THE INFLUENCE OF THE QUALITY OF IRRIGATION WATER ON SOIL PROPERTIES AND PLANT GROWTH UNDER GREENHOUSE CONDITIONS

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Bachelor of Science

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Stillwater, Oklahoma

1955

Submitted to the faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1957

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ACKNOWLEDGMENT

The writer feels indebted and wishes to express his gratitude to the following persons: Dr. Robert M. Reed, thesis adviser, for his constant supervision, advice, helpful criticisms and encouragement; Drs. Lester W. Reed and Charles Sarthou for their help, suggestions and information concerning this study; Mr. H. M. Galloway for furnishing the description of the soils used; and Dr. F. A. Graybill for advice on the statistical analyses of the data. For the financial assistance which made this work possible, the author offers his special thanks to the Agronomy Department.

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I. INTRODUCTION

The importance of irrigation in Oklahoma is reflected by the increased acreage within the state. In 1920 not a single farm was reported under irrigation, while in 1950 there were 466 farms with a total area of 34,071 acres. By 1955, the number of farms climbed to a total of 3,174 which accounted for 209,991 irrigated acres (56)[1].

Much research work has been done on the quality of irrigation water. The result of these studies show that poor quality of both surface and ground waters is a limiting factor for irrigation in many areas in this state, as well as in the other states in this country and abroad. The concentration and chemical composition of dissolved constituents in a water determine its quality for irrigation use. The salts most often encountered in Oklahoma are the chlorides, sulfates, and bicarbonates of sodium, calcium and magnesium. (59)

Three available sources of irrigation water are the ground water, streams, and ponds. Ground water is the most important source, then streams and lastly ponds. There are many areas where ground water is available, but the quality is questionable or unsatisfactory. Similarly, surface waters are often of poor quality because of their origin. There is a current tendency in many regions to divert all of the available water for irrigation. Thus, over a period of years the down stream

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[1]Figures in parenthesis refer to literature cited.

diversion may change from an uncontaminated river water to one with a substantial proportion of drainage return flow of poor quality water. In general, waters with a relatively large amount of dissolved solids or high conductivities are unsuitable for irrigation purposes. When an irrigation water of high salt content is used on soils of low infiltration and slow drainage rates, the soils should be flushed with liberal quantities of water in order to keep the salt content of the soil at or below a critical level.

There were two objectives in this study: first, to try to determine the effect of irrigation water of different chemical compositions and concentrations of dissolved constituents on the physical and chemical properties of three different textured soils; and secondly, to ascertain the influence of these salt-treated soils on the yields and chemical composition of sorghum forage. The data presented in this thesis were obtained from a greenhouse experiment.

II. REVIEW OF LITERATURE

Chemical Composition of Irrigation Waters

Irrigation waters are never pure, all contain some dissolved salts. The amount of salt may vary from a trace to a concentration so great that the water is unfit for agricultural use. The kinds of salts present in irrigation water are fully as important as the total amount. Boron, in the form of borates, in extremely small percentages may influence or kill crop plants. If the sodium content of irrigation water is high, it causes a reduction in soil productivity. On the other hand, the water may contain small amounts of ions which are essential plant food nutrients and will help in the maintenance of soil fertility.

The dominant salts (48), (53), (54) which occur in irrigation water do not exceed six to seven. In each of the ordinary simple salts there are two components or ions; one is the cation and the other is the anion. The predominant cations found in waters are calcium, sodium, potassium, and magnesium. The four principal anions are carbonates, bicarbonates, sulfates, and chlorides. In certain waters, nitrate ions occur in amounts similar to the other anions previously named and borates may also be present. Anions may be found in concentrations which are toxic to certain plants.

Hilgard (28) regarded as "White Alkali" those salts which left a white encrustation on the soil after the evaporation of the water. These were sodium chloride, sodium sulfate, sodium nitrate, magnesium sulfate, magnesium chloride, calcium sulfate, and calcium chloride. "Black Alkali" soils were characterized by salts which left a black coating. These were chiefly sodium carbonate and bicarbonate.

Important cations in irrigation water

Calcium is vital for plant growth and is desirable in irrigation water in limited quantities. The concentration of calcium plus magnesium should exceed that of sodium.

Magnesium resembles calcium in general characteristics.

Potassium is an essential element for plant growth and consequently the small amount usually found in irrigation water helps to maintain soil fertility.

Sodium is not essential for plant growth and large amounts can be injurious. When the content of sodium ions in the water exceeds that of calcium and magnesium, the sodium tends to be adsorbed by the soil colloids. Soils high in adsorbed sodium tend to run together when wet, develop large cracks when dry, and form hard clods. Such soils are slowly permeable and are difficult to wet when irrigated.

Important anions in irrigation water

Carbonates are not found in large amounts in water containing liberal quantities of calcium and/or magnesium because of the relatively low solubility of these carbonates. The presence of much carbonate in water usually indicates a high sodium percentage and an alkali-forming water.

Bicarbonates are common ingredients of irrigation water and in small amounts are not injurious to plants. If this anion is present in large quantities, there may be a precipitation of calcium and magnesium in water which will eventually be undesirable.

Sulfates have no direct harmful effect on soils. In large amounts they contribute to a high concentration of salts and subsequent injury. They furnish plants with the essential nutrient, sulfur.

Chlorides are found in most irrigation waters. In high concentrations, they are toxic to plants. However, most of the damage usually results from an increase in the total amount of total dissolved solids.

Nitrates occur in small quantities in most surface waters. Normal irrigation for one season with water containing 1 ppm of nitrates would add about as much nitrogen as one-half ton of barnyard manure.

Boron is found in irrigation water as borate ions which are injurious to plants even at very low concentrations. Less than 0.3 ppm of boron in irrigation water may be beneficial in keeping soil fertile, because it is required by growing plants. In larger quantities, boron may cause a direct injury.

Sources of the salts in irrigation waters

1. End products are liberated during the break down of rocks and minerals involved in soil formation.
2. Saline water deposits of the geologic past also are decomposed and produce salts.
3. In localized areas; carbon dioxide, chlorine, and boron in gaseous form usually mix with water vapor deep within the earth's crust. These liquids reach the surface through fissures and then combine with rain water to form mineral springs which are often hot.

Effect of sodium on the physical properties of soils

Sodium often comprises a considerable fraction of the total exchangeable cations in many of the soils of the arid region. In alkali soils, exchangeable sodium predominates on the surfaces of the soil colloids. The effects of this cation upon the physical properties of the soils are generally recognized and are caused by the swelling and dispersion of the colloids.

Garner (20) in his study of some of the soil properties related to the sodium problem in irrigated soils, found that the settling volume of the soils suspended in a 0.1 normal solution containing a mixture of calcium and sodium chlorides increased slightly as the sodium percentages ascended, but the expansion was not significant for sodium percentages below 70 per cent. When the concentration of the solution was decreased to approximately 0.02 normal or less, the soils tended to disperse after equilibrium had been reached. Then, the dispersed soil flocculated and settled out of suspension again. After dilution, the settling volume of the treated soils increased slightly as the sodium percentages of the solutions increased. Treatments of higher sodium percentages tended to disperse the soil. The quantity of dispersed soil and the concentration of the solution at which dispersion occurred varied with the sodium percentages of a given solution. After treatment with a high percentage of sodium salts, the soils deflocculated and formed massive aggregates of low bulk density which stabilized slowly to form large settling volumes of gelatinous consistency. He believed that the presence of such material in the field would tend to close all the macro pores and restrict water movement. It is likely however, that under most field conditions there would be a sufficient amount of electrolyte present to flocculate the soil, and that the undesirable physical properties of the soils were due to the properties of the flocculant rather than the dispersed condition. The poor physical state of saline soils is caused by the association of high sodium percentages with the flocs of the exchange complex of the clay.

According to Jones, as reported by Eitel (14) the colloidal swelling phenomena were largely determined by the dilution properties of the liquid solvent. The hydration of the cations was important for the equilibrium pH value in the clay suspension, for the calorimetric heat effect of wetting, for permeability, and the drying rate. The dry strength of monovalent base saturated clays was closely related to poor structure and the cation exchange capacity. Large weakly ionized or highly hydrated cations produced a stable, dense, poor structure. This structure caused a high dry strength and low permeability. On the other hand strongly ionized ions, especially hydrogen, had the reverse effects.

From his research on the effect of sodium on Putnam clay, Reeves (42) concluded that sodium influenced the swelling and hygroscopicity of that clay. The premeability ratios increased exponentially with larger amounts of exchangeable sodium. These ratios were directly related to the magnitude of cation exchange capacity or the total surface area.

The influence of exchangeable sodium on the physical properties of the chernozem soils was determined by Retner (43). Soils rich in O.M. like the Chernozems were more affected by the amount of exchanageable sodium than soils low in O.M. such as the Chestnuts. The application of sodium nitrate, which contributed a comparatively small amount of sodium to the adsorptive complex of the soil, produced a considerable retardation in the rates of capillary movement of the water and a decrease in the filterability of the chernozem soil. The replacement of sodium with calcium in the B horizon, which usually contains comparatively small amounts of exchangeable sodium, resulted in an increase in the filtration capacity of the soil and the rate of capillary rise of water. When from 50 to 70 per cent of the total exchangeable bases were replaced with sodium, plants did not develope and grow. This effect on plants was inversely related to the percentages of organic matter in the soil. Retner tried to grow oats and wheat in pots which contained soils that were saturated with 70 per cent of exchangeable sodium, 15 per cent of exchangeable calcium and the remaining 15 per cent with any other base. The plants died after germination. He believed the death of the plants might be attributed to the immobilization of micro nutrients in the soil or to a lack of available calcium which nourishes the plants and acts as a regulator for a whole series of processes connected with plant nutrition.

Cation equilibria in soils

Bray (7) stated that the equilibria between the exchangeable cations on the soil colloids and the electrolytes in the soil water influenced many important processes concerned with soil leaching and plant nutrition. A second aspect was the effect of a mixed cationic composition on the release or adsorption of an individual cation. For example, the influence of exchanageable calcium, magnesium, potassium and hydrogen on a mixture of potassium and sodium chlorides added to the system was determined. A third factor was the effect of relatively large, as well as relatively small, amounts of complementary ions. Bray concluded that the ratio of exchangeable cations was wide, the ratio among complementary ions was also wide and that the number of different kinds of ions present was largely due to the equilbria between the exchangeable cations and the soil solution. Ions of the electrolytes in the soil water were affected by the amount of each cation present, the exchangeable cations, and the type of exchange material. Cations from the soil solution were not adsorbed in similar quantities when they were present in equal amounts.

Wiklander (61) grew barley in kaolin and bentonite clays. He found that the ratio of calcium to sodium within the barley roots was higher when kaolin clay was the growth medium. On clays of higher exchange capacities such as bentonite, divalent ions tended to accumulate to a greater extent and become more firmly bound to the colloidal surfaces than monovalent ions. Also clay colloidal systems with greater exchange capacities released monovalent ions more readily than the divalent ions. (This was explained on the basis of the differences of ion diffusion between the mineral solution and the root acidiods as predicted from Donnan equilibrium, which favors a greater release of divalent ions than monovalent ions, while in the solution phase the reverse would be true.)

The cation equilibria of plants in relation to the soil were investigated by Van Itallie (57). On a completely base saturated sandy soil which was well supplied with organic matter, the amount of calcium within the plants was doubled when a single additional increment of calcium carbonate was added. However, another increment gave only a slight increase in the calcium content of the plants. The application of magnesium plus calcium distinctly reduced the calcium uptake. While all combinations of potassium additions, with or without calcium, decreased the calcium concentration in the plants. All treatments without sodium caused relatively constant low sodium values in the plants; however, sodium additions raised the sodium content of plants to a very high level. Generally, the plant absorption of a specific cation cannot be brought into a simple relationship with the concentration of that specific ion in any soil; but, is dependent upon the ratio of that specific ion to the others within the soil. Anions may influence the cation uptake due to their concentrations and to the cation/anion ratios.

The effect of various proportions of exchangeable sodium and calcium in the soil upon the growth of different plants was reported by Bower (6). He found that all plants grown in media, which consisted of a mixture of sand and synthetic exchange resins saturated with various levels of sodium, developed chlorosis and necrosis, and that there was an increase in the red pigmentation of the leaves. The intensity of these symptoms were directly proportional to the level of exchangeable sodium. Plants grown at the three highest concentrations of exchangeable sodium displayed signs of water stress on warm days and abcission of the lower leaves occurred during the latter part of the growth period. They grew poorly and there was a marked decrease in total accumulation of calcium and magnesium in the top parts of the plants. However, the roots of the plants were not affected by the sodium treatments. Although potassium was applied at a constant rate in all cultures the accumulation of this cation within the roots was inversely related to the amount of exchangeable sodium.

Effect of salts on plant growth

According to Hilgard (28) the evaporation of water from the soil is one of the most important factors which causes salt injury to plants. Since evaporation of the soil moisture at the surface concentrates the alkali salts to a level which is injurious to plants, it is obvious that evaporation should be prevented as much as possible. Three methods of retarding evaporation are; shading, mulching, and maintenance of loose aggregates on the surface of the soil throughout the dry season. He also stated, that of the salts studied, sodium sulfate was the least injurious to ordinary vegetation. Ahis (1) reported that soluble salts may cause injury to plants by preventing absorption of moisture, by a direct corrosive action, by a toxicity due to an excess of salts or ions by inhibiting biological activities, by retarding germination, or by producing an abnormal physical condition within the soil.

The effect of transpiration upon the absorption of minerals by plants was studied by Freeland (18), (19). He concluded that aeration, respiration, temperature, initial salt content of the root tissues as well as the culture medium, and available carbohydrates within the plants were factors which concerned the uptake of minerals. Transpiration resulted in an increase in mineral absorption. However, different mineral ions were not absorbed at the same rate, and the rate of uptake of each ion also varied with the kind of plant. Lipman (34) believed the effect of sodium chloride upon plant growth was conditioned by the climatic factors of temperature, light, and humidity.

Epstein and Hagens (16) stated that the absorption of inorganic salts by plant roots and other biological systems depended upon the metabolic processes. The absorption process was characterized by a considerable degree of selectivity. The discrimination between potassium and sodium was particularly striking. Most living cells would accumulate potassium in preference to sodium, even though the external environment was rich in sodium and poor in potassium.

Greaves and Lund (21) assigned an important role of salt toxicity to the effect of osmotic pressure, but also attached a considerable significance to the physiological action of salts and their ions upon the protoplasm. The normal functioning of protoplasm was inhibited and its chemical plus physiological properties were altered by salt activity.

While the fundamental mechanisms of salt absorption are probably the same for all plants, the influence of environmental factors during the long evolutionary process has left differences in the salt tolerances of various plants. It is generally accepted that salt accumulation by plants parallels respiratory and transpirational processes, although the mechanism is somewhat obscure. These statements were presented in a review by Steward (52) and later work confirmed his statement that a high transpiration rate increased mineral absorption (19).

Mixtures of salts are often less injurious to plants than individual salts of a similar concentration. Kearney and Harter (29) observed that calcium sulfate diminished the toxicity of magnesium and sodium salts. In connection with their research on the alleviation of the deleterious effects of "black alkali" soils, Harris et al. (25), (26) recorded similar results. They stated that, "This phenomenon may be due in part at least to the specific stimulation of plants growth by these substances rather than to any antagonistic action against sodium carbonate". Barnyard manure was effective in reclaiming soils which contained 2000 ppm or less of sodium carbonate. The combination of manure and sulfur was the most effective amendment used on the "black alkali" soils.

Harris and Butt (24) concluded that the use of irrigation water containing a mixture of 500 ppm of sodium carbonate or 1000 ppm of sodium chloride plus 4000 ppm of sodium sulfate was less harmful to plants than the most toxic individual salts. However, more than 4000 ppm of any salt mixture was dangerous. Harris as reported by Wall and Cross (59) noted that only about one-half as much alkali was required to inhibit the growth of plants in a sandy soil as compared to loamy soil.

Various common flowers were watered with 100, 200, 1000, and 2000 ppm of sodium chloride solutions by Krone and Weinard (30). They stated that growth was progressively reduced when the concentration of NaCl exceeded

220 ppm. Harris and Pittman (25) grew a variety of crops in tumblers of loam soil and reported that satisfactory yields of ordinary crops could not be obtained when salt concentrations higher than 4000 ppm of chloride, 800 ppm of carbonates, or 1200 ppm of sulfates were added to the soils. With certain crops, marked reduction in yield occurred with much lower concentrations.

In the determination of the sodium chloride tolerance, Lipman et al. (34) found that barley, peas, and beans were generally resistant. Low concentrations of sodium chloride and even concentrations as high as 10,000 ppm had a stimulating effect.

The effect of chlorides on the chlorophyll content of potato leaves was investigated by Basslavskaya and his co-worker (3). The addition of chlorides increased the water content of the plants, particularly the leaves. After 18 to 22 days, plants which received high doses of chloride, developed a paler color which became more distinct as the plants grew to maturity. The role of chloride and sulfate anions in the nutrition of Irish potato was also the objective sought by Eaton (13). Two distinct foliar symptoms were associated with his experiments. Sulfate treatments produced a tip burn which was very severe in the presence of ammonium ions. The second sign of inward rolling of the leaves occurred only when chlorides plus ammonium ions were applied.

According to Lawrence and Carson (31) two separate phenomena cause a deficiency of phosphorus in saline soils. First, certain soil compounds or ions are preventing the accumulation of phosphorus in available soil forms and secondly, some ions absorbed by plants inhibit the absorption and/or utilization of phosphorus. They believed that the second assumption was more plausible wherein the injury to cereal grains was due to the accumulation of excessive quantities of chloride and sulfate within the leaves even when adequate amounts of phosphorus were supplied; moreover, when the anion balance was shifted to normal conditions with high phosphate additions, normal growth was produced.

Chang et al. (10) attempted to determine the influence of sodium upon the growth of alfalfa and cotton on a Chernozem soil which contained several combinations of exchangeable sodium and calcium. Their findings corroborated the work of Bower (6) and Bray (7). Wallace (60) studied the effect of sodium on plant growth, however, his results differed from other investigators (6), (7), (10). He believed that sodium could be beneficial to plants in one of the following ways:

1- By replacing potassium in some of its functions when the supply of this element is low.
2- By preventing luxury consumption of potassium, thus conserving the supply.
3- By exerting an essential or beneficial influence, regardless of the potassium supply.
4- By overcoming any unbalance due to a wide Ca/K ratio in the plants.
5- By enhancing the absorption of other nutrient elements.

Although the potassium content of alfalfa tissues had not reached a critical limit, the yields of alfalfa in the field increased due to sodium utilization by the plants.

Lint and Nelson (33) investigated the influence of sodium on cotton. They reported that when cotton was grown at a very deficient level of either potassium or sodium, sodium was not effective in delaying the appearance of potassium deficiency symptoms more than 2 to 3 days. At deficient potassium levels, sodium additions significantly increased the numbers of bolls retained per plant. However, sodium did not have an effect at adaquate levels of potassium. Applications of sodium had relatively little influence on the accumulation of calcium in the tops of plants, seeds, mature roots and tops. Calcium had little influence on the uptake of potassium, but it did depress the absorption of sodium in all plants regardless of their physiological age. Frank (17) stated that sodium enhanced maturity of cotton even when the level of potassium was adequate. The addition of sodium to the nutrient solutions increased early fruiting and boll maturity of cotton which was grown under conditions of poor aeration, but the effect could not be demonstrated under conditions of good aeration.

Wadleigh et al. (58) grew kidney beans at different sodium chloride concentrations. They found that as the salt content of the soil increased, the frequency of irrigation within a given soil moisture regime decreased. Higher levels of soil salinity caused a reduction in plant growth by lowering the rate of water absorption. They also stated that the reduction in growth was primarily caused by decreased hydration of protoplasmic protein.

Elgabaly (15) used barley seedlings to measure salt tolerance and his results agreed with those of Bower (6). He discovered that an increase in sodium saturation of the soil, up to a certain point, was accompanied by an increase in the dry weight, length of shoots, and length of roots of the plants compared to those grown in pure calcium or sodium systems.

Plants grown in a sodium dominated culture had a very short, thick, brown roots with little tendency for branching, while those produced in calcium system had fibrous, thin white colored roots with normal branching. Plants grown in a culture which contained both calcium and sodium had fibrous roots which became thinner and lighter in color as the percentage of calcium saturation increased. The roots grown in a pure magnesium system were very similar to those found in the pure sodium culture. A sodium-magnesium system produced more fibrous and branching roots.

Ayers and his associates (2) examined the tolerance of barley and wheat to salinity. They observed that the stage of growth at which the barley plants were subjected to salinity stress was an important factor in determining the final response of the plant to salinity stress. Many plants seem to be particularly sensitive to salt during the germination and seedling stages and yet are quite tolerant during the latter part of their growth cycles. Although barley and wheat germinated well under moderate levels of salinity, a much better yield of grain was produced if the salinity did not develop until plants became well established.

Paul et al. (39) studied the factors of crop response to sodium applied as sodium chloride. They stated that the response to sodium by plants is dependent on four factors: (a) composition and drainage of the soil. (b) composition of the fertilizer (content of sodium). (c) soil types and (d) seasonal climate. Organic soils show some variation in their natural content of sodium, although they are generally very low. Crops generally are able to respond to heavier applications of salts or soils with good drainage than those with poor drainage. Truog et al (55) reported on the response of nine common plants to sodium fertilizer and his results were similar to those of Bower (6) and Elgabaly (15).

Both Means (36) and Scofield (49) suggested the desirability of using liberal quantities of water, when it was necessary to use water containing considerable quantities of dissolved salts. Scofield explained that a sufficient water should be used to leach the root zone and thus carry away the accumulated salts left by evaporation water. In essence, the greater the salt content of irrigation water the greater the quantities of water that should be used in irrigation.

III. METHODS AND MATERIALS

Description and sites of soils used in pot culture experiment

The site from which the soils were obtained is located on the north bank of Stillwater creek near Lake Carl Blackwell (13 miles west and 2 miles north of Stillwater, Oklahoma). The area was a farm until 1935 when it was taken over by the United States Government. From 1935 - 1947 it was not cropped; however, since 1947, it has been cropped to corn and castor beans with corn the prevalent crop. This land has the legal description; NW 1/4 of section 10, T 19 N., R. 1 W.

The soils series is Port, and the texture of the present soil usually varies from sandy loam to clay loam.

The profile is described as follows:

Port series

A_1 0-8" Reddish-brown (5 YR 4/3; 3/3 moist)[1] sandy clay, loam; compound medium coarse blocky and weak fine granular; permeable; pH 6.5; many roots and worms casts; a few fine black concretions; grades slowly to the horizon below.

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[1]Profile description furnished by Mr. H. M. Galloway, Soil Scientist Coop. U.S.D.A., SCS and Agronomy Dept. O.A.M.C.

AC 8-24" Reddish-brown (2.5YR 4/4; moist) clay loam; compound medium granular and weak coarse blocky; sticky when wet, friable to hard when dry; permeable; pH 7.0; numerous roots and worm casts; organic films on cleavage planes; grades slowly to horizon below.

C 24-54" Red (2.5 YR 4/6; 3/6 moist) clay loam; fragmental breakage; sticky when wet, friable to hard when dry; pH 7.5; few roots; evidence of stratification.

A clay loam soil which will be referred to as soil #1 was taken from a bank near where the Port soil description was made. The nature of the slopes and position of the site presupposes it to have considerable fluctuation of depth and texture of the surface horizon. This soil was collected principally from the AC horizon after scraping away the surface litter and A_1 layer. A loam soil designated as soil #2 was obtained from the A_1 horizon of the Port series in the wider second bottom. Soil #3 is a sandy loam which was also taken from the second bottom and is somewhat sandier than the Port sandy clay loam described. It differs also in having a well defined buried soil at 26 inches.

Preliminary laboratory analyses of the soils

A sufficient quantity of each soil was brought to the laboratory for analyses. The samples were air-dried and then processed by crushing the aggregates with a metal roller plus sieving through a twenty-mesh screen.

Determination of the soil texture was made by the Bouyoucos hydrometer method on a 50 gram sample (5). The soil reaction was measured with a Beckman glass electrode pH meter using the procedure outlined by Peech and English (40). The organic matter content and total nitrogen were run according to the methods of Piper (41). Extractable phosphorus and potassium were determined by the procedures of Harper (22). The cation exchange capacity was measured by the A.O.A.C. method (38). The moisture equivalent of the soils was determined by the methods proposed by Briggs and McLane (8) and later modified by Briggs and Shantz (9). The results of these laboratory tests are shown in Table I.

Greenhouse procedure

One-gallon glazed, non-porous pots were used for the pot culture study. Each pot was thoroughly washed and rinsed with distilled water. The drain holes were closed with rubber stoppers and one inch layer of sand was put on the bottom of each pot.

The chemical analyses of the soils revealed that basal additions of nitrogen, phosphorus, and calcium would be necessary in order to prevent these nutrients from becoming limiting factors in plant growth. Analytical grade salts of ammonium nitrate, monocalcium phosphate, potassium chloride and calcium carbonate were used in making the solutions for N, P, K, and Ca. The equivalent of 40# of available P_2O_5 and 20# of nitrogen per acre were applied to soil #1; 20# of available P_2O_5 and 50# of nitrogen were added to soil #2; and 3000# of limestone, 20# of available P_2O_5, 40# of water soluble K_2O, and 35# of nitrogen were applied to soil #3.

In an attempt to simulate water sources of different qualities, six salt additions were applied with the irrigation water to all pots. These salt additions were made every time water was added to the pots. The planted pots had four replications of each treatment, while the unplanted pots were only replicated twice. The salt additions and their rates of application are given in Table II.

On May 9, 1956 eight seeds of Redlan sorghum were planted in two rows one inch from the outside edge of the pot and half an inch deep. The pots were arranged in a completely randomized block design. To insure a good stand only distilled water was added until May 25. Then the various salt concentrations were added as shown in Table II and the individual pots were brought to their moisture equivalent levels and maintained at this level throughout the experiment by weighing the individual pots. On July 3, 1956 the plants were harvested and the vegetative yields were obtained.

Analyses after harvest

The forage samples were dried in an oven at 65° C and the dry weights of the plants from each pot were recorded; then they were ground in a Wiley mill. Nitrogen was determined by the Kjeldahl method (41). Phosphorus was measured by the method proposed by Shelton and Harper (50). Potassium and sodium were read on a model 18 Perkin-Elmer flame photometer, while calcium was determined with the Beckman Du flame photometer with photomultiplier attachment.

After the plants were harvested, soil samples were taken with a hand probe from the two replications of unplanted pots. These samples were air-dried and then processed for analyses. Field capacity at 1/3 atmosphere (45), (47), and hygroscopic coefficient at 15 atmospheres (44), (46) were determined. Total salts were measured according to the methods outlined by Harper (22). Water-soluble calcium and sodium plus exchangeable calcium and sodium were run on the Beckman flame photometer.

The green and dry weights plus the chemical composition of the forage as well as the total salt content of the soils were subjected to the analysis

TABLE I

SOIL CHARACTERISTICS DETERMINED BY LABORATORY ANALYSES

	Soil #1	Soil #2	Soil #3
Mechanical Composition	25.25% sand 46.00% silt 28.75% clay	39.5% sand 36.0% silt 24.5% clay	53.25% sand 30.00% silt 16.75% clay
Soil Class	Clay loam	Loam	Sandy loam
Moisture Equivalent	26%	13%	12%
Soil Reaction	pH 6.7	pH 6.1	pH 5.7
Per cent Organic Matter	3.64%	2.72%	2.24%
Per cent of Total Nitrogen	.15%	.04%	.09%
Cation Exchance Capacity	14.0 me per 100 gm	6.3 me per 100 gm	6.2 me per 100 gm
0.1 N Acetic Acid Extractable Phosphorus	28 lbs. per acre	44 lbs. per acre	46 lbs. per acre
Extractable Potassium	228 lbs. per acre	256 lbs. per acre	168 lbs. per acre

TABLE II

SALT TREATMENTS OF THE WATER APPLIED
TO SOILS USED IN THE GREENHOUSE STUDIES

Salt Additions	Rate of Application (ppm)			Rate of Application (g/l)	
	Na	Ca	S04	Na_2SO4	CaS04
1- 12.5% Na in 1000 ppm.	125	180	693	0.386	0.612
2- 25% Na in 1000 ppm.	250	67	682	0.772	0.228
3- 12.5% Na in 2000 ppm.	250	360	1386	0.772	1.224
4- 25% Na in 2000 ppm.	500	134	1364	1.543	0.455
5- 12.5% Na in 4000 ppm.	500	720	2778	1.543	2.448
6- 25% Na in 4000 ppm.	1000	268	2728	3.087	0.911

of variance using the procedure of Snedecor (51). Multiple range tests were also calculated (12).

IV. RESULTS AND DISCUSSION

The effect of salt treatments on the moisture relationships of the three soils

The hygroscopic coefficient values (15 atmospheres) of the three salt treated soils are shown in Table III and Figure 1. The first four salt additions had a moderately depressing effect on the hygroscopic coefficient of soil #1. Treatments 3 and 4 contained twice as much total salts as treatments 1 and 2. The hygroscopic coefficient values of soil #1 which received treatments 5 and 6 were 42 per cent below the value found on the untreated soil.

The various salt treatments did not affect the hygroscopic coefficient values of soil #2 in the same manner as soil #1. However, all the salt additions produced coefficients which were lower than the check. The total salts of treatment 3 had a greater influence than treatment 1 and 2 on the hygroscopic values of soil #2. The Na/Ca ratio was probably instrumental in determining the effect of treatment #3 vs. #4, and treatment #5 and #6 on this soil. Treatment 4 had less effect on soil #2 than treatment 5 and 6. These results agree with those of Baver (4) who found that Na-clays, at a high vapor pressure, swell and permit a greater amount of water to be absorbed than in the Ca-clay system.

The check pots of soil #3, had the lowest hygroscopic coefficient values. The Na/Ca ratios of the salt treatments usually had a greater influence on soil #3 than soils #1 and #2. There were a wide differences between treatments 1 and 2 plus treatments 5 and 6 in the hygroscopic values for soil #3. The Na/Ca ratio of treatment 2 was the most favorable for water absorption by soil #3.

Table IV and Figure 2 give the field capacities (1/3 atmosphere) of the three salt treated soils. Treatment 1, 2, and 3 caused a gradual decline in the field capacity values of soil #1. Treatments 5 and 6 had similar effects on the water holding capacities of soil #1.

The salt additions did not have the same influence on the field capacities of soil #2. The field capacity of soil #1 which received treatment 1 was 14.43, while treatment 2 decreased the field capacity of soil #2 to 13.34 per cent. This depressional effect was probably due to the higher sodium concentration in treatment 2. These findings agree with those of Baver (4) who reported that Na-saturated soils, at low vapor pressure, absorbed less water than H-saturated and Ca-saturated clays. This was attributed to greater dispersion and swelling of Na-clay at higher moisture content plus the possibility of the existence of hydrates of colloidal minerals. At low vapor pressure, the dehydrated Na-clay contained pores which were too small for the entrance of water molecules. Ca-clay, on the other hand, was more porous and was able to absorb more water. However, at high vapor pressure, the Na-clay swelled and absorbed a greater amount of water than the Ca-clay. The adsorption of water by colloidal clays was a function of the attractive forces on the surfaces of the particles. These forces were associated with the chemical and minerological nature of the crystal lattice and the hydration of the adsorbed cations.

The water retention capacities of soil #3 which received treatment 4 and 6 exceeded the values obtained on the untreated soil. Treatment 1 caused a slightly greater decrease in the field capacity value of soil #3 than did treatment 2. Treatment 6 produced a higher field capacity per-

TABLE III

HYGROSCOPIC COEFFICIENT PERCENTAGES
(15 ATMOSPHERES) OF THE THREE SALT TREATED SOILS

SOILS

SALT TREATMENTS	1	2	3
Check	6.49	4.81	3.89
1	4.84	4.10	3.27
2	5.05	4.01	4.10
3	5.15	3.66	3.65
4	5.24	3.90	3.47
5	3.80	2.85	2.82
6	3.63	3.95	3.49

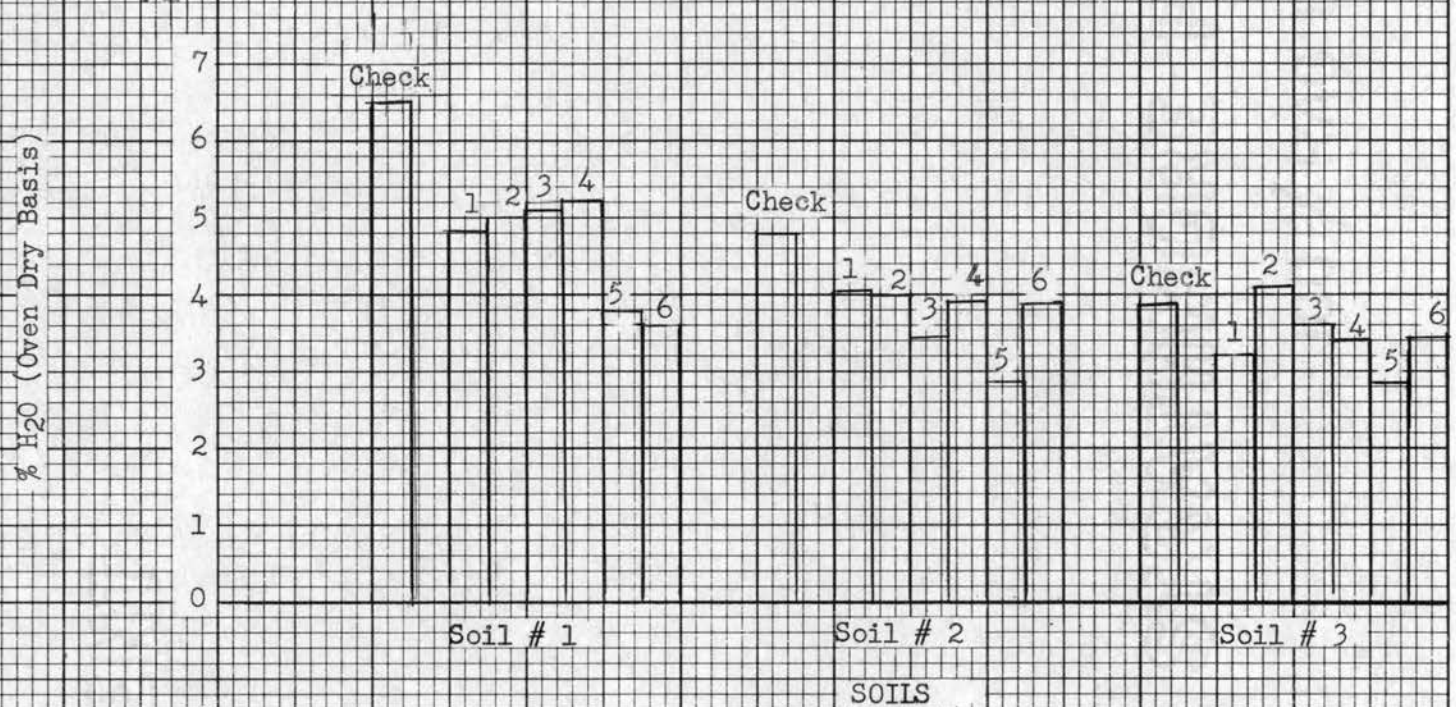

FIGURE 1

HYGROSCOPIC COEFFICIENT PERCENTAGES (15 ATMOSPHERES)
OF THE THREE SALT TREATED SOILS

centage for soil #3 as compared to soil #1 and #2; however, treatment 5 resulted in field capacity values of similar magnitudes on all three soils.

TABLE IV

FIELD CAPACITY (1/3) ATMOSPHERES) PERCENTAGES
OF THE THREE SALT TREATED SOILS

SOILS

SALT TREATMENTS	1	2	3
Check	14.43	13.65	12.86
1	13.34	11.86	11.37
2	12.59	10.01	11.65
3	11.11	12.87	11.32
4	12.87	13.36	13.02
5	12.37	12.04	11.88
6	11.96	12.44	13.38

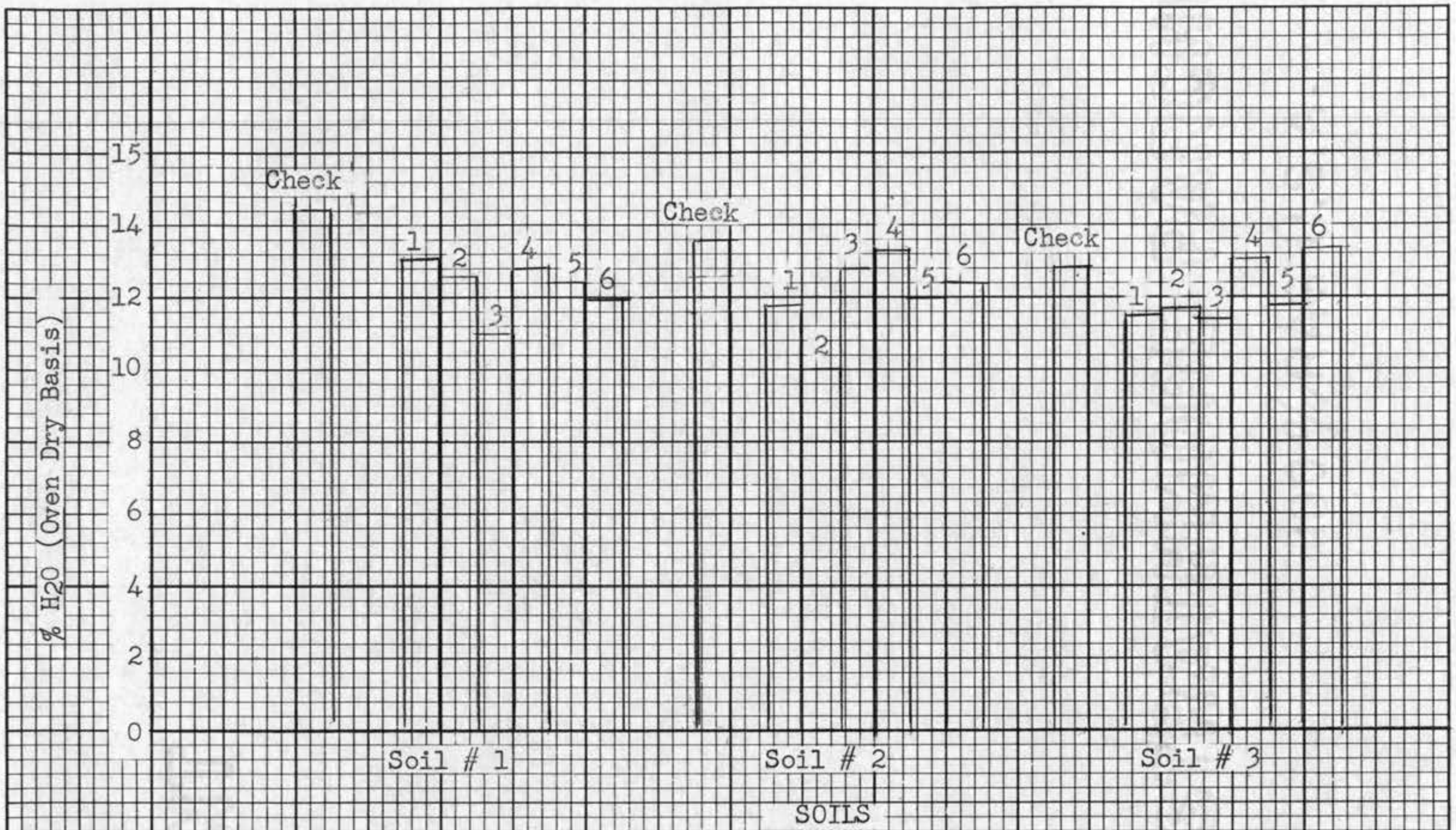

FIGURE 2

FIELD CAPACITY (1/3 ATMOSPHERE) PERCENTAGES
OF THE THREE SALT TREATED SOILS

The Influence of the Quality and Quantity of the Salt Additions on Some of the Chemical Properties of Soils

Total soluble salts

The quantity of salts added and the amount found in each treatment of the three soils are given in Tables V and VI. Generally, there was a marked increase in the amount of accumulated soluble salts with each increment of total salts added. The analysis of variance data in Table VII, shows that the different salt additions were highly significant in their effect on the total soluble salt content of the soils. However, the three soils were similar in total salt content for a given treatment.

The influence of the different salt treatments on the amount of total soluble salts found in the three soils is presented in the multiple range test (Table VIII.) The six salt treatments ranked in the order: 6, 5, 4, 3, 2, and 1. Treatments 1, 2, 3, and 4 produced similar effects. Also, there were no significant differences between 5 and 6.

TABLE V

TOTAL AMOUNT OF SALTS (EXPRESSED IN POUNDS PER ACRE) APPLIED TO THE SOILS UNDER GREENHOUSE CONDITIONS

SOILS

SALT TREATMENTS	1	2	3
1	10600	9300	7000
2	17900	15200	19000
3	25600	19000	16100
4	23000	18000	23000
5	42500	35000	29060
6	52100	60060	34080

TABLE VI

THE TOTAL SOLUBLE SALTS (EXPRESSED IN PPM) FOUND IN THE UPPER 6 INCHES OF THREE SALT TREATED SOILS UNDER GREENHOUSE CONDITIONS

SOILS

SALT TREATMENTS	1	2	3
1	2,650	2,325	1,750
2	4,475	3,800	1,450
3	6,400	4,750	4,025
4	5,750	4,000	5.750
5	10,625	8.750	7,265
6	13,025	15,050	8,520

* Each figure represents an average of two replications.

TABLE VII

ANALYSIS OF VARIANCE OF THE TOTAL SOLUBLE SALT CONTENT OF THE SOIL

SOURCE	d.f.	s.s.	m.s.	F.
Total	35	683,299,164		
Treatments	17	491,416,214	28,910,366	2.71*
Soils	2	35,857,539	17,928,770	1.68
Salts	5	416,916,647	83,383,329	7.82**
Soil x Salts	10	38,702,028	3,870,203	.3631
Error	18	106,514,280	10,656,831	

* Indicates significance at the 5 per cent level
** Indicates significance at the 1 per cent level

TABLE VIII

A MULTIPLE RANGE TEST SHOWING THE EFFECT OF DIFFERENT SALT ADDITIONS ON THE ACCUMULATION OF TOTAL SOLUBLE SALTS IN THE THREE SOILS

A. Standard Error of Mean; 1333.00

B. Results:

Treatments:

Means ranked in order:	6	5	4	3	2	1
	12187.00	8880.00	5333.00	5058.00	3242.00	2242.00

Note: Those means underscored by a solid line indicate similarity at the 5% probability level.

Those means underscored by a dotted line indicate similarity at the 1% probability level.

Water soluble and exchangeable sodium

The quantity of sodium applied in the various treatments on each soil is given in Table IX. The amount of water soluble and exchangeable sodium found in the soils are presented in Tables X and XI. Soil #1 which received treatment 2 contained more water soluble sodium than treatment 1 if treatment 3 vs. 4 and 5 vs. 6 were compared. However, a reverse trend occurred. The exchangeable sodium content of the soils for treatments 1, 2, 3, and 4 was directly proportional to the amount of sodium applied. For soil #2, treatment 1 and 2 produced the same amount of water soluble sodium, but treatment 1 resulted in a slightly greater accumulation of exchangeable sodium. Treatment 5 of soil #2 caused a smaller accumulation of water soluble and exchangeable sodium than the salt additions of treatment 6. The water soluble and the exchangeable sodium content of soil #3 usually varied directly with the amount of sodium applied. Treatment 3 was a notable exception. When treatment pairs (1 vs. 2, 3 vs. 4, and 5 vs. 6) were compared the treatments which received the highest sodium applications produced the larger quantities of water soluble and exchangeable sodium in the soil.

TABLE IX

TOTAL AMOUNT OF SODIUM (EXPRESSED IN POUNDS PER ACRE) APPLIED TO THE SOILS UNDER GREENHOUSE CONDITIONS

	SOILS		
SALT TREATMENTS	1	2	3
1	3347.50	1875.00	1790.00
2	7800.00	3781.25	3625.00
3	7337.50	2985.00	2958.00
4	15000.00	7334.25	7334.50
5	15584.00	7431.00	7770.25
6	28500.00	14945.50	14375.00

TABLE X

THE WATER SOLUBLE SODIUM (EXPRESSED IN POUNDS PER ACRE) FOUND IN THREE SALT TREATED SOILS UNDER GREENHOUSE CONDITIONS

	SOILS		
SALT TREATMENTS	1	2	3
1	930.00	1020.00	440.00
2	2030.00	1020.00	810.00
3	1460.00	1360.00	1640.00
4	1330.00	2290.00	2120.00
5	2050.00	2470.00	2100.00
6	1750.00	2850.00	3680.00

TABLE XI

THE EXCHANGEABLE SODIUM (EXPRESSED IN m.e./100 gms.) OF THE THREE SALT TREATED SOILS UNDER GREENHOUSE CONDITIONS

SOILS

SALT TREATMENTS	1	2	3
1	1.782	2.173	1.108
2	4.565	1.826	1.152
3	4.043	3.369	3.086
4	6.652	3.739	4.173
5	5.347	3.000	3.261
6	6.434	7.391	6.869

TABLE XII

TOTAL AMOUNT OF CALCIUM (EXPRESSED IN POUNDS PER ACRE) APPLIED TO THE SOILS UNDER GREENHOUSE CONDITIONS

	SOILS		
SALT TREATMENTS	1	2	3
1	4820.40	2700.00	2577.70
2	2090.40	799.98	971.50
3	10566.00	5445.00	4260.78
4	4020.00	1965.58	1965.65
5	22441.68	10700.64	11189.16
6	7638.00	4011.33	3852.25

Water soluble and exchangeable calcium

Table XII gives the amount of calcium added in each treatment on the three soils. The quantities of water soluble and exchangeable calcium are given in Tables XIII and XIV. After an examination of the treatment pairs it is shown that on soil #1 the water soluble calcium content of treatment 2 slightly exceeded treatment 1. The amount of water soluble calcium from treatment 3 was greater than treatment 4. Similarly, the water soluble calcium content of treatment 5 was more than treatment 6. The amount of exchangeable calcium in soil #1 which received treatment 1 was more than that of treatment 2; treatment 3 more than treatment 4; but in the case of treatments 5 and 6, the exchangeable calcium content of treatment 6 exceeded that of treatment 5. The water soluble and exchangeable calcium contents of the treatment pairs also revealed that these amounts were directly related to the calcium content of the water. The only pair that did not follow this pattern was treatment 1 and 2 and they varied in their water soluble calcium content. The amounts of water soluble calcium in soil #2 were similar to those of Soil #1, but the exchangeable calcium contents of the 6 treatment did vary directly with the calcium application. The water soluble calcium contents of soil #3 were generally directly related with the increase to the applications of calcium, but treatment 4, even though it received less calcium than treatment 3, was slightly higher in the water soluble calcium content. In amounts of exchangeable calcium, all 6 of the treatments followed the same pattern as soil #2.

TABLE XIII

THE WATER SOLUBLE CALCIUM (EXPRESSED IN POUNDS PER ACRE FOUND IN THREE SALT TREATED SOILS UNDER GREENHOUSE CONDITIONS

SOILS

SALT TREATMENTS	1	2	3
1	870.00	690.00	660.00
2	910.00	830.00	410.00
3	2230.00	1820.00	1240.00
4	750.00	670.00	1250.00
5	4040.00	3920.00	3280.00
6	2940.00	1420.00	1560.00

TABLE XIV

THE EXCHANGEABLE CALCIUM (EXPRESSED IN m.e./100 gms.) OF THE THREE SALT TREATED SOILS

SOILS

SALT TREATMENTS	1	2	3
1	7.250	4.825	6.300
2	6.600	5.020	4.150
3	8.800	6.600	5.200
4	6.950	5.700	3.720
5	5.800	4.100	4.450
6	8.400	6.100	5.950

The Effect of Salt Treatments on the Forage Yields

Green weight yield of the forage

The green weight yields of sorghum forage presented in Table XV indicated a variation in the influence of the different salt treated soils on plant growth. For soils #1 and 2, treatment 3 gave the highest yield while on soil #3 treatment 1 produced the greatest green weight. The average yield per pot for treatments 1, 2, and 3 on all soils was 75.08 grams, while treatments 4, 5, and 6 averaged 50.07 grams. The analysis of variance test (Table XVI) disclosed highly significant differences for both salt treatments and soils.

The multiple range test (Table XVII) showed highly significant differences among soils in their effect on green weight yields. Salt treatments taken as a source of variation for green weight yields of sorghum forage also gave significant differences as shown by the multiple range test (Table XVIII.) Although treatment 3 produced the highest average yields, it was similar in green weight yield to treatment 1. Treatment 3 gave a yield which was 25 per cent higher than treatment 6 which was the lowest of the group. Part of the difference of these yields may be attributed to the Ca/Na ratio of the salt additions.

The roots of plants grown on soils which received treatments 1, 2, and 3 were much thinner and had more branching than the roots of other treatments. When the soils were treated with salts which had a high Ca/Na relationship, the plants developed roots which were thicker, shorter, and less branched than the roots of plants grown on a low Ca/Na ratio. Their leaves were broader and had a darker green color; however, no major nutrient

TABLE XV

THE GREEN WEIGHT YIELDS OF SORGHUM FORAGE (EXPRESSED IN GRAMS PER POT) GROWN ON THREE SALT TREATED SOILS IN THE GREENHOUSE

SOILS

SALT TREATMENTS	1	2	3
1	75.70*	70.40	80.50
2	79.20	65.70	67.50
3	84.20	73.00	79.40
4	68.20	45.70	51,00
5	56.00	40.10	50.00
6	53.00	35.70	51.60

*Each figure represents an average os six plants per pot an a mean of four replications.

TABLE XVI

ANALYSIS OF VARIANCE OF THE GREEN WEIGHT YIELDS OF SORGHUM FORAGE PRODUCED ON THREE SALT TREATED SOILS UNDER GREENHOUSE CONDITIONS

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	17619.98	248.17	
Treatments	17	15455.30	909.13	22.69**
Soils	2	2521.92	1260.96	31.43**
Salts	5	12096.02	241.92	6.30**
Soils x Salts	10	937.36	93.74	2.30*
Error	54	2164.68	40.08	

TABLE XVII

A MULTIPLE RANGE TEST OF THE EFFECT OF DIFFERENT SALT TREATED SOILS ON THE GREEN WEIGHT YIELDS OF SORGHUM FORAGE

A. Standard Error of Means:	1.29		
B. Results:			
Soils	1	3	2
Means Ranked in Order	69.41	63.33	54.90
(5% level)	____	____	____
(1% level)	-----	-----	-----

TABLE XVIII

A MULTIPLE RANGE TEST OF THE INFLUENCE OF SALT ADDITIONS TO THE SOILS ON THE GREEN WEIGHT YIELDS OF SORGHUM FORAGE

A. Standard Error of Means:	1.83					
B. Results:						
Treatments:	3	1	2	4	5	6
Means ranked in order:	78.87	75.54	70.83	54.87	48.71	46.62
(5% level)	______	______		______	______	______
		______	______			
(1% level)	------	------		------	------	
		------	------		------	------

deficiency symptoms were recognized. Plants grown on soils which received treatments 4, 5, and 6 had shorter and narrower curling leaves than plants on the other treatments, and they also exhibited potassium deficiency. This might be attributed to the high sodium content in which was 500 ppm and above. When the temperature became quite high in the early summer, the lower leaves of these plants turned yellow and abscised. All plants began to display signs of moisture stress at this time.

Dry matter yield of the forage

The influence of salt additions on the dry matter yield of sorghum forage was similar to the effect on the green weight yield (Table XIX.) Again treatments 1, 2, and 3 for all soils gave a higher average yield than the last three treatments 4, 5, and 6. On all soils, treatment 3 produced the highest dry matter yield. The analysis of variance in Table XX revealed that the dry matter yield of the sorghum forage was very significantly affected by both the salt treatments and the soils. The influence of soils on the dry matter yield is given in the multiple range test Table XXI. At the 5 per cent probability level, all the soils were significantly different. However, at the 1 per cent level, soils 2 and 3 were quite similar in their effect on the dry matter yield. The influence of salt treatments on the dry matter yields of forage is portrayed in Table XXII. Treatments 1 and 3 produced similar green weight yields, but there was a highly significant difference in their effects on the dry matter forage yields. The dry matter yields obtained from treatments 1 and 2 were similar. Likewise, treatments 5 and 6 also produced similar yields.

TABLE XIX

THE DRY MATTER YIELD OF SORGHUM FORAGE (EXPRESSED) IN GRAMS PER POT) GROWN ON THREE SALT TREATED SOILS IN THE GREENHOUSE

SALT TREATMENTS	SOILS 1	2	3
1	22.40	19.20	20.80
2	23.50	19.60	19.05
3	25.06	21.90	22.50
4	18.70	13.50	14.90
5	16.60	11.20	13.40
6	15.08	10.60	13.90

TABLE XX

ANALYSIS OF VARIANCE OF THE DRY MATTER YIELD OF SORGHUM FORAGE (EXPRESSED IN GRAMS PER POT) GROWN ON THREE SALT TREATED SOILS IN THE GREENHOUSE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	1480.95		
Treatments	17	1312.19	77.19	24.70**
Soil	2	220.00	110.00	35.20**
Salts	5	1073.37	214.67	68.69**
Soils x Salts	10	18.82	1.88	.579
Error	54	168.76	3.12	

TABLE XXI

A MULTIPLE RANGE TEST OF THE INFLUENCE OF DIFFERENT SOILS ON THE DRY WEIGHT YIELDS OF SORGHUM FORAGE

A. Standard Error of Mean: 0.36056

B. Results:

Soils	1	3	2
Means ranked in order	20.21	17.40	16.08
(5% level)	____	____	____
(1% level)	-----	-----	-----

TABLE XXII

A MULTIPLE RANGE TEST OF THE EFFECT OF SALT TREATMENT TO THE SOILS ON THE DRY WEIGHT YIELDS OF SORGHUM FORAGE

A. Standard Error of Mean 0.5113

B. Results:

Treatments:	3	1	2	4	5	6
Means ranked in order:	23.17	20.80	20.70	15.69	13.72	13.17
(5% level)	____	____	____	____	____	____
(1% level)	-----	-----	-----	-----	-----	-----

The Influence of Salt Additions on the Chemical Composition of Sorghum Forage

Nitrogen

Sorghum forage grown on soil #1 regardless of salt treatments, had the highest average nitrogen content as shown in Table XXIII. For all treatments, the nitrogen content of the sorghum plants generally paralleled the green and dry weights. Both the soils and the salt additions were highly significant in their effect on the nitrogen composition of the forage as given in Table XXIV. Table XXV showed that soil #1 and 3 were similar in their influence on the nitrogen content of the plants, whereas the forage grown on soil #2 was very significantly lower in the amount of nitrogen than that produced on the other two soils. Treatment 3 produced the highest nitrogen content of the plants grown on all the soils as shown in Table XXVI. Absorption of nitrogen was similar on treatments 1 and 3 which had a Ca/Na ratio of 3:2. These treatments probably gave the soil organisms more favorable environment and creates less inhibition of nitrogen uptake. However, the nitrogen contents of sorghum grown on treatment 2 were also similar to those on treatment 1. Treatments 4, 5, and 6 as a group significantly depressed the absorption of nitrogen. Five hundred ppm of soluble sodium seems to be more than the sorghum plant can tolerate. This was reflected in decreased forage yields and a reduction in the uptake of nitrogen.

TABLE XXIII

THE NITROGEN CONTENT (EXPRESSED IN mgms PER POT) OF SORGHUM FORAGE GROWN ON THREE SALT TREATED SOILS IN THE GREENHOUSE

SOILS

SALT TREATMENTS	1	2	3
1	150.05	151.70	174.60
2	158.70	147.90	149.40
3	178.20	168.50	204.30
4	168.10	108.80	143.10
5	125.30	86.30	115.80
6	141.20	85.00	117.60

TABLE XXIV

ANALYSIS OF VARIANCE OF THE NITROGEN CONTENT OF SORGHUM FORAGE GROWN ON THREE SALT TREATED SOILS IN THE GREENHOUSE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	110421.41		
Treatments	17	68660.83	4038.87	5.22**
Soil	2	12181.56	3887.24	5.02**
Salts	5	47356.65	9471.33	12.24**
Soil x salts	10	9122.62	912.26	1.18
Error	54	41760.58	773.34	

TABLE XXV

A MULTIPLE RANGE TEST OF THE EFFECT OF SOILS ON THE NITROGEN CONTENT OF SORGHUM FORAGE PRODUCED ON THREE SALT TREATED SOILS IN THE GREENHOUSE

A. Standard Error of Mean: 5.6750

B. Results:

Soils	1	3	2
Means ranked in order:	153.36	150.80	124.72
(5% level)	———	———	———
(1% level)	- - -	- - -	- - -

TABLE XXVI

A MULTIPLE RANGE TEST OF THE INFLUENCE OF SALT ADDITIONS TO SOILS ON THE NITROGEN CONTENT OF SORGHUM FORAGE

A. Standard Error of Mean: 8.0278

B. Results:

Treatments	3	1	2	4	6	5
Means ranked in order:	183.66	158.84	151.99	139.98	114.61	109.14
(5% level)	———	———				
		———	———	———		
				———	———	———
(1% level)	- - -					
		- - -	- - -	- - -		
					- - -	- - -

Phosphorus

The phosphorus content of the sorghum forage grown on the three salt treated soils is given in Table XXVII. The amounts of phosphorus in the forage showed trends which were similar to those of nitrogen. The analysis of variance for phosphorus composition demonstrated highly significant differences for soils and salt additions (Table XXVIII.) The effect of soils on the uptake of phosphorus by the plants given in Table XXIX also followed the same pattern as that of nitrogen. Soil #1 and #3 were quite similar in their influence on phosphorus absorption, but both of them were very significantly different from soil #2. Treatment 3 ranked first in both phosphorus and nitrogen content of the forage as shown in Table XXX. The salt concentration and the Ca/Na ratio of this treatment evidently created relatively optimum conditions for nitrogen and phosphorus uptake. When the amounts of nitrogen and phosphorus absorbed by the plants were compared, the ranking of treatments 1 and 2 were interchanged. The phosphorus content of plants grown with treatment 4 was significantly different from the remaining treatments. Treatments 4, 5, and 6 caused a proportionally greater depression in phosphorus uptake as compared to that of nitrogen.

TABLE XXVII

THE PHOSPHORUS CONTENT OF SORGHUM FORAGE (EXPRESSED IN mgms PER POT) OBTAINED FROM THREE SALT TREATED SOILS IN THE GREENHOUSE

SALT TREATMENTS	SOILS 1	2	3
1	29.20	23.30	28.46
2	33.20	26.10	26.90
3	31.00	28.50	33.00
4	22.10	16.00	21.10
5	16.20	14.40	20.10
6	15.40	13.10	16.40

TABLE XXVIII

ANALYSIS OF VARIANCE OF THE PHOSPHORUS CONTENT OF SORGHUM FORAGE GROWN IN THREE SALT TREATED SOILS IN THE GREENHOUSE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	3577.55		
Treatments	17	3105.54	182.68	20.90**
Soil	2	287.23	143.61	16.43**
Salts	5	2641.62	528.32	60.45**
Soil x salts	10	176.69	17.70	2.02*
Error	54	472.01	8.74	

TABLE XXIX

A MULTIPLE RANGE TEST SHOWING THE EFFECT OF SOILS ON THE PHOSPHORUS CONTENT OF SORGHUM FORAGE PRODUCED ON THREE SALT TREATED SOILS IN THE GREENHOUSE

A. Standard Error of Mean:	0.60		
B. Results:			
Soils			
Means ranked in order:	24.62	24.13	20.29
(5% level)	————	————	———
(1% level)	- - - -	- - - -	- - -

TABLE XXX

A MULTIPLE RANGE TEST SHOWING THE INFLUENCE OF SALT ADDITIONS TO THE SOILS ON PHOSPHORUS CONTENT OF THE SORGHUM FORAGE

A. Standard Error of Mean:	0.8534					
B. Results:						
Salt Treatments:	3	2	1	4	5	6
Means ranked in order:	30.48	28.74	27.24	19.73	16.91	14.99
(5% level)	————	————		———	————	————
		————	————			
(1% level)	- - - -	- - - -	- - - -	- - - -	- - - -	
					- - - -	- - - -

Potassium

The composition data given in Table XXXI indicates that treatment 3 on soil #1 and #2 gave the largest amount of potassium within the forage. However, on soil #3, the plants which received treatment 1 had highest potassium content. The effect of soils and salt additions on the potassium composition of the sorghum forage was highly significant as shown in Table XXXII. The multiple range test (Table XXXIII) shows the effect of the soils on the amount of potassium in the sorghum forage. All the soils were very significantly different. Treatments 1 and 3 had a similar influence on the potassium content of the plants as given in Table XXXIV. The potassium composition of plants grown on treatments 4, 5, and 6 was similar. The difference in the average amount of potassium in the forage between treatments 1 and 3 did not exceed 6 per cent while the mean difference between treatments 3 and 2 was only 9 per cent. On the other hand, the difference in the amount of potassium absorbed by plants grown on treatments 2 and 4 was almost 40 per cent.

Thus, the salt additions which contained 250 ppm of sodium (treatments 1, 2, and 3) did not seem to retard or hinder the uptake of potassium and phosphorus, and to a large extent nitrogen. However, salt treatments which had more than 250 ppm of sodium interfered with absorption of potassium as well as nitrogen and phosphorus.

A tremendous decrease in the forage yield also occurred with the higher sodium additions. The decreased plant absorption of nitrogen and phosphorus in the presence of excess sodium may be attributed to changes in soil conditions such as the activity of organisms and soil reaction. There is an indication of antagonism between sodium and potassium which will partially account for the reduction in the absorption of potassium by the plants when high sodium levels have been applied to the soils.

TABLE XXXI

THE POTASSIUM CONTENT (EXPRESSED IN mgm PER POT) OF SORGHUM FORAGE OBTAINED FROM THREE SALT TREATED SOILS IN THE GREENHOUSE

	SOILS		
SALT TREATMENTS	1	2	3
1	520.00	476.30	531.80
2	503.10	485.70	492.60
3	588.00	579.90	414.20
4	425.20	230.20	285.60
5	311.10	246.20	274.30
6	332.30	210.10	274.30

TABLE XXXII

ANALYSIS OF VARIANCE OF THE POTASSIUM CONTENT OF THE SORGHUM FORAGE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	1232998.00		
Treatments	17	1107551.12	65150.06	28.04**
Soil	2	82850.78	41425.39	17.83**
Salts	5	971524.60	194304.92	83.21**
Soil x salts	10	53175.74	5317.57	2.28*
Error	54	125446.88	2323.09	

TABLE XXXIII

A MULTIPLE RANGE TEST OF THE EFFECT ON SOILS ON THE POTASSIUM CONTENT OF SORGHUM FORAGE

A. Standard Error of Mean:	9.89		
B. Results:			
Soils:	1	3	2
Means ranked in order:	446.29	395.62	363.92
(5% level)	___	___	___
(1% level)	---	---	---

TABLE XXXIV

A MULTIPLE RANGE TEST OF THE INFLUENCE OF SALT TREATMENTS ON THE POTASSIUM CONTENT OF THE SORGHUM FORAGE

A. Standard Error of Mean:	13.91					
B. Results:						
Treatments:	3	1	2	4	5	6
Means ranked in order:	545.72	509.54	493.88	296.16	277.25	272.44
(5% level)	___	___		___	___	___
		___	___			
(1% level)	---	---	---	---	---	---

Calcium

The calcium content of the sorghum forage is given in Table XXXV. Treatment 1 on all soils produced the largest amount of calcium in the plants. These results indicated that the uptake of calcium differed from that of nitrogen, phosphorus and potassium. The analysis of variance presented in Table XXXVI revealed that both salt additions and soils were highly significant in their influence on the calcium composition of the forage. The effect of soils on the calcium absorption did not follow the same pattern as the other nutrients; however, the means of the soils in descending order were 3, 1, and 2 (Table XXXVII.) Soils #1 and #3 were quite similar, while soil #2 was significantly different at the 5% probability level. The multiple range test Table XXXVIII showed that salt treatments influenced the calcium content of the forage in a different manner from the other nutrients which have previously been discussed. The means of the treatments were ranked 1, 3, and 2. Treatments 3 and 1 had a more favorable Na/Ca ratio which would enhance the availability of calcium.

TABLE XXXV

CALCIUM CONTENT (EXPRESSED IN mgms PER POT)
OF SORGHUM FORAGE OBTAINED FROM THREE SALT TREATED
SOILS IN THE GREENHOUSE

SALT TREATMENTS	SOILS 1	2	3
1	81.50	87.80	88.00
2	72.70	75.00	63.00
3	74.90	68.00	82.70
4	35.70	21.10	29.30
5	36.30	25.20	53.90
6	46.70	25.30	38.00

TABLE XXXVI

ANALYSIS OF VARIANCE OF THE CALCIUM
CONTENT OF SORGHUM FORAGE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	43631.97		
Treatments	17	38429.64	2260.57	23.46**
Soil	2	1089.88	544.94	5.65**
Salts	5	34421.80	6884.36	11.46**
Soil x Salts	10	2917.96	291.80	3.27**
Error	54	5202.33	96.34	

TABLE XXXVII

A MULTIPLE RANGE TEST OF THE EFFECT OF SOILS ON THE CALCIUM CONTENT OF SORGHUM FORAGE

A. Standard Error of Mean:	2.003		
B. Results:			
Soils:	3	1	2
Means ranked in order:	59.22	57.97	50.42
(5% level)			
(1% level)			

TABLE XXXVIII

A MULTIPLE RANGE TEST OF THE INFLUENCE OF SALT ADDITIONS ON THE CALCIUM CONTENT OF SORGHUM FORAGE

A. Standard Error of Mean:		2.8334				
B. Results:						
Treatments:	1	3	2	5	6	4
Means ranked in order:	85.83	75.22	70.16	38.47	36.66	28.89
(5% level)						
(1% level)						

Sodium

The sodium content of the forage represented in Table XXXIX indicated that treatment 4 produced the largest amount of sodium within the plant. The uptake of sodium on the three salt treated soils varied to a greater extent than did the absorption of nitrogen, phosphorus, and potassium. The analysis of variance shows that the influence of soils on the sodium composition of the plants was highly significant, while the salt additions were significant at the 5% level (Table XXXX.) The soils were ranked 1, 2, and 3 in the sodium content of the forage as shown in Table XXXI. Soil #1 was very significantly different from soils #2 and #3 which were similar. The difference between the means of soil #1 and #2 was approximately 40 per cent and between soils #1 and #3, 50 per cent. Thus, these differences in sodium absorption were much greater than those of nitrogen, phosphorus, and potassium. The multiple range test indicated that treatment 4 gave the largest amount of sodium in the forage (Table XXXXII.) Treatment 4 had 500 ppm of sodium and 134 ppm of calcium which is a Na/Ca ratio of 4:1. Treatment 2 which ranked second had the same Na/Ca ratio, but contained only one-half as much sodium. Thus, treatments 2 and 4 had more sodium available for plant absorption than treatments 1 and 3 in which there were undoubtedly antagonistic relationships between sodium and calcium. Plants which received treatment 4 were not only low in forage yield, but were also low in the amount of nitrogen, phosphorus, and potassium. Thus, the sodium content of this treatment must have exerted a detrimental influence on the growth of the forage.

TABLE XXXIX

THE SODIUM CONTENT (EXPRESSED IN mgms. PER POT) OF SORGHUM FORAGE OBTAINED FROM THREE SALT TREATED SOILS IN THE GREENHOUSE

SALT TREATMENTS	SOILS 1	2	3
1	13.00	6.20	5.20
2	18.50	7.40	5.60
3	12.30	8.60	7.50
4	25.60	11.70	7.00
5	8.30	6.50	5.40
6	5.90	11.20	5.70

TABLE XXXX

ANALYSIS OF VARIANCE OF THE SODIUM CONTENT OF THE SORGHUM FORAGE

SOURCE	d.f.	s.s.	m.s.	F.
Total	71	3895.29		
Treatments	17	1977.48	116.32	3.27**
Soil	2	776.75	388.49	10.94**
Salts	5	498.75	99.75	2.80*
Soil x Salt	10	701.75	70.17	1.97
Error	54	1917.81	35.51	

TABLE XXXXI

A MULTIPLE RANGE TEST OF THE EFFECTS OF SOILS ON THE SODIUM CONTENT OF SORGHUM FORAGE

A. Standard Error of Mean:	1.22		
B. Results:			
Soils:	1	2	3
Means ranked in order:	13.93	8.60	6.04
(5% level)	______	__________	__________
(1% level)	------	----------	----------

TABLE XXXXII

A MULTIPLE RANGE TEST OF THE INFLUENCE OF SALT ADDITIONS ON THE SODIUM COMPOSITION OF SORGHUM FORAGE

A. Standard Error of Mean:	1.72					
B. Results:						
Treatments:	4	2	3	1	6	5
Means ranked in order:	14.75	10.51	9.38	8.13	7.61	6.75
(5% level)	______	______				
		______	______	______	______	______
(1% level)	------	------	------	------		
		------	------	------	------	------

V. SUMMARY AND CONCLUSIONS

The influence of the quality of irrigation water on the physical and chemical properties of soils plus the effect on the vegetative yield and the chemical composition of forage was investigated in the greenhouse. Sodium and calcium sulfate were added to the irrigation water at three different concentration levels; 1000, 2000, and 4000 parts per million. Two percentages of sodium, 12.5 and 25 per cent, were used at each concentration. Redlan sorghum (vulgare pers.) was grown as an indicator crop on three soils of different textures. Hygroscopic coefficient (15 atmospheres), field capacity (1/3 atmosphere), total soluble salts, plus water soluble and exchangeable calcium and sodium of the three soils were determined. The yields of the forage were recorded and the plant samples were analyzed for nitrogen, phosphorus, potassium, calcium, and sodium.

From the results and statistical analyses of the data obtained in this experiment, the following conclusions seem justifiable.

1. The salt treatments did have a depressing effect on the hygroscopic coefficient values of the three soils. The influence was less evident for soil #3 on which treatment 2 had a slightly higher hygroscopic moisture percentage than the check.

2. The field capacity values of soil #1 were higher for the soils which received treatments that had a higher Ca/Na ratio. This did not hold true in treatment 3 vs. 4. Soil #3 showed a different trend from soil #1 and treatment 6 on soil #3 produced a higher field capacity than the check and the other treatments.

3. The total salt content of the three salt treated soils generally varied directly with the total salts applied. When treatment pairs (1 vs. 2, 3 vs. 4 and 5 vs. 6) were compared, the salt content of the soils were higher in those where the sodium percentage of the applied water was 25 per cent.

4. The amounts of water soluble and exchangeable sodium of the soils generally increased with each increment of sodium applied in the treatments. This did not hold true in treatments 4 and 6 of soil #1, plus treatment 2 of soils #2 and #3.

5. The water soluble calcium accumulation by the three soils was similar to that of the water soluble sodium. In the case of the exchangeable calcium, the increase was not directly proportional to the increments of calcium in the various treatments. Treatments 1 and 5 of soil #2 accumulated less exchangeable calcium than 1 and 6 of soil #2, although the calcium content of treatments 1 and 5 was much greater.

6. Each soil exerted a different effect on the yields of sorghum forage. The yields of the forage were significantly higher on soil #1. Treatments 1, 2, and 3 had the least effect on yield, while treatments 4, 5, and 6 distinctly depressed the yields.

7. The nitrogen and the phosphorus composition of the forage was affected in a manner similar to the yields. The effect of treatment on the nitrogen content was similar to phosphorus. However, in the amounts of phosphorus in the plants the means of treatment 2 ranked second instead of third, and treatment 6 was the lowest.

8. The influence of soils and salt additions on the potassium content of the forage was quite similar to nitrogen.

9. Both salt additions and soils were highly significant in their effect on the calcium composition of the forage. Soils #1 and #3 were quite

similar in their influence while the plants grown on soil #2 were significantly lower in the amount of calcium. Treatments 1 and 3 had a more favorable Na/Ca ratio which might have enhanced the availability of the calcium in these treatments.

10. The uptake of sodium on the three salt treated soils varied to a greater extent than the absorption of nitrogen, phosphorus, and potassium. The influence of soils on the sodium content of the plants was highly significant, while the salt additions were significant at the 5 per cent level. Treatments which contained a high Na/Ca ratio exerted a detrimental effect on the growth of the forage.

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