PLOT STUDIES ON THE EFFECTS OF NITRATES ON A SOUTHWESTERN RANGE

by

J. F. Arnold

A Thesis
submitted to the faculty of the
Department of Botany
in partial fulfillment of
the requirements for the degree of
Master of Science
in the Graduate College
University of Arizona

1936

Approved: D M Crooks, Major Professor ; May 11, 1936, Date

ACKNOWLEDGEMENTS

The writer acknowledges his indebtedness to Dr. W. G. McGinnies and Dr. C. M. Harrison, who first recognized the possibilities of the experiment, to Mr. M. J. Culley, of the United States Forest Service, for having placed the facilities of the Santa Rita Experimental Range at his disposal, and to those of the University of Arizona who have given their cooperative assistance in many ways.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

PLOT STUDIES ON THE EFFECTS OF NITRATES ON A SOUTHWESTERN RANGE

INTRODUCTION

The annual forage crop of western grazing lands apparently depends to a great extent upon the seasonal distribution of rain. However, it is now being realized that the general axiom "good rains mean good range cover" is not always applicable. Many pastures and ranges are found lacking both in quantity and quality, even after favorable rainy seasons. The grassland area on which the following experiments were conducted offers an example of such a range. Following the summer rains of 1935 this range developed a tall, dense cover of grass. From a vantage point overlooking this region the vegetation was found to be of a characteristically yellow color. Such a color suggested a deficiency of one or more factors which might limit the production of a high quality grass. A more complete inspection of the area revealed a predominance of annual grasses, a condition which may be considered an indicator of heavy use.

A brief sketch given by Barnes (1) outlines the causes leading to the depleted conditions of the present day grazing lands. A comparison between the early grazing lands and the present ranges shows a gradual decrease of range carrying capacities. The initial steps towards range impoverishment entered as the first waves of settlers marched from east to west and from Mexico northward. The first pioneer herds grew and multiplied rapidly on the unrestricted ranges of the West, until over-crowded conditions began to be felt. This rapid increase of stock was followed by the return tides from west to east of the trail herds. Large herds, starting in Texas, grazed their way across unfenced miles of range land towards eastern markets. Later, with the establishment of land ownership and the advent of the railroads, the trail herd system disappeared. The confining of individual herds to restricted areas followed chiefly as a result of overcrowded conditions and the disappearance of native grasses. The first major warning of range depletion came in the winter of 1886, when many of the large cattle companies of the Northwest suffered bankruptcy due to the starvation of large numbers of cattle. Later the Southwest experienced the same results.

These heavy losses of cattle offered a favorable opening for the entrance of the sheepman and his herds. On ranges where the native grasses had been removed cattle could no longer survive. The remaining trees and shrubs of such ranges offered good browse for sheep. Bands of sheep further stripped the vegetation left by the cattle. During this time the bitter competition between cattlemen and sheepmen resulted in the well-known "Range Wars". Each blamed the other for the depletion of the ranges. Many ranges have now been depleted to such an extent that even sheep can no longer survive on them. Goat herds have supplanted the sheep on such ranges, only to clean up the remaining vegetation. The changes from cattle to goats have been accompanied by a steady regression of many range covers. Ranges which once had a potentially high grazing capacity are gradually falling under the classification of marginal lands.

Such was the progress of range depletion until the government placed a curtailment on open ranges by first developing the protected national parks. The main purposes for establishing the National Parks System were based upon watershed protection and forest preservation. The present conservation programs are attempting to return the producing power of such disintegrated lands. So far, reclamation programs have dealt chiefly with the problems of vegetation losses and soil losses by erosion. Little consideration has been given to the more latent losses - losses of plant nutrients from the soil.

Since the study of plant nutrients in itself involves many intricate problems, the scope of this paper has been limited to a preliminary survey of the nitrate phase as a part of a single nutrient factor. It is hoped that this work will lead to a study of the other forms of nitrogen and finally to the other plant food elements in their relation to range management.

DESCRIPTION OF PLOTS

The site selected for the establishment of the experimental plots was chosen in the upper mesa and foothill belt of the Santa Rita Range Experimental Station. This choice was based upon the dense, even vegetation cover which is in direct contrast with the scarcity of vegetation at the lower elevations of the Reserve. This region was visibly subject to different intensities of grazing. The fence which divided the slightly grazed adjacent pasture* from the one in which the fertilizer plots were located marked a decided difference in grazing plants. In comparing the aspects of the experimental pasture with the adjacent pasture the experimental pasture showed a greater predominance of annual grasses. These chiefly included the annual species of six weeks triple-awn grass (Aristida adscensionis) and annual six weeks needle grama (Bouteloua aristidoides). The scattered perennial grasses included such species as: slender grama (Bouteloua filiformis), triple-awn grass (Aristida divaricata), Rothrox grama (Bouteloua rothrockii), Texas timothy (Lycurus phleoides), and others. The adjoining pasture was just the reverse, in that its plant cover was composed of a predominance of perennial grasses including such species as: slender grama,

*The word "pasture", when used in this paper, signifies a definitely fenced unit of range.

Rothrox grama, black grama (<u>Bouteloua eriopoda</u>), triple-awn grass, tanglehead (<u>Heteropogon contortus</u>), and cotton grass (<u>Valota saccharata</u>). The significance of the vegetational differences between these two pastures can be realized by the fact that the experimental area has been subjected to year-long grazing, while the adjacent pasture has been protected against grazing as a reserve during periods of drought. The prevalent annual grasses of the year-long grazed area is a prominent system of destructive cropping (12), for, as Sampson has pointed out, the most palatable plants - in this case the perennial grasses - are the first to decline under heavy use. The apparent sensitivity of this area to different intensities of grazing made it suitable for the location of the fertilizer plots.

Two fertilizer sets, each set consisting of one fertilizer plot and one check plot, were marked off on the most homogenous location of the area. One set was fenced against stock, while the other was left open to grazing. Within the exclosure which was erected July 24, 1935, two plots were staked off next to each other, measuring five by twenty meters. In Figure I the photograph shows the condition of enclosed plots shortly after the time the fertilizer application was made. The plot to the left of the stake is the check plot, for which the abbreviation used hereafter will be New CX-Chk (new cattle exclosure check plot), while the

Figure I. Plots of the new cattle exclosure at the time of sodium nitrate application. July, 1935.

Figure II. Condition of plots open to grazing at the time of sodium nitrate application. July, 1935.

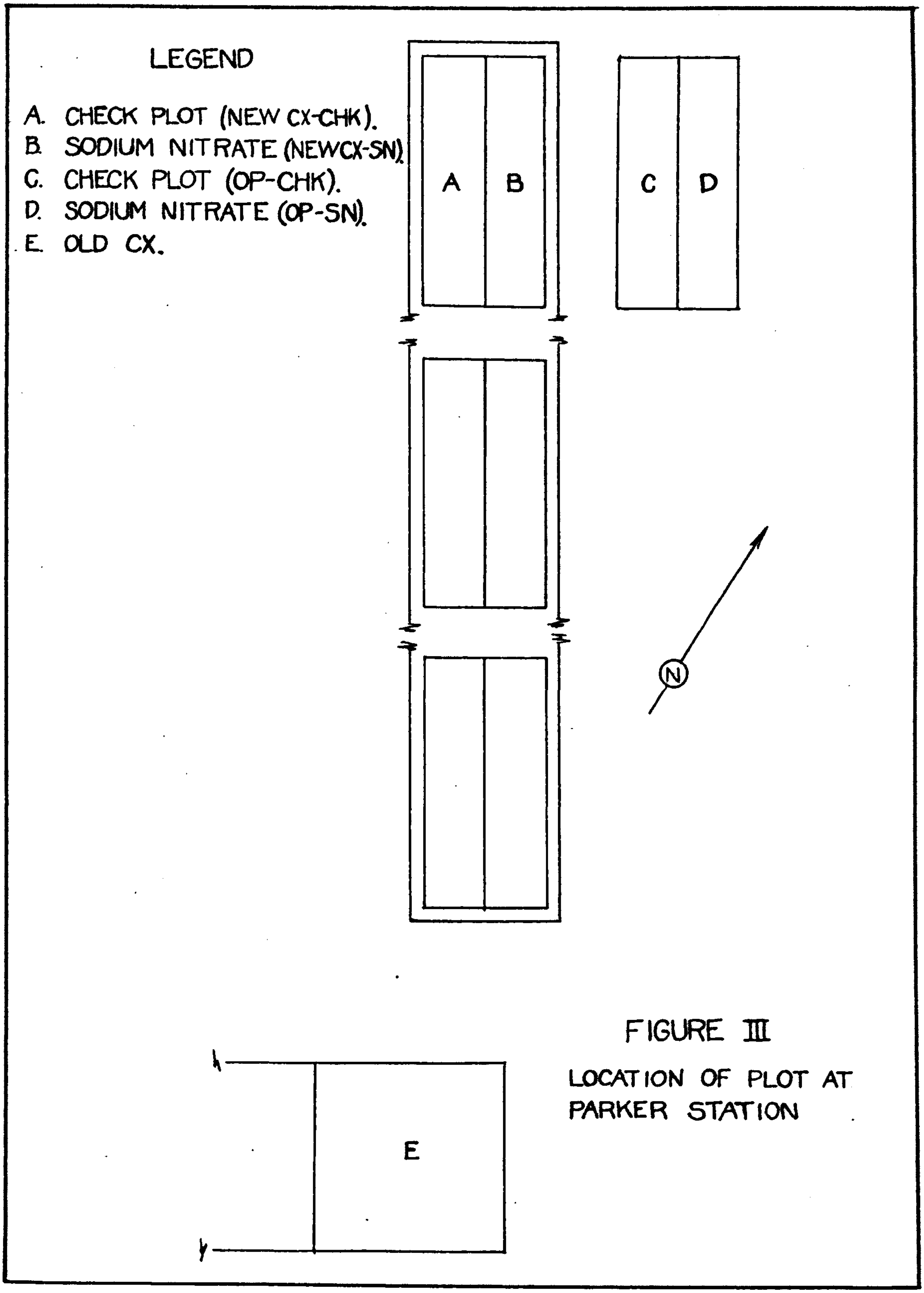


FIGURE III

LOCATION OF PLOT AT PARKER STATION

plot to the right is the sodium nitrate plot, New CX-SN (new cattle exclosure sodium nitrate plot). In the same manner, Figure II indicates the condition of the area open to grazing. The check plot is to the left of the stake in the foreground, the abbreviation for which is OP-Chk (open area check plot). To the right of the marker is the sodium nitrate plot for which is used the abridgment OP-SN (open area sodium nitrate plot). Figure III gives the relative position of the plots and exclosures to each other. Measurements were taken on this old cattle exclosure (old CX), Figure IV, in order to indicate the conservation of moisture and plant food elements on an area protected for about five years but receiving no other treatment.

EXPERIMENTAL METHODS

Soil Analysis

The success of a fertilizer application depends upon the characteristics of the soil. The favorable responses of the vegetation to sodium nitrate, as was given on this area, may not be obtained on other areas. Soils having a highly impervious subsoil or a high alkali content may not give the same results as those found on this area. The properties of a depleted range soil should be studied with respect to the presence and availability of plant nutrients before a method of fertilizing can be considered. A few of the physical and

Figure IV. Condition of old cattle exclosure. August 2, 1935.

chemical properties pertaining to edaphic conditions of the soil of this region are given as a basis for comparisons. The soil of the experimental area has been types as Huerfano (Tumacacori) Coarse Sandy Loam (15). The soil ranges from dark brown to almost black in color, being of alluvial origin and forming a fan at the base of the Santa Rita Mountains. The A horizon is quite homogeneous and reaches a depth of about five and a half feet in the locality of the fertilizer plots. Below five and a half feet is encountered a medium brown to reddish brown, loose, coarse, loamy sand to fine gravelly sand. Table I shows the percentage of the soil separates as was determined by the Bouyoucos Mechanical Analysis Method (2) and also shows the more or less uniform structure to a depth of at least five feet. From this analysis the soil should be classified as sand.

The appearance of this portion of the range during the height of its growing season indicates ideal soil conditions for the growth of grass. But the chemical analysis, as given in Table II, presents a different picture. The parts per million of total nitrogen, nitrates, and total water soluble salts are extremely low. The total nitrogen decreases with the increase of depth showing its origin to be from the small amount of organic matter and microorganic activity near the surface of the soil. The greatest amount of total water soluble salts occurs in the first foot where weathering pro-

Table I. Percentage of soil separates as determined by Bouyoucos Mechanical Analysis Method.

Foot	% Coarse Material	% separates of Screened Material Sand	Silt	Clay
1	27.8	82.1	10.5	7.4
2	29.3	83.1	10.5	7.4
3	30.3	82.1	9.5	8.4
4	33.3	82.1	9.5	7.9
5	37.2	84.1	9.0	6.9
6	37.9	85.1	9.0	5.9

Table II. Chemical soil analysis, results in parts per million.

Foot	Total Nitrogen	Nitrates	Total water soluble salts	PO_4 soluble in CO_2 water
1	280	trace	55	7.0
2	260	"	45	4.2
3	200	"	45	4.0
4	140	"	45	4.0
5	140	"	45	2.6
6	100	4	45	3.3

cesses are most pronounced. The phosphates also decrease with the depth. The fact that the greatest amount of nitrate nitrogen is found in the sixth foot may be accounted for by the leaching of this soluble salt to this level. As is indicated by the graphic representation of soil profiles (Figure V), rapid leaching is an important property of this soil, and as will be shown later, leaching combined with grazing has been the chief factor resulting in the soil deficiencies encountered here. The figures of both Table I and II are the results of an analysis of soil samples taken from the general area.

In spite of the deficiency of plant food elements, this soil has the beneficial characteristics which allow it to absorb and hold moisture readily. Its sandy nature renders the few plant resources present easily accessible. From the physical properties of the soil it can be understood why the experimental area was quite sensitive to different intensities of grazing. This fits in well with the problem.

Soil Nitrate Measurements

The first application of ten pounds of sodium nitrate to the five by twenty meter plots was made July 25, 1935. As a step in even spreading, the salt was thoroughly dissolved in a drum of water and applied by means of a hand sprinkling can. It was found that this method gave a much more even distribution of the fertilizer over the surface of the plot than a spreading of the dry salt. After the plot had been covered, water was sprayed over it in order to prevent the vegetation from being burned. The two plots, one within the new cattle exclosure (new CX-SN) and one open to grazing (OP-SN) were fertilized just after the summer rains had started, and just before the initial appearance of the summer growth.

Soon after the application of the sodium nitrate was made, soil samples from each of the areas were taken from one to five feet by the aid of soil tubes. It was necessary to drill two cores for each plot in order to get a 100 gram sample for the nitrate test. The soils were then air dried and screened free of the coarse material. One hundred grams of soil were weighed out accurately and tested for nitrates following the phenol-disulfonic method (9, 3).

The general procedure of the test was followed closely, with one modification. The 25 cc aliquots of the filtered 1:5 water extract were evaporated in a gas oven, the standard method of evaporation being over a steam bath.

The first soil profile of the unfertilized old cattle exclosure, Figure V, disclosed only a trace of nitrate nitrogen in the first foot, the trace being less than five parts per million. Likewise the samples taken to the fifth level gave little indication of the presence of nitrates. The profile representing the samples for the following week,

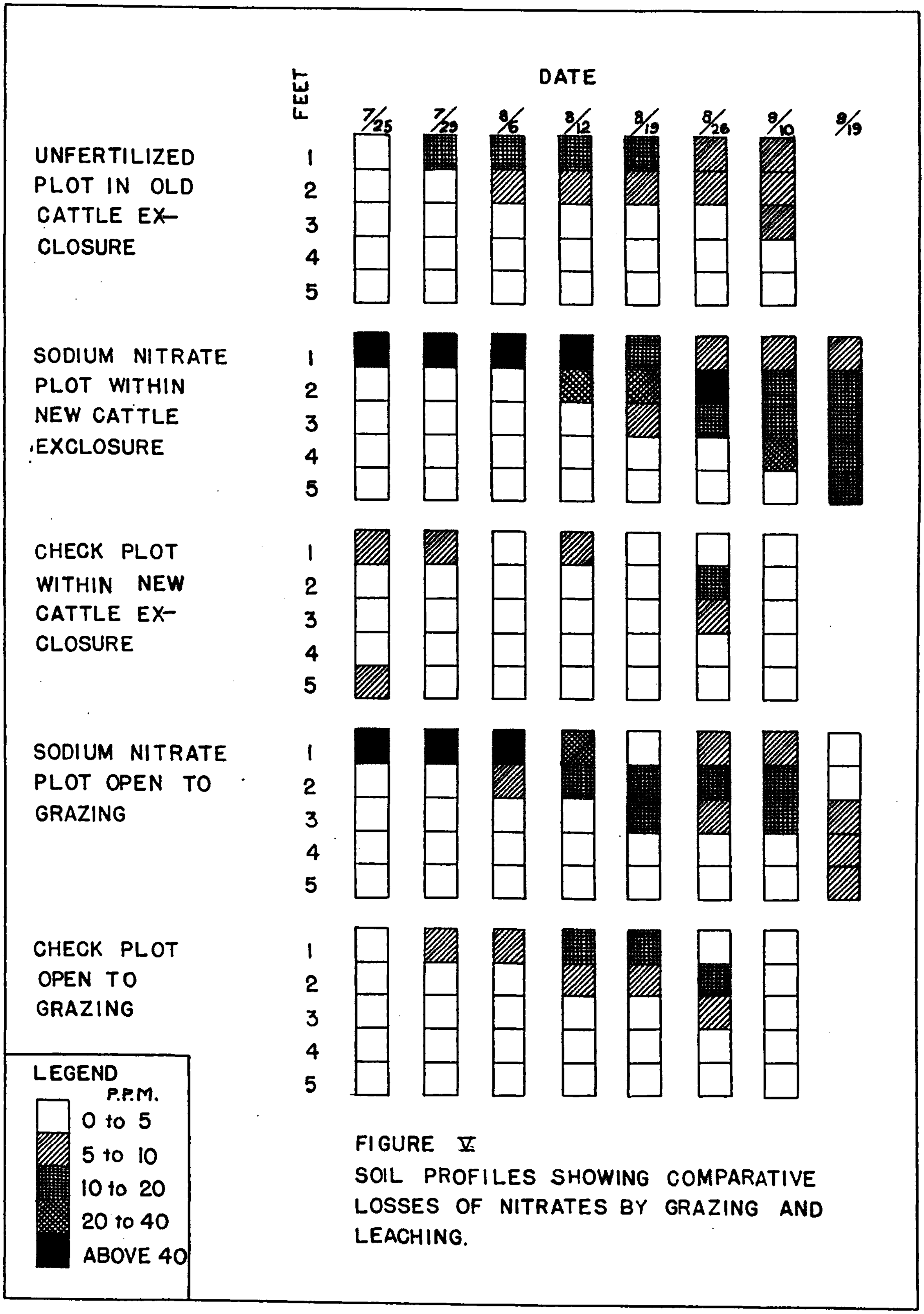


FIGURE V

SOIL PROFILES SHOWING COMPARATIVE LOSSES OF NITRATES BY GRAZING AND LEACHING.

taken July 29, showed ten to twenty p.p.m. nitrates in the first foot, a marked increase over the previous week. The nitrate determinations for the soil samples taken August 6 revealed not only the ten to twenty p.p.m. in the first foot, but also five to ten p.p.m. of nitrates in the second foot. Subsequent determinations showed that the nitrate nitrogen was restricted to the upper two feet, up to the 10th of September, when nitrates were found in the third foot.

The significance of the nitrate measurement on this area which has been under protection for about five years becomes evident when its profiles are compared with the check plot within the new cattle exclosure and with the check plot of the area open to grazing. The nitrate nitrogen of this old cattle exclosure was undoubtedly derived from the organic matter supplied by the ungrazed vegetation. The profile of July 25 probably showed no nitrate nitrogen, as the microorganisms of the soil had not yet acted upon the organic matter supplied by the crop of the previous year. This was probably due to the dry conditions of May, June, and the first part of July. As the moisture of the first summer rains penetrated the soil, the activity of the microorganisms on the dead grass stalks was initiated, resulting in a small supply of nitrate nitrogen. Another significant fact arises from comparison of the old cattle exclosure with the plots of the new cattle exclosure and open areas, in that the effects of leaching are much reduced on the old cattle exclosure. The interpretation of the soil profiles not only points to a conservation of nitrate nitrogen in the upper three feet of the soil, but also to the conservation of moisture (Table III). Therefore, the results presented by the data taken from this old cattle exclosure should be kept in mind as a possible means of not only returning the nitrates to the soil, but also of slowing up their loss by rapid leaching.

The soil profiles of the sodium nitrate plot within the new cattle exclosure show that the fertilizer did not descend to the second foot level for three weeks. After three weeks it had reached the second foot. The appearance of more than forty p.p.m. of nitrates in the second foot of the sixth profile (August 26), which was much more than the preceding week, was due to the second application of sodium nitrate on August 24. The shower of the 25th carried the added fertilizer into the second foot. A rapid drop of the fertilizer toward the fifth foot level occurred from August 26 through September 19. The gravitational moisture which had accumulated from the previous rains resulted in this rapid downward passage of the sodium nitrate.

An examination of the profiles collected from the sodium nitrate plot open to grazing disclosed a similar situation to that of the sodium nitrate plot of the new cattle exclosure. The fertilizer was removed from the first two feet of the sodium nitrate plot of the open area much more rapidly than from the sodium nitrate plot of the cattle exclosure. Since the depth of the leaching appeared to be about the same for the two plots, it seems possible that this loss was brought about through the removal of vegetation by grazing. It is probable that the sodium nitrate plot within the cattle exclosure permitted the soil to absorb and retain more moisture, thus slightly reducing the effect of leaching. The fact that the salts appear to have been retained in the upper two feet of the sodium nitrate plot of the cattle exclosure while they have been lost from the upper two feet of the sodium nitrate plot of the open area may be explained by the constant removal of forage from the latter. The plants which have been subjected to constant cropping were kept in a vegetative condition and therefore continued their demands upon the plant food elements of the soil. The plants of the sodium nitrate plot within the cattle exclosure withdrew much less nitrates as they approached maturity. Furthermore, the more dense vegetation covering the fertilized plot within the exclosure may have retarded rapid leaching and thus slowed up the downward movement of the salt from the upper two feet. The comparison of the sodium nitrate plot in the new cattle exclosure with the sodium nitrate plot of the open area gives a fair indication of the loss of plant nutrients from the soil by grazing.

The check plots of both the exclosed and open areas disclose minute quantities of nitrates in their untreated soils. They present a fair picture of the soil reactions occurring on a range under heavy use when compared with the old cattle exclosure and the fertilized plots. The irregular appearance of nitrates in the profiles of both check plots may have been caused by the local droppings of animals grazing this area before the plots were erected. Since definite portions of the plots were marked off for soil sampling, localities affected by droppings could not be avoided.

To summarize the results as presented by the soil profiles of the various plots: The old exclosure showed fair and constant amounts of nitrates as compared with the check plots which had been recently subjected to grazing. This points to rotational grazing as a possible means of conserving soil nitrates. From the comparison of the protected nitrate of the new cattle exclosure plot with the unprotected nitrate plot of the open area, the losses due to both grazing and leaching are exemplified.

Osmotic Value Measurements

Soon after the application of sodium nitrate to the plot open to grazing, it was noticed that the stock showed a distinct preference for the perennial grasses. Weekly osmotic value determinations were introduced as an attempt to estimate the physiological changes occurring within the plants, which warranted such an increased palatability. The reason for this increased selective grazing was first attributed to a greater succulence produced by the sodium nitrate upon the vegetation. Succulence refers to the quantity of plant sap. Osmotic value determinations, on the other hand, indicate the concentration rather than the amount of the cell sap. The data presented here represent only the increased cell sap concentrations of the fertilized plants. Mallery's cryoscopic method (7) was used to determine the osmotic values of the collected samples from the various plots. The tables of Harris and Gortner (4, 5) were used to express the osmotic values in atmospheres pressures.

The data representing the osmotic values were taken on Bouteloua filiformis. This perennial grama was one of the most intensively grazed species of the area. For this reason, it was selected as a representative species which might show a close relationship of any apparent increases of cell sap concentrations to fertilizing and intensified grazing. The perennial species on the fertilized plot of the open area were much more heavily grazed than those of the adjoining check plot. The predominating annual grasses of the fertilized plot showed no added attractiveness to stock over the annual grasses of the check plot. Such ephemeral species as annual six-weeks grama probably stored no more appreciable food products when fertilized with sodium nitrate than did those annual plants of the check plot. The cattle therefore showed no increased preference for the annuals of the fertilized plot over those of the check plot. Often uprooted annuals were found where an animal had accidentally pulled up a plant and then refused to eat it. In the case of perennials, when the vegetative parts were removed by cropping, the plant continued to produce new leaves and newly stored products. This process of regeneration, combined with the ability to store greater amounts of food materials, seems to render the perennial grasses more palatable than the annual grasses, and accounts for this selective grazing as shown by the cattle. The perennial grama *Bouteloua filiformis* was selected as the best representative species for these measurements as it was the most highly grazed.

Osmotic value determinations made on the plants subjected to fertilizer show higher cell sap concentrations than those made on the plants of the unfertilized check plots. Cell sap concentration depends upon two essential factors, namely: the water present in the plant tissues and the amount of dissolved substances (14). This solvent-solute ratio of the cell sap solution may vary with the degree of soil moisture, the rate of transpiration, and the amounts of synthesized materials within the cell. These factors should be kept in mind during the examination of the following graphs.

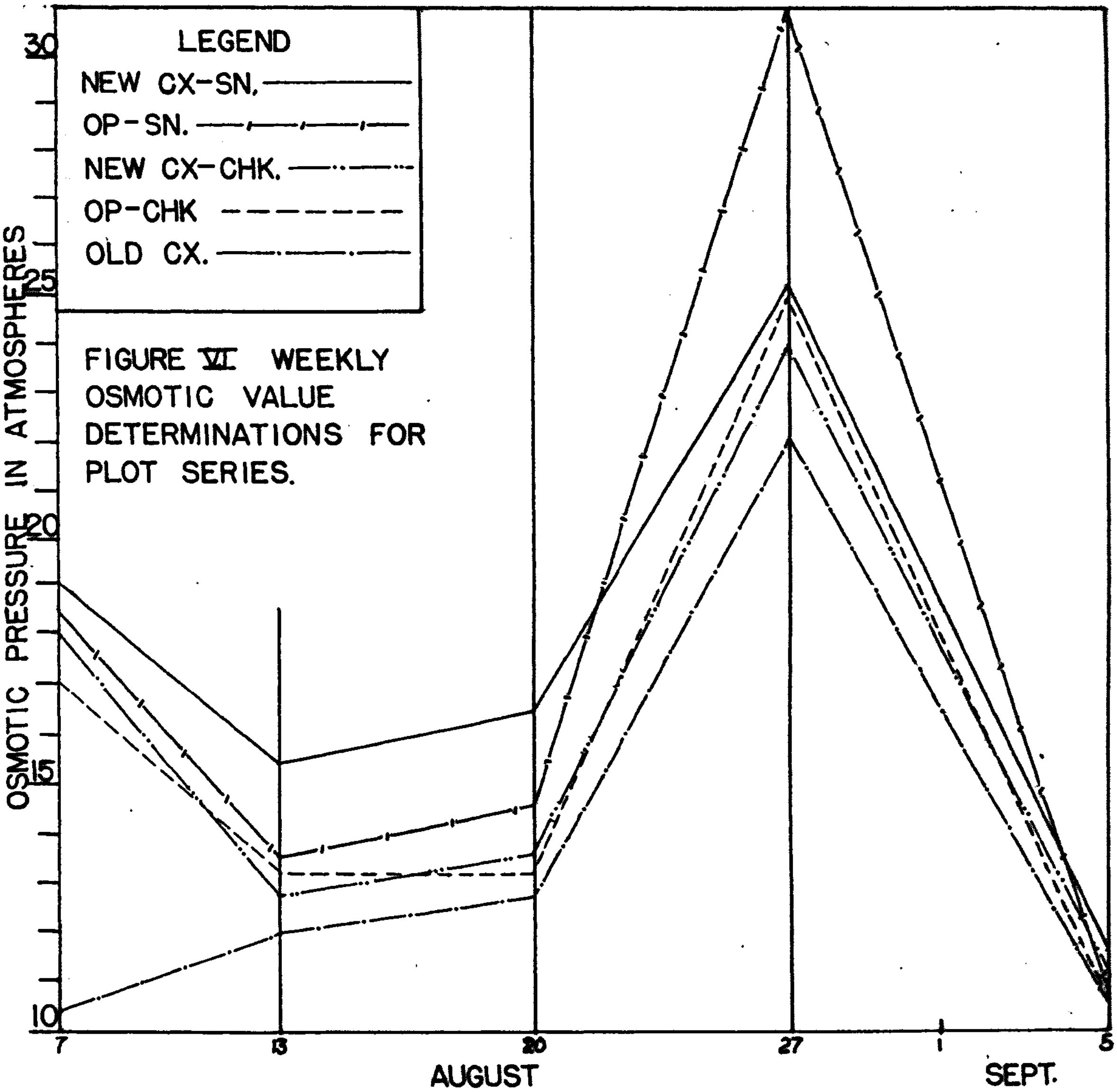
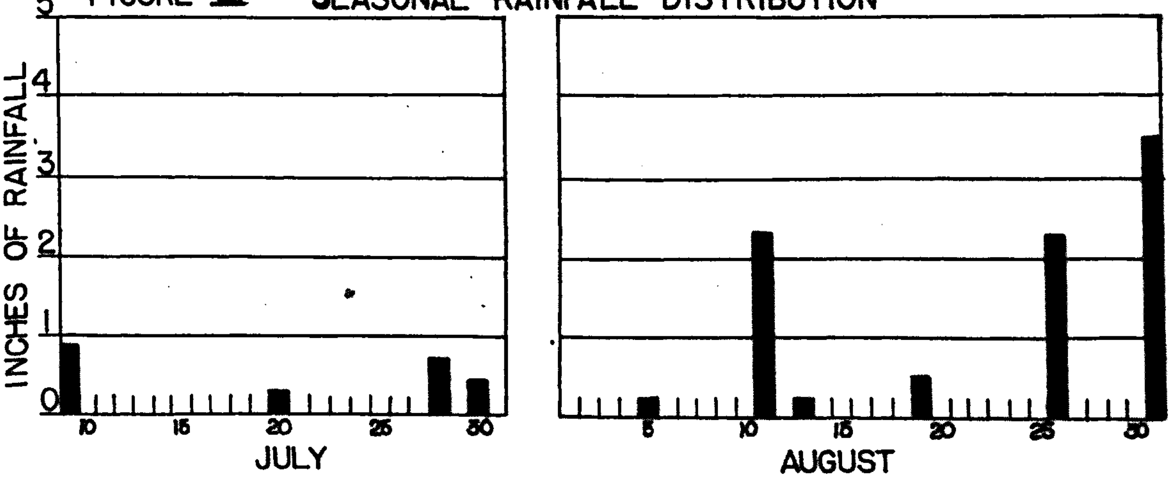


FIGURE VI WEEKLY OSMOTIC VALUE DETERMINATIONS FOR PLOT SERIES.

FIGURE VII - SEASONAL RAINFALL DISTRIBUTION



The osmotic values in terms of atmospheres pressure are represented by the graph in Figure VI. An investigation of this graph discloses the fact that the extracted plant sap of the fertilized plants gave higher osmotic value determinations than did the plants of the check plots. The grass samples collected from the sodium nitrate plot of the open area (OP-SN) gave the maximum osmotic value reading on August 27 of 31 atmospheres. From August 7 to September 5 the weekly determinations made on the plants of the fertilized plots gave values higher than those run on the plants of both protected and unprotected check plots. The sodium nitrate plot of the area open to grazing gave lower readings on August 7, 13, and 20 than the readings taken from the fertilized plot of the protected area (new CX-SN). From August 20 to September 5 the OP-SN plot yielded osmotic values higher than those of the sodium nitrate plot in the new cattle exclosure (new CX-SN). No reliable answer can be offered here explaining the reasons for this variable trend. In view of the fact that the vegetation of the open fertilized plot was kept closely grazed, it seems possible that the plants might have been subject to higher transpirational water losses per unit leaf area than the plants of the protected area. Also regenerative processes might have resulted in a higher content of osmotically active substances of the cropped plants. If this were the case, such factors would increase the osmotic values of the fertilized plants open to grazing. This is offered only as a suggestion and has not been substantiated experimentally. The lower readings of the samples taken from the fenced areas indicate a higher water content of the cell sap. The osmotic values of the sodium nitrate plot of the open area (OP-SN) are lower than the readings obtained from the fertilized plot of the cattle exclosure (new CX-SN) for August 7, 13, and 20. The maximum reading for the sodium nitrate plot within the cattle exclosure reached a value of about twenty five atmospheres, a lower value than that obtained for the sodium nitrate plot of the open area. The fertilized plots of both open and enclosed areas produced higher osmotic values on <u>Bouteloua filiformis</u> than did the check plots of these same areas. This implies that sodium nitrate induced an increase of the solutes in the solute-solvent ratio of the plant sap and consequently raised the osmotic value of the fertilized plants over the plants of the check plots. On this basis, it seems probable that the preference of the stock for the fertilized perennial grasses may have been associated with an increase of such synthesized products as proteins rather than increased succulence. This is substantiated by the feeding analysis.

The plotted data for the check plots of both enclosed and open areas follow rather closely the same trend. The check plot of the new cattle exclosure (new CX-Chk) gave a higher osmotic value reading on August 7 than the check plot of the open area (OP-Chk). On August 13 and 27 the values obtained from the check plot within the new exclosure fell below those of the open check plot. This again points out the fact that under grazing certain factors increase the osmotic values. In the case of the grazed check plot the top growth was not as heavily cropped as that of the unprotected fertilized plot. There was not the ostensible difference of density and top growth between the two check plots as there was between the sodium nitrate plots of cattle exclosure and open area. That the check plots rendered samples with lower osmotic values than the fertilized plots remains significant, even though the check plots of both enclosed and open areas showed no individual trends.

Osmotic value determinations for <u>Bouteloua filiformis</u> growing within the old cattle exclosure, an area under protection for several years, (Old CX) offered indicative evidence of the role played by such afctors as transpiration, soil moisture, and soil nitrates. This old cattle exclosure, in contrast to the rest of the range open to year long grazing, supported a predominance of perennial species. Few annual species were to be found within this exclosure. The tall, dense stand of perennial grasses offered a resistance to water losses by reducing the desiccating effects of sunshine and air currents. Apparently the accumulation of an organic litter conserved the soil moisture more efficiently throughout the growing season. This is evidenced by the percentages of soil moisture for the various plots as presented in Table III:

Table III. Percentage of Moisture for First Foot of Fertilized and Check Plots.

Plot	8/12	8/19	8/26	9/10
Old CX	6.95	7.14	7.80	4.17
New CX-SN		5.98	8.05	2.56
New CX-Chk		6.28	7.98	3.08
OP-SN	6.00	6.30	8.03	2.95
OP-Chk	4.48	6.10	7.95	3.03

The old cattle exclosure gives the highest and most consistent percentages of soil moisture. Also the soil nitrate concentration, although greater than that of the open range Figure V), was not sufficient to increase markedly the synthesized nitrogen produced of the plants and similarly the osmotic value. The higher soil moisture content and a low soil nitrate content resulted in a high water content of the plants of this area. Conversely, with the accumulated water of the solute-solvent ratio, the osmotic values for the perennial grama of this area were lower than any of the readings taken from the other plots.

A correlation of the seasonal osmotic value trend with the rainfall (Figure VII) indicates that the rise and fall of these values were governed chiefly by the life cycle of the plant. However, the amount and time of precipitation does seem to be reflected on the osmotic value measurements. Following the heavy shower of August 10, and the preceding showers as well, the osmotic values reached a minimum. This indicates that the resulting high moisture of the soil increased the water content of the plant tissues and thus lowered the osmotic values. Likewise, the drop of cell sap concentration followed closely the storm of the 26th of August.

From the foregoing discussion it may be concluded that the application of sodium nitrate increased the osmotic value of Bouteloua filiformis. The higher values of the grazed plots of the open area were probably due to certain factors introduced by grazing. The low readings obtained from the old cattle exclosure resulted from a conservation of moisture. Furthermore, it was pointed out that the high preference of the stock for the vegetation of the open fertilized plot might be attributed to the increase of the chemical make-up of the plant induced by the sodium nitrate.

Plant Analysis

Orr (10) has pointed out that "if cattle are grazed on poor pastures with low mineral contents the forage selected by the animals (with a free choice) is richer in minerals than that left uneaten. Animals thus have a natural instinct which leads them to crop the plants having the highest food value". Orr also recognized that cattle are more likely to suffer from inorganic deficiency than from an insufficiency of proteins and fat forming substances within the plant. In this experiment, however, the preference of the cattle for the fertilized cover seems to be due only to a nutritional increase of protein content, unless some of the inorganic nitrate existed as such within the plant. (Table IV) A comparison between treated and untreated plots shows a difference which is not alone a matter of increased quantity, but also of an increase in quality. These facts are pointed out by the following plant analysis.

A plant analysis was initiated for the purpose of further obtaining measurements of the physiological responses of the plants treated with sodium nitrate and for comparing the feeding value of fertilized and unfertilized plots. Again, the sampled species for these measurements was the heavily grazed perennial grama, Bouteloua filiformis. Two clippings were taken, the first on August 16 and 17 and the second on August 27. The first cropping was made just prior to the flowering and feeding stages, while the second was taken during the period of seed formation. Only the vegetative parts were taken for sampling, the inflorescences and seed stalks being removed. The samples were cut to within an inch of the soil's surface and placed in muslin sacks to air

Table IV. Compared feeding analysis for *Bouteloua filiformis* samples from plot series.

Plot	Moisture	Crude Protein	Fat	CaO	Ash	P_2O_5
Aug. 16-17						
Old CX	4.05%	12.0%	2.43%	.36%	7.17%	.62%
New CX-SN	2.76	19.5	3.07	.57	7.97	.82
New CX-Chk	3.27	12.2	2.92	.52	8.67	.84
OP-SN	3.03	20.6	1.64	.50	8.37	.86
OP-Chk	4.55	12.9	1.91	.56	8.62	.87
Aug. 27						
New CX-SN	3.43	11.12	2.30	.38	7.60	.63
New CX-Chk	3.17	7.19	2.74	.22	7.94	.65
OP-SN	Heavy grazing rendered no available sample					
OP-Chk	3.25	8.19	2.92	.25	8.00	.67

dry. The analytical determinations were obtained through the courtesy and cooperation of the Agricultural Chemistry Department of the University of Arizona.

Table IV presents the comparative compositions of the slender grama grown on the different plots. Here it can be seen that the greatest deviations occur in the percentages of protein matter in the plants of the fertilized plots. The lowest protein contents were found on the samples collected August 16 and 17 from the old protected cattle exclosure (old CX), the check plot of the new cattle exclosure (new CX-Chk), and the check plot open to grazing (OP-Chk). Fertilized plots of the new cattle exclosure (new CX-SN) and of the open area (OP-SN) yielded plants having much higher percentages of crude protein. The difference in plant proteins between the fertilized and the check plots of the new cattle exclosure was about 7.3%, while for the fertilized and unfertilized plots open to grazing there was a difference of 7.7%.

The samples collected from the fertilized cover within the new cattle exclosure on August 27 gave a higher protein composition by about 3.83% than that obtained from the samples growing on the unfertilized check plot. Heavy grazing of the sodium nitrate plot of the open area made the clipping of a sizable sample impractical. It was possible, however, to obtain a sample of about 500 grams from the much less grazed check plot. Since it was not possible to make a collection from the sodium nitrate plot open to grazing, no comparison can be made with the analysis of the check plot. This gives further evidence of the higher preference of the animals for the plants of the fertilized plot.

By a further examination of Table IV it can be seen that the treatment with sodium nitrate stimulated no gains in the other analyzed constituents. The percentages of moisture, lime, phosphate, and ash remained quite constant for the first clipping. The samples gathered on August 27 also gave fairly uniform percentages of moisture, lime, phosphate, and ash, but the composition for this set of samples were of a much lower percentage than those obtained on the first set of croppings.

The analysis for fats showed an inconsistency of percentage composition on the cropped samples of August 17. Both fertilized and check plots of the open area gave values much lower than the plots of the protected area. The fat percentages obtained from clippings of the sodium nitrate and check plots of the new exclosure were 3.07% and 2.92%, respectively. The sample taken August 27 from the open check plot gave a percentage composition of 2.92, a value greater than the composition of the first analyzed sample by 1.01%. No explanation can be offered for the cause of this deviation.

Quadrat Studies

Vegetational measurements presented so far have dealt with the compared qualitative responses of fertilized and unfertilized plots within the exclosure and on the open area. The quadrat being one of the commonest methods of studying the summation of factors governing range conditions (8), was used as a means of determining quantitative changes induced by fertilization and protection. Permanent meter quadrats were measured off on the sodium nitrate plots and check plots of both open and fenced areas. The usual procedure was followed in establishing these meter squares, the boundaries being permanently marked with iron pegs. The uniformity of the plants covering the general area selected for the site of the series facilitated the location of the quadrats with respect to representative vegetation and even grazing. Besides listing the typical species, this method was used to estimate changes in the numbers and areas of individual plants.

A list of the number of plant individuals and their respective areas or numbers of stems was made on July 31 and August 26 for the series of plots. From the figures of Table V, the inventory implies a predominance of annual grasses over perennial grasses and weeds. The annual species included annual triple-awn grass (*Aristida adscensionis*),

Table V. Permanent meter quadrats on different plots showing number of individual plants.

Species	CX-SN 7/31	CX-SN 8/26	CX-Chk 7/31	CX-Chk 8/26	OP-SN 7/31	OP-SN 8/26	OP-Chk 7/31	OP-Chk 8/26
Annual grasses								
Aristida adscensionis	38	87	49	75	175	82	199	116
Bouteloua aristidoides	503	926	542	1043	1945	2282	1285	1389
Panicum sp.		4		4	1	1	1	16
Perennial grasses								
Aristida divaricata	20	24	16	16	22	25	18	20
Bouteloua filiformis	21	24	43	45	25	32	16	15
Lycurus phleoides						5		1
Valota saccharata	1							
Total	583	1065	650	1183	2168	2427	1519	1557
Difference	482		533		259		38	
Weeds								
Aristolochia sp.	1							
Franseria sp.	14							
Kallstroemia grandiflora				12				
Moluga sp.		22		7				
Sida diffusa	3			1				
Solanum elaeagnifolium	3							1
Unknown sp.		10	2	6				
Total	21	32	2	26				1
Difference	11		24					

six weeks grama (Bouteloua aristidoides), and an annual species of Panicum. The enumerated perennial grasses were composed of a perennial triple-awn grass (Aristida divaricata), slender grama (Bouteloua filiformis), cotton grass (Valota saccharata), and Texas timothy (Lycurus phleoides). The listed weeds formed a small portion of the total composition of the quadrat.

A comparison between the number of perennial and annual plants for the plots of the new cattle exclosure shows a perennial composition of about 10% for the first census on July 31. Between July 31 and August 26 the annual grasses increased to such a degree that the perennial species composed about 5% of the total plant population within the boundaries of the quadrat. The compared figures for the plot-quadrats of the open area show a rather constant perennial percentage of from 2% to 3% of the total populations. For a comprehensive understanding of the data obtained from the permanent quadrats it is necessary to keep this high annual-perennial ratio in mind.

An investigation of the figures given in Table V shows an increase of 482 individual grass plants between inventories for the quadrat of the sodium nitrate plot within the new cattle exclosure (New CX-SN). There was an increase of about 533 individuals on the check quadrat of the cattle exclosure (CX-Chk) between the listings of July 31 and August

26. The quadrat of the grazed fertilized plot on the open area (OP-SN) added 259 grass plants between the two listings, while the grass population of the check quadrat on the open area (OP-Chk) increased by only 38 individuals. It is apparent that the total number of plants of the fertilized quadrat within the cattle exclosure is less than the total number of plants of its corresponding check quadrat and that the added number of grass individuals between July 31 and August 26 was less for the sodium nitrate quadrat than for the check. The figures for the plot-quadrants of the open area present just the opposite. The quadrat of the fertilized plot excelled the quadrat of the check plot both in population and individual plant areas between the first and second listings. The attenuated population of the sodium nitrate plot within the cattle exclosure may be explained as resulting from the plant competition induced by the application of sodium nitrate. It was observed at the time of the listing that the plants had increased markedly in diameter on the fertilized plots. This is verified by the measured areas of the perennial grasses and the data on the harvested dry weights. Where the cover has been kept closely cropped as in the case of the open fertilized plot, competition has not curtailed the plant population. This may explain the larger number of individuals of the quadrat on the open fertilized plot as compared with the quadrat of the adjoining open check plot.

Grazing in this case modified the factor of competition.

In the case of the perennial grasses, the quadrat of the sodium nitrate plot within the new cattle exclosure added seven new individuals between July 31 and August 26. During the same period the check quadrat within the same exclosure gained two plants. The quadrat of the open fertiliger plot showed an increase of 14 perennial plants. Only three new individuals were added during this time to the quadrat of the open check plot. The increases measured by the quadrats under treatment over the check quadrats even in the small ratios of 7 to 2 and 14 to 3 is quite significant. If these meter samples gave a true representation of the 5 x 20 meter plots, the magnification of such increases becomes important. However, over-emphasis can be placed upon the perennial gains in numbers of individuals on the results of the first year. Data collected from the quadrats of the second year should show important gains if the treatment of the plots with sodium nitrate has increased the crop yield and likewise the viability of the seeds. The study of the annual ruderal grasses becomes important when compared with the percentage of perennial grasses. Second year quadrat records should detect progressional changes in succession, induced by fertilization and protection.

The figures of Table VI present the measurements recorded on the size of the individual plants. These measure-

Table VI. Permanent meter quadrats on different plots showing area in sq. cm. and number of stalks*.

Species	CX-SN 7/31	CX-SN 8/26	CX-Chk 7/31	CX-Chk 8/26	OP-SN 7/31	OP-SN 8/26	OP-Chk 7/31	OP-Chk 8/26
Perennial grasses								
Aristida divaricata	42	160	23	64	49	51	64	73
Bouteloua filiformis	27	117	70	193	61	153	33	71
Lycurus phleoides						5		1
Valota saccharata	6	6						
Total	75	283	93	257	110	209	87	145
Difference	208		164		99		58	
Weeds								
Aristolochia sp.	7							
Franseria sp.		18						
Kallstroemia grandiflora				5				
Moluga sp.		22		7				
Sida diffusa	3			1				
Solanum elaeagnifolium	3							1
Unknown sp.		10	2	7				
Total	13	50	2	20				1
Difference	37		18					

* Areas of perennial grasses are given in sq. cm., while the sizes of weed individuals are recorded in total number of stalks.

ments were taken from the bases of each of the plants. Since the annual grasses complete their life cycle within a single season, it was considered unnecessary to calculate their individual areas. The annual triple-awn grass and the six-weeks grama rarely extended their basal areas beyond a single square centimeter. For these reasons no area determinations were taken on the annual grass species. From the preceding discussion on quadrat studies it was disclosed that only slight increases in the number of perennial individuals were recorded, the highest increases occurring where sodium nitrate was applied. The figures of Tables V and VI disclose the fact that the 42 perennial plants growing within the quadrat of the sodium nitrate plot in the cattle exclosure plot (CX-SN) covered an area of about 75 square centimeters. The check quadrat within the cattle exclosure (CX-Chk) gave a total number of 59 perennial grass plants having a total area of 93 square centimeters as determined by the inventory of July 31. By August 26 the number of plants had increased to 61, while the total area had enlarged to 257 square centimeters. For the quadrat of the open sodium nitrate plot (OP-SN) the number of perennial grass plants multiplied from 47 to 62, while their respective areas increased from 110 to 209 square centimeters. Although there was an addition of only 3 individuals to the 34 originally listed perennial grass plants within the quadrat of the open check plot, their total area expanded from 87 square centimeters to 145 square centimeters. From these figures it can be seen that the perennial grasses of the sodium nitrate plot fenced against stock registered an increased area of about 208 square centimeters, while the check quadrat of the same exclosure resulted in a gain of 164 square centimeters between the first and second counts. An increase of 99 square centimeters was recorded on the quadrat of the fertilized plot open to grazing, while its respective check quadrat showed an increase of 58 square centimeters between July 31 and August 26.

From these figures it is apparent that the extension of the grass areas has probably resulted from two factors - namely, fertilization and protection against cropping. The fertilizer plots of both fenced and open range showed increases of plant areas over their corresponding check plots. Likewise, the plots under protection disclosed an average enlargement much greater than the fertilized and check plots open to grazing. This was true even though the average number of perennial grasses listed by both quadrats of the cattle exclosure were fewer than those listed on the quadrats of the sodium nitrate and check plots of the open area.

Little significance has been placed on the number of weed species and their respective stock numbers, as presented in Tables V and VI. These subdominant species were registered by the first listing of July 31. By the second listing on August 26, these individuals had either died or dried up. The average population of forbs was greater on the fertilized plots than was recorded by the quadrats on the check plots. Likewise, their total number of stems was greater on the sodium nitrate plots than on the check plots of both areas.

In general it was found from the quadrat records that the number of individuals increased on the fertilized plots, except where competition entered and limited the increases of plant individuals. This was found to be the case of the fertilized plot within the cattle exclosure where the vegetation was prootected against grazing. The fertilized plots disclosed an increase of perennial grass plants as well as an enlargement of their individual areas. Protection apparently contributed to the increases in the areas of the individual perennial grass plants.

Height Growth Studies

Individual plant growth studies were carried out over a period of about three weeks with the purpose in mind of further examining responses of range vegetation to fertilizing and protection. The short period over which these records were made and the few plant individuals used prevent the data presented in Table VI from being highly significant. However, the figures do offer several indications and for this reason have been included.

In the method employed here five plants of Bouteloua filiformis were selected and numbered with metal tags in each of the plots and within the old cattle exclosure. The number of leaves were counted and each of the plants measured on August 7, 14, and 21.

A brief review of Table VII discloses that the five plants of the old cattle exclosure (old CX) had increased from an average number of 79 leaves on August 7 to an average number of 119 on August 21, an average increase of 40 leaves. Likewise, the average height of these leaves had mounted from 5.9 inches to 11.15 inches, an average increase of 5.75 inches. The five representatives of the sodium nitrate plot within the cattle exclosure (CX-SN) increased in the average number of leaves from 70.8 to 92.8, an average addition of 22 leaves per plant. Their average heights changed from 2.55 inches to 6.70 for the three weeks period, an average increase of 4.15 inches. The five plants of the check plot within the cattle exclosure (CX-Chk) recorded an average addition of 6.6 leaves per plant between the measurements of August 7 and August 21. The first count listed an average of 51.8 leaves, as compared with 58.40 leaves as the average number recorded on August 21. Their corresponding average height growth increased from 2.30 inches to 6.20 inches, giving an added difference of 3.9 inches. An average number of 41.4 leaves were listed on August 7 for the five representative plants growing

Table VII. Height-growth studies for <u>Bouteloua filiformis</u> on fertilizer plots at Parker Station.

Plot	Plant No.	Number of leaves* 7/17	8/14	8/21	Average height** 7/17	8/14	8/21
Old CX	6	56	69	92	5.25	7.5	11
" "	7	118	142	207	6.5	10	13
" "	8	60	64	76	5.5	8	9
" "	9	94	100	114	5.25	8.5	9.5
" "	10	67	68	106	7	10.5	13.5
Average		79	88.6	119	5.90	8.9	11.15
New CX-SN	1	65	68	53	2	3.5	7
" " "	2	74	115	101	3.25	4.5	7.25
" " "	3	71	109	129	2	2.5	5.25
" " "	4	75	96	92	2.25	3.25	7
" " "	5	69	94	89	3.25	4	7.25
Average		70.8	96.4	92.8	2.55	3.55	6.70
New CX-Chk	1	43	49	54	2.5	4.5	7.5
" " "	2	53	76	70	2.25	2	4.5
" " "	3	47	61	62	2	2.5	6.5
" " "	4	50	61	34	3	4.5	7.25
" " "	5	66	74	72	2	2.5	5.25
Average		51.8	64.2	58.4	2.30	3.2	6.20
OP-SN	1	46	88	74	3	2.5	5.25
" "	2	55	90	85	2.25	2	3.5
" "	3	23	51	46	2	2.25	4
" "	4	45	65	70	2.5	2	4.5
" "	5	38	58	54	2.5	3	4.5
Average		41.4	70.4	65.8	2.35	2.30	4.30
OP-Chk	1	61	59	38	3	4	6.5
" "	2	31	29	36	3	3.5	4
" "	3	46	65	74	3.25	3	4
" "	4	33	57	39	2.25	3	5.25
" "	5	27	41	35	3	3	4.5
Average		39.6	50.2	44.4	2.80	3.25	4.85

* Number of leaves ½ inch or more in length.
** Average height taken of entire plant.

on the open sodium nitrate plot (OP-SN). By August 21 this number had increased to 65.8, resulting in an average increase of about 24.4 leaves per plant. The average length of the leaves increased from 2.3 inches to 4.3 inches, an added growth of about 2 inches.

On August 7, the five selected plants of the check plot of the open area (OP-Chk) averaged 39.6 leaves, while by August 21 the count listed an average of 44.4 leaves per plant, giving an average increase of only 4.8 leaves per plant. The corresponding length of these leaves increased from 2.80 to 4.85, an average addition of 2.05 inches per plant.

The preceding figures disclose the fact that the five selected plants of slender grama, protected against grazing for a number of years within the old cattle exclosure produced the highest average number of leaves per plant. Also the average heights of these individuals were the greatest for all the plots studied. This gives an indication of the tall, dense stand of vegetation which covered the old cattle exclosure. A correlation of this heavy stand of plants with the osmotic values and soil moisture determinations indicates further a conserved moisture supply.

Of the fenced area the five representatives of the sodium nitrate plot within the cattle exclosure averaged the next highest number of leaves per plant, and likewise gave an average height per plant second to that of the old cattle exclosure. This plot excelled its adjoining check plot in both average number of leaves and average length of leaves. These increased differences may be attributed to the influence of the sodium nitrate. Both fertilized and unfertilized plots of the cattle exclosure gave measurements higher than those of the open plots. Thus protection as well as fertilization tended to increase the average number of leaves and height of growth.

Dry Weight Measurements

On December 7 the well-cured crops of both fertilized and unfertilized plants within the cattle exclosure were harvested. An equal sized portion, about five meters square, of each plot was clipped and weighed accurately. Figure VIII demonstrates the compared size of the harvested vegetation from both plots. It is visibly conspicuous that the harvest of the fertilized plot, to the left of the picture, is much larger than the crop of the check plot, to the right. The net dry weight obtained from the grass produced by the fertilized plot equaled 5,487.2 grams. The harvest of the check plot weighed 2,131.2 grams. A difference of 3,356.0 grams represents the increased amount of dry matter yielded by the fertilized plot over the amount of dry matter grown on the check plot, an increase of 167%.

Figure IX presents the appearance of the enclosed plots

Figure VIII. Compared harvested crops of sodium nitrate and check plots within cattle exclosure. December 7, 1935.

Figure IX. Appearance of fertilized and unfertilized plots of cattle exclosure at the time of clipping. December 7, 1935.

at the time the cured grass crop was removed. The sodium nitrate plot shows a dark color as contrasted to the light color of the unfertilized check plot. This darker color is the result of a dense crop of winter annual seedlings.

Seasonal Aspects as Shown by Photographic Records

Photographic records were introduced as a permanent record of visible changes brought out by fertilization and protection. Figures I and II represent the appearance of the cattle exclosure and the open plots at the time the sodium nitrate was applied to the fertilized plots. Since the new exclosure was fenced just previous to the application of the fertilizer, both the cattle exclosure and the open area appear very similar. It is apparent from these photographs that the top growth of the previous season has been removed by grazing. It was pointed out in the previous discussion that cattle rejected the annual plants. Under stress even the dried annuals are consumed, as is evidenced in Figures I, II, and IV. These pictures, having been taken at the end of a drought period and just preceding the summer rains, demonstrate that both annuals and perennial grasses have been removed. On areas where there are sufficient perennial grasses, clumps of annual grasses remain untouched throughout the year.

Figure IV discloses the condition of the old cattle exclosure just as the range was beginning to respond to the first of the summer showers. The crop of the previous year was still conspicuous at the time this picture was taken. The tall, heavy stand of dry stalks stand out clearly as compared with the short grass of the surrounding open range. The undisturbed vegetation within this exclosure indicates the former conditions of the range. In place of the annuals of the adjacent open range, the cattle exclosure shows a predominance of such perennial species as Aristida divaricata, Bouteloua filiformis, Valota saccharata, Erioganum wrightii, and scattered plants of Acacia and Mimosa. This experimental exclosure duplicated the character of an adjoining pasture which has been retained as a reserve pasture to be grazed by cattle only during periods of stress.

Figures X and XI show respectively the late summer and autumn conditions of the sodium nitrate and check plots within the new cattle exclosure. The sodium nitrate plot nearest the fence to the right of the illustration may be distinguished from the check plot on the left by its lighter color. This lighter color is more distinct in the picture taken September 8, 1935. The earlier maturation and heavier seed crop of the sodium nitrate plot gives it the lighter color. The darker portions of the photograph mark the adjacent check plot as well as the surrounding unfertilized area. In Figure XI the vegetation surrounding the sodium nitrate plot had assumed the light, mature color, making it difficult

Figure X. Cattle exclosure showing late summer aspect of sodium nitrate and check plots. September 8, 1935.

Figure XI. Autumn aspect of fertilized and unfertilized check plots within the cattle exclosure. October 6, 1935.

to differentiate between the fertilized plot and the surrounding unfertilized range.

The late summer and fall aspects of the sodium nitrate and check plots open to stock are respectively shown in Figures XII and XIII. The picture taken September 8, 1935, demonstrates conspicuously the demarcation lines separating the fertilized plot from the check plot and the rest of the open range. The line at the farthest end of the plot is pointed out by the arrow. It has resulted from intensified grazing, giving evidence that the fertilized vegetation was cropped in preference to the surrounding natural range cover. The photograph taken of the same area on October 6 manifests a difference in color between the top-dressed plot and the surrounding open pasture. The color distinction is just the opposite of that evidenced by the picture of the cattle exclosure. Here, the sodium nitrate plot is marked by the darker color, as contrasted to the light harvest color of the rest of the unfertilized range. From this illustration it can be surmised that the removal of the top-growth through heavy grazing has prolonged the vegetative condition of the treated plot. A comparison between the check plots of the open and fenced areas points out the lower stand of vegetation covering the open area.

Figure XIV presents the appearance of the old cattle exclosure in late summer. The perennial stand within the

Figure XII. Open area demonstrating preferred grazing of fertilized plot. September 8, 1935.

Figure XIII. Prolonged vegetative condition of cropped sodium nitrate plot. October 6, 1935.

exclosure was somewhat darker in color than the outside annual vegetation. However, the difference in color was not sufficient to be recorded in the picture. Figure XV gives the aspect of the old cattle exclosure as it appeared about a month later. Whereas the annual grasses of the open pasture had matured by this time, the perennial stand within the old protected area still retained its green color.

The appearance of the winter aspect of the cattle exclosure is shown by Figures VIII, IX, and XVI. The cover of both open and cattle exclosed areas shows the same dry color of the cured grass crop. However, on the portions of the check and sodium nitrate plots which have been open to grazing a difference in color can be observed. A heavier mat of winter annual seedlings growing on the fertilized plot, Figure XVI, to the left, gives it a distinctly darker color than the check plot, to the right. This demonstrates the persistent influence of the sodium nitrate, even though most of the fertilizer has been removed from the first foot, as shown by the profile of Figure V.

DISCUSSION

A brief study of the soil of the experimental area showed that its coarse texture favored a rapid penetration of rain water. The loose structure also permitted rapid leaching, which was shown by the nitrate profiles in Figure V. It was observed that the quantities of the applied

Figure XIV. Old cattle exclosure, late summer aspect. September 8, 1935.

Figure XV. Autumn aspects of old cattle exclosure. October 6, 1935.

Figure XVI. Winter aspect of new cattle exclosure, demonstrating increased crop of winter annuals on sodium nitrate plot. December 7, 1935.

sodium nitrate were rapidly carried to the lower horizons. The low silt and clay fractions resulted in a low retention power, which explains in part the low content of soluble salts and nitrates. However, this low chemical composition rendered the soil sensitive to fertilizer applications and resulted in a fairly rapid response of the treated vegetation. Had the composition of the soil been high in certain harmful salts the treatment with sodium nitrate would have reflected no such gains as were obtained. From these brief considerations a mechanical and chemical analysis becomes essential before a consideration can be made of a practical method of applying fertilizer to a depleted range.

It has been the purpose of the soil nitrate studies to indicate the annual amounts of nitrate nitrogen carried off in the form of beef. No literature has been found in which a correlation has been made between nitrate losses and grazing as applied to western ranges. Lysimeter plots have been used to measure soil nutrient losses resulting from artificially cropped and uncropped plots, but these experiments have dealt chiefly with the amounts taken up by the plant and the quantities of soil nitrates lost through leaching.

The profiles of Figure V indicate nitrogen losses, both by leaching and grazing. The profile of the sodium nitrate plot within the new cattle exclosure recorded the amounts of nitrates taken up by the plant and the amounts lost through leaching. When the heavy sodium nitrate losses of the fertilized plot open to grazing were compared with the losses of the fertilized plot within the cattle exclosure, amounts of nitrate nitrogen lost through grazing can be observed. The profiles represented the depleting process of only a single growing season. From this it can be realized how grazing practices over a period of many years have resulted in the nutrient starvation of many range lands.

The soil profiles of the old cattle exclosure, Figure V, showed a higher soil nitrate content than the check plots and the surrounding range. This higher nitrate-nitrogen content resulted from the accumulation of organic matter within the protected area.

The incorporation of accumulated plant residues into the soil offered the chief source of soil nitrates. The importance of this source is best set forth by Russell (11): "The residues of the dead plant return to the soil more than the living plant had taken away; during its life it has been synthesizing starch, cellulose, protein, and other complex material, much of which falls back on the soil when it is dead."

Hence, the incorporation of organic matter in a soil, otherwise an inanimate mineral body, is the most important energy source of the soil. A removal of the vegetation, then, means an exhaustion of the energy source. The supply of nitrates by symbiotic and non-symbiotic bacteria is probably negligible on a grass range. It is even possible for soil organisms to compete with plants for soil nitrates on a range where heavy grazing might have induced a high carbon/nitrogen ratio of the soil. From these facts, the tremendous expenditure of soil resources from our ranges can be realized as the result of continued removal of vegetation.

From the example set by the old cattle exclosure, complete protection can be acknowledged as a means of supplying nitrogenous materials to ranges where a deficiency of this element persists. Controlled rotational grazing on a seasonal basis may remove almost as much of the nitrate sources as year long grazing. Grazing practices which have adjusted the periods of cropping to the most favorable time of the year (13) alleviate such harmful effects created by cropping. Under such a regulated system, the propagating methods of the grasses, such as tillering, remain unhampered, and consequently the range cover is preserved. However, the removal of vegetation still results in the removal of the chief nitrogen source. Thus it is that often good ranges may be found lacking in high nutritional values. Such ranges are evidenced by a yellow color, even following a season of favorable showers.

The observed preference of the grazing animals for the top-dressed vegetation correlated with the increased nutritional values of the plants growing on the unprotected fertilized plot. The intensive grazing resulting from this preference kept the cover of the fertilized plot very closely cropped. It would be impractical, therefore, to make fertilizer applications on only a small part of a range or pasture, where concentrated grazing might produce harmful effects. However, it might prove advantageous to protect the treated areas until a definite rejuvenation of the range had restored a good stand of perennial cover and the source of soil nitrates.

Figure VI showed how the application of fertilizer stimulated the top-dressed plants. The vegetation grown on the fertilized plots showed a higher cell sap concentration than the samples taken from the plant cover of the check plots. Although no standard was adopted in this experiment, osmotic value determinations may prove useful as a criterion in estimating the quality of range vegetation. It was shown that stock preferred to graze the fertilized vegetation which was found to have a higher protein content than the surrounding unfertilized areas. The osmotic values were highest for the samples taken from the grazed sodium nitrate plots. Thus a correlation was shown to exist on the fertilized plots between the increased preference of the stock and the high osmotic values. An osmotic value index for judging the nutritional value of grazing plants would have to take into consideration such factors as those affecting transpiration and soil moisture. The tall stands of protected plants probably conserved moisture more efficiently and thus lowered the osmotic value. A correlation between the rainfall, Figure VII, and the osmotic values, Figure VI, indicated a lowering of the cell sap concentration following the heavier showers. Though the effect of rainfall stimulated a lowering of the osmotic value, the seasonal trend remained unchanged. Thus the osmotic values determined on the plants of the experimental plots were increased by the use of sodium nitrate.

It will be recalled from the previous results that the osmotic values for the series of the two areas gave the lowest pressure in atmospheres between August 13 and August 20. Readings taken on August 27 gave the highest cryoscopic measurements for all the plots. The tabulated data of Table IV, on the other hand, disclosed the highest chemical compositions for the samples collected on August 16 and 17 and the lowest percentage composition for the cropping collected on August 27. The maximum and minimum chemical compositions obtained, therefore, are just the inverse of the lowest and highest osmotic values. It was also previously mentioned that the osmotic values depended upon the solute-solvent ratio of the cell sap. In correlating the data obtained from the chemical analysis with the measurements on osmotic values, it must be remembered that the osmotic depend upon the amount of material in solution within the cell. The analyzed plant samples from the sodium nitrate plots showed higher amounts of crude proteins. Proteins which are in a colloidal state can not be measured cryoscopically, while those of a transferable form are osmotically active. The high osmotic values of the open sodium nitrate plot indicate that cropping may have increased the amounts of osmotically active nitrogen.

As was pointed out, on natural pastures certain plants and plant parts are grazed in preference to others. In a study of hill pastures Godden (13) found the average difference in composition in 35 pairs of similar samples between "eaten" and "uneaten" parts. He found the percentage composition of calcium on the grazed parts to equal .56%, while on the uneaten matter it was .30%. The percentage of phosphates in the grass eaten was .60%, while the uneaten grass contained a percentage of .37%. For the grazed vegetation a nitrogen content of 2.54% (16% crude protein) was found, while on the ungrazed plants a composition of 1.82% (11.37% crude protein). By using these figures as a criterion for judging the figures of Table IV, it can be seen that the percentages of calcium presented here are within the limits set by Godden. Percentages of phosphates for the plant analysis of this experiment were somewhat higher, while the chemical composition of nitrogen or crude protein was slightly lower than the figures given by Godden. Based on Godden's figures, then, the percentages of chemical composition given here range fairly well within his limits between eaten and uneaten grass.

It should be mentioned here that such top-dressing treatments of range covers can be employed as a means of rectifying mineral and nutritional deficiencies in stock. Direct feeding of mineral concentrate may be cheaper, but the best results are obtained by incorporating the needed minerals in the plants (10). By this means the range cover can be improved at the same time the mineral deficiencies of the cattle are being corrected. From the plant analysis it was observed that the treatment with sodium nitrate definitely invested in the range cover a higher protein content. The qualitative gain was found to correlate with the heightened preference of stock for the treated plot. Besides enriching the range cover, this method may be employed to correct deficiencies in cattle.

Quadrat studies as well as growth records reveal the quantitative changes produced on range vegetation by the application of fertilizer. From the data collected by these two methods, the influence of the sodium nitrate increased the areas, the number of leaves, and to a slight degree the lengths of the leaves. It was found that the seasonal increase of chiefly annual plants was greater on the grazed fertilizer plot of the open area than on the adjacent check plot. Within the cattle exclosure the increase of summer annuals was less for the fertilized plot than for the check plot. However, the fertilized plot showed greater increases in the areas of the individual plants than did the fertilized plot open to grazing. Since the plants of the fertilizer plot within the cattle exclosure were allowed to grow unhampered, area increases probably resulted in the competition between individuals. This may explain why the plant population of the fertilized plot with the exclosure was less than that of its adjacent check plot. Grazing delayed the area increases induced by the application of sodium nitrate. This left more of the soil surface open to be inhabited by a larger number of annuals. Consequently, the open sodium nitrate plot showed an increased number of plants over those of the check plots.

The increase of perennial grasses of the fertilized plots over their respective check plots was very slight. A larger production of perennial grasses induced by fertilization could not be expected the first year, for the addition of new perennial seedlings, even within the protected area, depended chiefly upon the seed crop of the previous year. This seed crop, being exposed to grazing during the preceding summer, was probably low in quantity as well as viability.

Although the application of sodium nitrate registered only a slight increase in the perennial population over the untreated check plots, the areas of the individual grasses were definitely enlarged. Area extensions of the perennial grasses of the fertilized plots excelled the area increases measured in their respective check plots, the sodium nitrate plot within the cattle exclosure recording the highest area additions.

The increase in the areas, the number of leaves, and the weight of the plants, as stimulated by the use of sodium nitrate, naturally resulted in a higher crop yield. It was found that the cured harvest of the sodium nitrate plot within the cattle exclosure gave a weight more than twice the weight of the check plot.

The possibility of fertilizing ranges depends chiefly upon this increased crop production. The question arises, would such an increment be large enough to warrant a profitable compensation for the application of sodium nitrate to certain range covers? This can be answered directly only by further experimentation.

Orr (10) has already recognized the necessity of returning to depleted pastures the soil nutrients which have been consumed by beef markets. He says, "There is little doubt that within the next few years mineral fertilizers will be used in increasing quantities with the object of increasing the carrying capacity of the pasture and increasing the rate of production of the animals grazing them." This is also applicable to our western cattle ranges. Such returns can be made through either a conservation of the organic matter supply or through the addition of mineral fertilizers.

The seasonal aspects of the plot series as represented by the photographs disclose two important facts. The persistent green color of the fertilized plot open to grazing even after the rest of the range has assumed the dry aspect of fall, indicates the prolonged vegetativeness occurring on the sodium nitrate plot. It was pointed out that grazing delayed the maturation of the fertilized plot while under protection the fertilized plot and the open range reached maturity at the same time. Besides the prolonged vegetativeness of the grazed area, the sodium nitrate seemed to increase the seed crop of the plot within the exclosure. This assumption,, based on Figures X and XI, was not verified by seed tests. However, it may be found that the fertilization of locally protected areas and strips may be used as a means of producing heavy, viable seed crops. Such seed crops could be collected and used in revegetating depleted ranges or could be so centered that they form stations for natural seed dissemination. These centers would have to be composed of the best perennial species of the particular region in which they are situated.

SUMMARY

1. A series of plot studies were carried out at Parker Station on the Santa Rita Experimental Range to test the influence of sodium nitrate fertilizer upon the range conditions of this area.

2. A preliminary chemical and mechanical analysis was made to determine the general properties of the soil.

3. A sodium nitrate fertilized plot and an unfertilized check plot were set up, both within a cattle exclosure and on the open range.

4. Soil nitrate determinations were made on the various plots. A comparison between the soil profiles of the sodium nitrate plots and their respective check plots of both the cattle exclosure and open areas indicated losses of soil nitrates as a result of grazing.

5. Weekly osmotic values, as determined cryoscopically, were made on Bouteloua filiformis for all the plants. The plant samples taken from the fertilized plots of both areas had higher cell sap concentrations than the check plots.

6. Two chemical analyses for Bouteloua filiformis were collected during the season in order to follow the effect of fertilizing on the plant proteins.

7. List quadrats were made to enumerate the characteristic plants of the experimental area and to follow the plant

changes induced by the sodium nitrate. The fertilizer increased the number of individual plants, except where a more luxuriant growth resulted in competition.

8. Growth studies on the fertilized plants showed increases in the number and lengths of leaves as compared to plants on the unfertilized plots.
9. The matured crops of the protected area were harvested on December 7. The sodium nitrate plot gave a dry weight yield of more than twice that of the check plot.
10. An increase in the density of the plant cover, palatability, harvested dry weights, and seed production was indicated on the fertilized plots of the experimental range; however, before fertilizing practices can be economically applied to other ranges the cost must be weighed against live weight returns produced in cattle. Such cost estimations would necessitate further experimentation.

BIBLIOGRAPHY

1. Barnes, Will C.
1913. Western grazing grounds. Sanders Publishing Co., Chicago, Illinois.

2. Bouyoucos, C. J.
1930. A comparison of the hydrometer method and the pipette method for making mechanical analysis of soils. Journ. Am. Soc. Agronomy, Vol. 22, No. 8.

3. Fred, E. B. and Waksman, S. A.
1928. Laboratory manual of general microbiology. McGraw Hill Book Co., New York.

4. Harris, J. Arthur
1915. An extension to 5.99^{o} of tables to determine the osmotic pressure of expressed vegetable saps from the depression of the freezing point. Journ. of Botany, 2: 218-419.

5. Harris, J. A. and Gortner, R. A.
1914. Notes on the calculation of osmotic pressure of expressed vegetable saps from the depression of the freezing point, with a table for the values of P for - 0.001^{o} to -2.999^{o}. Reprint from Am. Journ. Bot., 1: 75-78.

6. Maximov, M. A.
1930. A textbook of plant physiology. McGraw Hill Book Co., New York.

7. Mallery, T. D.
1935. Changes in the osmotic value of the expressed sap of leaves and small twigs of Larrea tridentata as influenced by environmental conditions. Ecological Monographs, Duke Univ. Press.

8. McGinnies, W. G.
1930. The value of physical factor measurements in range research. Ecology, Vol. 11, No. 4.

9. Noyes, H. A.
1919. Accurate determination of soil nitrates by phenol disulforic acid method. Journ. of Indus. and Eng. Chem., Vol. 11, No. 3, pp. 213-218.

10. Orr, J. B.
1929. Minerals in pastures. H. K. Lewis and Co., Ltd., London.

11. Russell, E. J.
1935. Soil conditions and plant growth. Longman's Green and Co., New York.

12. Sampson, A. W.
1924. Native American forage plants. John Wiley and Sons, Inc., New York.

13. Sampson, A. W.
1923. Range and pasture management. John Wiley and Sons, Inc., New York.

14. Stoddard
1935. Osmotic pressure and water content of prairie plants. Plant Phys., Vol. 10.

15. Youngs, F. O. and Poulson, E. N.
Soil survey of the Santa Rita Experimental Range, Arizona. In press.