Herbage Yields in Relation to Soil Water and Assimilated Nitrogen

J. F. CLINE AND W. H. RICKARD

Highlight: *Soil water, herbage assimilated nitrogen, and herbage were measured in the field and used to estimate the effectiveness of nitrogen fertilization to increase yields in cheatgrass communities. The application of regression analysis to estimate the amount of nitrogen fertilizer needed to increase herbage in relationship to available soil moisture is presented. When herbage nitrogen is in the range of 0.5 to 0.7% at the end of the spring growing season, nitrogen rather than soil water appears to limit herbage production.*

Studies of nitrogen fertilization of rangelands clearly show that added nitrogen is not effective in increasing herbage when soil water is limiting (Owensby et al. 1970; Stroehlein, 1968; Dahl, 1963).

In southeastern Washington the growth of cheatgrass (*Bromus tectorum*) and other alien winter annuals is closely related at least phenologically to the growth of winter wheat. Seeds germinate in the fall and plants mature in the spring with the onset of soil drought. It was anticipated that the soil water and nitrogen relationships that apply to wheat production would also apply to yields of the alien annuals.

Liggett (1959) fitted field data to several mathematical forms to predict the amount of nitrogen fertilizer needed to obtain maximal yields of dryland wheat in relation to the amount of available soil moisture. Ankerman and Waddoups (1968) use early spring measurement of soil water in conjunction with measurements of available soil nitrogen to recommend the amount of nitrogen fertilizer needed to produce maximal yields of winter wheat commensurate to available soil water.

Methods

Three abandoned fields located on the Atomic Energy Commission's Hanford Reservation, Benton County, Washington, were studied from 1968 to 71. The fields, located at different altitudes, 183, 305, and 518 m above sea level, each have supported more or less even swards of cheatgrass, intermixed with various amounts of annual forbs, especially tansy mustard (*Descurainea pinnata*) and tumble mustard (*Sisymbrium altissimum*) for nearly 30 years. Soil water was measured in the upper meter of soil profile at the beginning of the spring growing season and periodically thereafter throughout the growing season. Soil samples were taken at decimeter depth increments from two holes at each site using a sand auger. Soil water content was determined upon oven drying at 105°C for 48 hours. An estimate of the permanent wilting percentage was measured at −15 bars using a pressure membrane apparatus (Richards and Weaver, 1944).

Herbage was harvested periodically from 10 to 20, 0.1 m^2 randomly selected plots at each site throughout the growing season to obtain peak herbage yields. Herbage was dried at 60°C, its nitrogen content determined by Kjeldahl procedures (Jackson, 1962), and phosphorus content determined by procedure of Olsen and Dean (1965).

In 1971 additional plots were established at the field at the highest altitude to assess the effect of added nitrogen upon herbage production. This field was chosen for the nitrogen treatments because earlier studies had shown that this site had the greatest abundance of soil moisture. Five levels of nitrogen (0, 1.1, 3.3, 6.6 and 11.1 gN/m^2) were applied to 4 m^2 plots in early February, using NH_4NO_3 pellets distributed uniformly as possible over each plot by hand. Each treatment was replicated five times in a random block design.

The authors are with the Ecosystems Department, Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Washington.

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Results and Discussion

The peak standing crops of herbage for the years 1969 to 71 are summarized in Table 1. The ranges varied between 127 and 328 g/m^2. The average yields over the 3-year period at the three different altitudes ranged between 221 and 273 g/m^2. The year-to-year variation was not as pronounced at the highest altitude as it was at the two lower elevations and is attributed to a more stable soil moisture supply.

Table 1. Herbage (g/m^2) and nitrogen content (%) and nitrogen utilization ratios in three different fields.

Item and year	Field altitude 183 m	305 m	518 m
Herbage[1]			
1969	328 ± 28	327 ± 26	226 ± 15
1970	165 ± 11	127 ± 8	208 ± 20
1971	No sample	211 ± 11	263 ± 38
Average	273	221	232
Nitrogen content[1]			
1969	1.19 ± .05	0.89 ± .09	0.52 ± 0.04
1970	1.46 ± .20	0.86 ± .08	0.75 ± 0.07
1971	No sample	0.95 ± .02	0.64 ± 0.06
Average	1.32	0.90	0.64
Nitrogen utilization ratio $\frac{\text{yield } (g/m^2)}{gN/m^2}$			
1969	66	91	173
1970	69	115	130
1971	No sample	105	155
Average	67	104	152

[1] Means and standard errors.

Table 2. Soil chemical analyses from the upper decimeter of soil in cheatgrass communities.

Item	Field altitude 183 m	305 m	518 m
N (%)[1]	.11 ± .007	.094 ± .007	.073 ± .004
P (ppm)[1]	11 ± 1	31.4 ± 3.9	33.8 ± 1.4
K (ppm)[1]	1382 ± 90	1404 ± 99	1082 ± 47
pH (range)[1]	6.4 - 6.9	7.0 - 7.3	7.4 - 7.8
Sand (5)	38	37	31
Silt (%)	54	52	56
Clay (%)	8	11	13

[1] Means (n = 5) and standard errors.

The nitrogen content of herbage at peak standing crop ranged between 0.52 and 1.46% (Table 1). The highest altitude consistently had the lowest nitrogen content and averaged only 0.64% over a 3-year period. When the herbage, expressed as g/m^2, is divided by the nitrogen assimilated by the herbage, expressed as gN/m^2, the most efficient use of nitrogen was made at the highest elevation, and the least efficient use was made at the lowest elevation. Chemical analyses of soil also showed that less nitrogen was present in the soil at the high altitude field (Table 2).

As expected, amount of soil water available for plant use varied greatly from year to year among the three different sites (Table 3). During the years 1968 to 71 the stored soil water ranged between 3.9 and 11.3 cm in the upper meter of soil profile. The driest year was 1968 and the wettest 1969. However, the average water use was similar at all altitudes. Some moisture percolated below 1 m deep at the high altitude field, and some soil water held at tensions above permanent wilting remained in the soil profile at the end of the spring growing season (Fig. 1). This lack of effective soil water usage is attributed to the paucity of available nitrogen to sustain a maximum yield.

During the years of study, soil water usage, measured as the yield in g/m^2, divided by the centimeters of available soil water lost from the soil profile, ranged between 19 and 26 at the high altitude field. However, the ranges were wider at the lower altitudes (Table 3). This indicates that over a several-year period soil water is not such a strong force in limiting herbage yields at the higher altitude as it is at the lower altitude.

To further illustrate the differences in soil water use at the medium and the high altitudes, the 1971 herbage growth curves and concomittant soil water depletion curves are shown in Figure 1. These curves show that peak production at the medium altitude occurred when soil water was depleted in May. The peak yield at the high altitude occurred in early June, but the soil profile at this time still contained some available water. It was concluded that herbage yield at the high altitude was limited by nitrogen rather than soil water. When the nitrogen content of herbage is about 0.64%, it seems that nitrogen rather than moisture is limiting herbage.

Table 3. Soil water use (cm) during growing seasons 1968-71 and calculated water efficiency ratios in three different fields.

Item and year	Field altitudes 183 m	305 m	518 m
Water used			
1968	No sample	4.2	3.9
1969	10.0	11.3	10.8
1970	7.1	10.5	9.0
1971	No sample	8.4	10.2
Average	8.55	8.3	8.5
Water efficiency ratio	$\frac{\text{yield g/m}^2}{\text{water (cm)}}$		
1968	No sample	19.8	19.6
1969	38.2	28.8	20.6
1970	23.2	12.1	23.1
1971	No sample	25.1	25.8
Average	30.7	21.45	22.3

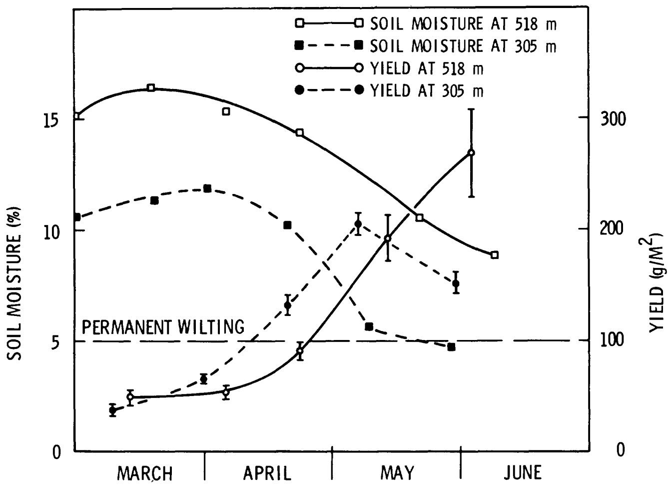

Fig. 1. *Moisture in the upper decimeter of soil and yield of standing herbage at two altitudes during the 1970 growing season.*

The field data were subjected to regression analyses to show the relationships of herbage yields to both nitrogen content of herbage and available soil water. The equation for soil water and yield Y (yield) = 29.7 + 27.6W (water) is significant at the 5% level (Equation 1). The equation for nitrogen content N (N in herbage) = -1.3 + 0.02Y (yield) is significant at the 5% level (Equation 2).

The equation Y (yield) = 71.1 + 41.1N (nitrogen) + 21.0W (water) derived from a stepwise linear regression showed that 71% of the variance in yield was due to nitrogen effect, 12% due to soil water effect and 17 is error not attributable to either soil water or nitrogen. To test the hypothesis that nitrogen was limiting herbage yields at the highest elevation, fertilizer was added before the onset of rapid spring growth. As expected, added nitrogen increased herbage yields (Table 4). The highest yield was obtained on plots with the most added fertilizer. The predicted yields in Table 4 were derived from the regressions formulated previously (Equations 1 and 2). There is generally good agreement between predicted and measured yields although occasional large discrepancies are also apparent. Further tests of this kind are needed on the low altitude fields to refine the predictability of nitrogen applications and herbage yields.

Table 4. Comparison of measured and predicted yields from nitrogen treated plots at 518 M altitude.

Fertilizer added (gN/m^2)	Yield (g/m^2) Measured[1]	Predicted
1.1	241 ± 34	205
3.3	490 ± 60	324
6.6	480 ± 70	508
11.1	724 ± 65	755

[1] Expressed as means and standard errors.

The effect of added nitrogen on rangeland herbage is subject to considerable variability because of the vagaries of weather. The problem is to predict available soil water in advance of the growing season. Under the climatic regime of southeastern Washington, soil moisture is stored in the soil profile in fall and winter and is depleted in spring by evapotranspiration. By June there is little or no growth water available.

In this region available soil water can be measured by sampling in late February or early March. Abundant soil water at this time can be expected to result in good herbage yields later in the year. However, abundant precipitation during the growing season could also contribute to increases in herbage when winter storage was limited. Ankerman and Waddoups (1968) add 0.6 of the average rainfall during the growing season to the measured soil water. The following steps are suggested to determine the amount of nitrogen fertilizer needed to increase herbage yields in cheatgrass swards. (1) Measure the centimeters of available soil water and available nitrogen in the upper meter of soil prior to rapid growth. (2) Enter the centimeters of available soil water in Equation 1 and determine the yield for that quantity of water. (3) Enter the yield (g/m^2) obtained above (step 2) in Equation 2 and determine the amount of nitrogen expected in that amount of herbage. The difference between the total nitrogen needed to produce the herbage (step 3) and the measured available nitrogen is the amount of nitrogen to add. If the difference is 0 or a negative number, any added nitrogen would not be effective during that particular season. Nitrogen added to the soil and not used by plants during the same growing season may be lost by wind and water erosion, but some is likely to persist in the root zone and become available to plants the following year.

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Water Storage Capacity of Contour Furrows in Montana

EARL L. NEFF

Highlight: *A field study in eastern Montana related water storage capacity of contour furrows constructed by Model B furrowing machines to furrow age. New contour furrows have a water storage capacity of nearly 1 inch, but this decreases with time owing to natural weathering, intrafurrow dam failure, and furrow breaching. Contour furrows have an average effective life of 25 years, but this ranges from less than 20 years to more than 35 years, depending on initial construction. A new furrowing machine design is suggested that would leave intrafurrow dams of undisturbed soil material, resulting in furrows with either the same storage capacity but at a greatly reduced cost per acre, or over twice the storage capacity at about the same cost per acre as furrows built by a Model B machine.*

Mechanical land treatments have been applied to western rangelands for many years to reduce surface runoff, reduce sediment production, and increase desirable forage. These treatments provide surface water storage, which increases infiltration time and results in more soil water storage for plant use. Branson, et al. (1966) published a comprehensive literature review and results of mechanical treatment effects on rangeland in Wyoming, Montana, Colorado, New Mexico, Utah, and Arizona. They point out: "Although mechanical treatments have been applied extensively, relatively few published reports contain quantitative data on the results of such treatments." The investigation reported here was conducted in Montana to assess contour furrow water storage capacity and longevity.

Contour furrowing is the most common mechanical treatment applied to Montana rangelands on the public domain. While several different designs of furrowing machines have been used in the past, in more recent years the Model B contour furrower developed under the sponsorship of the Range Seeding Equipment Committee by the Equipment Development Center, U.S. Department of Agriculture, Forest Service, San Dimas, Calif., has been used almost exclusively. The Model B contour furrower constructs two furrows 6 to 10 inches deep and 20 to 25 inches wide on 5-foot centers. A ripper tooth precedes the furrowing discs and rips the soil 10 to 14 inches deep, and a dam-building device can be adjusted

The author is research hydraulic engineer, U.S. Department of Agriculture, Sidney, Montana.

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