.45	24.21	31.73	22.52	38.16	45.33

L.S.D. .05 = 9.85 .01 = 12.96

Table 11. **Average salt concentration at four sampling depths on four sampling dates expressed as conductivity in millimhos per centimeter with least significant differences**

Date	Depth in inches			
	0 - 2"	2 - 4"	4 - 8"	8 - 12"
Sept. 8	49.56	41.30	22.02	17.12
Sept. 23	79.89	36.49	23.83	18.99
Oct. 11	57.80	26.70	19.54	19.92
May 8	142.33	44.04	30.55	24.29

L.S.D. .05 = 9.85 .01 = 12.96

Table 12. **Average salt concentration in ridges (R) and furrows (F) on four sampling dates expressed as conductivity in millimhos per centimeter with least significant differences**

Location	Date			
	Sept. 8	Sept. 23	Oct. 11	May 8
R	43.31	47.81	42.50	64.98
F	21.69	31.76	19.48	55.21

L.S.D. .05 = 6.97 .01 = 9.16

Table 13. **Average salt concentration in ridges (R) and furrows (F) at four sampling depths expressed as conductivity in millimhos per centimeter with least significant differences**

Location	Depth in inches			
	0 - 2"	2 - 4"	4 - 8"	8 - 12"
R	103.75	48.36	26.48	20.44
F	61.05	25.91	21.49	19.69

L.S.D. .05 = 6.97 .01 = 9.16

Table 14. Combined analysis of variance for conductivity data

No.	$S\bar{d}$	L.S.D. (.05;.01)	Source	df	S.sqs.	M.sqs.	F
256	2.51	4.92 6.48	Reps	3	79929.31	26643.10	33.08**
128	3.55	6.97 9.16	Treatments	7	116482.96	16640.42	20.66**
256	2.51	4.92 6.48	Depth	3	628765.02	209588.34	260.20**
256	2.51	4.92 6.48	Date	3	139904.20	46634.73	57.90**
512	1.77	3.47 4.57	Locations	1	80407.69	80407.69	99.83**
32	7.09	13.91 18.30	Treat.x Depth	21	99908.99	4757.57	5.91**
32	7.09	13.91 18.30	Treat.x Date	21	46236.75	2201.75	2.73**
64	5.02	9.85 12.96	Treat.x Loc.	7	9938.10	1419.73	1.76
64	5.02	9.85 12.96	Depth x Date	9	215290.10	23921.12	29.70**
128	3.55	6.97 9.16	Depth x Loc.	3	70164.55	23388.18	29.04**
128	3.55	6.97 9.16	Date x Loc.	3	6574.19	2191.40	2.72*
			Error 183 - 765	942	758760.36	805.48	
			Total	1023	2252362.22		

Table 15. Summary table showing average pH values at each depth on four sampling dates with eight soil treatments; L.S.D. values are given where appropriate

Depth	Date	Control		$CaSO_4$		Manure		Sawdust	
		R	F	R	F	R	F	R	F
2"	Sept. 8	9.95	9.90	9.92	9.52	9.60	9.58	9.68	9.50
	Sept. 23	9.80	9.98	10.02	10.10	9.65	9.48	9.78	9.95
	Oct. 11	9.90	9.45	9.75	9.88	9.75	9.48	9.85	9.78
	May 8	9.70	9.92	9.72	9.80	9.70	9.70	10.00	9.80
4"	Sept. 8	9.95	9.98	10.02	9.90	9.62	9.58	9.95	9.90
	Sept. 23	9.92	9.92	10.20	10.15	9.78	9.55	9.88	10.05
	Oct. 11	9.95	9.75	10.00	9.98	9.70	9.62	9.90	9.78
	May 8	10.05	9.88	10.12	10.15	9.78	9.53	9.98	9.82
8"	Sept. 8	9.98	9.98	10.08	9.95	9.62	9.65	9.85	9.88
	Sept. 23	10.02	10.02	10.25	10.18	9.62	9.60	10.00	10.10
	Oct. 11	10.02	9.88	10.02	9.98	9.65	9.62	9.90	9.82
	May 8	10.05	9.88	10.20	10.15	9.68	9.65	9.98	9.88
12"	Sept. 8	10.05	10.05	10.08	9.95	9.68	9.65	9.90	9.88
	Sept. 23	10.08	10.05	10.20	10.20	9.60	9.60	10.10	10.12
	Oct. 11	10.00	9.90	10.00	9.98	9.68	9.68	9.90	9.92
	May 8	10.02	10.02	10.12	10.10	9.62	9.65	9.98	9.80

Table 15. (cont'd.)

Depth	Date	Straw R	Straw F	Krilium R	Krilium F	PR 78 R	PR 78 F	H_2SO_4 R	H_2SO_4 F	Location LSD .05	Location LSD .01	Treatment LSD .05	Treatment LSD .01
2"	Sept. 8	10.02	9.90	10.05	9.85	9.75	9.77	9.68	9.40	.14	-	.28	.38
	Sept.23	10.00	9.82	10.10	9.90	9.75	9.95	9.68	9.35	-	-	.32	.42
	Oct. 11	10.00	9.62	9.85	9.62	9.85	9.58	9.68	9.00	.16	.22	-	-
	May 8	9.78	9.90	9.80	9.85	9.70	9.82	9.55	9.78	-	-	-	-
4"	Sept. 8	10.08	10.08	10.10	10.00	9.78	9.95	10.05	10.08			.25	.39
	Sept.23	10.12	9.92	10.10	10.02	9.95	10.05	9.98	9.98	-	-	.28	-
	Oct. 11	10.05	9.60	9.82	9.78	9.88	9.92	10.02	9.55	.15	-	-	-
	May 8	10.10	10.05	9.95	9.88	10.00	10.08	10.02	10.02	-	-	.26	-
8"	Sept. 8	10.10	10.08	10.05	9.98	9.80	9.95	10.15	10.08	-	-	-	-
	Sept.23	10.12	9.98	10.10	10.02	9.95	10.08	10.10	10.10	-	-	.20	.27
	Oct. 11	10.08	9.80	9.88	9.85	10.05	10.05	10.02	9.85	-	-	.26	-
	May 8	10.10	10.08	9.98	9.90	10.02	10.08	10.08	10.05	-	-	.26	-
12"	Sept. 8	10.05	10.00	10.05	10.05	9.82	9.98	10.12	10.10	-	-	.23	-
	Sept.23	10.02	10.05	10.05	10.00	10.02	10.05	10.18	10.10	-	-	.24	.32
	Oct. 11	9.98	9.85	9.90	9.95	10.10	10.02	9.98	9.90	-	-	.19	-
	May 8	10.00	9.98	9.95	9.88	10.00	10.00	10.05	10.00	-	-	.23	.31

Table 16. Average pH in each of the four replicates with least significant differences

Reps.	pH averages	L.S.D. .05	L.S.D. .01
1	9.82	.04	.06
2	10.02		
3	9.94		
4	9.84		

Table 17. Average pH under eight soil treatments with least significant differences

Treatments	pH averages	L.S.D. .05	L.S.D. .01
Control	9.94	.06	.08
Gypsum	10.02		
Manure	9.64		
Sawdust	9.89		
Straw	9.98		
Krilium	9.94		
P.R. 78	9.93		
Sulfuric acid	9.90		

Note: Tables 16 to 26, inclusive, are the analyses of variance tables of pH data for the replicates, treatments, depths, dates and locations and their interactions, with L.S.D.'s at the .05 and .01 levels where appropriate.

Table 18. Average pH at four sampling depths with least significant differences

Depth in inches	pH averages	L.S.D. .05	L.S.D. .01
0 - 2"	9.76	.04	.06
2 - 4"	9.93		
4 - 8"	9.96		
8 - 12"	9.96		

Table 19. Average pH on four sampling dates with least significant differences

Date	pH averages	L.S.D. .05	L.S.D. .01
Sept. 8	9.90	.04	.06
Sept. 23	9.96		
Oct. 11	9.84		
May 8	9.92		

Table 20. Average pH under ridges (R) and furrows (F) with least significant differences

Location	pH averages	L.S.D. .05	L.S.D. .01
R	9.93	.03	.04
F	9.87		

Table 21. Average pH under eight soil treatments at four sampling depths with least significant differences

Depth in inches	Treatments Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
0 - 2"	9.82	9.84	9.62	9.79	9.88	9.88	9.77	9.51
2 - 4"	9.92	10.06	9.64	9.91	10.00	9.96	9.95	9.96
4 - 8"	9.98	10.10	9.64	9.92	10.04	9.97	10.00	10.05
8 - 12"	10.02	10.08	9.64	9.95	9.99	9.98	10.00	10.05

L.S.D. .05 = .12 .01 = .16

Table 22. Average pH under eight soil treatments on four sampling dates with least significant differences

Date	Treatments Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
Sept. 8	9.99	9.93	9.62	9.82	10.04	10.02	9.85	9.96
Sept. 23	9.98	10.16	9.61	10.00	10.01	10.04	9.98	9.93
Oct. 11	9.86	9.95	9.65	9.86	9.87	9.83	9.93	9.75
May 8	9.94	10.05	9.66	9.90	10.00	9.90	9.96	9.94

L.S.D. .05 = .12 .01 = .16

Table 23. Average pH under eight soil treatments in ridges (R) and furrows (F) with least significant differences

Location	Treatments Control	Gypsum	Manure	Sawdust	Straw	Krilium	PR78	H_2SO_4
R	9.96	10.04	9.67	9.91	10.04	9.98	9.90	9.96
F	9.90	10.00	9.60	9.87	9.92	9.91	9.96	9.83

L.S.D. .05 = .09 .01 = .11

Table 24. Average pH at four sampling depths on four sampling dates with least significant differences

Dates	Depth in inches 0 - 2"	2 - 4"	4 - 8"	8 - 12"
Sept. 8	9.75	9.94	9.95	9.96
Sept. 23	9.83	9.97	10.02	10.03
Oct. 11	9.69	9.83	9.90	9.92
May 8	9.78	9.96	9.98	9.95

L.S.D. .05 = .09 .01 = .11

Table 25. Average pH in ridges (R) and furrows (F) on four sampling dates with least significant differences

Location	Date Sept. 8	Sept. 23	Oct. 11	May 8
R	9.92	9.97	9.91	9.93
F	9.88	9.95	9.76	9.91

L.S.D. .05 = .06 .01 = .08

Table 26. Average pH in ridges (R) and furrows (F) at four sampling depths with least significant differences

Location	Depth in inches 0 - 2"	2 - 4"	4 - 8"	8 - 12"
R	9.81	9.96	9.98	9.98
F	9.72	9.89	9.94	9.95

L.S.D. .05 = .06 .01 = .08

Table 27. Combined analysis of variance for pH data

No.	$S\bar{d}$	L.S.D. (.05;.01)	Source	df	S.sqs.	M.sqs.	F
256	.022	.04 .06	Reps	3	6.60	2.2000	36.18**
128	.031	.06 .08	Treatments	7	12.18	1.7400	28.62**
256	.022	.04 .06	Depth	3	6.92	2.3067	37.94**
256	.022	.04 .06	Date	3	2.09	.6967	11.46**
512	.015	.03 .04	Locations	1	0.91	.9100	14.97**
32	.062	.12 .16	Treat. x depth	21	3.86	.1838	3.02**
32	.062	.12 .16	Treat. x date	21	2.62	.1248	2.05**
64	.044	.09 .11	Treat. x loc.	7	0.71	.1014	1.67
64	.044	.09 .11	Depth x date	9	0.23	.02555	0.04
128	.031	.06 .08	Depth x loc.	3	0.19	.0633	1.04
128	.031	.06 .08	Date x loc.	3	0.66	.2200	3.62*

Error	183 + 765	942	57.26
Total		1023	94.23

df - degrees of freedom
S.sqs. - sum of squares
M.sqs. - means of squares
F - F value