Estimating Herbage Production on Semiarid Ranges in The Intermountain Region[1]

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Large year-to-year changes in herbage yields on semiarid rangelands make it difficult to estimate grazing potential. Such estimates are useful in ranch planning and in making yearly adjustments in stocking rates. Although there is no perfect solution to these problems, a number of studies have shown a close correlation between the amount of precipitation and range herbage yields.

High and significant correlation coefficients between precipitation and subsequent herbage yields were presented by Craddock and Forsling (1938) r=0.944, Hutchings and Stewart (1953) r=0.944, and Blaisdell (1958) r=0.945. Their results established that precipitation variation was the dominant factor causing herbage yield fluctuations on semiarid ranges in the Intermountain Region. Precipitation during the winter-spring period was most closely correlated with subsequent herbage yields. These papers support the findings reported by workers elsewhere in the west (Army *et al.*, 1959; Bennett *et al.*, 1954; Burnett and Moldenhauer, 1957; Harper, 1957; Johnson, 1959; Keating and Mathews, 1957; Moldenhauer and Keating, 1958; Patton, 1927; Pingrey and Dortignac, 1959; Reynolds and Springfield, 1953; Rogler and Haas, 1947; Sarvis, 1941; Smoliak, 1956; Stitt, 1958; Thomas and Osenburg, 1959; Thomas and Young, 1954).

Correlation coefficients and regression equations define the herbage yield dependence upon precipitation, but do not provide a suitable technique for application to other areas. A given soil may produce as little as 10 pounds of herbage per inch of precipitation whereas another may produce 100 pounds. Consequently, regression equations developed from measurements of yield and precipitation on one experimental area are not directly applicable to other areas. However, if the actual yields and precipitation amounts were expressed in proportion to long-time expectations, an herbage-response line representative of many different areas could be computed.

This paper presents precipitation and herbage-yield records and derives a single herbage-response line that may be useful for estimating long-time yield averages and annual herbage yields on sagebrush-bunchgrass ranges in the intermountain states.

Pattern For Solution

The expression of actual yields and precipitation amounts from various experimental areas in proportion to long-time expectations requires the following: (1) The median amount of precipitation for each area, (2) an estimate of the median herbage yield for each, and (3) actual precipitation and yield amounts, respectively, expressed in percent of the median precipitation and median yield.

Median Crop-Year Precipitation

Precipitation frequency distributions of semiarid and arid regions generally show a typical skewness to the right. The median precipitation amount, which is the midpoint of arrayed precipitation data, therefore estimates the long-time expectation more reliably than does the mean. Furthermore, as pointed out by Daubenmire (1956) the median is less influenced by a single extreme than is the mean.

In a single growing season herbage growth depends largely on the amount of precipitation received immediately before and during the growing season. Therefore, the crop-year precipitation amounts are not the same as calendar year amounts. The crop-year must begin at the close of a previous growing season and terminate at the close of a current growing season. In the Intermountain Region the crop-year may begin on July 1 and terminate June 30 of the following year. However, precipitation in July and August is generally very low and seldom effective in promoting plant growth. The authors choose to tabulate precipitation from September 1 to June 30 and identify the crop-year period by the calendar year in which it terminates.

The median crop-year precipitation amount for any weather-recording station may be determined from the complete precipitation record published by the U. S. Weather Bureau. Actual precipitation amounts are used because widely applicable techniques for reliably estimating effective precipitation are not available. Precipitation effectiveness might be estimated for local areas by techniques described by Daubenmire (1957), Thomas and Osenbrug (1959), and Thornthwaite and Mather (1957).

Median Herbage Yield

The herbage produced on an area with a median amount of

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Table 1. Crop-year precipitation amounts and herbage yield by series and years.

Years[a]	Series 1		Series 2		Series 3		Series 4		Series 5		Series 6		Series 7	
	P[b]	Y[c]	P	Y	P	Y	P	Y	P	Y	P	Y	P	Y
1	8.4	406	8.4	403	8.4	453	8.4	318	8.4	252	8.4	820	8.4	1,336
2	5.9	317	5.9	321	5.9	341	5.9	344	5.9	270	5.9	486	5.9	715
3	14.3	1,368	14.3	1,258	14.3	1,296	14.3	1,163	14.3	1,266	14.3	1,991	14.3	1,977
4	13.1	965	13.1	1,168	13.1	1,236	13.1	858	13.1	906	13.1	1,115	13.1	1,394
5	6.1	588	6.1	694	6.1	744	6.1	697	6.1	640	6.1	793	6.1	732
6	9.7	735	9.7	763	9.7	884	9.7	621	9.7	571	9.7	716	9.7	993

Years[a]	Series 8		Series 9		Series 10		Series 11[d]		Series 12[e]		Series 13[f]	
	P	Y	P	Y	P	Y	P	Y	P	Y	P	Y
1	11.4	813	14.0	1,551	8.4	536	6.5	264	7.8	304	6.8	5,067
2	14.0	1,053	8.4	1,020	5.9	287	5.8	209	7.0	378	12.7	7,970
3	8.4	714	5.9	520	14.3	1,021	3.6	104	10.5	549	7.0	4,498
4	5.9	446	13.1	2,099	13.1	924	7.3	241	8.5	466	7.8	5,572
5	14.3	1,386	16.2	1,940	16.2	1,233	3.4	128	9.5	447	7.0	3,807
6	13.1	1,201	6.1	956	6.1	436	3.3	75	14.1	555	8.8	6,039
7	6.1	722	9.7	1,179	9.7	778	6.3	238	10.0	423	6.9	5,200
8	9.7	674					5.0	271	10.4	326	8.8	5,778
9							9.6	468	10.0	347	9.3	6,923
10									9.2	419		
11									9.9	532		
12									8.0	476		
13									7.4	235		

[a]Series 1, 2, 3, 4, 5, 6, and 7 include years 1954, 1955, 1956, 1957, 1959, and 1960.
Series 8 includes years 1952, 1953, 1954, 1955, 1956, 1957, 1959, and 1960.
Series 9 includes years 1953, 1954, 1955, 1957, 1958, 1959, and 1960.
Series 10 includes years 1954-1960, inclusive.
Series 11 includes years 1939-1947, inclusive.
Series 12 includes years 1936, 1937, 1938, 1939, 1940, 1941, 1942, 1947, 1949, 1950, 1952, 1953, and 1954.
Series 13 includes years 1924-1932, inclusive.
[b]P = Crop-year precipitation in inches and tenths.
[c]Y = Yield in lb/A.
[d]Hutchings and Stewart, 1953
[e]Blaisdell, 1958. Yields include grasses and forbs.
[f]Craddock and Forsling, 1938. Yields are expressed in days of sheep grazing per 40-acre pasture.

precipitation may be defined as the sustained-herbage-yield capacity but is referred to in this paper as the median herbage yield. The concept of median yield applies most directly to stable communities of native vegetation in good or excellent range condition, but also may apply to seeded stands of either native or introduced species when the latter are well adapted to the environment. Native vegetation in poor or fair condition should express a normal response to precipitation fluctuations over a few years and could be characterized by a median yield within those limitations. A median yield for any area may be estimated from linear regression of precipitation-yield series.

Precipitation and Yields in Percent of Median Amounts

If one assumes that a median amount of precipitation would produce a median yield for any range area, these two median values may be enumerated as 100 percent for all areas. The percentage expression of precipitation and yield amounts will be called, respectively, precipitation and yield indices. The indices transform precipitation and yield data from different areas into common terms having similar ecological interpretation and thus may be subjected to pooled statistical analysis.

The authors propose the hypothesis that yield indices in semi-arid closed communities of native or well-adapted introduced species fluctuate with precipitation indices in a fairly uniform and predictable manner.

Procedures

Thirteen precipitation-yield series were compiled (Table 1) from sources described as follows:

Series 1: *Agropyron desertorum* (Fisch.) Schult. (standard). Stands for this series were seeded at Squaw Butte Range near Burns, Oregon in the spring 1952, and were part of a species adaptability study that included series 2-7, inclusive. Yields of mature herbage from 3 replications were clipped by hand, oven-dried, averaged, and reported in lb/A at a moisture content of 10 percent. Yields in 1953-1957 were reported by Cooper and Hyder (1958).

Series 2: *Agropyron desertorum* (Mandan 571). See series 1.

Series 3: *Agropyron desertorum* (Nebraska 10). See series 1.

Series 4: *Agropyron cristatum* (L.) Gaertn. (Fairway crested wheatgrass). See series 1.

Series 5: *Agropyron cristatum* (A-1770). See series 1.

Series 6: *Agropyron sibiricum* (Willd.) Beauv. (P-27). See series 1.

Series 7: *Poa ampla* Merr. (Sherman big bluegrass). See series 1.

Series 8: *Agropyron desertorum* (standard). This series was an old stand of crested wheatgrass seeded at Squaw Butte Range about 1940. Yield data in 1952-1956 were obtained in a study of response to N fertilization (Sneva *et al.,* 1958). Yields in 1957-1960 were obtained from new plots established near the fertility plots for continuing the yield series. Yields of mature herbage from 5 replications were clipped by hand, oven-dried, averaged, and expressed in lb/A at 10 percent moisture. Series 8 includes only the yields from unfertilized plots.

Series 9: *Agropyron desertorum* (standard). This series includes yields from plots fertilized with 30 lb/N/A. The stand is described in series 8. Nitrogen was applied by surface broadcast of ammonium nitrate in the fall each year.

Series 10: Native sagebrush-bunchgrass range at Squaw Butte. The primary forage species were *Agropyron spicatum* (Pursch) Scribn., *Koeleria cristata* (L) Pers., *Sitanion hystrix* (Nutt.) J. G. Smith, *Festuca idahoensis* Elmer, *Stipa thurberiana* Piper, *Poa secunda* Presl., and small amounts of other grasses and forbs. The area includes 40 acres of good-condition sagebrush-bunchgrass range that was sprayed with 2,4-D (2,4-dichlorophenoxy acetic acid) for big sagebrush control in 1952. Mean yields of mature herbage at 10 percent moisture were obtained in 1954-1960 by hand clipping 60 randomly located samples each 48 square feet. The area was grazed in late summer each year.

Series 11: Native range, salt-desert shrub formation, Desert Experimental Range near Milford, Utah. Yields are expressed in lb/A air dry, and were published by Hutchings and Stewart (1953).

Series 12: Native range, sagebrush-bunchgrass formation, U. S. Sheep Experiment Station near Dubois, Idaho. The combined yields of grasses and forbs are expressed in lb/A air dry as published by Blaisdell (1958).

Series 13: Native range, sagebrush formation, U. S. Sheep Experiment Station near Dubois, Idaho. Forage yields are expressed in sheep-days of grazing per 40-acre pasture as published by Craddock and Forsling (1938).

Precipitation records for the Idaho location were obtained from "Climatological Data for Idaho" as published by the U. S. Weather Bureau, and records for the Utah location were obtained from S. Hutchings by personal communication.

Precipitation records for Squaw Butte Experiment Station were obtained at the experimental range. Squaw Butte yield data were obtained from areas within a half-mile of the weather recording instruments.

Results

Median Precipitation Amounts

Median precipitation amounts obtained from long-time records were as follows:

Squaw Butte Range, Oregon ....11.3 inches
Desert Experimental Range, Utah .... 4.1 inches
U. S. Sheep Experimental Station, Idaho .... 9.3 inches

Estimating Median Herbage Yield

Actual herbage yields and precipitation amounts for each series were subjected to least squares analysis. Correlation coefficients, regression equations, and estimated median yields are given by series (Table 2). Each median herbage yield was estimated from regression by substituting the appropriate median precipitation amount for X in the equation and solving for Y.

Table 2. Correlation coefficients, regression equations, and estimated median herbage yield for each of the 13 series.

Series	Correlation coefficient (r)	Regression equation[a]	Median herbage yield[b]
1	0.911	$Y = -240 + 101X$	901 lb/A
2	0.896	$Y = -173 + 98X$	934 lb/A
3	0.894	$Y = -134 + 100X$	996 lb/A
4	0.801	$Y = -34 + 73X$	791 lb/A
5	0.835	$Y = -232 + 92X$	808 lb/A
6	0.842	$Y = -232 + 127X$	1,203 lb/A
7	0.896	$Y = 10 + 123X$	1,400 lb/A
8	0.885	$Y = 23 + 82X$	950 lb/A
9	0.935	$Y = -62 + 132X$	1,430 lb/A
10	0.984	$Y = -116 + 82X$	811 lb/A
11	0.929	$Y = -69 + 52X$	144 lb/A
12	0.605	$Y = 104 + 33X$	411 lb/A
13	0.909	$Y = 678 + 599X$	6,249 sheep-days[c]

[a]When:
Y = Estimated herbage yield in lb/A
X = Crop-year precipitation inches.

[b]Estimated herbage yield when X = median precipitation in inches.

[c]Forage yields are expressed in sheep-days of grazing per 40-acre pasture.

Table 3. Precipitation and herbage yield indices by series and years.

Years[a]	Series 1		Series 2		Series 3		Series 4		Series 5		Series 6		Series 7	
	P[b]	Y[c]	P	Y	P	Y	P	Y	P	Y	P	Y	P	Y
1	74	45	74	43	74	45	74	40	74	31	74	68	74	95
2	52	35	52	34	52	34	52	43	52	33	52	40	52	51
3	127	152	127	135	127	130	127	147	127	157	127	166	127	141
4	116	107	116	125	116	124	116	108	116	112	116	93	116	100
5	54	65	54	74	54	75	54	88	54	79	54	66	54	52
6	86	82	86	82	86	89	86	79	86	71	86	60	86	71

Years[a]	Series 8		Series 9		Series 10		Series 11		Series 12		Series 13	
	P	Y	P	Y	P	Y	P	Y	P	Y	P	Y
1	101	86	124	108	74	66	159	183	84	74	73	81
2	124	111	74	71	52	35	141	145	75	92	137	128
3	74	75	52	36	127	126	88	72	113	134	75	72
4	52	47	116	147	116	114	178	167	91	113	84	89
5	127	146	143	136	143	152	83	89	102	109	75	61
6	116	126	54	67	54	54	80	52	152	135	95	97
7	54	76	86	82	86	96	154	165	107	103	74	83
8	86	71					122	188	112	79	95	92
9							234	325	108	84	100	111
10									99	102		
11									106	129		
12									96	116		
13									80	57		

[a]Years within each series are identified in Table 1.
[b]P = Precipitation index.
[c]Y = Herbage yield index.

Percentage Transformations

Precipitation amounts and herbage yields (Table 1), when expressed in percent of respective median precipitation amounts and median yields, are called precipitation indices and herbage yield indices, respectively (Table 3). From them (95 index pairs) a single regression equation may be computed to obtain a common herbage-response line.

Common Herbage Response Line

Yield indices were plotted over respective precipitation indices and fitted by linear regression (Figure 1); however, only 94 of the 95 pairs were used in the computations. The very high pair of index values in series 11, year 1947, which would occur very infrequently, were omitted to obtain a better fitting line through the bulk of data. The regression equation ($Y = 1.11X - 10.6$), standard error of estimate ($Sy.x = 18.4\%$), and correlation coefficient ($r = 0.880$) are included in Figure 1.

Discussion and Conclusions

Table 2 presents 13 different regression equations that illustrate the problem involved in using quantitative precipitation-yield relations in range management. Each area has its own peculiar quantitative relation determined by the exact nature of the vegetation and its environment. Consequently, knowledge about the dependence of yield precipitation has not been of practical value. Individual studies on experimental areas are limited to a relatively few years that may provide weak estimates of average precipitation, average yield, and regression. Yet the duplication of such studies on all range sites would be a formidable task.

This paper evolved from the hypothesis that a common yield-response line might be computed from data expressed in percentage of median yield and precipitation. The percentage indices placed all the data on a comparable basis and permitted a logical pooled analysis of the precipitation-yield relation in those qualitative terms. Linear regression describes adequately the yield dependence on precipitation within the range of data examined. However, one may theorize that a complete yield-response line would be a sigmoid curve and that the line presented in Figure 1 estimates the center portion thereof.

The estimated median yield (by definition, the sustained-herbage-yield capacity) for any area may be computed from a single yield sample as follows: (1) *Determine the median crop-year precipitation amount* from the complete precipitation record that is representative of the area under consideration, (2) *compute the precipitation index* for the year in which herbage yield has been sampled, (3) *estimate the herbage yield index* from Figure 1 or by direct computation from the regression equation, and (4) *compute the estimated median yield* by dividing the yield index in its decimal form into the individual actual

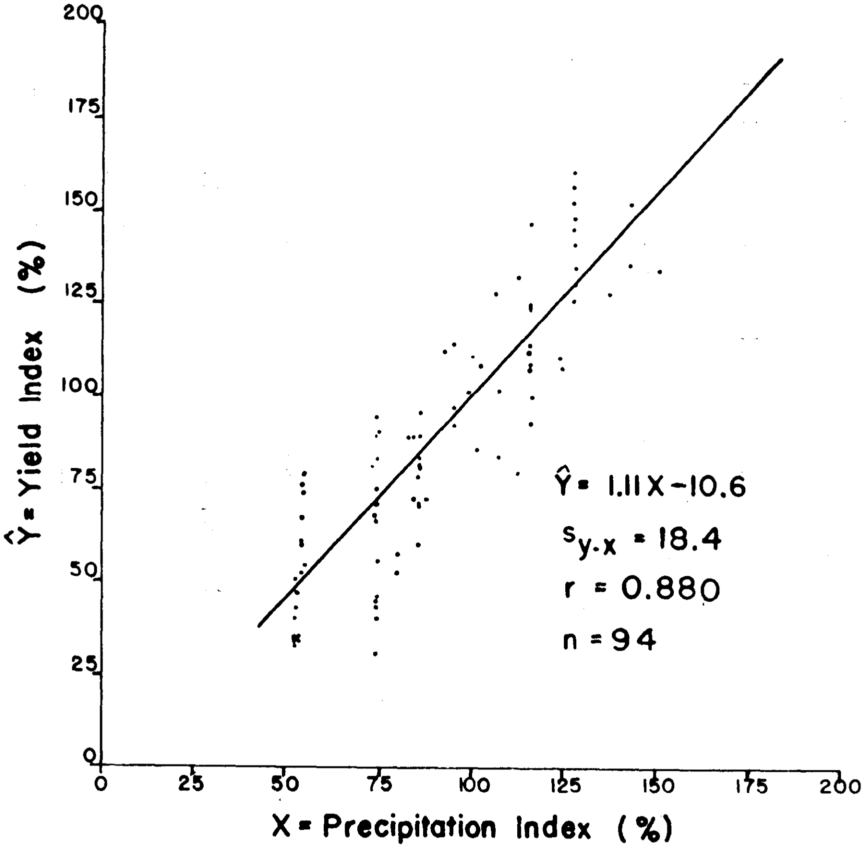

FIGURE 1. Herbage-yield response to variation in precipitation.

yield. For example, if the actual yield was 900 lb/A and the yield index was 127 percent, then 900/1.27 estimates the median yield at 710 lb/A.

Since environmental conditions other than precipitation influence yields, the median yield may be estimated more accurately from 2 or more years of actual yields.

Median yields may be estimated from range surveys to improve estimates of grazing capacities. The authors previously referred to this need as one of adjusting range production to a median year (Sneva and Hyder, 1960). Such application should not, however, cause the range manager to relax in over-confidence, because proper grazing management depends on qualitative as well as quantitative factors (Stoddart, 1960).

The yield-response line may be used to estimate expected yields in an individual year on an area for which the median yield has been estimated previously, as follows: (1) *Compute the precipitation index* for the individual year, (2) *determine the yield index* from Figure 1, and (3) *multiply median yield by the yield index* in its decimal form. For example, if the median yield had been previously estimated as 710 lb/A, then in a year with a yield index of 127 percent the actual yield is estimated to be 710 x 1.27 = 900 lb/A. This procedure may be used to forecast the annual herbage crop as early as April 1. In that case winter precipitation (September 1-March 1) is compiled and the median April-May-June precipitation amount added to obtain an estimate of crop-year precipitation. Subsequently, the three steps enumerated would be followed. The forecast could, of course, be revised to include actual precipitation preceding May 1, June 1, and July 1.

The yield-response line may be applied to animal days of grazing as well as to herbage yields although herbage yields and forage yields are not identical. The yield-response line represents total herbage yields. In mixed-species vegetation individual herbaceous species show different yield trends among years (Blaisdell, 1958) and present a problem of fluctuating composition as well as total yields. Forage-yields and animal-days-of-grazing are influenced by species composition as well as by herbage yield. Therefore, one would expect a larger error of estimate when the yield-response line is applied to animal days of grazing or to estimates of forage yield for mixed-species vegetation.

Summary

Thirteen precipitation-yield series from studies conducted in Oregon, Utah, and Idaho were pooled for the calculation of a common herbage-yield response line. For each of the 3 locations the median precipitation amounts were derived from complete precipitation records. Median herbage yields were calculated for each of the 13 precipitation-yield series directly from linear regression equations. Subsequently, each precipitation-yield pair was expressed in percent of corresponding median precipitation and median herbage yield. The percentage values were called precipitation indices and yield indices, respectively. From those indices a single regression line was computed to represent a common yield dependence on changes in precipitation. The regression equation was: $Y = 1.11X - 10.6$, where X is the precipitation index and Y is the yield index. The standard error of estimate was 18.4 percent, and the correlation coefficient with n-2 = 92 degrees of freedom was 0.880.

The median herbage yield of other semiarid ranges in the Intermountain Region may be estimated from a single yield sample as follows: (1) *Determine median crop-year precipi-*

tation from the complete precipitation record, (2) *compute the precipitation index* for the year in which herbage yield has been sampled, (3) *estimate the median herbage yield index* Y by direct computation from the regression equation with the precipitation index substituted for X, and (4) *compute the estimate of median yield* by dividing the yield index in its decimal form into the individual yield sample.

The method provides a basis for estimating the long-time median herbage yield of a range from median precipitation or the herbage yield in any given year from an individual crop-year precipitation amount.

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