Soil Moisture as a Predictive Index to Forage Yield for The Sandhills Range Type[1]

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The problems inherent in managing rangeland where wide fluctuations in forage production and rainfall occur are well known to livestock men on the Great Plains. Annual percipitation at Akron, Colorado, averages about 17 inches and varies from 10 inches to 27 inches. Grazing programs that will minimize the effects of wide forage fluctuations resulting from precipitation flucuations have been the subject of many varied proposals. The most common has been to recommend that ranges be stocked with a basic breeding herd at a rate that is not detrimental to range land during drought years. Any excess forage produced, in average or above-average years, would be utilized by purchased livestock or by "carried over" yearling livestock. A reliable method for predicting forage production in advance of the grazing season could be of great value in implementing such a program.

In an attempt to develop a method for predicting forage production on sandhill range, a study was made of the factors that tend to influence yield of forage at the Eastern Colorado Range Station near Akron, Colorado.

Rogler and Haas (1947), working with native mixed prairie in North Dakota, found that the important variables affecting yield were the amount of soil moisture the preceding fall and the amount of precipitaton for the current season. Reynolds (1954) found that variations in forage production on desert grasslands were almost entirely associated with annual rainfall. He found that a small annual deficiency in rainfall over a long series of years had an effect similar to a large annual deficiency over a shorter period. This demonstrates the possibility that precipitation amount in previous years can have a significant effect on current forage production.

Hallsted and Coles (1930), Hallsted and Mathews (1936), and Cole and Mathews (1940), working in the Great Plains region, found a definite relationship between soil-moisture storage at seeding time and yield of wheat. However, Brengle (1960), working on 13 sites in Eastern Colorado, found no significant correlation between stored soil moisture in September (seeding time) and yield of wheat. He did find that available moisture in early spring, at the time when growth and tillering begins, was significantly correlated to yield of wheat. Also, he found that depth of moisture distribution was apparently as critical as total moisture in affecting yields.

Cole and Mathews (1940) pointed out that the water content of soil could be approximated by the depth to which the soil was wet.

Description of the Study Area

The Eastern Colorado Range Station is located 16 miles north of Akron, Colorado. The soils in the experimental area are predominantly Blakeland loamy sand and Valentine sand, and they support a mixture of short, mid, and tall grasses. This study was limited to the sandhills range site in good condition. Undulating topography, having no drainage pattern, characterizes this site. Major forage species are blue grama *(Bouteloua gracilis* (H.B.K.) Lag.), prairie

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Table 1. Coefficients of correlation relating yield of grass to factors which might affect yield.

	Dependent Variable—Herbage Yields by Seasons				
Independent Variable	May 1 to June 20	June 21 to Aug. 7	Aug. 8 to Oct. 1	Total Yield	May 1 to Aug. 7
Precipitation during the period	r = 0.603	0.834*	0.907*	0.893**	0.731
Evapo-transpiration water during period	r = 0.744	0.860*	0.931**	0.954**	0.857*
April Mean Temperatures	r = 0.411				
Precipitation preceding year	r = 0.194				
Precipitation preceding two years	r = 0.830*				
Evapo-transpiration water + April Mean Temperatures	R = 0.860*				
Evapo-transpiration water + precipitation preceding two years	R = 0.983**	0.934**	0.878*	0.947**	0.857*
Evapo-transpiration water + precipitation preceding two years + April mean temperatures	R = 0.984**				

*Significant at the 5% level.
**Significant at the 1% level.

sandreed grass (*Calomovilfa longifolia* (Hook.) Scribn.), and needle-and-thread grass (*Stipa comata* Trin. and Rupr.).[2]

The average frost free period is 140 days (from May 15 to early October). New leaves of native grasses are normally ready for grazing the first week in May. Seventy percent of the annual precipitation comes in the form of rain during the period from April 1 to August 31.

Methods and Materials

This paper includes data from a grazing study initiated in 1955 and continued through 1961. Data were collected from three pastures. The grazing season was from May 1 to October 1 each year. Forage production was obtained by clippings, or harvests, and made at six- to seven-week intervals during the season. Prior to the start of grazing, 62 portable cages (2 feet by 4 feet) were randomly placed in each pasture to exclude grazing from sample plots which were 1.6 feet by 3.0 feet. In the vicinity of each cage, two non-caged plots haveing forage density and species composition similar to the caged plot were marked with 60-penny nails.

Yield sampling was accomplished by estimating the weight of forage produced on the caged plot and one of the non-caged plots at each cage location. After estimating herbage yield, the forage under each fourth cage was clipped to ground level, weighed, and air dried. The clipped wight served as a check for the estimated weights obtained from the same plots. Regression formulas, computed from the estimated and clipped forage weights, were used to correct any bias in the estimated yields.

Forage production by clipping period was calculated as follows:

1) Yield to June 20 was the average of the air dry weight per plot from the caged or non-grazed plots.
2) Yield June 20 to August 7 was the average of the air dry weight per plot from August 7 caged plots less the average air dry weight from June 20 non-caged (grazed) plot.
3) Yield August 7 to October 1 was the average of the air dry weight per plot from the caged plots October 1 less the average air dry weight per plot from the non-caged plots August 7.

Soil moisture samples were obtained in duplicate from 16 square foot plots on similar topography in each of the study pastures; the soil moisture data reported are from the same three pastures for which forage yields are given.

Soil moisture samples were taken periodically from March 15 until mid-September at one

Table 2. Coefficients of correlation relating yield of grass to criteria that may be suitable as predictive indices to grass yeld.

	Dependent Variable—Herbage Yields by Season			
Independent Variable	May 1 to June 20	June 21 to Aug. 7	Total Yield	May 1 to Aug. 7
Depth of moist soil October 1 (beginning of crop-year)	r = 0.434		0.349	0.334
Depth of moist soil March 15	r = 0.528*		0.279	0.348
Depth of moist soil April 1	r = 0.617**		0.408	0.408
Depth of moist soil April 15	r = 0.806**		0.518*	0.797**
Depth of moist soil May 1	r = 0.910**	0.594**	0.309	0.612**
Depth of moist soil April 15 + precipitation preceding two years	R = 0.926**		0.749**	0.866**
Available soil moisture April 15	R = 0.748**			

*Significant at the 5% level.
** Significant at the 1% level.

[2]*Scientific names from nomenclature by Harrington, H. D. 1954. Manual of the plants of Colorado. Sage Books, Denver. 666 pp.*

or two week intervals. They were taken in six-inch and one-foot sections to a depth of 66 inches with a standard soil tube. The soil was weighed, oven dried at 110° C., and reweighed. Moisture percentages were computed from the oven dry weights. These moisture percentages were converted to inches of moisture (volume-weight basis) so that precipitation could be combined with soil moisture for study.

Available soil moisture, as used in this paper, will consist of the total soil moisture less the moisture remaining in the soil at the "minimum point of exhaustion." To obtain a realistic evaluation of the true wilting point, moisture samples were taken at the time when the plants on the study area began to show moisture stress. The soil moisture at this point coincided rather closely with that point described by Rogler and Haas (1947) as "the minimum point of exhaustion."

Measurements of the depth of moist soil (in inches) were also made at the time of soil moisture sampling. These measurements were made easily, since there usually was a distinct line separating moist soil from dry soil. The dry soil, in most instances, approximated soil where the moisture was at the "minimum point of exhaustion." This measurement will be referred to as "the depth of moist soil" throughout the remainder of this paper.

Data from actual soil sampling were not available for some years on the October 1 and March 15 dates (Table 2). In these instances, supplementary soil moisture information was obtained from Colman fiberglass units buried at depths of 3, 9, 15, 21, 30, 42, and 60 inches. Readings were obtained by a soil moisture ohm meter. Readings obtained from this meter were considered to delineate, within three to six inches, that depth where the soil became dry (no available moisture). This depended on the spacing of the buried fiberglass units.

Since forage production data were available for three distinct periods of time during the summer, it was possible to estimate the water use by range plants during each of the periods. Available soil moisture (in inches) at the beginning of a period was added to the inches of precipitation during the period; subtracted from this amount was the remaining available soil moisture at the end of the period; the resulting figure represented the water lost by evaporation and transpiration. This evapo-transpiration loss was used as a measure of the total water available to the plant for growth. To avoid confusing it with available soil moisture it will be referred to as evapo-transpiration water.

The simple and multiple correlation coefficients reported in Tables 1 and 2 were calculated using the methods as outlined by Snedecor (1956).

Results and Discussion

Evaluation was made of factors that might affect the yield of grass by correlating the yield of grass with some of these factors. These correlations of grass yield during various portions of the growing season with various environmental factors are presented in Table 1.

Precipitation which fell during the period represented by each harvest was correlated to yield of grass; however, precipitation alone was not significantly correlated to yield of grass for the first, or spring period. Evapo-transpiration water during the period showed a higher correlation than did precipitation alone, but this correlation was not significant at the 5 percent level (Table 1).

April mean temperatures significantly affected the date of initial leaf growth on these ranges but did not effect the yield of grass during the first period (Table 1). Also, spring grass yield showed no significant correlation to precipitation dur-

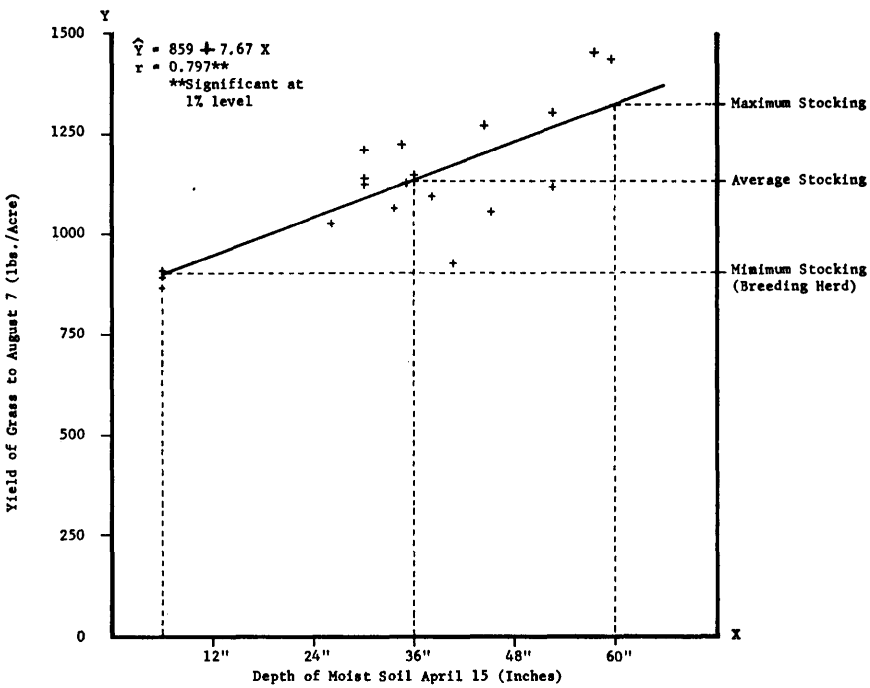

FIGURE 1. Linear regression showing relation of depth of moist soil April 15 to yield of grass and stocking rates.

ing the previous year. However, spring grass yields were significantly correlated to precipitation of the previous two years.

The best relationship, as shown by the correlation coefficients, was found when a combination of the factors that may affect yield were related to the yield of grass (Table 1). The most significant correlation was found when the combined effect of evapo-transpiration water and the preceding two years' precipitation were related to grass yield. Therefore, evapo-transpiration water for the period, and precipitation the preceding two years, appear to account for most of the fluctuations in grass yield during the first six or seven weeks of grass growth. The addition of the April mean temperatures to this combination (Table 1) added little to the relationship.

Although a knowledge of the factors affecting yield of grass is essential in understanding the reasons for fluctuations in annual forage yields, they may not be useful as predictive indexes. To be of value, a predictive index must provide information as to potential yield prior to harvest of the crop, and as far in advance of that date as accuracy allows. Possible indices suggested by the data for predicting seasonal forage yield at a preseason date are:

1) *Precipitation received during the two preceding years.* Precipitation in the preceding two years and yield of grass were found to be significantly correlated for the first clipping (Table 1), but the relationship can be improved by considering, in addition, the soil moisture storage or depth of moisture distribution.
2) *Soil Moisture.* If a single factor is to be used to predict the approaching season's yield of forage, either stored soil moisture or depth of moist soil probably has the best potential. Cole and Matthews (1940) suggested the use of the depth of wet soil as an approximation of the water content of soil. Rogler and Haas (1947) also suggest that the depth of moist soil is more practical as an index for use by ranchers. However, they were of the opinion that available soil moisture was the more accurate.

   A comparison of the depth of moist soil to inches of available soil moisture showed a highly significant correlation coefficient (r = 0.829) for the April 15 samplings made in this study. Also, no differences were found in their relative ability to predict the yield of grass that could be expected by August 7 from measurements made on April 15. Since a measure of the depth of moist soil was easily obtained, it was used as the preferred predictive index in this study.
3) *Combinations of the above.* This approach is likely to be the most accurate if sufficient information is available to allow for use of multiple regression formulas.

Coefficients showing the relationship between these potential indices and the subsequent season's grass yield were computed for several dates beginning in the fall. These coefficients are presented in Table 2.

April 15 was the earliest date from which yields of grass made by August 7 were accurately predicted from depth of moist soil (Table 2). The combined effect of the preceding two years' precipitation and depth of moist soil April 15 apparently gave the most accurate index. This was true for all clipping periods. However, due caution should be taken when attempting to use regression equations to estimate yields of grass from measured independent variables, if the value of the variables are outside the range of the data used in the computation of the regression equation. For example, the combined precipitation for two preceding years never exceeded 31 inches during the course of this study; however, climatic records reveal that the sum of two consecutive years' precipitation has exceeded 40 inches on occasion. Attempts to predict yields that might be expected where two years prior precipitation was 40 inches is of questionable value if the multiple regression formula from this study is used. Until this information is available, it will be sufficient here to note that the prior two years' precipitation does significantly affect yield of grass in subsequent years.

Stored spring soil moisture was found to be a major factor contributing to maximum potential yield of grass. Soil moisture available during the spring period provided the greatest amount of air-dry yield per inch of evapo-transpiration water. Average production per inch was 128 pounds, compared to 81 pounds for early summer, and 48 pounds for late summer. Therefore, each inch of available soil moisture produced 128 pounds of air-dry grass, on the average, with no additional rainfall. Thus, preseason stored soil moisture was a direct contributing factor to grass yield. For this reason, spring droughts, which limit soil moisture storage, can have a tremendous effect on the potential grass yield. Possibly this was the reason that the measurements of the spring soil moisture had such a close relationship to the following season's grass production. This was particularly true for the production to August 7.

Data from Table 1 indicate that yields of grass during the period from early August to October 1 were almost entirely dependent upon evapo-transpiration water available during that period. Therefore, it is unlikely that spring soil moisture will have any bearing on yields of forage that late in the summer. Yields during this period varied from 0 to over 400 pounds. It was considered practically impossible to predict what this yield would be from data available in the spring. Should accurate climatic forecasts become available in the future, yield predictions including this period may become feasible. However, accurate prediction of the first two periods is of sufficient value that complete disregard of yield of the final period should be of minor concern.

Significant regrowth after the first week in August is probably the exception rather than the rule. In five of the six study years, 96 percent of the total forage production had been produced by August 7. The data indicate that five inches of precipitation are required during July and August before appreciable regrowth occurs during the period after August 7. The precipitation in July and August exceeded five inches in only five of the past 25 years (the average is 3.58 inches). However, should 400 pounds of forage be forthcoming after August 7, predictions would be in error by this amount.

The use of soil-moisture depth on April 15 as a guide to grazing potential the coming season is illustrated in Figure 1. Many livestock men know from experience the carrying capacity of their range during drought years, average years, and high yield years. Their major difficulty is in predicting the amount of forage production to be expected for the coming year so that proper livestock adjustments can be made in the spring. Assuming that the major barrier to proper stocking rates is the lack of knowledge of potential forage production, a chart similar to the one shown can be of considerable value. On range similar to the study-area, six inches of moist soil would indicate a minimum stocking rate for the coming season, or enough for the breeding herd if the recommendation as outlined in the introduction is followed. Moist soil to a depth of 36 inches would indicate average stocking, and 60 inches or more of moist soil would indicate potential production to support maximum stocking. If numbers of livestock are preferable for this purpose, actual numbers can be inserted in place of, or in addition to, the descriptive terms (maximum, minimum, average stocking) as used here.

While the principle presented here is probably valid in other range provinces, the actual measurements given should be used with caution outside sandhills similar to the study area.

Summary and Conclusions

1. Depth of moist soil and the amount of soil moisture on April 15 were both found to be usable indices and about of equal value for predicting the amount of grass which will be produced by early August. Since depth of moist soil is the easier of the two to obtain, it will probably be the most practical to use as a predictive index.
2. Yields of grass from about August 7 to October 1 were found to be largely dependent upon available evapo-transpiration water during that period. Therefore, yields of grass during this period probably cannot be predicted with accuracy from April 15 soil moisture measurements. However, this was considered to be of minor concern since only four percent of the total forage production was made during this period in five of the six study years.
3. The two previous years' total precipitation was found to have a significant influence on the yield of grass during the spring growth period. One previous year's precipitation did not have a significant effect on spring grass yields. The reasons were not readily apparent.
4. The effect of the current seasonal climatic factors seemed to cancel, by mid-season, any effect of prior year's precipitation. However, the prior two years' precipitation (in inches) and the depth of moist soil (measured on April 15) when related to grass yields, gave the highest correlation coefficients obtained.
5. Spring drought, which limited the storage of moisture prior to the grazing season, was found to be the most critical factor limiting potential grass yield.

LITERATURE CITED

BRENGLE, K. G. 1960. Soil moisture and yield of winter wheat in Eastern Colorado. Colo. Agr. Expt. Sta. Tech. Bull. 69. 9 pp.

COLE, JOHN S. AND O. R. MATHEWS. 1940. Relation of the depth to which the soil is wet at seeding time to the yield of spring wheat on the Great Plains. U.S. Dept. Agr. Circ. 563. 20 pp.

HALLSTED, A. L. AND E. H. COLES. 1930. A preliminary report of the relation between yield of winter wheat and moisture in the soil at seeding time. Jour. Agr. Res. 41:467-477.

HALLSTED, A. L. AND O. R. MATHEWS. 1936. Soil moisture and winter wheat with suggestions on abandonment. Kans. Agr. Expt. Sta. Bull. 273. 46 pp.

REYNOLDS, HUDSON G. 1954. Meeting drought on Southern Arizona rangelands. Jour. Range Mangt. 7:33-39.

ROGLER, GEORGE A. AND HOWARD J. HAAS. 1947. Range production as related to soil moisture and precipitation on the Northern Great Plains. Jour. Amer. Soc. Agron. 39:378-389.