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George A. Rogler and Howard J. Haas[2]

THE importance of proper rangeland management and control of range livestock numbers from year to year is well known to range men in the Northern Great Plains. The quantity of native grass varies greatly from year to year in this region, because of the wide fluctuation in precipitation. For this reason, many ranchers protect themselves against the unpredictable bad years by grazing moderately every year. This often results in a tremendous waste of grass in good years. It is obvious that a reliable method of predicting range production in advance of the grazing season would be of great value to ranchers. They could increase or decrease livestock numbers and manage their rangeland in accordance with the predicted amount of native grass for the coming season. In an attempt to develop a method of prediction, a study was made of the relationship of the amount of fall soil moisture to range production the following year at the Northern Great Plains Field Station, Mandan, N. D. The relationship of precipitation from April to July, inclusive, to current season production was also studied. Eighteen years data were available for studies of forage production as measured by hay yields. Nineteen years data were available for beef production as measured by gains.

REVIEW OF LITERATURE

Certain investigators have found a rather close relationship between the yields of both winter and spring wheat and the amount of soil moisture at seeding time.

Hallsted and Coles (4)[3] showed in their studies that there was a high correlation between the percentage soil moisture in the surface 3 feet at seeding time and the yield of winter wheat the following year. They suggested that the principal use of their data would be for the purpose of predicting crop failures. Among their conclusions was the statement that the smaller the quantity of stored moisture at seeding time, the more dependent the crop on the weather during the growing season and the greater the chances of a failure.

Hallsted and Mathews (5) studied yields of winter wheat and soil moisture data from three stations in central and western Kansas. They were able to show from their data that there was a close relationship between the depth to which the soil was wet in the fall at seeding time and the yield of winter wheat the following season. They were also able to show that the depth to which a given soil is wet is a reliable measure of the amount of available water in that soil.

Data from 15 stations in the Great Plains were used by Cole and Mathews (3) to show the relationship between the depth to which soil was wet at seeding time and the yield of spring wheat. They concluded that when the soil was wet only 1 foot or less seeding was not warranted because of the frequent failures. With

[1]These investigations were conducted cooperatively by the U. S. Dept. of Agriculture, Agricultural Research Administration, Bureau of Plant Industry, Soils, and Agricultural Engineering, former Division of Dry Land Agriculture, and the North Dakota Agricultural Experiment Station, Fargo, N. D. Received for publication January 10, 1947.

[2]Agronomist, Division of Forage Crops and Diseases, and Associate Agronomist, Division of Soils, Fertilizers, and Irrigation, respectively. Mr. J. T. Sarvis was in charge of the project under which these investigations were carried on from 1915 to 1941, inclusive. The collection of most of the soil moisture data was under the supervision of Mr. J. C. Thysell.

[3]Figures in parenthesis refer to "Literature Cited", p. 38

increases in the depth of moist soil, the margin of safety became greater. They concluded further that the highest assurance of good yields occurred when the soil was wet to a depth of 3 feet or more.

Cole and Mathews (2) discussed some of the soil moisture data that are used in this paper. The data they used were for the period 1916 to 1936, inclusive, which showed that sod removed water in the lower foot sections (3 to 6 feet) to a lower point in comparison with the wilting coefficient than did wheat. Their suggestion was that the lower foot sections under sod are lightly occupied by roots of deep-rooted perennial plants that do not remove the water rapidly in any one year, but because of their continuing draft are able to remove the water more completely than those of an annual crop.

Annual precipitation was shown by Cole (1) to have a high positive relationship to yield of spring wheat in the Great Plains. He pointed out that carryover of moisture in the soil from the previous year sometimes influenced yields to the point where they were markedly above the expected production based on total quantity of current year precipitation.

Pengra (6) studied the effect of precipitation on crop yields in central South Dakota. He divided the precipitation into a preseasonal period of August 1 to March 31 and a seasonal period of April 1 to July 31. The preseasonal precipitation was used as an estimate of the supply of moisture available in the soil at planting time. In the case of small grains, correlation coefficients for preseasonal precipitation and yields were larger than the corresponding coefficients for yields and seasonal precipitation. In the case of corn, the seasonal coefficient was much larger than that for preseasonal precipitation. He found in general that seasonal precipitation was rarely great enough to overcome a marked deficiency in soil moisture available at planting time.

Sarvis (7) described the investigations carried on from 1916 to 1940, inclusive, under the long-time grazing experiment of which the studies shown in the present paper are a part. He stated that because of the long growing season of the mixed native grasses and because of different levels of root development that soil moisture is more completely exhausted by native vegetation than by wheat. He found that early season precipitation (April, May, and June) exerts a greater influence on the production of native grasses than it does on such crops as wheat.

A press release from the U. S. Dept. of Agriculture summarized preliminary work done by Barnes in Wyoming on the relationship of fall soil moisture to next year's grass on the range.[4] It stated that this relationship was close and that studies were being continued to find a soil moisture figure that ranchers can use to predict the following year's range.

EXPERIMENTAL PROCEDURE

The area upon which these studies were conducted is located approximately 3.5 miles south of Mandan, N. D., and the soil is mainly Williams silt loam. It was in native sod of a mixed prairie type when acquired by the government for experimental purposes in 1915 and has remained in native sod since that time.

Data presented in this study dealing with the relationship of native forage yields to soil moisture and precipitation were obtained from a mowing experiment initiated in 1919. A typical mixed prairie climax type of vegetation grew on the area where forage yields were taken during the entire course of the experiment. The most important grasses of this mixed prairie association were *Bouteloua gracilis* (H. B. K.) Lag., *Stipa comata* Trin. and Rupr., and *Agropyron smithii* Rydb. *Stipa comata* made up the major portion of the harvested native forage from 1920 to 1933, inclusive. After the severe droughts of 1934 and 1936, *Agropyron smithii* replaced *Stipa comata* as the major component of the harvested forage.

For the purpose of studying the effect of fall soil moisture on the following season's forage yields, soil moisture data were used which were obtained in an undergrazed pasture adjacent to the mowing experiment. The vegetation in the undergrazed pasture was quite similar to that in the mowing experiment. Moisture equivalent determinations also showed the soil to be similar in the two locations. Soil moisture samples were taken at four points around a permanent quadrat 4 meters square.

[4]U.S.D.A. Press release CS-831-46 issued May 5, 1946.

The relationship of soil moisture and precipitation to cattle gains was determined on a 30-acre pasture that had been over-grazed each year since its establishment in 1916 as part of a long-time grazing experiment. Since approximately all forage on this over-grazed pasture was removed by grazing each year, gains per acre have been assumed to be a measure of the total forage production. Sarvis (7) gives a general description of the long-time experiment.

The vegetation in this over-grazed pasture rapidly changed after the start of the experiment to a short grass type consisting almost entirely of *Bouteloua gracilis*. For a number of years *Artemisia frigida* Willd., which is a deep-rooted unpalatable perennial weed, was very prevalent. This weed was reduced to a point where it was of no importance after these severe droughts of 1934 and 1936.

Soil moisture samples were obtained at four locations around a permanent quadrat 4 meters square located in the 30-acre over-grazed pasture. The soil moisture data obtained have been used in the present study to determine the effect of varying quantities of moisture in the fall on gains per acre the following season.

The dates of sampling for the years included in this study ranged from August 28 to November 6. In some years moisture determinations were not made in the fall. It was necessary therefore to eliminate these years from the study.

Moisture samples were taken in foot sections to a depth of 6 feet, with the standard soil tube. The soil was weighed, oven-dried at 100° to 110° C, and re-weighed. Percentage moisture was determined on the dry weight basis. The percentage moisture was converted to inches of moisture in order that precipitation could be combined with soil moisture for study. In determining the inches of available water present in the soil, the minimum point of exhaustion was used instead of the wilting coefficient since plants will withdraw moisture to a point below the latter. The minimum point of exhaustion was determined for each foot section by averaging the inches of water in the soil at those times when it was considered that all of the moisture had been removed that the plants were capable of exhausting. The inches of available water in the fall were determined by subtracting the minimum point of exhaustion from the moisture present at the time of sampling. All further discussion of soil moisture in this article refers to available water only.

Precipitation was measured near the area where both forage yields and gains were obtained. In determining the effect of precipitation on forage yields and gains, data for the months of April through July only were used for the respective production years. It was found by the use of correlation coefficients that these were the months in which precipitation had the greatest influence on yields and gains.

RESULTS

Detailed data showing the years of study, precipitation from April to July, inclusive, of the production year, available moisture in the 3- and 6-foot depths of soil the preceding fall, forage yields, and cattle gains per acre are presented in Table 1.

FORAGE YIELDS AS RELATED TO MOISTURE

Soil moisture and yields.—Correlation and regression coefficients were determined for the purpose of showing the relationship between available fall soil moisture in the 3- and 6-foot depths and native forage yields the following season from data shown in Table 1. Highly significant coefficients of .72 and .74 were obtained for the correlation of forage yield and available soil moisture in the surface 3 feet and 6 feet, respectively. Scatter diagrams of yields and moisture are shown in Fig. 1. The line showing the regression of yield on available soil moisture is superimposed on the diagram concerned. The vertical distance of each dot from the line measures the error in calculating the yield from the available soil moisture by means of the regression equation.

TABLE 1.—*Precipitation from April to July, inclusive, available soil moisture, forage yields, and cattle gains per acre from 1918 to 1945, inclusive, Northern Great Plains Field Station, Mandan, N. D.*

Year	Precipitation April–July, incl., in.	Forage data			Gain data		
		Available soil moisture*		Forage yield per acre, lbs.	Available soil moisture*		Gain per acre, lbs.
		Surface 3 feet, in.	Surface 6 feet, in.		Surface 3 feet, in.	Surface 6 feet, in.	
1918	8.21	—	—	—	2.13	5.88	51.8
1920	6.54	0.69	3.61	238	0.19	2.31	58.7
1923	9.27	0.51	1.69	247	0.19	1.31	50.2
1924	8.95	1.04	1.91	652	1.02	1.88	81.5
1925	10.41	1.22	1.58	212	1.29	2.26	52.7
1026	6.41	0.57	1.42	29	0.51	1.52	24.8
1927	12.82	0.67	1.05	628	0.69	1.49	80.7
1928	12.08	2.95	3.68	278	3.01	3.82	56.7
1929	6.78	0.81	1.48	172	0.73	1.49	39.3
1930	6.94	0	0.20	137	0.02	0.59	28.5
1931	8.40	0.73	1.08	232	0.30	1.21	59.5
1932	10.20	0.23	0.52	630	0.14	1.04	68.8
1933	6.43	0.14	0.25	59	0.22	0.63	35.3
1934	5.23	0	0.18	37	0	0.10	12.2
1936	0.93	0.04	0.04	0	—	—	—
1941	13.00	1.71	2.04	421	1.48	1.86	101.9
1942	12.55	4.74	6.53	1,034	4.13	4.53	89.8
1943	13.11	3.14	6.42	998	2.90	5.04	118.8
1944	11.08	1.77	6.18	692	0.85	4.76	107.1
1945	6.36	—	—	—	1.65	5.27	113.4
Average	8.79	1.16	2.21	372	1.13	2.47	64.8

*Soil moisture data collected the fall preceding the year shown.

Fig. 2 is a block chart giving the actual and estimated or expected forage yields based on the amount of available soil moisture the preceding fall for each year studied. It is apparent from a comparison of the actual and expected values that factors other than soil moisture had a pronounced effect on yields even though a highly significant positive relationship existed between the two variables. One of the most important factors influencing yields in addition to soil moisture was current season precipitation. For example, the actual yield in 1924 was much higher than the expected yield, due to a high June rainfall. In like manner, lower than average rainfall in some years resulted in actual yields lower than expected on the basis of the amount of soil moisture.

In order to place the measurement of soil moisture on a more practical basis, an attempt was made to convert inches of available water to feet of moist soil. Expressing the moisture in inches is more accurate, but is impractical for the rancher. No record was kept as to whether the soil at various depths felt dry or moist at the time of

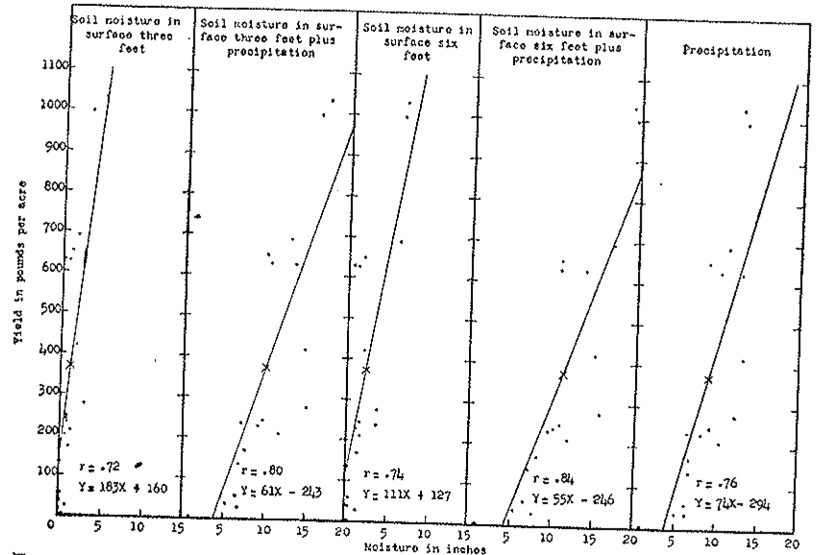

FIG. 1.—Diagrams showing the regression of native forage yields on available fall soil moisture in inches in two depths, on precipitation from April to July, inclusive, and on a combination of soil moisture and precipitation at Mandan, N. D.

sampling, thus it was necessary to compute the feet of moist soil from the inches of available water. Hallsted and Mathews (5) considered a foot section of soil to be moist when 0.5 inch or more of available moisture was present. This meant that the soil was not necessarily wet to field capacity to be considered moist. The moisture might be concentrated in a few inches of the foot section or distributed through-

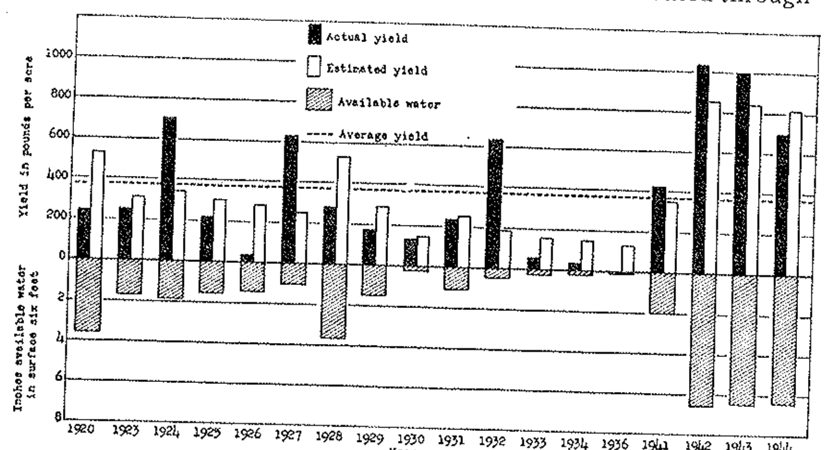

FIG. 2.—Actual and estimated native forage yields in pounds per acre and inches of available water in the surface 6 feet of soil the preceding fall at Mandan, N. D.

out. The above procedure was followed in the present study, that is, when less than 0.5 inch of available moisture was present in a foot section, it was considered dry. When 0.5 inch or more moisture was present it was considered moist. The soil in this study contained approximately 1.5 to 2.0 inches of available water per foot, depending upon the depth, when filled to capacity. In a few cases, dry layers of soil were found between moist layers. Since at least some of the roots were perennial, it was assumed that moisture at the lower depths was available to the plants in spite of the dry layer.

Table 2 shows the frequency of occurrence of designated yields of forage associated with a specified number of feet of moist soil in the surface 6 feet. It will be noted from the table that when the soil is dry in the fall, the chances of obtaining high yields the following season are small. As the number of feet of moist soil increases, the chance of obtaining high yields likewise increases.

It was found that the soil was dry to a depth of 6 feet in the fall 44% of the years studied. There was 1 foot of moist soil in 28% of the years and 3 feet or more of moist soil in 28% of the years. When the soil was dry, 88% of the yields were below 372 pounds per acre, which was the mean for the entire period. With 1 foot of moist soil only 40% of the yields were below the mean. Likewise, with 3 feet or more of moist soil, only 40% of the yields were below the mean. Although there was the same percentage of yields below the mean with either 1 foot or 3 feet or more of moist soil, Table 2 shows the average yield under the latter condition to be much higher. From these data it is evident that below average yields can be predicted fairly accurately when the soil is dry the preceding fall. With increasing quantities of moist soil in the fall, increasingly higher yields can be expected the following season on the average, but prediction is less accurate.

TABLE 2.—*Frequency of occurrence of designated yields of native forage per acre associated with specified quantities of moist soil in the surface 6 feet the preceding fall.*

Feet of moist soil in surface 6 feet	Forage yields in pounds per acre					
	199 or less	200 or more	400 or more	600 or more	800 or more	Average
None	6 in 8 or 75.0%	2 in 8 or 25.0%	1 in 8 or 12.5%	1 in 8 or 12.5%	0 in 8 or 0%	164
1 foot	0 in 5 or 0%	5 in 5 or 100.0%	3 in 5 or 60.0%	2 in 5 or 40.0%	0 in 5 or 0%	429
2 feet*	—	—	—	—	—	—
3 feet or more	0 in 5 or 0%	5 in 5 or 100.0%	3 in 5 or 60.0%	3 in 5 or 60.0%	2 in 5 or 40.0%	648

*There were no cases with only 2 feet of moist soil.

Precipitation and yields.—It is evident from the data in Table 1 that the amount of precipitation has a marked positive influence on native forage yields. A study was made of the effect of precipitation during various periods on forage yields. The highest correlation coefficient (.76) was obtained when the precipitation for the period April to July, inclusive, was used. A scatter diagram and regression line of yields on precipitation for April to July, inclusive, is shown in Fig. 1. For the years in which forage yields were taken, the April-July precipitation was equal to or above the average of 8.95 inches 56% of the time. Seventy per cent of the yields for these years were above average. During 44% of the years the April–July precipitation was below average. In these years, the yields were below average 100% of the time.

Soil moisture plus precipitation, and yields.—In order to determine the effect of both fall soil moisture and precipitation on forage yields they were combined to give a single value for each year. Inches of available soil moisture in the surface 3 feet and surface 6 feet were each added to the April–July precipitation. A highly significant correlation coefficient of .80 was obtained for soil moisture in the surface 3 feet plus precipitation and forage yield. When the soil moisture in the surface 6 feet was added to the following April–July precipitation, an even higher coefficient of .84 was obtained.

Scatter diagrams and regression lines shown in Fig. 1 for yields and for soil moisture and precipitation added together, show a high positive relationship between yields and the combined moisture value. The "goodness of fit" of regression lines for yield on soil moisture both at 3-foot and 6-foot depth plus precipitation was considerably better than when soil moisture and precipitation were considered separately.

It is evident that the value obtained, where soil moisture was added to precipitation, could not be used for prediction purposes. Nevertheless, it is apparent from the data that the two most important variables determining yield are the amounts of soil moisture the preceding fall and current season precipitation.

CATTLE GAINS AS RELATED TO MOISTURE

Studies were made of the effect of varying quantities of soil moisture and precipitation on cattle gains. These studies were similar to those discussed above. Since the animal variable was brought into the study in addition to the variables of soil moisture and precipitation, it was not expected that as high positive relationships would be obtained for gains and soil moisture or precipitation as were obtained for those variables and forage yield.

Soil moisture and gains.—Correlation and regression coefficients were determined from the data presented in Table 1 for the soil moisture in the 3-and 6-foot depths and gains in pounds per acre the following season. The correlation coefficients for gains and soil moisture in the 3-foot and 6-foot depths were .52 (significant) and .64 (highly significant), respectively. Regression lines were superimposed on scatter diagrams of gains and moisture shown in Fig. 3. It is apparent that there was a positive relationship between soil moisture and gains, but the "goodness of fit" of the regression lines in both the diagram of the 3-foot and 6-foot depths was not high.

Fig. 4 is a block chart giving the actual and estimated or expected gains based on the amount of available soil moisture in the surface 6 feet. The chart shows considerable discrepancy between expected and actual gains in some years. These discrepancies existed because

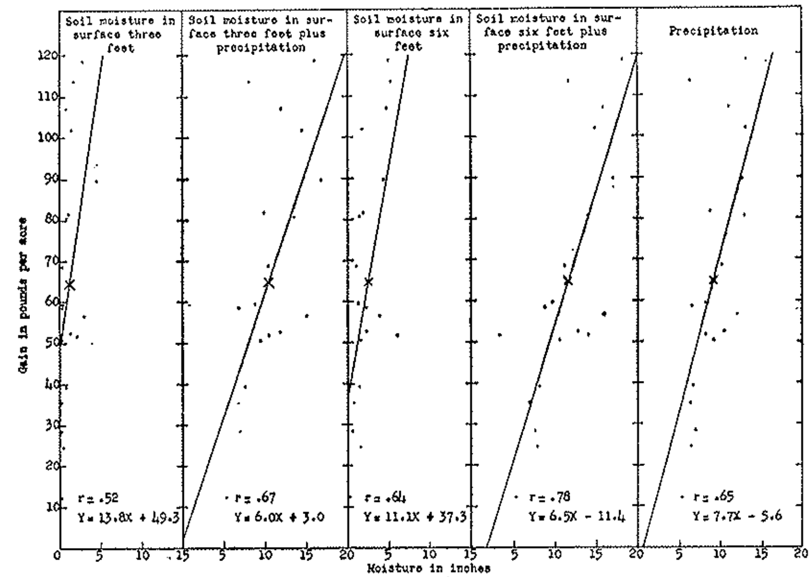

FIG. 3.—Diagrams showing the regression of cattle gains on available fall soil moisture in inches in two depths, on precipitation from April to July, inclusive, and on a combination of soil moisture and precipitation at Mandan, N. D.

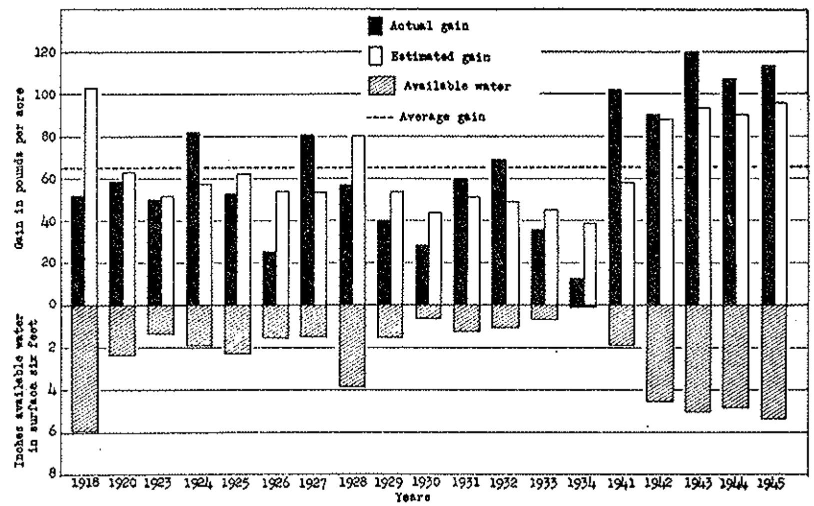

FIG. 4.—Actual and estimated cattle gains in pounds per acre and inches of available water in the surface 6 feet of soil the preceding fall at Mandan, N. D.

factors other than the amount of soil moisture had a marked influence on gains. Some of these factors may have been the poor or good distribution of rainfall which would influence the continuous production of nutritious grass, high or low seasonal temperatures which have a direct influence on cattle gains, and the condition of the cattle themselves. Thin and thrifty cattle would make more rapid gains, at least at the start of the season, than those carrying more flesh.

The available soil moisture in the surface 6 feet of the pasture in which gains were taken was converted to the number of feet of moist soil as described under the heading "Forage Yields as Related to Moisture". Table 3 shows the frequency of occurrence of designated gains per acre associated with a specified number of feet of moist soil in the surface 6 feet. It is evident from the data presented in this table that when the soil is dry in the fall, chances of obtaining high gains the following season are small. With an increasing number of feet of moist soil the chance of obtaining high gains also increases. It was found that the soil was dry to a depth of 6 feet in the fall during 42% of the years studied. Twenty-one per cent of the time there was 1 foot of moist soil and 37% of the time there were 3 feet or more of moist soil. When the soil was dry, 88% of the seasonal gains per acre were below 64.8 pounds which was the average for the entire period. With 1 foot of moist soil only 25% of the gains were below average. Forty-three per cent of the gains were below average when there were 3 feet or more of moist soil. Even though there were more gains below average with 3 feet or more of moist soil than with 1 foot, Table 3 shows the average of these gains to be much higher than those when there was 1 foot of moist soil.

TABLE 3.—*Frequency of occurrence of designated cattle gains per acre associated with specified quantities of moist soil in the surface 6 feet the preceding fall.*

Feet of moist soil in surface 6 feet	Gains in pounds per acre						
	19.9 or less	20 or more	40 or more	60 or more	80 or more	100 or more	Average
None	1 in 8 or 12.5%	7 in 8 or 87.5%	3 in 8 or 37.5%	1 in 8 or 12.5%	0 in 8 or 0%	0 in 8 or 0%	39.8
1 foot	0 in 4 or 0%	4 in 4 or 100.0%	4 in 4 or 100.0%	3 in 4 or 75.0%	3 in 4 or 75.0%	1 in 4 or 25.0%	79.2
2 feet*	—	—	—	—	—	—	
3 feet or more	0 in 7 or 0%	7 in 7 or 100.0%	7 in 7 or 100.0%	4 in 7 or 57.1%	4 in 7 or 57.1%	3 in 7 or 42.9%	85.2

*There were no cases with only 2 feet of moist soil.

Precipitation and gains.—Fig. 3 shows a scatter diagram and regression line of gains per acre on April–July precipitation. This diagram was constructed from data shown in Table 1. The correlation coefficient of .65 for the relationship of gains and precipitation was highly significant. The "fit" of the regression line was not as good as that of the line for forage yield on precipitation shown in Fig. 1 because of the greater number of factors influencing cattle gains. The April–July precipitation for the years used in studying gains was above the average of 9.20 inches 47% of the time. With this amount of precipitation, gains per acre were above the average of 64.8 pounds 67% of the time. Fifty-three per cent of the time the April–July precipitation was below average. Under these conditions, 80% of the gains were below average.

Soil moisture plus precipitation and gains.—In order to determine the relationship of both soil moisture and precipitation to gains per acre, the available inches of soil moisture in the surface 3 feet and surface 6 feet were added to the April–July precipitation for each year. Correlation coefficients were determined for these values and gains. Scatter diagrams and regression lines are shown in Fig. 3. A highly significant coefficient of .67 was obtained for the correlation of gains and soil moisture in the surface 3 feet plus April–July precipitation. A highly significant coefficient of .78 was also obtained for gains and soil moisture in the surface 6 feet plus April–July precipitation.

It is apparent from a study of the regression line for gains per acre on soil moisture in the surface 6 feet plus precipitation that expected values came closer to actual values than for any other variables considered in relation to gains.

DISCUSSION

There might be some question whether seasonal gains per acre or seasonal gains per head would be more logical to use in a study of the relationship of soil moisture and precipitation and gains. For the purpose of this paper, gains per acre were used because this gain factor seemed to describe most fully the total forage production. Actually, the results would have been quite similar if gain per head instead of gain per acre had been used. This is indicated by an extremely high correlation coefficient of .95 for seasonal gain per head and seasonal gain per acre as determined from the data obtained on the overgrazed pasture for the years covered in the study.

It is obvious that the prediction of gains would be of more value to ranchers than the prediction of forage yields. Since a correlation coefficient of .83 was obtained for forage yields and gains per acre, the data presented in this paper on soil moisture and forage yields are also of value in relation to soil moisture as effecting gains.

An attempt was made to predict actual intensities of grazing that could be used the following season when there was a certain amount of soil moisture in the fall. The gain data used were taken from a number of pastures grazed at various intensities. A trend was evident showing that heavier intensities of grazing could profitably be used when there were increasing amounts of soil moisture. It was impossible, however, because of the limited amount of data, to predict even within fairly wide limits the proper grazing intensities based on the amount of fall soil moisture.

The data presented here may be of considerable value in forecasting range production within certain limits. They are principally of value in predicting chances of low range production ahead of the season. The smaller the quantity of soil moisture or the less depth of moist soil in the fall, the more likely the native forage production will be low the coming season.

SUMMARY

This study was made to determine the relationship of the amount of soil moisture the preceding fall and current season April–July precipitation to native forage yields and gains per acre.

The data showed highly significant correlation coefficients of .72 and .74 for the amount of fall soil moisture in the surface 3 feet and surface 6 feet, respectively, and native forage production the following season.

When soil moisture was above or below average, forage yields also showed a positive relationship of being above or below average. On the area where forage yields were taken the soil was dry to a depth of 6 feet 44% of the time. When dry, 88% of the yields were below average. Increasing depths of moist soil produced, in general, increasingly higher yields of hay the following season.

A highly significant correlation coefficient of .76 was obtained for April–July precipitation and yield the same season. Above average April–July precipitation was accompanied with above average yields 70% of the time. When the precipitation was below average, yields were below average 100% of the time.

By adding the amount of soil moisture to the April–July precipitation a higher positive relationship was obtained for this value and yields than when either soil moisture or precipitation were used separately.

There was a positive relationship between soil moisture and gains, but it was not as high as that for forage yields because of the additional variation brought in by the animal unit.

On the area where gains were measured the soil was dry to a depth of 6 feet 42% of the time. When dry, 88% of the gains were below average. As in the case of forage yields, increasing depths of soil moisture produced, in general, increasingly higher gains.

A highly significant correlation coefficient of .65 was obtained for April–July precipitation and gain. Above average April–July precipitation was accompanied by above average gains during 67% of the time. When the precipitation was below average, 80% of the gains were below average.

When the amount of soil moisture in the fall was added to the April–July precipitation, a higher positive relationship was obtained for this value and gains than when either soil moisture or precipitation was considered alone in relation to gains.

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