Correlations of Precipitation and Temperature with Spring, Regrowth, and Mature Crested Wheatgrass Yields

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Highlight: Yields of crested wheatgrass on August 1 and May 15 and its August 1st regrowth, with or without N fertilizer, were correlated with 45 temperature and precipitation variates. Correlation coefficients for mature yields with monthly precipitation were highest for combinations of eight or more consecutive months, beginning the previous July, August, or September. The inclusion of growing season temperature increased the coefficient of determination by a maximum of 8 percentage units. The best combination for predicting unfertilized mature yield was July–May precipitation plus mean March, April, and May temperatures and accounted for 64% of the total yield variation. Mean February temperature with March precipitation accounted for 83% of the variation in spring yield.

On the Oregon high desert the winter snows dissipate; the grass greens, grows, withers, and dies. The relationships that exist therein between climatic factors and yield response are relatively unknown. Only Blaisdell (1958) has discussed the literature and examined in the field the response of growing plants to various climatic parameters in a locale similar to the cold, dry desert of eastern Oregon.

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This paper presents the simple correlations (r) of crested wheatgrass (*Agropyron desertorum* (Fisch.) Schult.) yield with temperature and precipitation occurring during selected calendar periods over 14 years. It presents also, yield relations obtained through multiple correlation (R) and of selected combinations of the more highly related simple correlations.

Study Area

The Squaw Butte Experiment Station lies 42 miles west of Burns in southeastern Oregon at an elevation of 4,500 feet. This high desert receives about 12 inches of precipitation annually. About 60% of the total precipitation is received during the fall and winter months, often as snow. Twenty-five percent falls as rain during the months of May and June. The summer months of July, August, and September are dry. Over a 34-year recording period the annual precipitation extremes have been approximately 6 and 17 inches. Mean monthly maximum temperature is 35° in January and 85°F in July. The temperature extremes recorded have been −24° and 104°F.

The study site was seeded in the mid-forties with an unknown selection of crested wheatgrass (*Agropyron desertorum*). Prior to seeding the site was dominated by big sagebrush (*Artemisia tridentata*) and native bunchgrasses (*Agropyron spicatum, Festuca idahoensis, Koeleria cristata, Stipa thurberiana,* and *Sitanion hystrix*). The site is typical of the northern fringe of Great Basin and Range Province where crested wheatgrass has been introduced.

The soil underlying the study site is a sandy loam of basaltic origin with a caliche layer approximately 2 feet below the soil surface. Most of these semiarid soils have not been classified. Eckert (1957) has described some of the soils of the more important vegetational types.

Prior to and during the study period, the site in which the study was located was grazed by cattle or mowed each fall. Thus, the grass stand should have been in good state of vigor at the initiation of the trial.

Materials and Methods

Herbage of crested wheatgrass was harvested from 10 unfertilized permanent plots (0-N) and 10 permanent plots annually fertilized with 30 pounds of nitrogen (30-N) per acre in the years 1957–1970, inclusive. Yield from 48 ft^2 (4 × 12 ft), obtained by hand clipping within a 10′ × 12′ treatment area, was sampled on May 15 ± 2 days (spring yield) and on August 1 ± 5 days (mature yield). Regrowth from the plots harvested on May 15 was sampled on August 1. The collected herbage was oven dried in a forced air dryer and the oven-dry weights recorded. The study was conducted as a randomized block with 5 replications. Herbage yield and its response to N and clipping have been published previously (Sneva 1973).

Daily temperature and precipitation were recorded at the Station's headquarters less than ¼ mile from the study site. Climatological records for Squaw Butte Experiment Station are available in "Climatological Data" for Oregon.[1]

Herbage yield and precipitation and temperature recorded during 45 selected calendar periods were subjected to correlation analysis. Multiple correlation regression analyses were subsequently utilized to examine multiple and partial relations of some of the more highly correlated single relations.

Results

Simple Relations

Climatic Relations

Because of the integrated nature of temperature and precipitation, their relations merit examination. Only in October was there a significant ($P<0.05$) negative relationship for mean monthly precipitation with mean monthly temperature ($r=-0.56$). Nonsignificant ($P>0.05$) but negative correlations were obtained in the months of August, November, April, and June. In all other months the correlation was positive but nonsignificant.

Yield Relations

Spring yields for fertilized and unfertilized plots were negatively correlated with regrowth yield (Table 1), but coefficients were low and nonsignificant ($P<0.05$). Their correlation with mature yield was even weaker and the sign of the coefficient was variable. The correlation between regrowth and mature yield was significant ($P<0.05$) in all comparisons with the coefficient highest with N. Thirty-six to 51% of the variability in mature yields could be associated with fluctuations in regrowth yield.

Spring Yield

With but one exception temperature was poorly correlated with spring yield (Table 1). Mean monthly temperature for February was negatively correlated with unfertilized spring yield ($P<0.01$, $r=-0.70$) and with fertilized spring yield ($P<0.05$, $r=-0.54$). Beginning in February, coefficients of mean monthly temperature were generally higher and negative more often for comparisons without N than with N.

No significant correlation coefficients were obtained from any precipitation variates tested with fertilized spring yield (Table 1). Significant coefficients were obtained with August alone and March to May 15 precipitation variates ($r=0.56$ and -0.55, respectively) with unfertilized spring yields. The spring precipitation was negatively associated with yield as were most precipitation periods tested.

Regrowth Yield

Precipitation or temperature variates significantly correlated with mature yield were also generally significantly correlated with regrowth yield (Table 1). The primary exception was April precipitation, which was significantly ($P<0.05$) correlated with regrowth but not mature yield; and in March precipitation was significantly correlated ($P<0.05$) with unfertilized mature yield but not with regrowth yields. The relationship was reversed for precipitation in March and unfertilized grass yield. A major difference between correlations of mature and regrowth yield was that with N, correlations consistently increased with mature but not with regrowth yield comparisons.

Table 1. Simple correlation coefficients (*r*) of crested wheatgrass (fertilized and unfertilized) yield with themselves, temperature, and precipitation periods.

Variates		Yield variates and N rate					
		Spring		Regrowth		Mature	
No.	Description	0-N	30-N	0-N	30-N	0-N	30-N
Forage yield		1.00	—	—	—	—	—
1	Spring, 0-N	0.80**	1.00	—	—	—	—
2	Spring, 30-N	−0.24	−0.26	1.00	—	—	—
3	Regrowth, 0-N	−0.36	−0.34	0.95**	1.00	—	—
4	Regrowth, 30-N	0.03	0.02	0.70**	0.71*	1.00	—
5	Fall, 0-N	−0.08	0.14	0.60*	0.68**	0.87**	1.00
6	Fall, 30-N						
Monthly mean temperature		0.14	−0.08	−0.33	−0.36	−0.07	−0.20
7	July	−0.30	−0.38	−0.54*	−0.46	−0.59*	−0.58*
9	August	−0.29	−0.51	0.40	0.43	0.06	−0.06
9	September	0.22	0.15	0.10	0.16	0.03	−0.10
10	October	−0.37	−0.24	−0.07	−0.08	−0.17	−0.23
11	November	−0.03	0.06	0.11	0.12	0.14	0.04
12	December	0.13	0.33	−0.17	−0.21	−0.44	−0.25
13	January	−0.70**	−0.54*	0.17	0.18	−0.31	−0.21
14	February	−0.21	−0.05	−0.28	−0.26	−0.10	−0.17
15	March	0.49	0.27	−0.27	−0.23	0.12	−0.02
16	April	−0.23	0.07	0.41	0.43	0.42	0.70**
17	May	−0.25	−0.05	0.32	0.41	0.36	0.61*
18	May 1–15 (period mean)	—	—	0.48	0.51	0.25	0.54*
19	May 16–31 (period mean)	—	—	−0.48	−0.44	−0.24	−0.26
20	June						
Sum of monthly mean temperature (inclusive)							
21	March to May	—	—	−0.01	0.04	0.40	0.48
22	March to May 15	−0.06	0.09	0.06	0.18	0.42	0.58*
23	March to June	—	—	−0.25	−0.18	0.25	0.32
24	May 16 to July	—	—	0.15	0.24	0.00	0.33
Total precipitation							
25	July	0.14	0.22	0.24	0.37	0.29	0.36
26	August	0.56*	0.44	0.02	−0.04	0.36	0.33
27	September	−0.16	−0.22	0.25	0.29	−0.05	0.04
28	October	−0.44	−0.28	0.33	0.26	0.23	0.22
29	November	0.22	0.26	0.27	0.26	0.27	0.48
30	December	0.06	0.08	0.36	0.42	0.18	0.27
31	January	0.05	0.15	0.40	0.39	0.30	0.35
32	February	−0.15	0.01	−0.28	−0.28	−0.11	−0.02
33	March	−0.47	−0.38	0.29	0.41	0.54*	0.46
34	April	−0.28	−0.08	0.67**	0.53*	0.33	0.33
35	May	—	—	0.21	0.22	0.45	0.29
36	June	—	—	0.48	0.40	0.26	0.21
Total precipitation (inclusive)							
37	July to May 15	−0.25	−0.04	0.76**	0.75**	0.72**	0.81**
38	August to May 15	−0.27	−0.07	0.74**	0.71**	0.69**	0.77**
39	September to May 15	−0.41	−0.18	0.69**	0.68**	0.56*	0.64*
40	March to May 15	−0.55	−0.37	0.54*	0.53	0.56*	0.46
41	May 16 to July	—	—	0.45	0.44	0.29	0.17
42	July to February	0.05	0.19	0.60*	0.59*	0.54*	0.71**
43	July to March	−0.11	0.06	0.68**	0.72**	0.71**	0.84**
44	July to April	−0.16	0.03	0.75**	0.75**	0.70**	0.82**
45	July to May	—	—	0.75**	0.75**	0.75**	0.83**
46	July to June	—	—	0.78**	0.77**	0.73**	0.78**
47	August to March	−0.14	0.02	0.67**	0.69**	0.70**	0.82**
48	August to April	−0.19	−0.00	0.74**	0.72**	0.68**	0.79**
49	August to May	—	—	0.73**	0.72**	0.73**	0.80**
50	August to June	—	—	0.78**	0.74**	0.72**	0.76**
51	September to June	—	—	0.75**	0.74**	0.61*	0.67**

* = $P<0.05$.
** = $P<0.01$.
n-2 = 12.

[1]Climatological Data—Oregon. E.D.S., N.O.A.A., U.S. Dep. of Commerce.

Mature Yield

Mean monthly temperature, during the previous fall and winter, was generally negatively correlated with mature yield with and without N (Table 1), but significantly so only in August ($r=-0.59$ and $r=-0.58$) for 0-N and 30-N, respectively. Positive temperature correlation with mature yield began in April and continued until June when the relation reversed. In May, temperature accounted for 49% of the mature yield fluctuations of fertilized crested wheatgrass ($r=0.70$). Significant temperature relations with unfertilized mature yield did not exist during the winter and spring period.

Monthly precipitation was weakly correlated with mature yield (Table 1). The only exception was March, when precipitation and mature yield were significantly correlated ($P<0.05$, $r=0.54$) in unfertilized plots.

Precipitation variates of at least 8 consecutive months were all significantly ($P<0.05$) and positively correlated with mature yield. These periods could begin in July or as late as September of the preceding year and end as early as February or as late as June of the crop year. The correlations were always higher for comparisons with N than without N. Similarly, correlations for periods beginning in July or August and ending in February, March, April, May, or June showed a general increase through May, but decreased when June precipitation was added. Correlations for periods ending in March, April, May 15, or June but beginning in July, August, or September generally decreased as the period was shortened or as the beginning date was delayed. Highest correlations were those from periods beginning in July or August of the previous year and extending through May of the crop year. Using only July through May precipitation, the coefficient of determination (DC)[2] values estimate that 57 and 69% of mature yield variation for unfertilized and fertilized crested wheatgrass, respectively, could be accounted for.

Multiple Effects

Along with the 2 significant simple relations (August precipitation and February temperature), 5 other variables were simultaneously regressed with unfertilized spring yield (Table 2). In so doing, the August precipitation effect was found to be insignificant, while February temperature remained a dominant variable and March precipitation became a significant contributor, raising the *CD* from 50 to 83%. Mean April temperature, which approached a significant relation ($P<0.05$) with spring yield, increased the *CD* by only 3 percentage units in the presence of February temperature and March precipitation.

A subsequent analysis that included the yield data of 1971 and 1972 (n=16) also examined spring yields of the fertilized plots (Table 2). The 3 factors: February temperature, March precipitation, and April temperature accounted for 84% of spring yield variability of unfertilized grass but only 50% of that for fertilized grasses. In both cases, April temperature, based upon *t* values,[3] is relatively ineffective in increasing the *CD*.

Multiple regressions combining precipitation and temperature variates for regrowth and mature yields are presented in Tables 3 and 4, respectively. The addition of temperature to the precipitation variates did not generally increase the *CD* substantially for either unfertilized regrowth or mature yield. Maximum increase was about 10 percentage units when using a 5-variable equation. Mean temperature for a multiple-month period was generally less effective for increasing the *CD* than when the mean temperature of each month individually was used. August temperature, highly significant when simply correlated, reverted to a nonsignificant contributor when evaluated after correcting for July–June precipitation.

The amount of yield variation accounted for (*CD*) remained the same or increased with each additional climatic variable included in each equation, but increases beyond the 2nd or 3rd variable were generally small (Tables 3 and 4). Changes in the standard deviation from regressions were also small but most often decreased with the 2nd variable entry and thereafter showed an increase.

Discussion

These results are similar to those reported by Blaisdell (1958); i.e., only the long-term precipitation periods of 8 or more months were closely correlated with subsequent mature yield, and temperature influence was small. He also found that late winter and early spring temperature had a negative effect on the earliness of plant development. This concurs with the effect of February and March temperatures on spring yield.

There are also dissimilarities between these results and those of Blaisdell's. These differences do not necessarily mean a direct conflict of results but rather may be reflecting differences resulting from the communities studied. Blaisdell studied native vegetation, a mixed community, comprised of about 25% forbs at an elevation approximately 600 feet above that of Squaw Butte and received slightly less precipitation per year. He stressed the fact that the community rather than its individual components, shows the greatest harmony to the climatic factors imposed upon it. In this study, the community response is expressed as an extension of the individual response. One could argue that relations developed with general climatic descriptors such as monthly means for a single species stand rarely will be as sound as those developed with a mixed species stand. If, in the future, the specific climatic descriptors peculiar to growth and yield functions of crested wheatgrass are found, development of a stronger relation with fewer factors for a single species stand than a mixed community should be possible. The fact that significant correlations were obtained similar to those reported

Table 2. Coefficients of determination (*CD*), *t* values, and standard deviation ($S_{y.x}$) for a 7-variable stepwise regression for estimating spring yield (unfertilized, 0-N) and for 3 variable standard regressions for estimating spring yield (unfertilized, 0-N, and fertilized 30-N).

Precipitation and temperature variates	*CD*	*t*	$S_{y.x}$
0-N			
February tp (x_1)	50	−3.73	)
March ppt (x_2)	83	−2.56	)
April tp (x_3)	85	1.37	)
March–May 15 ppt (x_4)	88	0.35	) 10.4
March tp (x_5)	88	−0.55	)
May–May 15 ppt (x_6)	89	0.44	)
August ppt (x_7)	89	0.34	)
0-N			
February tp (x_1)	—	−5.10	)
March ppt (x_2)	—	−5.07	) 9.1
April tp (x_3)	84	−1.44	)
30-N			
February tp (x_1)	—	−2.49	)
March ppt (x_2)	—	−2.30	) 41.9
April tp (x_3)	50	0.09	)

[2]*CD*—Coefficient of Determination is $r^2\times 100$ or $R^2\times 100$ and is a measure of the variation accounted for by the variable or variables being correlated.

[3]*t* is a test of the partial correlation coefficient and is an independent measure of that factor's contribution of the total accountability.

Table 3. Coefficients of determination (*CD*), and standard deviation ($S_{y.x}$) values of multiple regressions for estimating crested wheatgrass regrowth (unfertilized).

Precipitation and temperature variates	*CD*	*t*	$S_{y.x}$
July–March ppt (x_1)	46	2.80	37.9
March tp (x_2)	46	0.00	39.5
July–April ppt (x_1)	56	3.28	34.3
April tp (x_2)	58	−0.75	34.9
March tp (x_3)	58	0.09	36.6
July–May ppt (x_1)	56	2.92	34.3
April tp (x_2)	58	−0.86	34.8
May tp (x_3)	60	−0.52	36.0
March tp (x_4)	60	−0.27	37.8
July–May ppt ($_1$)	56	4.02	34.3
March–May tp (x_2) (mean)	59	0.98	34.3
July–May 15 ppt (x_1)	57	3.77	33.7
May 15–July tp (x_2) (mean)	57	−0.10	35.2
July–June ppt (x_1)	61	3.34	32.2
June tp (x_2)	65	−1.28	31.7
April tp (x_3)	68	−1.24	31.7
May tp (x_4)	72	−0.92	31.8
March tp (x_5)	72	0.31	33.6
July–June ppt (x_1)	61	4.50	32.2
March–June tp (x_2)	67	−1.42	30.9
July–June ppt (x_1)	61	4.40	32.2
March–May tp (x_2) (mean)	64	−0.90	32.5

Table 4. Coefficients of determination (*CD*), and standard deviation ($S_{y.x}$) values of variables within multiple regressions for estimating mature crested wheatgrass yield (unfertilized).

Precipitation and temperature variates	*CD*	*t*	$S_{y.x}$
July–March ppt (x_1)	50	3.62	52.2
March tp (x_2)	55	1.05	52.0
July–April ppt (x_1)	49	3.54	53.0
March tp (x_2)	54	1.06	52.3
April tp (x_3)	57	0.80	53.2
July–May ppt (x_1)	57	3.03	48.7
April tp (x_2)	62	1.15	47.6
March tp (x_3)	63	0.57	49.0
May tp (x_4)	64	0.28	51.5
July–May ppt (x_1)	57	3.63	48.7
March–May tp (x_2)	62	1.21	47.8
July–June ppt (x_1)	53	2.66	50.6
April tp (x_2)	57	0.92	50.6
March tp (x_3)	60	0.80	51.1
May tp (x_4)	61	0.43	53.3
June tp (x_5)	61	0.12	56.4
July–June ppt (x_1)	53	3.48	50.6
March–May (x_2)	60	1.36	48.9
July–June ppt (x_1)	53	3.48	50.6
March–June tp (x_2)	60	1.36	48.9
July–June ppt (x_1)	53	2.20	50.6
August tp (x_2)	55	−0.63	51.9

for native vegetation is evidence that crested wheatgrass is well adapted to this area.

In a previous paper, Sneva and Hyder (1962) chose to describe the crop year precipitation as that which was received during September to June, inclusively. That selection was based upon 10 yield series at Squaw Butte over a short time period and included native and other introduced grasses along with crested wheatgrass. It now appears that the yield fluctuations of crested wheatgrass are better described by a precipitation period beginning in July of the previous year and terminating in May of the growing year. However, using precipitation alone, that period would not be essentially different from other periods beginning in July and ending in June or beginning in August and ending in May. With the addition of the mean March–May temperature to the July–June precipitation period, 64% of the variation in mature yield can be accounted for. Although the amount of variation in mature yield accounted for here is not as great as that reported previously using precipitation (Sneva and Hyder 1962), the present approach has utility in removing variation to define trends and treatment effects more readily. Apropriate equations based on data terminating in March or April can be used to plan adjustments in the grazing season to take advantage of surplus forage and to utilize forage more efficiently.

Growing season precipitation, while generally not significantly associated with mature yield, was in positive relation with yield. This differs from results reported by Blaisdell. However, when June precipitation data were included, correlations always decreased similar to those reported by Blaisdell who explained the negative relationships to be resulting from a negative relation of June precipitation with precipitation of the preceding months. At Squaw Butte, this latter relationship was positive but nonsignificant. In eastern Oregon, June is the beginning period for the summer-type convectional storms. The intense land surface heating subsequent to development of such storms can be detrimental to plant growth and probably accounts for the negative relation between June temperature and mature yield. If June were dominated by such storms, one would expect a positive relationship between June precipitation with June temperature; in fact, however, a negative relation existed. I would conclude that in June, frontal storm systems still prevail and dominate the climatic scene; and when such storms are absent, land surface heating occurs to the extent that growth is retarded, possibly through water stress.

The importance of June precipitation, which is the 4th largest monthly contributor to the precipitation total, is difficult to define because of masking effects of temperature and soil moisture depletion as well as being confounded by occurring in the terminal growth period of crested wheatgrass and during the changing of storm patterns from frontal system to convective storm. Under the frontal storm system and its associated cloud cover, the causative effect of temperature fluctuations is defined as the storm system. However, during summer months, with no frontal storm systems, the primary source of precipitation is from convectional thunderstorms. In this, fluctuations in precipitation are caused by temperature.

Should soil moisture depletion occur rapidly, the upper levels of crested wheatgrass roots may, in June, be in a semidormant state and relatively unresponsive to rainfall. June precipitation, when included with previous months' precipitation, resulted in a decrease in the correlation with mature yield; but with regrowth yield, the correlation was increased. In the latter case, clipping on May 15 generally removed the growing point. Regrowth is from dormant buds. While we know that total defoliation at that time temporarily stops root growth, there is little information on the influence of this new shoot growth on the activity of roots near the surface. The fact that regrowth yields were positively correlated with June precipitation suggests that a direct effect is involved despite the negative influence of temperature at this time on mature yield and the relation between precipitation and temperature.

Nitrogen-fertilized grasses not only utilize soil moisture more efficiently, but also more rapidly than do unfertilized grasses (Sneva et al. 1958). Higher correlations for yields of fertilized grasses with precipitation variates that were significantly correlated with unfertilized yields is a logical consequence. Temperatures in May were more strongly correlated with fertilized crested wheatgrass yield than with unfertilized yield. Though unexamined in this report, the combination of precipitation variates with May temperature appears to be useful for evaluating mature yield of fertilized crested wheatgrass.

There is another possible explanation for higher correlations in the presence of N fertilizer. Nitrogen is believed to be second only to precipitation in limiting yield in semiarid regions. In this set of response data there are 2 years in which I feel that the lack of N or an abundance of N was apparently the primary factor influencing yield of unfertilized grasses. A scatter diagram for mature yield plotted against July to May precipitation (Fig. 1) illustrates this. The first was 1958, which was the 3rd consecutive year of high precipitation, yet herbage yield was low. A corresponding low yield on fertilized plots that year did not occur. It is believed that the three exceptional growth years of 1956, 1957, and 1958 depleted the soil N supply to levels such that in 1958, N became a more limiting factor than precipitation. The second occurrence of N dominance was in 1969. In that year, exceptionally high yields of unfertilized grasses were obtained considering the amount of precipitation received. Those exceptional yields are believed to have resulted from N carryover in 1968, a year in which less than 6 inches of precipitation was received during the crop year. Thus, 1968 was in a sense much like a fallow year and the unused N carried over into 1969.

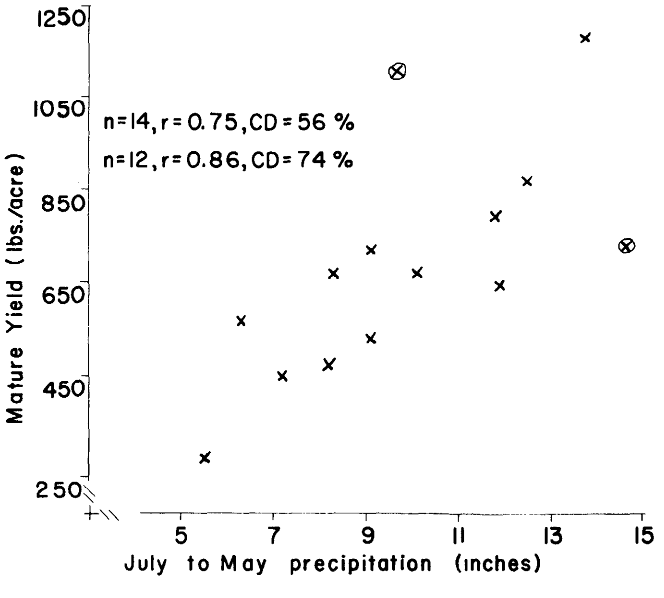

Fig. 1. *Scatter diagram for mature crested wheatgrass yield (unfertilized) against September to May, inclusive precipitation. Circled values are years 1958 and 1969.*

It is important to recognize that if such years were eliminated from the analyses, higher *r*'s would result. In this set of data, elimination of those 2 years increased the correlation from 0.75 to 0.86, and increased the *CD* from 56 to 74%. It should also be noted that the inclusion of these 2 years (which tend to balance each other) would contribute more to the variability about the regression line than to the slope of the response.

Knowledge of year sequence, which develops soil N into a primary rather than a secondary factor influencing yield, enhances our ability to use effectively the precipitation-yield relation. In the practical sense, it is perhaps better to utilize the simpler response information and correct for the year sequence effect when it occurs rather than to develop a sophisticated model that includes year sequence effect. The former can be achieved with fewer years' data than can the latter.

Regrowth and mature yield were significantly correlated with each other, with or without N. Thus, similar correlation between regrowth and mature yield with the various periods were anticipated. However, correlations for mature yield from fertilized plots were higher than correlations for mature yield from unfertilized plots. Such a relation did not occur for regrowth because in the presence of N, regrowth yield was not increased in all years, particularly the dry ones, thereby weakening the relation.

The validity of the positive contribution of the previous July and August precipitation to the following year's yield is questionable. This is particularly so because the mean monthly precipitation was only 0.31 and 0.54 inch, respectively, for July and August with an evaporation potential of 10 to 20 times those amounts. It is possible that these effects are artifacts of this particular set of years. However, it is interesting to note that over the same period of years, the yield of native grasses responded in an opposite manner with July and August precipitation (unpublished data). Within our native grass complex, numerous species, particularly bluegrass, are known to respond to late summer rains; thus, such precipitation would not be saved for the following year. In contrast, crested wheatgrass, which by July is near peak maturation, responds slowly, if at all, to moisture additions (Keller 1959; Hyder 1961). Therefore, the moisture received in those months is probably not used by the grass. Moisture in July and August could be instrumental in building the supply of soil N. The enhancement of nitrogen mineralization in sandy loam soil through intermittent drying and wetting has been demonstrated by Schreven (1967). Conceivably, the positive effect of July and August precipitation on the subsequent year's yield might be an indirect effect of an accumulation of soil nitrogen.

Crested wheatgrass has been primarily seeded for spring grazing. The factors influencing spring yield have not previously been examined, although Blaisdell (1956) did examine climatic relations with early spastic and phenological development. Mean yield of crested wheatgrass on May 15 approximates 550 and 300 lb/acre, with and without N, respectively (Sneva 1973). Hyder (1967), Sharp (1970), and Handl and Rittenhouse (1972) suggest that 200–300 lb/acre of available forage is needed to provide optimum mature animal performance; thus, grazing of unfertilized crested wheatgrass could begin in early May and grazing of fertilized crested wheatgrass could begin somewhat earlier. Strong variations among years have previously made turnout onto crested wheatgrass pastures a "seat of the pants" estimate. Such a "state of the art of range management" allows for little, if any, grazing plan development before turnout. The significant relation developed here from spring yield with February temperature and March precipitation have potential for predicting the amount of forage available on May 15, and, through growth function extrapolation, the amounts available on dates prior to May 15.

The impact of February temperature upon the early growth of crested wheatgrass had not previously been considered seriously. Mean temperature in February is 30.1°F with the range extending from 25.6 to 40.0. The mean temperature increases to 35.0°F in March and subsequently to 43.2 in April. Temperature in February is most variable, a reflection of the tremendous variation in soil surface conditions receiving or reflecting the incoming solar radiation. A warming of the soil and air temperature in February causes the initiation of growth at a time when current and subsequent temperatures are unfavorable for growth and perhaps physiologically damaging. Cool temperatures in February delay the initiation of growth until more favorable temperature sequences are assured for more efficient and rapid growth.

The negative association of March temperature suggests that even in March, air temperatures are still below an optimum level for growth and that subsequent spring yield is reduced because of warm March temperatures. While that relation was not significant, the relationship of March precipitation with spring yield was significant and negative. Since temperature and precipitation in March were positively correlated, it is the author's interpretation that increasing March precipitation does not cause subsequent yield decline, but rather reflects an associated temperature increase that is unfavorable for maximum yield on May 15.

Only in April was a positive relation between temperature and spring yield developed, suggesting that consistency in growth threshold temperature level had been achieved. During April, precipitation was negatively correlated with yield; and again, the suggestion is made that this is not real, but rather an expression of a temperature-precipitation relation which has reversed itself relative to growth. This is substantiated by the negative association between April precipitation and temperature means.

Implications

The results of this study, spanning a 14-year period, provide additional relations that bring us closer to satisfactorily predicting the starting time for grazing as well as the total forage produced on crested wheatgrass stands in eastern Oregon.

Unfertilized crested wheatgrass yields on May 15 varied from 167 to 437 and averaged 296 lb/acre. Eighty-three percent of yield variation was accounted for with February temperature and March precipitation. The standard errors associated with these equations suggest that the yield estimate will be within 10% of the true yield 95% of the time. Addition of April temperature or March to May 15 precipitation can improve the equation but for actual use such an equation is not practical; however, for research purposes in adjusting yields between years to remove year effect the inclusion of those variables may be justified.

Thirty pounds of N raised the mean spring yield of crested wheatgrass to 548 lb/acre and caused a 221% increase in the yield range. Predication of these yields was not good with the best equation tested accounting for 50% of yield variation and with a confidence half-interval at the 95% probability level of approximately 23%.

Sixty to seventy percent of the regrowth yield variation could be accounted for by equations that included July to June precipitation and temperature combinations that included the months of March, April, May, and June. Standard errors for all such equations were relatively wide with 95% confidence half intervals approximately 35% at the mean level of productivit (282 lb/acre).

Correlations of climatic variables with mature yield o unfertilized crested wheatgrass were reduced in this stud because in 2 years response was interfered with by the lack of c an excess of nitrogen resulting from year sequence phenomena It is inferred from Table 4 that adequate prediction of matur yields can be reliably estimated as early as the first of April an can be improved upon as the season progresses. Ninety-fiv percent confidence intervals developed from the standard error associated with regressions variables shown in Table 4 indicat that yield estimates are within 25% of the true yield. Because w have the knowledge of year sequence effect within these matur yield regressions, the variation in yield accounted for by th regression and the estimate of error associated with that estimat are in reality closer approximations than the stated value indicate.

The information developed in this study provides the basi relations from which we can predict spring and mature yield c crested wheatgrass growing on like soils and under like climati variation to that of the study site. The utility of these relation can be broadened immensely by transferring the quantitativ regression to qualitative relationship whereby yield is expresse in percent of median year precipitation amount as proposed b Sneva and Hyder (1962). With that transformation the onl additional information required for yield estimation is th current season's climatic record expressed in the proper form

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