5-1957

The Alkali Tolerance of Tall Wheatgrass

David L. Carter
Utah State University

THE ALKALI TOLERANCE OF TALL WHEATGRASS

by

David L. Carter

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Chemistry

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

1957

ACKNOWLEDGMENT

I am deeply grateful to Dr. Howard B. Peterson for his suggestions and guidance in the selection and conduct of the thesis problem. My sincere appreciation is also given to James P. Thorne for his suggestions and the equipment and space where much of the laboratory analysis was conducted.

David L. Carter

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Alkali land occurs adjacent to nearly every extensively irrigated area. Much of this land is too alkaline to produce profitable crops. Each year thousands of acres of land are going out of production because of increasing alkalinity. This presents one of the most acute problems which confronts irrigation agriculture today.

Previous work on this problem has been done with the objective of trying to find methods of reclaiming alkali soils. There are, however, no methods for complete reclamation that are economically feasible for all alkali soils.

Information concerning the level of alkalinity that a plant species can tolerate is needed. It is thought that the alkali tolerance of plants is a function of the stage of growth. Most species are most sensitive in the germination stage. With such information at hand, possible minor amendments and practices can be recommended during the sensitive period to improve conditions for plant growth and development until the plant reaches a stage in which it is more tolerant to alkaline conditions.

In the search for plant species that can tolerate alkaline conditions and give some economic return from alkali lands it is very probable that new species will be introduced as hay and pasture crops. At the present time tall wheatgrass (*Agropyron elongatum*) is one of the most promising species being used.

In this study an attempt was made to determine the alkali tolerance of tall wheatgrass in several stages of growth and to find the most sensitive stage.

Another purpose was to find a suitable method for determining the alkali tolerance of plant species.

REVIEW OF LITERATURE

Alkali soils

Alkali soils are very common in many parts of the world. They generally occur adjacent to extensively irrigated areas. Isrealson (1950) pointed out that nearly all saline and alkali soils occur because of poor irrigation practices.

The United States Salinity Laboratory (1954) defined alkali soils as soils that contain sufficient exchangeable sodium to interfere with growth of most crop plants, either with or without appreciable quantities of soluble salts.

> Saline-alkali soils. Soils that contain sufficient exchangeable sodium to interfere with the growth of most crop plants, and containing appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15, and the electrical conductivity of the saturation extract is greater than 4 mmhos per centimeter at 25° C. The pH reading of the saturated soil is usually less than 8.5.
>
> Nonsaline-alkali soils. Soils that contain sufficient exchangeable sodium to interfere with the growth of most crop plants, but do not contain appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15 and the electrical conductivity of the saturation extract is less than 4 mmhos per centimeter. The pH reading of the saturated paste is usually greater than 8.5.

Thorne and Peterson (1954) noted that the term alkali has been used commonly in the past to designate all soils high in soluble salts. Such broad usage of the term is not acceptable since it implies a caustic alkaline condition.

Alkali soil as a medium for plant growth

The causes of poor growth of plants often observed upon soils containing a high proportion of exchangeable sodium are not completely understood. Breazeale and McGeorge (1932) have shown that high pH values of soils which are frequently associated with the presence of exchangeable sodium may be responsible for various nutritional disorders in plants. There is also evidence that a high degree of saturation of the soil exchange complex with exchangeable sodium may in itself be quite detrimental. They concluded that plants are not able to absorb phosphate or nitrate ions from solutions of greater alkalinity than is represented by pH 7.6, and that the hydroxyl ion depresses and almost prevents the absorption of phosphate and nitrate ions by plants. They stated that without doubt, carbon dioxide is the most important single factor in the fertility of alkaline soils.

Thorne and Peterson (1954) point out that the specific effects of alkali on plants are distinct from the effects of salinity and are due to a high caustic alkalinity, to toxicity of the carbonate ion, and to the direct effects of exchangeable sodium. Some portions of plant roots along with other organic matter are dissolved at pH values greater than 9.0.

Crop response to alkali soils

Ratner (1935) studied the influence of various proportions of exchangeable sodium and calcium on the growth of plants. In pot tests the yields of oats and wheat were not decreased at 30 percent exchangeable sodium. At 50 percent exchangeable sodium there was a decrease in the yield, and at 70 percent exchangeable sodium all the plants died. Ratner concluded that the sodium toxicity resulted from a lack of available calcium. This conclusion is accepted by many of the workers in the field of soil science today.

Thorne (1944) studied the growth and mineral content of Stone tomato plants in relation to various ratios of sodium and calcium and of potassium and calcium adsorbed on bentonite clay and mixed with pure quartz sand for a culture medium. He found that the yield of plants was decreased as the level of exchangeable sodium exceeded 40 percent of the exchange capacity of the clay. The highest level of sodium tolerated by the plants was between 60 and 70 percent of the total exchange capacity. Calcium uptake was decreased with increasing levels of exchangeable sodium.

Bower and Wadleigh (1948) studied the influence of various levels of exchangeable sodium upon growth and cationic accumulation by dwarf red kidney beans, garden beets, and Rhodes and Dallis grasses. The tolerance of the different species to the presence of exchangeable sodium in the substrate varied greatly. Beans were found to be especially sodium sensitive. Growth of this species was markedly decreased at exchangeable-sodium-percentages as low as 15 and was almost completely inhibited at the 3 highest levels, which were 45, 60, and 75 percent of the exchange capacity. In sharp contrast to the results with beans, Rhodes grass and garden beets were found to be very sodium tolerant. Significant reduction in the growth of these species occurred only at the highest level employed. The growth of Dallis grass was not significantly lowered at exchangeable-sodium-percentages of 30 or less but at the higher sodium levels practically no growth was obtained.

Researchers at the United States Salinity Laboratory (1954) point out that plants vary greatly in their ability to tolerate alkali soils. Others suggest the need for more work on the tolerance of plants to alkali conditions using specific promising species.

Tall wheatgrass

Tall wheatgrass (Agropyron elongatum) was introduced into the United States from Turkey in 1909. It is a coarse, nonlodging, late-maturing bunchgrass. It grows 2½ to 6 feet tall and is very productive.

It is resistant to cold and drought and makes excellent spring and fall recovery. The grass is fairly palatable and remains green 3 to 6 weeks longer than other forage grasses. It grows rapidly and gives high yields of forage and hay on saline and alkali soils. The seed is large. The plant is often used for erosion control. It is presently used for range reseeding and seed production in Utah, Colorado, Nevada and Wyoming (Weintraub, 1953).

Hafenrichter and co-workers (1949) described tall wheatgrass as a coarse, tall, stemmy bunchgrass. Even so, they pointed out that it is much more palatable than its appearance indicates, and its yields are among the highest of any grasses tested. It is common to find its production as high as 8 tons of hay per acre.

Robertson and Jensen (1953) found tall wheatgrass to be the highest yielding of 51 varieties of grasses tested on range plots in Nevada. They noted its excellent regrowth after fall harvesting as a promising quality for fall pasture.

Relationship of tall wheatgrass to saline and alkali soils

Campbell (1955) reported a crop tolerance study conducted in Montana. He found that tall wheatgrass was one of the most alkali tolerant crops that he planted.

Thorne and Bennett (1952) reviewed papers and reported that tall wheatgrass was being planted on many highly saline soils in Utah and Nevada. Good emergence and survival of this species have been reported where most other species of grasses and legumes failed.

Forsburg (1953) conducted a salt tolerance study using many species of grasses and legumes. He found that tall wheatgrass was the most salt tolerant species in the group. He reported that tall wheatgrass grew well and gave high yields on soils where the conductivity of the saturated extract was 24 mmhos per centimeter. Nearly all other species could not exist at such conductivities.

Beetle (1955) reported that tall wheatgrass has 2 outstanding qualities with respect to other grasses. These qualities are its hardiness to cold and drought along with late forage production and its ability to produce excellent forage on grounds too alkaline to grow any other useful crop.

One disadvantage of tall wheatgrass is that it is very slow in establishment. It takes 6 to 7 years for the crop to come into full production. However, it produces at a maximum for many years after establishment (Beetle, 1955). Therefore it may take several years to get high production of the crop on saline and alkali soils.

METHOD OF PROCEDURE

There are no recognized methods for evaluating the alkali tolerance of plants. In this study 4 approaches were tried. They consisted of (1) collecting and analyzing soil samples from the root zone of tall wheatgrass growing on alkali soils in the field, (2) growing tall wheatgrass in the green-house at different levels of alkalinity with additional ammendment treatments, (3) growing tall wheatgrass in solution culture in the green-house and (4) a germination study.

Tall wheatgrass seed used in these experiments was from a commercial planting. The seed germination rate was 99.5 percent.

Experiment 1. Analysis of field samples

Four farms were located in northern Utah where tall wheatgrass was growing on naturally alkali soil. At each location the fields were studied until a good yield gradient was located. The gradient consisted of an area in the field where all levels of yield occurred in consistently decreasing order in approximately a straight line to a point where no plants survived. Soil samples were collected from the root zone of the plants at 5 intervals in the gradient. The first sample came from the root zone of plants where yield was greatest with the other samples coming from the root zone of plants at approximately equal distances and equal yield decreases. The last sample in each group was collected in the area where no plants survived. The yield decreases were given ratings from 1 to 5 in order of decreasing yield.

A total of 60 samples was collected. This included 20 samples from the Clarence Anderson farm in Trenton, Utah, 20 samples from the Glen

Mason farm in Plymouth, Utah, 10 samples from the Burt Eliason farm in Snowville, Utah, and 10 samples from the Robert Crook farm in Trenton, Utah.

The samples were analyzed for pH, electrical conductivity of the saturation extract, saturation percentage, water soluble sodium, ammonium acetate extractable sodium, cation exchange capacity, and air dry moisture percentage (United States Salinity Laboratory, 1954). From the analyses the exchangeable sodium was found and the exchangeable-sodium-percentage was calculated.

Experiment 2. Green-house pot culture study

Two bulk samples of soil were collected. They consisted of a Kirkham loam (saline-alkali soil) from Spanish Fork, Utah, and a Kilburn gravelly loam (non-calcareous soil) from Brigham City, Utah. A third material used was a sand-clay mixture. The sand was also from Brigham City, and the clay, a Utah bentonite, from Plymouth, Utah.

In order to prepare the desired soils, a series of leaching chambers was used. These chambers were glazed earthenware crocks approximately 14 inches in diameter and 24 inches deep. They had a small hole in the bottom and were satisfactory for leaching purposes when soil 6 to 8 inches in depth was used with solution filling the remainder of the crock.

About 200 pounds of the Kirkham loam was placed in the chambers and leached with a calcium chloride solution. It was then leached free of excess salts, leaving a soil with a calcium saturated complex. Another fraction of the original soil was leached with water to remove the excess salts and leave an alkali soil.

A similar quantity of the Kilburn gravelly loam was leached in the same manner with sodium chloride followed by water in order to produce an alkali soil.

The clay was divided into 2 equal portions. One portion was leached with sodium chloride solution and the other with calcium chloride solution, each being followed by leaching with water.

The sand was washed with water to remove any soil particles or soluble salts.

The materials were dried and all but the sand were crushed to make mixing more convenient and precise.

The fractions of each respective material, one fraction being alkaline and one being calcium saturated, were mixed to give 5 resulting portions. The portions were different in their levels of alkalinity, the levels being 20, 30, 40, 50 and 60 percent exchangeable sodium. The clay was then mixed with the sand at the rate of 1 part clay to 15 parts sand. At this point a sample of each portion was taken and analyzed for exchangeable-sodium-percentage. Each portion was then equally divided and ferric sulfate was added at the rate of one ton per acre to one resulting portion of each material at each alkali level. The design was a 5 x 3 x 2 x 2 factorial with complete randomization.

The pots were watered and fertilized with ammonium nitrate and treble super phosphate to give 40 pounds per acre nitrogen (N) and of phosphate (P_2O_5). Three pots of each soil portion were planted to tall wheatgrass, using 6 seeds per pot. The initial planting was made April 3, 1956. The emerged plants were counted every 24 hours until a constant number was found in all pots.

On April 10, tall wheatgrass seedlings which had been started March 25 were transplanted into the remaining pots. It was felt that transplanting the seedlings would inhibit their growth about one week, so they were started one week earlier than the seeding in the pots.

Survival records of all pots were kept for 2 weeks and then at regular intervals following until the plants were harvested. The plants were harvested on June 4, and the weights of the green tops, dry tops, dry roots, and total dry yield were found. The analysis of variance tables were completed for all 4 sets of yield data.

Experiment 3. Solution culture study

The pH of alkali soils is usually quite high. This study was conducted to show the effects of high pH on the growth of tall wheatgrass and to find the pH tolerance of the grass. The plants were grown at 5 pH levels in opaque gallon jars with forced aeration. Eight replications were used.

The solution culture used was the full strength recommended by Hoagland and Arnon (1950), and was composed of K_2HPO_4 at one me/l, KNO_3 at 5 me/l, $Ca(NO_3)$ at 10 me/l, $MgSO_4$ at 4 m/l and a mixture of minor elements was added to give 0.5 p.p.m. of boron, 9.5 p.p.m. of manganese, 0.05 p.p.m. of zinc, 0.02 p.p.m. of copper, 0.01 p.p.m. of molybdenum and 0.02 p.p.m. of iron.

The pH levels used were 8.5, 9.0, 9.5, 10.0 and 10.5. The pH was adjusted daily by adding NaOH solution while stirring and checking the readings with a pH meter.

The solutions were replaced by fresh solutions every 7 days.

Tall wheatgrass seeds were planted in sand June 18 and allowed to grow for 10 days and then transferred to the solution culture at the rate of 4 seedlings per pot. The seedlings were allowed to grow for 16 days and were harvested and weighed to find the total yield. The analysis of variance was completed for the data.

Experiment 4. Germination study

Germinating seeds are usually sensitive to adverse conditions such as high pH. In order to determine the highest pH in which the seeds would germinate, several different approaches were followed.

Pure quartz sand was washed to remove all foreign matter and portions of it were mixed with sodium hydroxide solutions until the desired pH of the mixture was reached. The pH levels used were 8.5, 9.0, 9.5, 10.0, 10.5, 11.0, 11.5, and 12.0. The concentration of all solutions used was kept below 0.02 normal so that the osmotic pressure would not be a limiting factor.

After a portion of sand saturated with solution was adjusted to a desired pH, it was placed in pie tins to the depth of approximately one-half inch. A filter paper was placed upon the sand and 50 tall wheatgrass seeds were placed upon the paper. The pan was then put on the shelf and another pan turned up-side-down on top of it so that moisture would not escape. The experiment was conducted at 22° C.

The pH of the saturated sand was checked and adjusted daily, until the seeds had germinated and the roots and tops were 2 to 3 inches in length. The total number of seeds germinating in each pan was recorded and other observations were made.

This experiment was conducted again using a mixture of Na_3PO_4 and Na_2HPO_4 to adjust the pH of the sand-solution mixture. It was assumed that this mixture would give a more constant pH than NaOH because of its buffer capacity.

A similar study was made using petri dishes as containers and blotter paper as a moisture-holding source for the seed. The seed was placed on the blotter paper and the paper was then wetted by a solution of the desired pH. The wetting was done daily. This trial was also conducted twice using the same pH levels and solutions as in the previous trial. It was then partly repeated using petri dishes coated with paraffin wax because it was felt that there may be some reaction of alkaline solutions with the walls of the containers.

All of the previous trials in this germination study were repeated using no seeds in an attempt to determine the effect of germinating seeds in the pH if such effects existed. This was done because it was believed that the germinating seeds may have been the cause of the decrease in pH which was found in all cases.

RESULTS AND DISCUSSION

Experiment 1. Analysis of field samples

The exchangeable-sodium-percentage of the soil samples collected from the root zone of tall wheatgrass plants in the field ranged from 2 to 74 percent. Table 1 shows the number of soil samples in the different exchangeable-sodium-percentage ranges.

Table 1. Number of samples having an exchangeable-sodium-percentage in different range groups

Yield rating*	Exchangeable-sodium-percentage			
	0-20	20-40	40-60	above 60
1	5	4	2	1
2	3	7	1	1
3	4	6	2	0
4	4	6	2	0
5	5	1	3	2

* Yield rating 1 is the highest yield and 5 is no yield.

The data indicate that there is no critical level of exchangeable-sodium-percentage that tall wheatgrass can tolerate. No specific group of samples indicated such a critical level.

The relationship of exchangeable-sodium-percentage to crop yield in the field is shown in figure 1. From this figure it can be concluded that there is little, if any, relationship of exchangeable-sodium-percentage to the yield of tall wheatgrass. However, the level of alkalinity with some other factor not measured in this experiment may

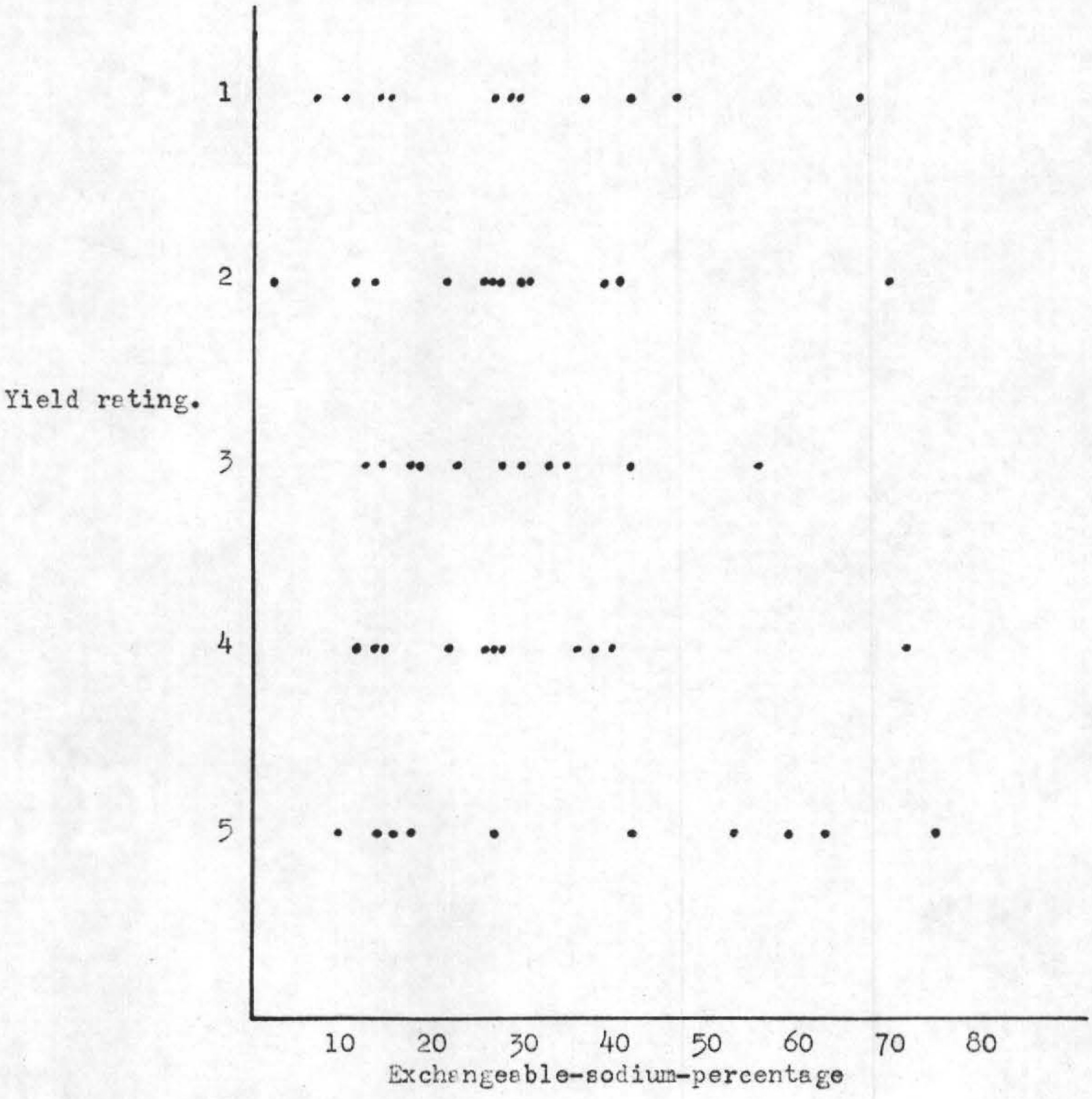

Figure 1. A scatter diagram showing the relationship of the exchangeable-sodium-percentage of soil samples collected from the root zone of tall wheatgrass plants to the yield of the crop in specific areas in the field.

have marked effects on the growth and production of tall wheatgrass.

The pH of a soil sample is often related to the exchangeable-sodium-percentage. A pH reading of 8.5 or greater of a saturated soil paste almost invariably indicates an exchangeable-sodium-percentage of 15 or greater (United States Salinity Laboratory, 1954).

It is believed by many workers that the most important factor inhibiting plant growth on alkali soils is the high pH. In this study no relationship was found between the crop yield and the pH of the soil samples collected from the root zone of the plants (figure 2).

It is true that high pH will cause the dissolving or decomposition of some organic compounds, including parts of plant roots. This study shows that tall wheatgrass has a resistance to high pH.

The electrical conductivities of the saturation extracts of these field samples were all relatively low. There was no relation between the conductivity of the saturated extract of these samples and the yield of tall wheatgrass (figure 3). A reduction in yield caused by high conductivity would not be expected because the highest value recorded was 4.8 mmhos per centimeter, and Forsburg (1953) found that no reduction in growth of tall wheatgrass could be detected at conductivities of 18 mmhos per centimeter.

The highest and lowest values of exchangeable-sodium-percentage, pH and electrical conductivity of the saturation extract are near the same for all yield ratings. These data are given in table 2, and they substantiate the conclusion that there is no relationship between the yield and these 3 factors.

All of the data from this study indicate that there is no direct effect of the 3 measured factors on the yield of tall wheatgrass.

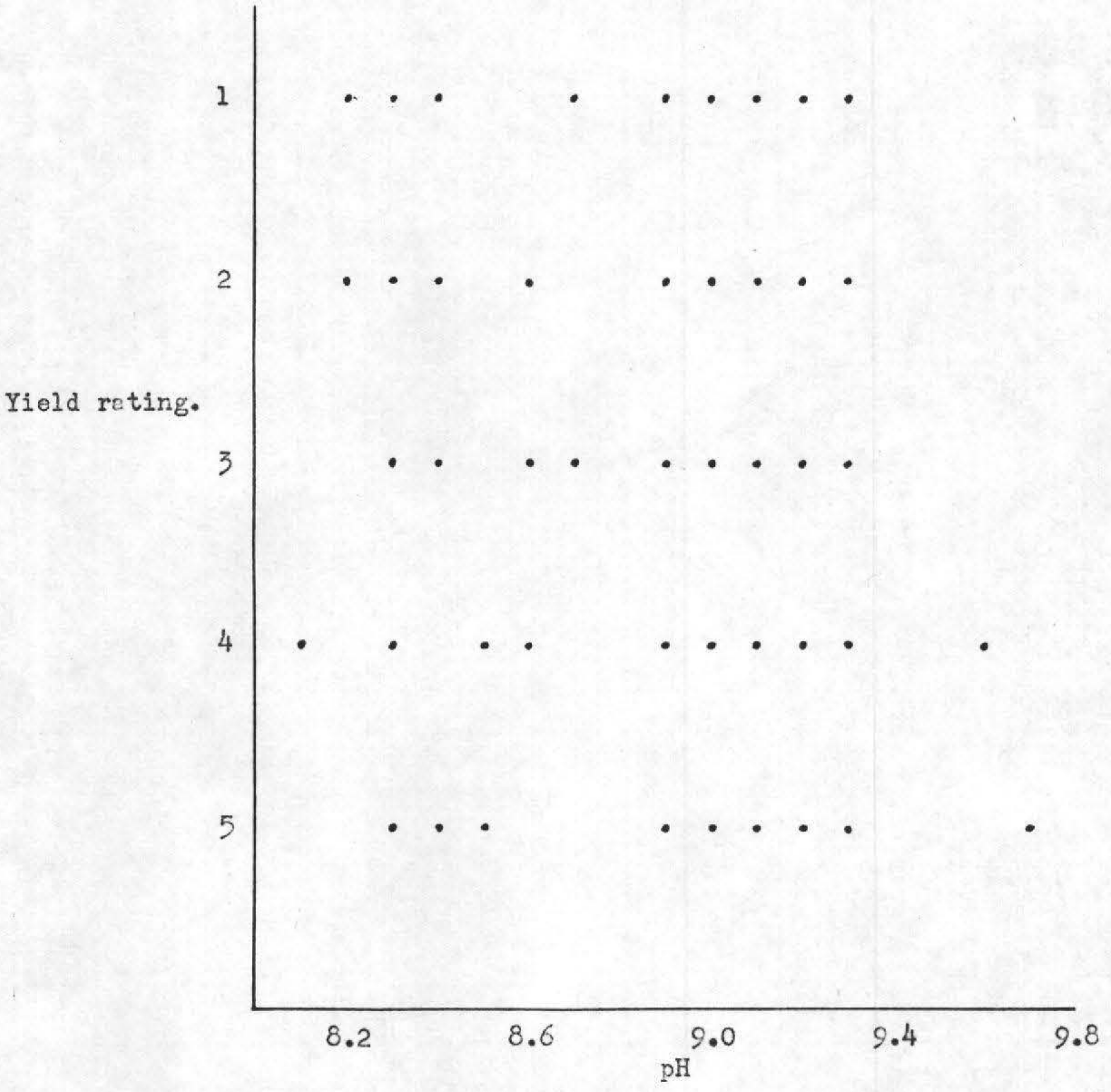

Figure 2. A scatter diagram showing the relationship of the pH of soil samples collected from the root zone of tall wheatgrass plants to the yield of the crop in specific areas of the field.

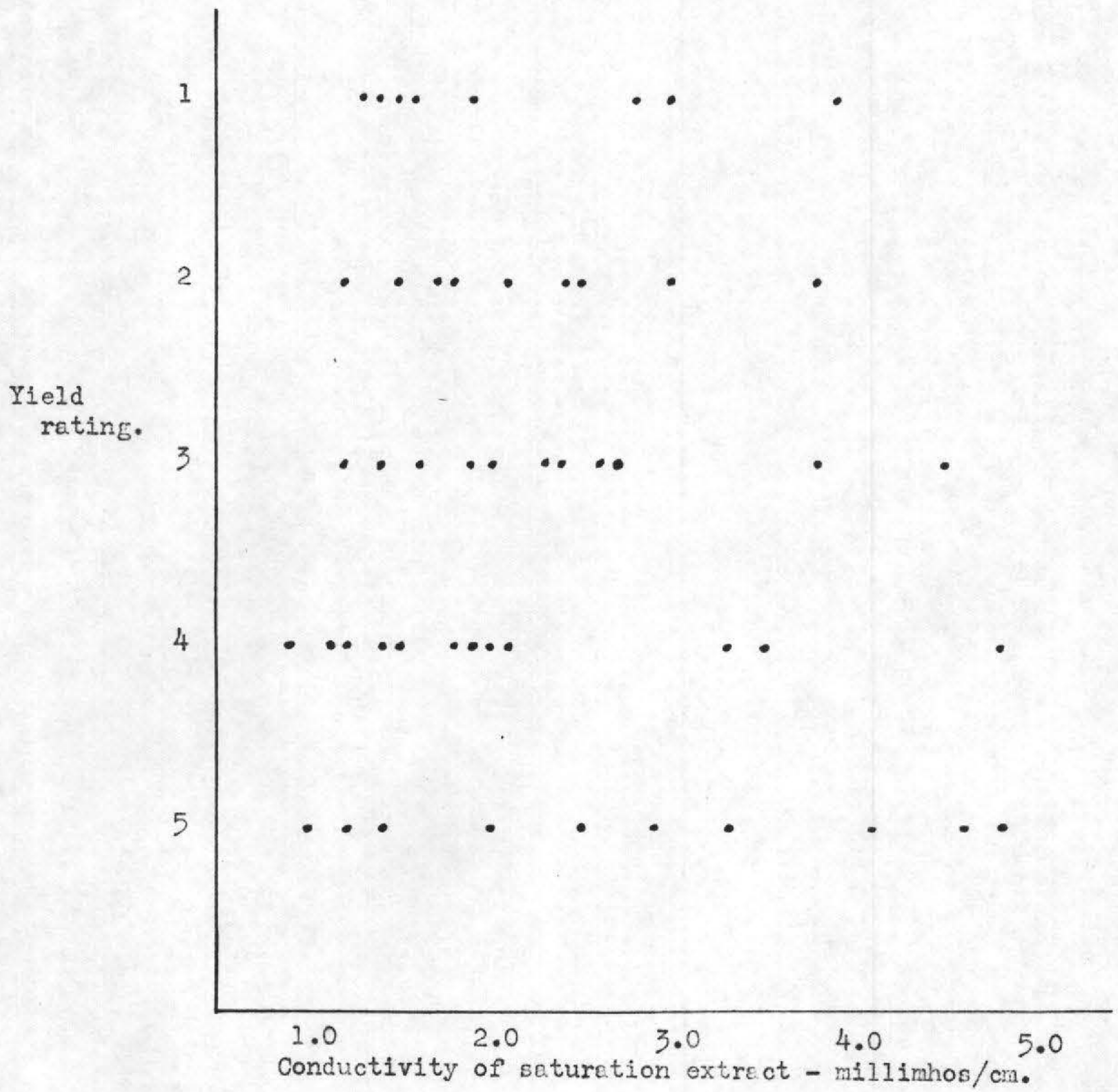

Figure 3. A scatter diagram showing the relationship of the conductivity of the saturation extract of soil samples collected from the root zone of tall wheatgrass plants to the yield of the crop on specific areas in the field.

Table 2. The maximum and minimum values recorded for exchangeable-sodium-percentage (ESP), pH, and electrical conductivity of the saturated extract (EC_s) from analysis made on soil samples from the root zone of tall wheatgrass plants in yield rated areas

Growth rating	Maximum values			Minimum values		
	ESP	pH	EC_s*	ESP	pH	EC_s
1	66	9.3	3.9	7	8.2	1.3
2	69	9.3	3.8	2	8.2	1.2
3	55	9.3	4.5	12	8.3	1.2
4	71	9.6	4.8	13	8.3	0.9
5	74	9.7	4.8	9	8.3	1.0

* EC_s is given in millimhos/cm.

Neither does there appear to be any effect on growth of any combination of these factors.

The fact remains that something inhibited the growth of tall wheatgrass in these field areas studied. A factor such as the method of planting, the degree of compaction, the moisture content, or some other factor that was not measured in this study must have had marked effects on the plant species behavior.

Experiment 2. Green-house pot culture study

The desired levels of exchangeable-sodium-percentage or alkali were accurately produced by the methods used on all 3 soils in this study as shown in table 3.

It would have been desirable to have had higher levels of alkalinity to see if there was a level where tall wheatgrass could not survive.

The results of the daily emergence counts indicated that the emergence of tall wheatgrass was inhibited at high alkali levels in

Table 3. The exchangeable-sodium-percentage (ESP) of samples from each level of alkali desired from each soil

Alkali level desired	Alkali levels produced		
	Sand-clay	Kilburn gravelly loam	Kirkham loam
20	20	19	20
30	31	31	31
40	40	40	40
50	49	49	51
60	60	59	59

some pots. The inhibiting was only at the highest level applied, as shown in table 4. The seed germinated very rapidly in all pots even though there was some inhibition, and practically all seeds germinated.

High levels of alkalinity cause a dispersion of the soil colloids and the soil tends to become very compact. This was very noticeable in the high levels of alkalinity in pots where emergence was inhibited. This compact soil condition would adversely influence the emergence of the coleoptile. In such soils there tends also to be a lack of oxygen which is necessary for the germination of seeds. Since the emergence rate in the sand-clay mixture was not inhibited, it would indicate that these 2 factors would likely be inhibiting the emergence. The sand-clay mixture was mostly sand and therefore maintained good soil properties even though the levels of alkalinity were high.

After the seedlings were established they grew very rapidly with no differences in the growth rate of the tops that could be noticed by observation, except that the leaf blades of plants on the sand-clay mixture were broader and the plants appeared more vigorous.

After the seedlings which were started in sand were transplanted

Table 4. The mean emergence in plants per pot of a tall wheatgrass seeding made on 3 alkali soils at given time intervals

ESP	Sand-clay	Kilburn gravelly loam	Kirkham loam
		April 10, 1956	
20	6.00	5.94	5.98
30	5.96	5.99	5.98
40	5.97	6.00	5.96
50	6.00	5.96	5.96
60	5.95	4.76	3.02
		April 14, 1956	
20	6.00	5.94	6.00
30	5.96	5.99	5.98
40	5.99	6.00	5.95
50	6.00	6.00	5.96
60	5.95	5.92	5.94

to their respective pots, it was found that there was 100 percent survival of all plants in all pots. The growth rate of plants measured by increase in length was approximately 15 cm. per plant per day for the 2 weeks following the transplanting.

The completed analysis of variance for total dry yield, yield of dry roots, yield of green tops, and the yield of dry tops presented significant results which are given in table 5.

There were highly significant differences in the methods of planting tall wheatgrass (table 5). The treatment means for the 2 methods used were 2.92 for transplanting and 1.73 for seeding. The units are grams total yield per pot. The significant differences were common to all parts of the plants analyzed, and hence only the total yield data were presented in table 6.

These significant differences in the methods of planting show that alkali soils have marked effect on the germination stage of tall wheatgrass. These effects are probably true for the reasons mentioned earlier, namely, the lack of oxygen and the compaction of alkali soils.

The study suggests that better yields of tall wheatgrass would be harvested if some soil ammendments would be made to improve soil conditions during the germination stage of the plants. Minor ammendments in small areas surrounding the seeds would probably be sufficient to aid in establishing a stand of the grass.

The addition of ferric sulfate to the soil significantly reduced yield of the tops of tall wheatgrass plants, but had no effect on the total yield or the yield of plant roots. The data for green tops gave means of 1.98 grams per pot where ferric sulfate was added at the rate of one ton per acre and 2.14 grams per pot on pots with no ferric

Table 5. The analysis of variance for yield of tall wheatgrass grown in 3 alkali soils

Source of variation	Degrees of freedom	Mean squares			
		Total dry yield	Dry roots	Green tops	Dry tops
Total	179				
Method of planting	1	6417.75**	4031.85**	1111.04**	258.24**
Ferric sulfate added	1	65.76	0.68	113.60*	27.53**
Method x ferric sulfate	1	57.12	28.40	6.05	2.84
Exchangeable-sodium-percentage (ESP)	4	184.85**	186.82**	34.20	1.88
ESP x method	4	21.73	17.65	24.93	2.53
ESP x ferric sulfate	4	109.82*	98.41*	30.44	2.80
ESP x method x ferric sulfate	4	13.23	9.16	11.44	0.40
Soil	2	3939.47**	3334.32**	546.78**	32.75**
Soil x method	2	13.00	10.64	48.45	9.11**
Soil x ferric sulfate	2	15.68	13.02	95.24*	5.48*
Soil x method x ferric sulfate	2	15.68	65.17	11.85	5.22*
Soil x ESP	8	87.35*	54.57	39.33	6.33**
Soil x ESP x method	8	73.94	60.35	46.59	1.45
Soil x ESP x ferric sulfate	8	128.13**	108.37*	47.92	4.17**
Error	128	36.63	32.44	27.22	1.40

* Significant at 5 percent level of F.

** Significant at 1 percent level of F.

Table 6. The total dry yield* of tall wheatgrass grown at 5 alkali levels on 3 soils

Alkali level	Soil					
	Sand-clay		Kirkham loam		Kilburn gravelly loam	
ESP	Fe**	none	Fe	none	Fe	none
			Seeding			
20	3.19	2.39	1.40	1.01	1.73	1.63
30	2.97	2.95	1.03	0.88	1.90	2.00
40	1.82	3.15	1.53	2.19	1.00	1.01
50	1.15	2.18	0.70	1.04	1.18	1.18
60	2.54	2.13	1.12	0.77	0.97	1.15
			Transplanting			
20	4.47	4.03	2.22	2.30	3.71	3.56
30	2.71	4.59	2.11	2.62	3.60	2.66
40	3.31	5.03	2.14	2.29	1.97	1.99
50	3.79	2.97	2.11	2.81	2.07	2.15
60	4.41	2.83	2.24	2.38	1.85	2.43
Mean	3.25		1.71		2.02	

* The average yield in grams per pot

** Fe designates the application of ferric sulfate at the rate of one ton per acre.

L.S.D. = 1.18 grams per pot at 1 percent level.

sulfate treatment. The means for dry tops were 0.70 and 0.77 grams per pot for the addition of ferric sulfate and no ferric sulfate treatment, respectively.

This treatment reduced top growth in some way, but the manner in which the yield of plant tops were inhibited is not known.

The effects of the exchangeable-sodium-percentage levels of soil on the yield of tall wheatgrass is rather complex. As can be seen from the analysis of variances, there were significant differences in total dry yield and the yield of dry roots of tall wheatgrass at different alkali levels. This is not true with the tops of the plants, however.

Figure 4 shows the relationship of alkali levels of all soils to the total dry yield of tall wheatgrass in this study. A similar curve could be plotted using the data for yield of dry roots. There was nearly a linear relationship between yield and alkali levels.

Very little is known about the top-root ratio of tall wheatgrass. There was nothing found in the literature on this subject. This makes the interpretation of this study difficult because there is very little evidence to show that the relationship in figure 4 will continue to be true after the plants get older and more fully established. Beetle (1955) pointed out that tall wheatgrass is very slow in establishing. It does not produce at a maximum rate until usually its seventh year. Many changes could take place in this period. Since there was 100 percent survival of all plants until the harvest period, one may conclude that the effects of alkali on tall wheatgrass are to retard the rate of establishment. This effect shows up in the roots only. It is evident that there is a need for information on root systems and root yields of tall wheatgrass already established on alkali soils in the field.

Perhaps the root-top ratio of tall wheatgrass is decreased as the

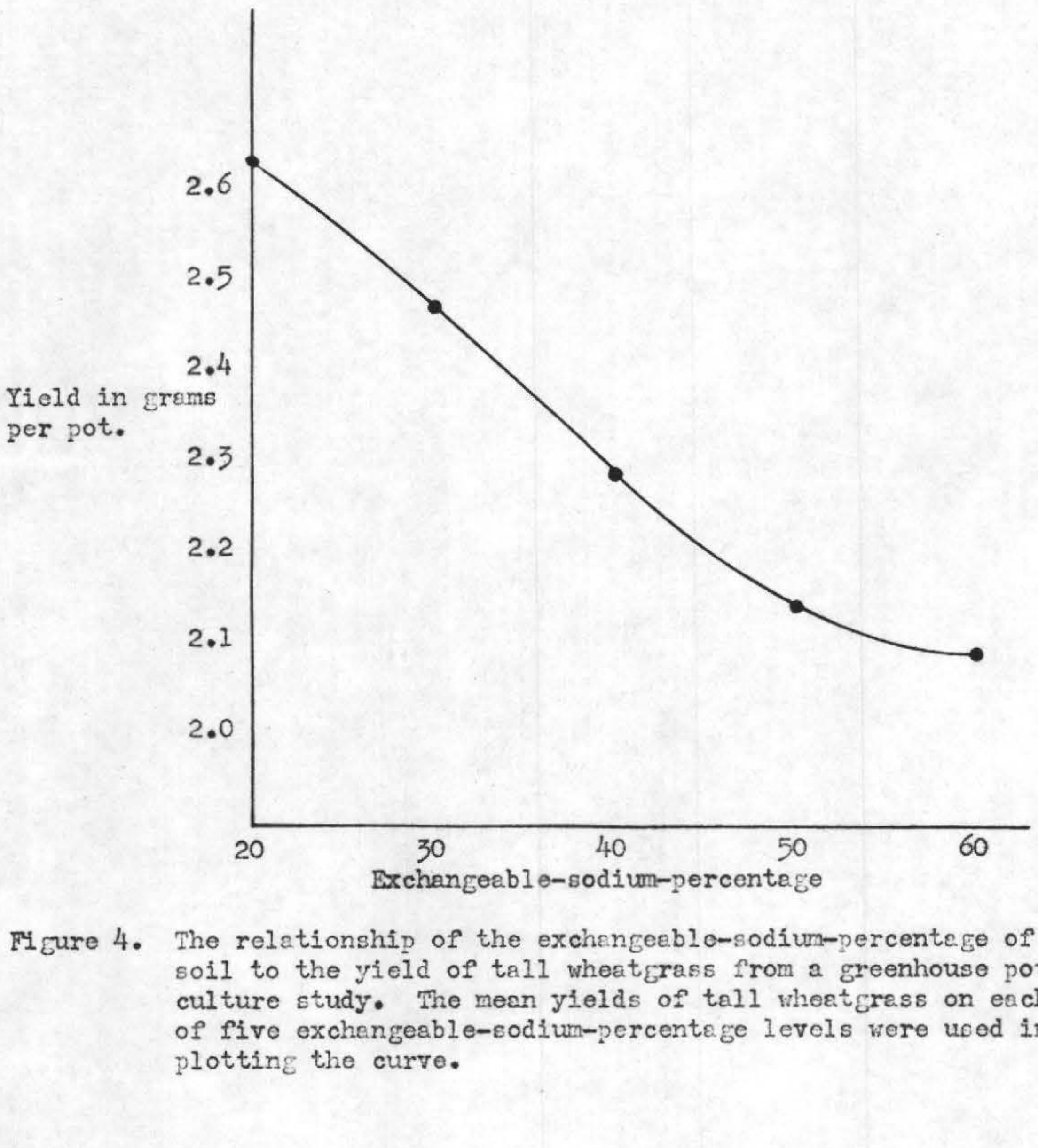

Figure 4. The relationship of the exchangeable-sodium-percentage of soil to the yield of tall wheatgrass from a greenhouse pot culture study. The mean yields of tall wheatgrass on each of five exchangeable-sodium-percentage levels were used in plotting the curve.

level of alkalinity in the soil where it is grown increases. On the other hand there may be increased root growth as the plants age on alkali soils.

The effects of the exchangeable-sodium-percentage and ferric sulfate interactions were significantly different in all cases except for tops. This means that the combined effect of the 2 factors are different at the different levels of alkali. There was no definite trend for these interactions.

There was a highly significant difference between mean yields from the 3 soils, as shown in table 6. These yield differences were likely a result of the different physical conditions of the soils. The Kirkham loam produced the lowest yield and it had the poorest physical conditions for plant growth. The soil had small soil particles and after leaching for preparation it was in a dispersed state. This soil was more compact than either of the other two. Therefore, there was less aeration in the soil, which would inhibit plant growth.

The sand-clay mixture maintained good physical conditions and gave much higher yields than the other 2 soils. The Kilburn gravelly loam maintained better structural properties than the Kirkham loam, but its physical condition was not nearly as good as the sand-clay mixture. This soil produced a moderate yield of tall wheatgrass.

The soil by method of planting interaction was significant for the data from the yield of dry tops of tall wheatgrass. Transplanting produced 0.33 grams per pot of dry tops more than seeding on the Kirkham loam. The increase was 0.20 grams per pot on the Kilburn gravelly loam and 0.19 grams per pot on the sand-clay mixture. The Kirkham loam appeared to have stronger inhibiting effects on the germination and early growth which is probably due to the very poor physical conditions of that soil.

The soil by ferric sulfate interaction was significant for the yield of tops. On pots of Kilburn gravelly loam there was a decrease in yield of green tops of 0.44 grams per pot where ferric sulfate was added. The decrease in yield on the sand-clay was only 0.08 grams per pot and there was an increase on the Kirkham loam of 0.05 grams per pot on pots where ferric sulfate was applied.

It is not understood why there was a decrease in yield of tops when ferric sulfate was added. However, since the Kirkham loam had the poorest physical conditions, the slight increase in yield on that soil may be explained by the ability of ferric sulfate to cause colloids to become flocculated. The slight increase, even though it was not significant, likely was caused by an improvement of the physical conditions of the soil.

The 3 factor interaction concerning the soil, the method of planting and the ferric sulfate is significant for the data from the yield of dry tops. The data show no trend however and are not meaningful.

The soil by alkali interaction also was significant for the data from total dry yield and from the yield of dry tops. Again there was no trend or pattern of the data (table 7).

The soil by alkali level by ferric sulfate interaction was significant except for the data from the yield of green tops. These data showed no apparent trend even though other factors such as significant differences in the soils, in the ferric sulfate applied, and the alkali level of the soil indicated that the interaction would be meaningful.

This study showed that the alkali tolerance of tall wheatgrass was affected by many factors. In this case the method of planting and the soil used were very critical in their effects.

Table 7. The yield in grams per pot of dry tops at 5 levels of alkali on 3 soils used in a green-house pot culture study

ESP	Kilburn gravelly loam	Kirkham loam	Sand-clay
20	0.81	0.64	0.77
30	0.82	0.59	0.80
40	0.61	0.69	0.83
50	0.71	0.71	0.84
60	0.67	0.72	0.83

Experiment 3. Solution culture study

The growth rate of tall wheatgrass in solution culture media decreased as the pH of the solution increased above pH 9.0. Table 8 gives the analysis of variance of the data, and table 9 presents the means and gives the significant differences.

There seems to be an optimum alkaline pH for the growth and yield of tall wheatgrass which was very near pH 9.0. The highest yield was harvested at this pH. This apparent optimum may not be too meaningful because there may be an optimum at some acid pH. There was a relationship of the pH of solution in the culture pots and the yield of the crop, as shown in figure 5. This would also likely be true of the pH of the soil or soil solution.

The pH of the soil is associated with the exchangeable-sodium-percentage of the soil at the higher pH levels or above pH 8.5. Therefore, if pH values above 9.0 are caused by the alkalinity of the soil, there will be a reduction of yield directly from the high alkalinity.

This study indicated that one of the most important factors affecting plant growth on alkali soils was the high pH associated with

Table 8. The analysis of variance of the data collected from the yield of tall wheatgrass grown in solution culture media of different pH levels

Source of variation	Degrees of freedom	Mean squares
Total	39	——
pH levels	4	0.05105**
Error	35	0.00444

** Significant at 1 percent level of F.

Table 9. The mean yield in grams per pot of plants grown at different pH levels in solution culture media. The means are ranked in order of increasing yield and any 2 means not underlined by the same line are significantly different. The least significant range (LSR) is given at the end of each line.

pH	10.5	10.0	9.5	8.5	9.0
Mean yield	2.17	2.58	2.71	3.42	3.71
					0.0987*
				0.0971	
			0.0945		
		0.0905			

* The highest mean must be 0.0987 units greater than any mean to be significantly different at 1 percent level. The second greater mean must be 0.0971 units greater than any mean to be significantly greater, and so on.

the high alkalinity. As indicated earlier there may be a starvation for plant nutrients at the higher pH levels of the soil or solution. These results would tend to substantiate this belief.

Figure 6 shows the relative yield of plant tops and roots at each pH level in the solution culture.

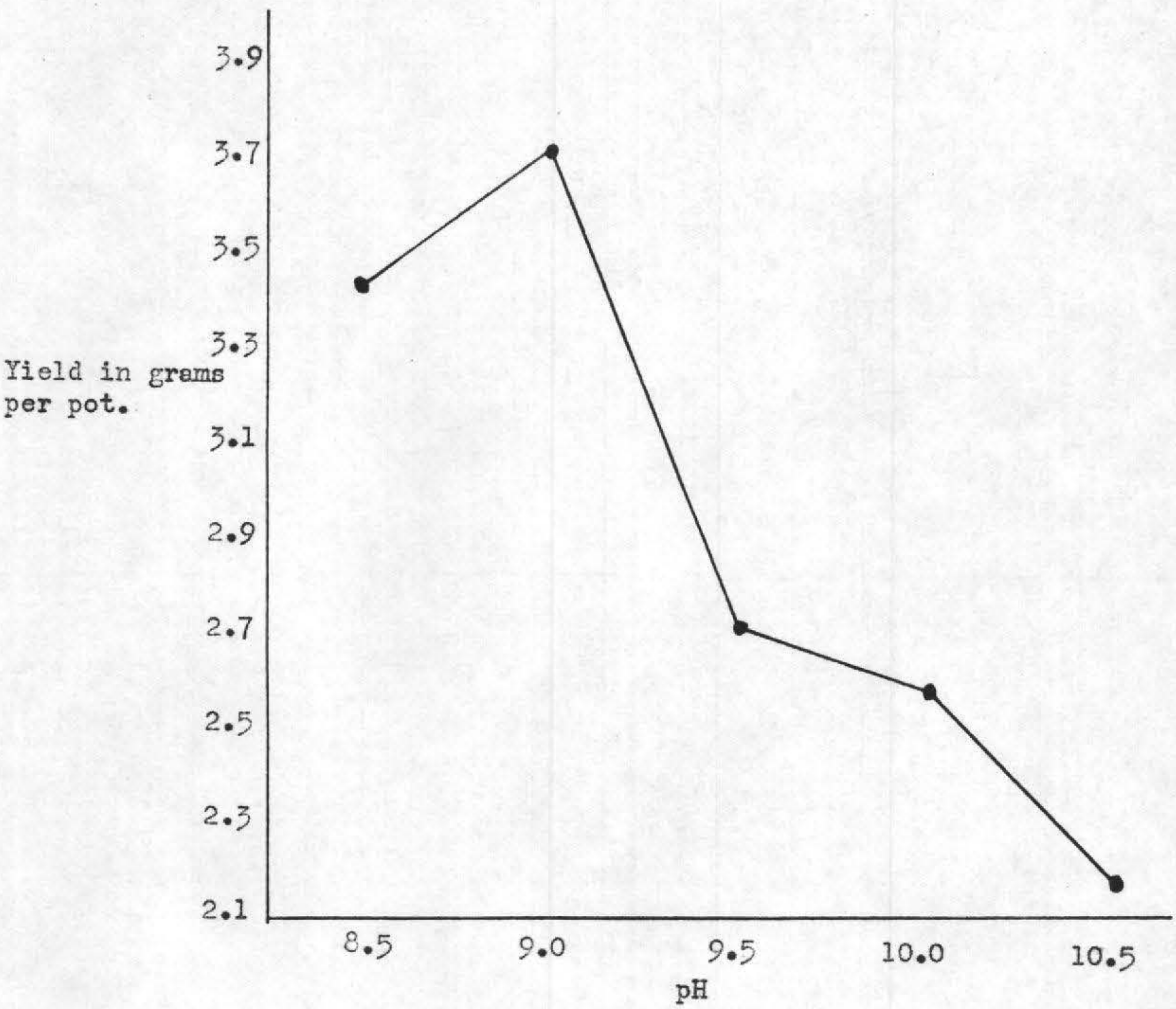

Figure 5. The relationship of the mean yields of tall wheatgrass grown in solution culture media to the pH of the solution used. The mean yield of each pH level was used in plotting.

Figure 6. Plants grown at different pH levels in solution culture. From left to right the levels are 8.5, 9.0, 9.5, 10.0, and 10.5.

Experiment 4. Germination study

Several procedures were followed in an attempt to determine the effect of different levels of pH on the germination of tall wheatgrass seeds. Sand and blotter paper were both used to hold moisture, and NaOH and Na_3PO_4-Na_2HPO_4 buffer were used to maintain the pH of the moisture media.

It was found that there was a daily reduction of pH of the media used. This was presumed to be partly caused by the germinating seeds until it was found that the same reduction occurred when no seeds were used. It was then decided that there was a possibility that the solutions were reacting with the container walls. This was again proved false when the same reduction was found after the walls of petri dishes being used were coated with paraffin wax. It may be concluded that some other factor caused the reduction in pH. Perhaps CO_2 of the atmosphere was responsible.

The data are presented in tables 10 and 11 to show the reduction of pH every 24 hours. Data from only one 24-hour measurement are reported, but all other measurements were very nearly the same.

The pH of each medium was adjusted to the original desired value each day following the pH measurement until the seeds had germinated and had been counted.

It is true that the pH levels were not held constant as had been originally planned. However, high pH levels were used in order to maintain a minimum pH of 10.5 in some media.

Whenever the minimum pH was below 10.0, there was excellent germination and no differences could be detected in the way that the seeds germinated. At pH 10.0 to 10.5 all seeds germinated but there were

Table 10. The reduction in pH in 24 hours of the media used for germinating tall wheatgrass seeds. NaOH and Na_3PO_4-Na_2HPO_4 buffer were both used for adjusting pH.

Starting	NaOH		Na_3PO_4-Na_2HPO_4 buffer	
	Sand	petri-dishes	sand	petri-dishes
8.5	7.8	7.6	7.8	7.7
9.0	8.4	8.1	8.2	8.5
9.5	8.7	8.6	8.8	8.6
10.0	9.1	8.9	9.0	9.2
10.5	9.6	9.3	9.5	9.5
11.0	9.9	9.8	9.9	9.9
11.5	10.2	10.3	10.1	10.3
12.0	10.5	10.6	10.6	10.4

Table 11. The reduction in pH of the media without seeds in 24 hours. NaOH and Na_3PO_4-Na_2HPO_4 buffer were both used for adjusting pH.

Starting	NaOH		Na_3PO_4-Na_2HPO_4 buffer	
	Sand	Petri-dishes	Sand	Petri-dishes
8.5	7.9	7.5	7.8	7.8
9.0	8.2	8.0	7.9	7.9
9.5	8.8	8.6	8.7	8.7
10.0	8.9	9.2	9.0	9.0
10.5	9.4	9.5	9.5	9.5
11.0	9.8	9.9	9.8	9.9
11.5	10.0	10.3	10.2	10.2
12.0	10.7	10.6	10.4	10.5

differences in the way that germination took place.

At minimum pH of 10.5 there was no root growth and top growth was limited. It must be remembered that where the minimum pH was 10.5 there was a maximum pH of 12.0, and where the minimum pH was 10.0 the maximum pH was 11.5. Therefore the critical value of pH which affects germination must lie between the maximum and minimum values.

Where the minimum pH was 10.0, the top growth was normal but the root growth was not. The seeds would send out one small root which would grow to a length of about one-half inch and then it would die. Another root would then grow and die following the same pattern. This would continue several times. This indicates that at this pH level the seeds could not germinate living plants because the roots would not live.

Figures 7 and 8 show the relative germination of seeds at 3 pH levels and the germinating seeds at the 2 highest pH levels where the maximum pH was 12.0 and 11.5 and the minimum pH was 10.5 and 10.0, respectively.

There were no noticeable effects on germination of tall wheatgrass seeds where the maximum pH was 11.0 and the minimum pH was 9.6. It is difficult to set the actual critical value from this type of study, but there is at least a critical range of pH that affects the germination of the seeds.

It would be desirable to find a method to maintain constant pH levels to set the critical levels. This study was not successful in such an attempt.

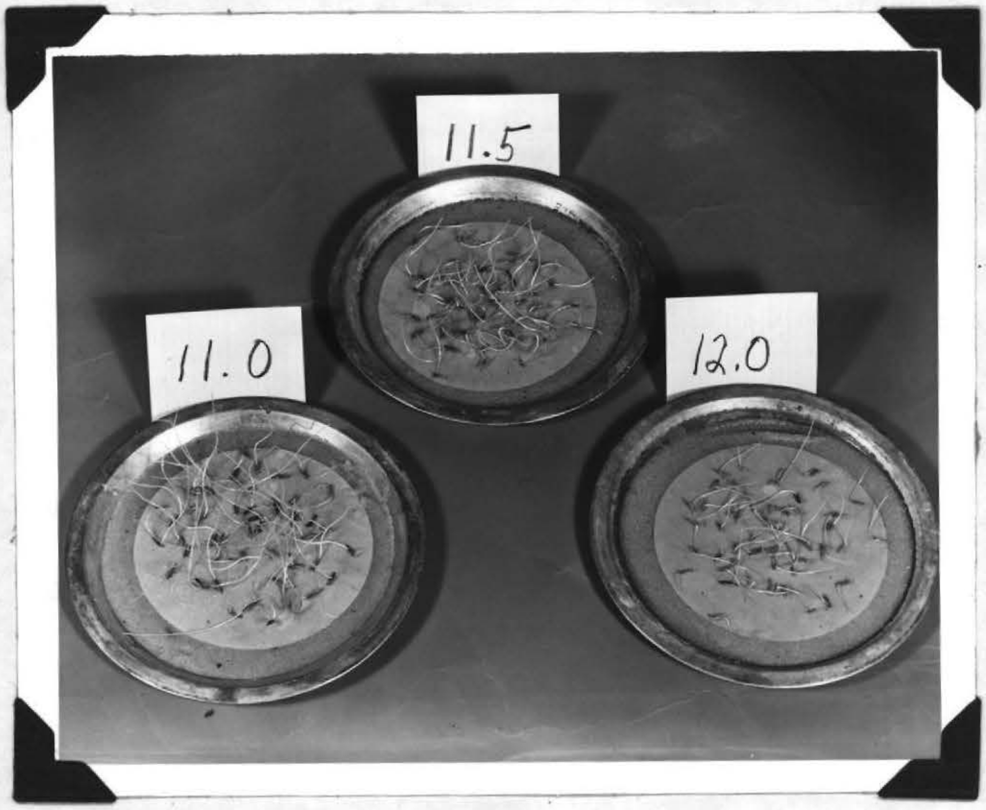

Figure 7. The relative germination at 3 pH levels of the germinating media. The maximum pH is given on the photograph. pH 11.0 represents a range of pH from 9.6 to 11.0, pH 11.5 represents a range of pH from 10.0 to 11.5, and pH 12.0 a range of 10.5 to 12.0.

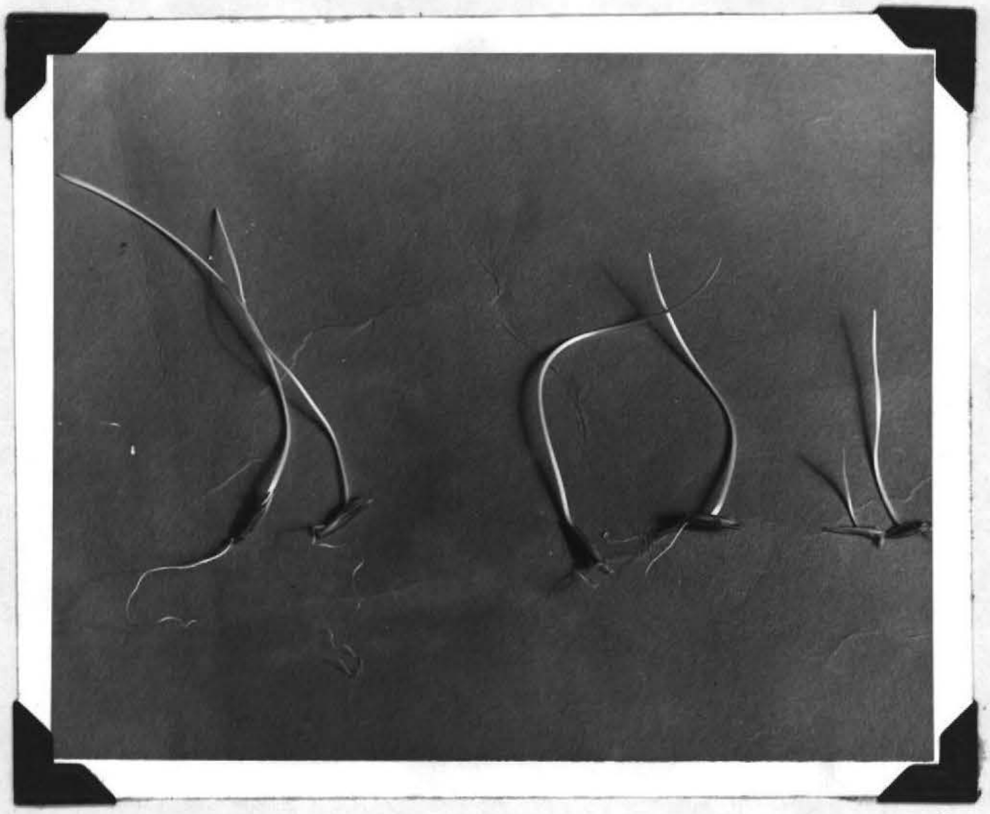

Figure 8. The effects of high pH on the germination of tall wheatgrass. From left to right are seedlings from pan of pH range 8.5 to 10.0, range 10.0 to 11.5, and range 10.5 to 12.0. The lower range shows normal growth.

SUMMARY AND CONCLUSIONS

1. The purpose of this study was to determine the alkali tolerance of tall wheatgrass (Agropyron elongatum). It was also an attempt to determine the effects of properties of the soil and solution arising from high alkalinity on the germination and growth of tall wheatgrass.

2. The analysis of field samples collected from the root zone of tall wheatgrass plants growing on alkali soil indicated that there was no relation of the yield of tall wheatgrass to the level of alkalinity in the soil. It was further demonstrated that there was no relation of the pH of the soil to the yield.

3. In green-house pot culture study there was nearly a linear decrease in yield of tall wheatgrass with an increase in the exchangeable-sodium-percentage of the soil. There were great differences in the yield of tall wheatgrass on different soils of high alkalinity. The highest yield was harvested from soils which maintained better physical properties at the higher levels of alkalinity. This suggests that poor physical conditions caused by alkali soils is a factor in the alkali tolerance of a plant species.

4. Seedlings transplanted to alkali soils grew better than plants seeded directly. This indicates that tall wheatgrass is most sensitive to high alkalinity in the germination stage of growth. Minor ammendments to alkali soils to improve its physical properties during the germination stage of tall wheatgrass would likely increase the growth rate and yield of the plant. Such minor ammendments could be made only

in small areas surrounding the seeding area of the soil.

5. The pH of solution used for solution culture studies affected the yield of tall wheatgrass. Highest yields were harvested at pH 9.0. As the pH of the nutrient solution increased from pH 9.0 to 10.5, there was a marked reduction in the yield of the crop. Nutrient solution of pH 8.5 also yielded significantly less than solution of pH 9.0, but was significantly higher in yield than the pH levels above 9.0.

6. The germination of tall wheatgrass seeds was not affected by pH until a range of pH 10.0 to 11.5 was used. This shows a quality of tall wheatgrass that is favorable for its establishment on alkali soils.

7. The alkali tolerance of tall wheatgrass was found to be relatively high, but a critical level of alkalinity at which tall wheatgrass cannot survive was not determined. How complete the plant is established is very important with respect to its alkali tolerance.

8. Future alkali studies of this type should include the analysis of the plant materials to determine more closely the disturbance in plant metabolism from the effects of high alkalinity. More information is also needed about the root growth, root yield, and root-top ratio of tall wheatgrass.

LITERATURE CITED

Beetle, A. A. 1955. Wheatgrasses of Wyoming. Wyoming Agr. Exp. Sta. Bul. 336.

Bower, C. A., and Wadleigh, C. H. 1948. Growth and cationic accumulation by four species of plants as influenced by various levels of exchangeable sodium. Soil Sci. Soc. Am. Proc. 13:218-223.

Breazeale, J. F., and McGeorge, W. T. 1932. Nutritional disorders in alkaline soils as caused by deficiency of carbon dioxide. Ariz. Agr. Exp. Sta. Tech. Bul. 41.

Campbell, R. E. 1955. Reclamation of heavy textured saline-alkali soil on the Huntly Irrigation Project, Montana. Mont. Agr. Exp. Sta. Annual Progress Report.

Forsburg, D. E. 1953. The response of various forage crops to saline soils. Can. Journ. Agr. Sci. 33:542-549.

Hafenrichter, A. L., Mullen, Lowell A., and Brown, Robert L. 1949. Grasses and legumes for soil conservation in the Pacific Northwest. U. S. Dept. Agr. Misc. Pub. 678.

Hoagland, D. R., and Arnon, D. I. 1950. The water culture method for growing plants without soil. Calif. Agr. Exp. Sta. Cir. 347.

Isrealson, Orson W. 1950. Irrigation principles and practices. New York: John Wiley and Sons, Inc.

Ratner, E. I. 1935. The influence of exchangeable sodium in the soil on its properties as a medium for plant growth. Soil Sci. 40: 459-468.

Robertson, Jos. H., and Jensen, Edwin H. 1953. Forage grasses for hay and pasture. Nev. Agr. Exp. Sta. Mimeo. Cir. 4.

Thorne, D. W. 1944. Growth and nutrition of tomato plants as influenced by exchangeable sodium, calcium and potassium. Soil Sci. Soc. Am. Proc. 9:185-189.

Thorne, D. W., and Bennett, W. H. 1952. Soil management for grasslands on irrigated salted soils. Proceedings of the Sixth International Grassland Congress 1:815-812.

Thorne, D. W., and Peterson, H. B. 1954. Irrigated soils, their fertility and management. New York, Toronto: The Blakiston Co., Inc.

United States Salinity Laboratory. 1954. Diagnosis and improvement of saline and alkali soils. U. S. Dept. Agr. Handbook 60.

Weintraub, Francis C. 1953. Grasses introduced into the United States. U. S. Dept. Agr. Handbook 58.