Int. J. Biometeor. 1982, Vol. 26, number 4, pp. 263-276.

# Relation of Precipitation and Temperature with Yield of Herbaceous Plants in Eastern Oregon

by

Forrest A. Sneva*

ABSTRACT. – Eighteen years of herbage yields of range grasses and concomitant precipitation and temperature fluctuations were examined with correlation and regression techniques. Antecedent precipitation was the dominant factor influencing yield of perennial herbaceous species, while both temperature and precipitation were important for prediction of yield of downy bromegrass, a winter annual. Total yield of the herbaceous community was closely correlated with precipitation received during the September to June period (r = 0.92); however, September to March precipitation was also highly correlated (r = 0.89). These correlations provide timely and useful estimates of native range production on eastern Oregon ranges. Sixty to 92% of yield variation was accounted for by the regression models for 9 of the 12 species or species groups examined.

## INTRODUCTION

"For 11 of the 17 western states the combined amount of precipitation in any current season and preceding year accounts for 65 to 78% of the variation in forage yield." (Sampson, 1952). The 11 states mentioned were all east of the Rocky Mountains. Research in the past 25 years suggests that Sampson's statement is true for most of the rangelands west of the Rockies (Blaisdell, 1958; Pingrey and Dortignac, 1959; Reynolds and Springfield, 1963; Sneva, 1977; and Sneva and Hyder, 1962).

This paper relates 18 years of concomitant temperature and precipitation observations with production of range plants and further strengthens the premise that range forage yield is primarily dependent upon antecedent precipitation. Furthermore, this dependency is sufficiently strong to provide the basis for annual forecasting of range forage yield.

## STUDY AREA

The Squaw Butte Experiment Station lies 68 km west of Burns in southeastern Oregon at an elevation of 1372 m. The annual precipitation is about 30 cm but during the study period ranged from approximately 13 to 40 cm, both long term record extremes. About 60% of the total precipitation is received during the fall and winter months, often as

* Range Scientist, USDA, Agricultural Research Service, Burns, Oregon 97720, USA

snow. Twenty-five percent falls as rain during the months of May and June. The summer months of July, August, and September are normally dry. Mean monthly maximum temperature is 1.8° in January and 29.4° C in July. The temperature extremes recorded have been −31.1 and 40.0°C.

The study area was a 16 ha native big sagebrush-bunchgrass pasture that in 1952 was in fair to good condition. In the spring of 1952 the pasture was treated with 2,4-D for brush control. Sagebrush cover reduction was greater than 95%. In addition to big sagebrush (*Artemisia tridentata* Nutt.), low sagebrush (*A. arbuscula* Nutt.), green rabbitbrush (*Chrysothamnus viscidiflorus* Hook. Nutt.), and horsebrush (*Tetradymia canescens* DC.) were present but low in abundance during the study period. Grass and grass-like species found are presented in Table 1 with identifying acronym. Palatable broadleaf plants (forbs) encountered were: *Achillia, Senecio, Agroseris, Crepis* spp and species of the Cruciferae family. Unpalatable broadleaf (weeds) encountered were: *Aster, Astragulus, Erigeron, Lupinus, Phlox,* and *Leptodactylon* species.

The soil is a sandy loam of basaltic origin with a caliche layer from 45 to 76 cm below the soil surface. Most of these semi-arid soils have yet to be classified but Eckert (1957) described some of the soils of the more important vegetation types.

The pasture was grazed each year by cattle, after grass maturity. Stocking was based on the yield estimate of forage species with herbage removal permitted to the extent of 50% utilization or 336 kg/ha residue remaining, whichever was the lowest. Downy bromegrass was considered as a non-forage species. Thus, in most years utilization was less than 50% of the total herbaceous production present.

## MATERIALS AND METHODS

Daily temperature and precipitation were recorded at the National Oceanic and Atmospheric Administration's cooperative weather station 0.3 km from the study site and are available in "Climatological Data" for Oregon.

Herbage yield was obtained each year from hand-harvested samples in July or August. In 1953 and 1954 yield estimates were derived from 300, 0.9 $m^2$ quadrats with species composition estimated visually. Thereafter, yield was estimated from 60, 4.5 $m^2$ samples with composition estimated by hand separation at the time of harvest. Not all species shown in Table 1 were present in sufficient quantity to provide adequate samples, thus, some species were grouped at harvest. The following perennial grasses were grouped under Miscellaneous Grasses (MG): Indian ricegrass, Cusick bluegrass, Sandberg bluegrass, foxtail wheatgrass, basin wildrye; however, because the latter made a strong recovery following brush control it was handled as a separate species beginning in 1957. The two needlegrasses were grouped under Thurber needlegrass, the most abundant of the two. All forbs were harvested as a single unit as were weeds, except that weeds were not measured until 1958.

Correlation coefficients were generated from individual species yield, grouped yields, and yield of all species less yield of weeds with monthly precipitation, mean monthly temperature, 6 long term precipitation combinations (> 9 consecutive months), 13 short term precipitation combinations (> 2 < 4 consecutive months) and 10 combinations of monthly temperature (>2<5 consecutive months) for the periods of 1953 to 1970 and 1985 to 1970. The impact of previous years' precipitation upon the current year total yield also was examined by correlation techniques. Differential response by species to brush control occurred, particularly with Junegrass and bott-

Table 1. Herbaceous species present in 40-acre study pasture

| Acronym | Species | Common |
|---|---|---|
| Agsa | *Agropyron saxicola* Scribn. & Smith Piper | foxtail wheatgrass |
| Agsp | *Agropyron spicatum* (Pursh) | bluebunch wheatgrass |
| Brte | *Bromus tectorum* L. | downy bromegrass |
| Ca | *Carex* spp | dryland sedge |
| Elci | *Elymus cinereus* Scribn. and Merrill | basin wildrye |
| Feid | *Festuca idahoensis* Elmer | Idaho fescue |
| Kocr | *Koleria cristata* (L) Pers. | Junegrass |
| Orhy | *Oryzopsis hymenoides* (Roem. & Schult.) | Indian ricegrass |
| Posa | *Poa sandergii* Vasey | Sandberg bluegrass |
| Pocu | *Poa cusickii* Vasey | Cusick bluegrass |
| Sihy | *Sitanion hystrix* (Nutt.) J. G. Smith | bottlebrush squirreltail |
| Stco | *Stipa comata* Trin. & Ripr. | needle-and-thread |
| Stth | *Stipa thurberiana* Piper | Thurber needlegrass |

lebrush squirreltail (Hyder and Sneva, 1956). To determine if the response of these two species to precipitation and temperature was altered or masked by that response effect, additional analyses of these two species were conducted.

Simple and multiple regression analyses for each species grouping was completed following correlation analysis. Climatic factors for multiple regression analysis were selected on their significance after simple correlation analysis.

The 12 months of precipitation and temperature data are based on a cropyear from July through June, with the harvested yield taken in July and August of the calendar year in which the cropyear ended. All references herein to monthly relationships are within the cropyear context.

## RESULTS AND DISCUSSION

INTER-PLANT RELATIONS. – The mean total yield during the study was 762 kg/ha and the range was 108 to 1206 kg/ha (an 11-fold range) (Table 2). Bluebunchgrass was a primary contributor to total yield and its yield fluctuation across years was the smallest (six-fold range) of all species or species group. Downy bromegrass, an introduced annual, contributed less than 5% to total yield prior to 1956, increased in subsequent years, and over the 18-year period was the second largest contributor to yield. Miscellaneous grasses contributed an average of 6% of the total yield, most of which was Sandberg bluegrass. Sampling error for total yield at the 95% confidence level varied over years from about 10 to 17% of the year mean and averaged 13%.

Yield of bluebunch wheatgrass was most highly correlated with total yield

Table 2. Mean yield (kg/ha), yield range (kg/ha), and mean composition (%) for herbaceous species and groups

| Acronym | Mean Yield | Yield Range | Composition |
|---|---|---|---|
| | kg/ha | kg/ha | % |
| Agsp | 179 | 55-306 | 24 |
| Kocr | 104 | 11-297 | 14 |
| Elci | 50 | 8-165 | 7 |
| Feid | 49 | 3-132 | 6 |
| Sihy | 46 | 8-114 | 6 |
| Stth | 29 | 4-55 | 4 |
| MG | 49 | 8-149 | 6 |
| Brte | 169 | 2-447 | 22 |
| Forbs* | 19 | 0-46 | 2 |
| Weeds** | 66 | 2-175 | 9 |
| Total | 762 | 108-1206 | 100 |

* Palatable broadleaf plants.
** Unpalatable broadleaf plants.

($r=0.93^{++}$; $+= P<0.05$; $++= P<0.01$) and yield of Idaho fescue ($r=0.87^{++}$) but was also significantly correlated with yield of Thurber needlegrass, Junegrass, and miscellaneous grasses. Bottlebrush squirreltail was strongly correlated with Junegrass ($r = 0.89^{++}$), miscellaneous grasses ($r= 0.75^{++}$) and less strongly correlated, but significantly so, with Thurber needlegrass and forbs. Junegrass correlations with other plants were similar to those of bottlebrush squirreltail, but the correlation with Idaho fescue ($r = 0.65^{++}$) with total yield ($r = 0.67^{++}$) and with Thurber needlegrass ($r = 0.69^{++}$) was significant. Yield of downy bromegrass was poorly correlated with all other species groups except for total yield ($r = 0.51$). Downy bromegrass correlations with Thurber needlegrass, bottlebrush squirreltail, Junegrass, and miscellaneous grasses were negative.

INTER-TEMPERATURE AND PRECIPITATION RELATIONS. – Correlations among monthly temperature (Table 3) were consistently low and the signs of the coefficients showed no particular trends among consecutive months. Three comparisons (July vs April, July vs June, and November vs March) were significant ($P < 0.05$) although seemingly unimportant.

Similarly, coefficients among monthly precipitation amounts (Table 3) were consistently low and the signs of the coefficients were indicative of no particular trends. Six monthly combinations produced significant coefficients ($P < 0.05$) but none were among consecutive months and no trends were evident.

Correlation coefficients of mean monthly temperatures with monthly precipitation amounts of different months were also generally low and the signs of the coefficients erratic. Within month comparisons were significant only for October ($r = -0.58^{+}$) and April ($r = 0.51^{+}$; the signs of the coefficients were positive during the months of

Tabel 3. Mean monthly temperature (°C), temperature range, precipitation (cm) and precipitation range for the 18-year study period

| Month | Temperature | | Precipitation | |
|---|---|---|---|---|
| | Mean | Range | Mean | Range |
| | C | | CM | |
| July | 18.9 | 16.6-21.8 | 0.76 | 0- 3.56 |
| August | 18.3 | 15.5-21.6 | 1.62 | 0- 6.91 |
| September | 14.6 | 11.6-19.9 | 1.02 | 0.03- 3.66 |
| October | 9.1 | 6.1-12.5 | 2.29 | 0- 8.61 |
| November | 2.7 | 0.8- 5.7 | 2.82 | 0.74- 6.22 |
| December | –1.4 | –2.9- 1.2 | 3.48 | 0.97-12.45 |
| January | –2.6 | –7.4- 3.2 | 3.96 | 1.01- 8.13 |
| February | –.7 | –3.2- 4.4 | 2.16 | 0.38- 5.08 |
| March | 1.9 | –.1- 3.9 | 2.26 | 0.15- 8.15 |
| April | 5.4 | 1.5- 8.9 | 1.73 | 0.08- 5.97 |
| May | 10.1 | 7.3-14.2 | 3.35 | 1.27- 9.70 |
| June | 14.4 | 10.9-18.4 | 2.95 | 0.74- 6.45 |

December, January, February and March, but negative in April, May and June. It is difficult to assess the impact of the within-month precipitation-temperature relations upon forage growth because of the integrated nature of the two variables. Sneva (1979) has shown that during the winter months precipitation raises day time temperature, primarily the maximum temperature of the day. Day time temperature during the growing season was reduced by precipitation. Here also the modification is primarily of the maximum temperature of the day. Thus, we have a situation in which one variable may be masking another and standard techniques for separation of such variables were not effective. It is important, even though the correlation coefficients are weak (partly because mean temperature is used herein), to recognize that these relationships are operative and impact upon range forage production.

BRUSH CONTROL RESPONSE EFFECTS. – Yield response of individual species to brush control have been shown by a number of researchers. In this paper I am not concerned with the response by the individual species to brush control but with the possibility of interference or masking by those responses of the individual's response to fluctuations in temperature and precipitation. The response correction was evaluated in two ways: 1) by comparison of correlation coefficients obtained from analysis of all years (1953 to 1970) with those from 1958 to 1970, which eliminated the years 1953 to 1957 when the initial and major grass response to brush control occurred; and 2) by correction of the yield data for brush control response trend, correlation of adjusted values with precipitation and temperature data, and comparison of those coefficients with those obtained in the initial analysis from unadjusted yield data.

Correlation coefficients of yields with climatic parameters were generally higher for the longer time period (1953 to 1970) than for the shorter (1958 to 1970), but correlations for like periods were generally in the same relative order. However, for bottlebrush squirreltail and Junegrass, correlations for the shorter time period were highest for those periods with nine or more consecutive months. Additionally, correlations of yield from those two species with periods of precipitation during the growing season were consistenly and significantly reduced with the shorter time period. Thus, that comparison did suggest some correlation interference of the two grasses, bottlebrush squirreltail and Junegrass with climatic variables.

To provide a means for removal of brush control response effects for Junegrass and bottlebrush squirreltail the raw yield data of each were fitted with a quadratic equation. Only that of bottlebrush squirreltail will be presented (Fig. 1). The equation $Y = 1936.6 - 56.4X + 0.41X^2$ where Y = adjusted yield (kg/ha) in a given year and X = the yield year; i.e., (1965 = 65) accounted for 79% of the variation. The standard error of the estimate was 17 kg/ha with a mean yield of 46 kg/ha. Using the equation the measured yields of bottlebrush squirreltail were all adjusted and the adjusted yield values were correlated with the original climatic parameters. In a similar fashion the yields of Junegrass were also adjusted. A quadratic equation, $Y = 3989.2 - 117.2X + 0.87X^2$, that accounted for 68% of the variation and had a standard error of the estimate of 66 with yield mean of 104 kg/ha was used to correct the harvest yield data. In the subsequent section correlation coefficients for bottlebrush squirreltail and Junegrass will be those obtained with adjusted yield values rather than sample values.

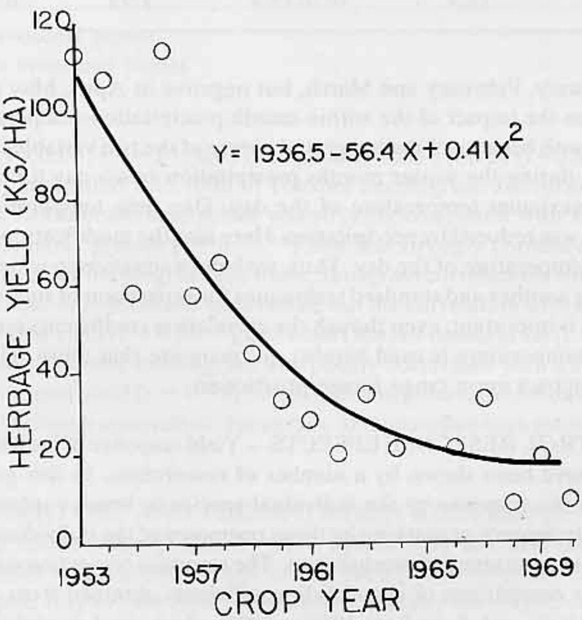


Fig. 1. Brush release response pattern for bottlebrush squirreltail.

TEMPERATURE-YIELD RELATIONS. – Yield of all plant species and groups were poorly correlated with monthly temperature from July through February. Only yield of Thurber needlegrass was significantly correlated with mean temperature in October ($r = 0.47^{+}$) and total yield significantly correlated with that of November temperature ($r = 0.47^{+}$). Mean monthly temperature in July was negatively correlated with all yields, as was November's mean temperature, while mean temperature for December was positively correlated for all species groups.

Mean monthly temperature or sums of monthly temperature means during the growing season were generally poorly correlated with yield, but some exceptions were evident. Yield of bluebunch wheatgrass correlated with May temperature ($r = 0.47^{+}$); yields of Thurber needlegrass, bottlebrush squirreltail, miscellaneous grasses, and forbs correlated with June temperature ($r = -0.52^{+}$, $r = 0.56^{+}$, $r = 0.51^{+}$, $r = 49^{+}$, respectively), total yield correlated only with May temperature ($r = 0.47^{+}$. Yield of downy bromegrass was correlated with February through April temperature ($r = -0.49^{+}$). Junegrass yield correlated with temperatures of February plus March ($r = 0.56^{+}$), February through May ($r = 0.51^{+}$), and April plus May ($r = 0.64^{++}$). Yield of bottlebrush squirreltail correlated only with April plus May temperature ($r = 0.53^{+}$). Yield relations with February through March temperature and with June temperature were nearly all negative.

These results suggest that temperature is related to mature herbage yield, but the associations are not strong. There are, however, some trends in the temperature-yield correlation that deserve consideration. Winter temperatures were always positively related with mature yield. Because temperature during winter months increases as precipitation increases the positive winter temperature relation with mature yield may not be real but in fact may reflect the higher precipitation amounts associated with those higher winter temperatures. A negative relation existed between most grasses and temperature during February and March. Mean February and March temperatures averaged −0.7 and 1.9°C, respectively (Table 3). Initiation of growth during those months due to seasonal warm up may expose tender growth parts to extremely cold nighttime temperatures capable of inflicting physiological damage and subsequent reduction in yield. Only in April and May did positive relations exist with yield and temperature, at which time mean monthly temperature was in a favorable growth range (>5.6°C). During June the temperature relation with yield reversed and again was negatively correlated with yield. Here too, the fluctuations of precipitation may be responsible for the temperature relation for in June, as temperatures increased, precipitation generally decreased. However, it might also be inferred that in some years temperature in June rises above the maximum threshold for optimum growth and reduces the yield.

PRECIPITATION-YIELD RELATIONS. – Precipitation for the months of July through February or for consecutive monthly combinations within that period was correlated inconsistently with some species groups. Yield of Thurber needlegrass and of forbs did not correlate significantly with precipitation at any period for that time of the year. Yield of Idaho fescue and miscellaneous grasses correlated only with December plus February precipitation ($r = 0.47^{+}$) and ($r = 0.58^{+}$), respectively while that of bottlebrush squirreltail correlated with precipitation in November ($r = 0.57^{+}$) and in December plus February ($r = 0.66^{++}$). Yield of Junegrass correlated with precipitation in August through November ($r = 0.55^{+}$), September through November ($r = 0.60^{+}$), October plus November ($r = 0.49^{+}$), December plus February ($r = 0.56^{+}$) and November ($r = 0.59^{+}$). Precipitation of September through November, October plus November, and November was correlated with bluebunch wheatgrass ($r = 0.69^{++}$, $0.60^{++}$, and $0.59^{+}$) and total yield ($r = 0.73^{++}$, $0.63^{++}$, and $0.62^{++}$), respectively. Bluebunch wheatgrass yield also correlated with precipitation from September plus October ($r = 0.58^{+}$) and in January ($r = 0.47^{++}$). Downy bromegrass differed because its yield correlated with precipitation in August through October ($r = 0.60^{++}$), August through November ($r = 0.54^{++}$), September plus October ($r = 0.57^{+}$), September through November ($r = 0.59^{+}$), September ($r = 0.50^{+}$), and January ($r = -0.52^{+}$). Only in August did the relation between yield and precipitation exhibit negative associations. Yield of weeds correlated only with precipitation in September through November ($r = 0.56^{+}$).

Growing season precipitation or precipitation for periods thereof was significantly correlated with yield of bluebunch wheatgrass, forbs, Idaho fescue, miscellaneous grasses, and total yield (Table 4). No significant relations during the growing season developed for Thurber needlegrass, bottlebrush squirreltail, Junegrass, or downy bromegrass: however, the correlation coefficient for downy bromegrass with June precipitation approached significance at the 0.05 level. Yield of weeds correlated with May plus June precipitation ($r = 0.56^{+}$).

Table 4. Precipitation-yield correlation coefficients for periods with the growing season

| | Precipitation Period | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Forage Class | March* | May | March to April | March to May | March to June | April to May | April to June | May to June |
| Agsp | $0.48^{+}$** | – | $0.53^{+}$ | $0.59^{+}$ | $0.61^{++}$ | $0.53^{+}$ | $0.49^{+}$ | – |
| Feid | $0.52^{+}$ | – | $0.47^{+}$ | $0.52^{+}$ | – | – | – | – |
| MG | – | $0.66^{+}$ | – | $0.59^{+}$ | $0.59^{++}$ | $0.69^{++}$ | $0.60^{++}$ | $0.57^{+}$ |
| Forbs | – | $0.79^{++}$ | – | $0.56^{+}$ | $0.69^{++}$ | $0.69^{++}$ | $0.74^{++}$ | $0.83^{++}$ |
| Total | – | – | – | $0.59^{+}$ | $0.71^{+}$ | $0.58^{+}$ | $0.64^{+}$ | $0.57^{++}$ |

* Monthly precipitation amount or sum of monthly precipitation for the months shown (inclusively).

** $^{+} = P < 0.05$; $^{++} = P < 0.01$.

Monthly precipitation amounts accumulated over a 7-month period or more beginning in July, August or September and ending in March, April, May, or June were, with a few exceptions, significantly correlated with total yield and yield of most individual groups of species (Table 5). The exceptions were Thurber needlegrass, which was poorly correlated with all periods; downy bromegrass, which was significantly correlated with only September through April and with September to March precipitation amounts, and forbs, which did not significantly correlate with September through April or with September through March precipitation amounts. Eighty-five percent of the coefficients for these long term precipitation periods were highly significant ($P < 0.01$) and, judged from $r^2 \times 100$ values, precipitation in those periods accounted for as much as 85% of the variation in yield.

Clearly, the amount of precipitation was the primary determinant of mature yield of the herbaceous range production. This agreed with results of Blaisdell (1958) for native range production in the Upper Snake River Plains and of Sneva (1977) for crested

Table 5. Correlation coefficients for yield and precipitation amounts accumulated over 7 or more months

| Class | July-June | August-June | September-June | September-May | September-April | September-March |
|---|---|---|---|---|---|---|
| Agsp | 0.80++* | 0.79++ | 0.84++ | 0.89++ | 0.89++ | 0.88++ |
| Feid | 0.59+ | 0.58+ | 0.64++ | 0.73++ | 0.72++ | 0.73++ |
| Stth | 0.41 | 0.38 | 0.41 | 0.45 | 0.40 | 0.37 |
| Sihy | 0.67++ | 0.64++ | 0.60+ | 0.55+ | 0.56+ | 0.61+ |
| Kocr | 0.72++ | 0.69++ | 0.66++ | 0.67++ | 0.67++ | 0.73++ |
| MG | 0.67++ | 0.67++ | 0.73++ | 0.78++ | 0.68++ | 0.67++ |
| Forbs | 0.62++ | 0.64++ | 0.62++ | 0.59+ | 0.40 | 0.43 |
| Brte | 0.44 | 0.46 | 0.44 | 0.38 | 0.50+ | 0.49+ |
| Weed | 0.74++ | 0.70++ | 0.75++ | 0.73++ | 0.76++ | 0.77++ |
| Total | 0.88++ | 0.89++ | 0.92++ | 0.92++ | 0.91++ | 0.89++ |

*+ = $P < 0.05$; ++ = $P < 0.01$.

wheatgrass. Our results also agreed with Blaisdell's conclusions that (1) precipitation amounts accumulated over the longer periods of time rather than amounts accumulated over short time periods are correlated more strongly with subsequent yield and (2) that yields of the aggregate of plants are more often highly correlated with precipitation than the yield of individual species. The relations differ from those reported by Blaisdell (1958) only in response of yield to late spring and early summer precipitation. He found April to June and June precipitation amounts to be negatively correlated with subsequent yields. In the present study those periods of precipitation were always positively correlated with yields although not always significant. Thus, he found highest correlations of long term precipitation with yield for those periods ending in March. Correlation coefficients in this study for long term periods ending in March were as high or higher than those reported by Blaisdell (1958) but were generally exceeded by correlation coefficients from periods that included monthly precipitation as late as June.

Previously, Sneva (1977) related crested wheatgrass yields to similar precipitation and temperature periods over 14 years. The study offers interesting correlations for comparison. Correlation coefficients of precipitation with native range yields increased as the starting month for precipitation accumulation was delayed from July to September; however, correlation coefficients for yields of crested wheatgrass decreased (Table 6). The differences between responses of crested wheatgrass and grasses of the native flora to late summer precipitation may account for differences in the trends of correlation coefficients observed. Crested wheatgrass displays a strong summer dormancy (Hyder, 1961; Keller, 1959) and makes little use of the sporadic, thunder shower precipitation occurring in late summer. With high evaporation rates during that period, it is also unlikely that much of such precipitation is stored in the soil for use in the subsequent year. However, it has been shown that such intermitent precipitation does stimulate nitrification (Schreven, 1967) and nitrogen may be stored in the soil and a contributing factor to increased yield in the subsequent year. Native grasses on the other hand, particularly the bluegrasses, do respond to late summer rains; thus precipitation in July and August is essentially used up in the current year and is not available for growth in the subsequent year. The regrowth derived from such late summer rains is of leafy material and much of it disappears over winter, and is lost prior to the subsequent year's yield harvest.

Correlation coefficients of native plant yields with precipitation periods beginning in September but ending in March, April, May, or June showed an increasing trend (although differences were small) from March to June (Table 6). The highly significant correlations of native range forage yields with precipitation for 7 or more months (Table 5) also suggest that predicted estimates may be possible with acceptable accuracy as early as the end of March. This would provide sufficient time for management to consider yearly adjustment and operation alternatives. Though a direct comparison for crested wheatgrass is not possible, a similar trend was noted for periods beginning in August and July except than when the month of June was included the coefficient was reduced considerably. This may indicate that the crested wheatgrass growth season is more advanced than the bulk of the native range species and that June precipitation has less impact on it.

Table 6. Comparisons of correlation coefficients of crested wheatgrass yields and native range yields with precipitation

| Forage Class | July-June | August-June | Sept.-June | Sept-May | Sept.-April | March |
|---|---|---|---|---|---|---|
| Native range | 0.88 | 0.89 | 0.92 | 0.92 | 0.91 | 0.89 |
| Crested wheatgrass | 0.73 | 0.72 | 0.61 | 0.73*<br>0.75** | 0.63*<br>0.70** | 0.70*<br>0.71** |

* Period began in August.
** Period began in July.

Correlations discussed up to now concerned only the current 12 month cropyear of July to June. Elsewhere in the West, researchers have shown that precipitation in the year or a portion of the year prior to the current cropyear benefited the correlation between yield and precipitation. I examined this relation by correlating total yield with June-July precipitation of the current season plus cropyear precipitation in the previous 1, 2 and 3 years. Examined in this fashion for the yield years 1956 to 1972 the correlation coefficients were lower for the longer precipitation periods ($r = 0.85^{++}$, $r = 0.45$, $r = 0.52$, and $r = -0.32$) for 1, 2, 3 and 4 years, respectively and only precipitation in the current cropyear was significantly correlated with current year yield. Since yield responses of most perennial range grasses and of total yield were similar, it is unlikely that response of individual species to previous year precipitation would differ greatly from that of total yield. Thus, the current cropyear precipitation is inferred to be the primary factor influencing forage yield.

PREDICTIVE REGRESSION MODELS. – Stepwise regression analysis for each species or species group was used with combinations of temperature and precipitation periods selected on the basis of outcome of the previous correlation analysis. Regression analyses for Sihy and Kocr utilized the adjusted yields previously discussed, whereas all other regressions used uncorrected harvest yields. Based upon the $R^2$ values, the following have been selected to present for illustrating opportunities for yield prediction.

*Bluebunch wheatgrass.* – Yields of this grass were estimated best by the model: $Y = -52.1 + 10.2X$ where X = precipitation (cm) from September through May. This variable alone accounted for 75% of the yield variation with a standard error of the regression of 44.8 kg/ha. Yield estimates by models using accumulative precipitation beginning in September and ending in April, May, or June were only slightly less acceptable.

*Idaho fescue.* – The precipitation period September through May also was most closely associated with yield of this grass and yields of this grass were estimated best by $Y = -33.6 + 3.6X$. However, the model accounted for only 48% of the variability with a standard error of 28 kg/ha. In a similar fashion, precipitation periods from September through April or through March could be used to produce equally acceptable models.

*Miscellaneous Grasses.* – Like the two aforementioned grasses, the yield of this group of grasses was best estimated by September through May precipitation. The regression model: $Y = -19.4 + 2.6X$ accounted for 67% of the variation and had a standard error of 13.4 kg/ha.

*Weeds.* – Yield of weedy species was best estimated by the model $Y = -44.5 + 60X$ where X = September through May precipitation. The model accounted for 58% of the yield variation and had a standard error of 35.8 kg/ha. Precipitation periods of September through April or through June or from July to June would provide a similar and equally acceptable model.

*Basin Wildrye.* – Yield of this grass was poorly estimated even by the best model utilizing July through June precipitation. The model $Y = -25.1 + 2.7X$ accounted for 28% of yield variation with a standard error of 35.8 kg/ha.

*Junegrass.* – Precipitation from September through April accounted for 51% of the yield variation for this grass and the model: $Y = 40.8 + 5.6X$ had a standard error of 39.4 Kg/ha. A four-factor model: $Y = -326.9 + 7.5X_2 + 12.5X_2\ 7.6X_3 - 5.4X_4$ where $X_1$ = December through February precipitation, $X_2$ = November precipitation, $X_3$ = sum of March through May temperature means, and $X_4$ mean June temperature increased the $R^2$ to 77%. However, as judged by the partial regression coefficients only $X_1$, $X_2$, and $X_3$ variables were substantial contributors to the regression.

*Bottlebrush Squirreltail.* – Like Junegrass, the best single variable, September through June precipitation accounted for only 39% of the yield variation. A five-factor model: $Y = 16.9 + 2.2X_1 + 1.6X_2 + 1.8X_3 - 1.1X_4 - 0.2X_5$ where $X_1$ = December through February precipitation, $X_3$ = April plus May mean temperature, $X_3$ = mean June temperature, $X_4$ = mean January temperature, and $X_5$ = September through November precipitation increased the $R^2$ to 70%. As judged by the partial regression coefficients, the first two factors were the primary determinants.

*Thurber Needlegrass.* – The yield of this species which also contained small amounts of needle-and-thread was the least associated with climatic factors of all tested. A three-factor model: $Y = -67.1 + 0.5X_1 + 0.03X_2 - 0.6X_3$ where $X_1$ = October mean temperature, $X_2$ = November precipitation, and $X_3$ = sum of March through June temperature means accounted for only 42% of the yield variation.

*Forbs.* – Thirty-nine percent of the yield variation of forbs was accounted for by precipitation from August through June. The model $Y = -8.2 + 0.8X$ had a standard error of 9 kg/ha. The $R^2$ was increased to 67% with a three-factor model: $Y = 33.2 + 3.1X_1 + 0.002X_2 + 0.17X_3$ where $X_1$ = *August through* November precipitation, $X_2$ = April precipitation, and $X_3$ = May mean temperature. Partial regression values suggest that $X_1$ and $X_3$ were the most valuable determinants.

*Downy Bromegrass.* – A model based on September through June precipitation accounted for the 47% of the yield variation of this annual grass. The model $Y = -73.9 + 11.0X$ had a standard error of 100 kg/ha. A four-factor model, $Y = 1531 + 20.3X_1 + 17.3X_2 - 30.4X_3 - 30.4X_4$ where $X_1$ = March through June precipitation, $X_2$ = September through November precipitation, $X_3$ = sum of February through April mean temperatures and $X_4$ = May mean temperature accounted for 92% of the variation with a standard error of 50 kg/ha. As judged by the partial regression coefficients, all four factors were substantial contributors to the regression although only $X_1$, $X_3$ and $X_4$ were statistically significant at the 95% level.

The preceding regression models of individual species or of species groups did not always provide as good a model as was desired. This is probably not because a closer association does not exist but rather is a reflection of an inadequate sample size both in space and in time. Plot size or number of samples taken was probably most limiting for species other than bluebunch wheatgrass and downy bromegrass. Basin wildrye, because of its tendency to grow in patches, was probably estimated rather poorly. Response to brush control in 1952 also contributed to the yield variability. That response primarily centered in several species such as bottlebrush squirreltail and Junegrass, and even though adjusted data were used for those species there was undoubtedly extraneous error that reduced the integrity of the data. However, it is also possible that low correlation coefficients for plants of secondary ecologic importance in the locale are a reflection of plants not in their preferred environmental niche.

Models for the individual species are informative and useful for reseach and ecological interpretation. The primary objectives of this research and the major management need of the animal grazing industry is the knowledge of the factors associated with the total yield of the community and the opportunity to forecast those yields.

Total yield was best estimated by the regression utilizing September through June precipitation which accounted for 83% of the yield variation. The model $Y = -214.5 + 34.6X$ had a standard error of 132.2 kg/ha. The plot of this relationship is shown in Fig. 2. Regression models developed from precipitation periods of September through March, April, or May, or from July through June, or from August through June also produced similar and acceptable models. The regression for total yield on September through March is also presented in Fig. 2. This model accounted for only slightly less variation than the September through June model, and the standard error increased to

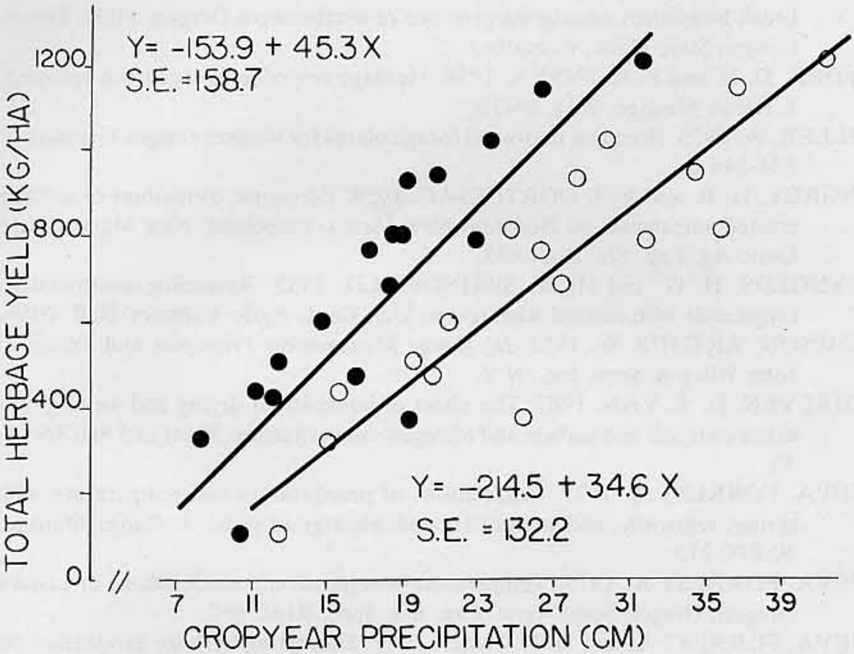


Fig. 2. Regression models for total yield with September through March precipitation (open circles) and with September through June precipitation (closed circles).

157.9 kg/ha. This model does permit an estimate of the range forage yield prior to the grazing season and gives management an opportunity to plan grazing strategy.

## ACKNOWLEDGEMENTS

The research is a cooperative investigation of the USDA, Agricultural Research Service, and the Oregon State Agricultural Experiment Station, Squaw Butte Experiment Station, Burns. Technical Paper No. 4935 of the Oregon State Agricultural Experiment Station.

## LITERATURE CITED

BLAISDELL, J. P. 1958. Seasonal development and yield to native plants on the upper Snake River plains and their relation to certain climatic factors. U.S. Dept. Agric. Bull. 1190.

Climatological Data for Oregon. National Oceanic and Atmospheric Administration, Environmental Data Service. National Climatic Center, Asheville, N.C.

ECKERT, R. E., Jr. 1957. Vegetation-soil relationships in some *Artemisia* types in Northern Harney and Lake counties, Oregon. Ph.D. Thesis. Oregon State Univ., Corvallis. 208 p.

HYDER, D. N. 1961. Growth characteristics of crested wheatgrass in the big sagebrush-bluebunch wheatgrass province of southeastern Oregon. Ph.D. Thesis. Oregon State Univ., Corvallis.

HYDER, D. N. and F. A. SNEVA. 1956. Herbage response to sagebrush spraying. J. Range Manage. 9(1): 34-38.

KELLER, W. 1959. Breeding improved forage plants for western ranges. Grasslands. 334-344 p.

PINGREY, H. B. and E. J. DORTIGNAC. 1959. Economic evaluation of seeding crested wheatgrass on Northern New Mexico rangeland. New Mexico State Univ. Ag. Exp. Sta. Bull. 433.

REYNOLDS, H. G. and H. W. SPRINGFIELD. 1953. Reseeding southwestern rangelands with crested wheatgrass. U.S. Dept. Agric. Farmers' Bull. 2056.

SAMPSON, ARTHUR W. 1952. *In, Range Management Principles* and *Practices.* John Wiley & Sons, Inc., N.Y.

SCHREVEN, D. A. VAN. 1967. The effect of intermittent drying and wetting of a calcareous soil and carbon and nitrogen mineralization. Plant and Soil 16:14-32.

SNEVA, FORREST A. 1977. Correlations of precipitation and temperature with spring, regrowth, and mature crested wheatgrass yield. J. Range Manage. 30:270-275.

SNEVA, FORREST A. 1979. Temperature-precipitation considerations in eastern Oregon. Oregon State Agric. Exp. Sta. Spec. Rept. 537.

SNEVA, FORREST A. and D. N. Hyder. 1962. Estimating herbage production on semi arid ranges in the intermountain region. J. Range Manage. 15(2): 88-93.