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# Environmental and Biologic Observations on Contrasting Slopes of Small Earth Mounds*

## Introduction

Winter annuals, although not prominent plants of the undisturbed shrub steppe vegetation of southeastern Washington, are important as colonizers of disturbed soil. On disturbed soil cheatgrass, *Bromus tectorum,* an exotic plant, persists for many years. It was expected that the vegetation of contrasting slopes of artificially formed earth mounds would show contrasts in productivity as measured by weekly harvests of above-ground biomass. To our knowledge, there have been no studies made comparing the effect of slope exposure on net production of winter annuals.

This paper presents field observations on the environment and biomass of winter annuals growing on contrasting north and south exposures on small, cone-shaped, artifically formed earth mounds during the spring of 1969. The mounds, each about three meters tall and eight meters in diameter, are located on the Atomic Energy Commission's Hanford Reservation, Benton County, Washington at an elevation of approximately 400 feet above mean sea level (Fig. 1). The mounds were probably made in the early 1950's from *in situ* materials and consist of a heterogeneous mixture of fine-textured glaciofluvial and eolian materials intermixed with quantities of rounded pebbles, gravels, and cobbles. During the existence of the mounds, plant invasion has not been disturbed by man or by grazing domestic animals.

The vegetation growing on the mounds over the past several years has consisted almost entirely of winter annuals, especially cheatgrass (*Bromus tectorum*), tansy mustard (*Descurainea sophia*), tumble mustard (*Sisymbrium altissimum*), and jagged chickweed (*Holosteum umbellatum*). The only perennial plant observed is Sandberg bluegrass (*Poa secunda*) which is mostly restricted to a few scattered clumps on the north-facing slopes. The summer annual, Russian thistle *Salsola kali,* also has grown on the mounds especially the north-facing slopes. However, *Salsola* has not appeared every year.

## Methods Employed

Productivity was determined by harvesting above-ground plant parts weekly throughout the most active part of the growing season from mid-March to mid-May 1969. A total of six mounds were used during the study. Every week early in the harvest season, a plot, 1 x 1 foot square, was harvested from the north and south slopes of the

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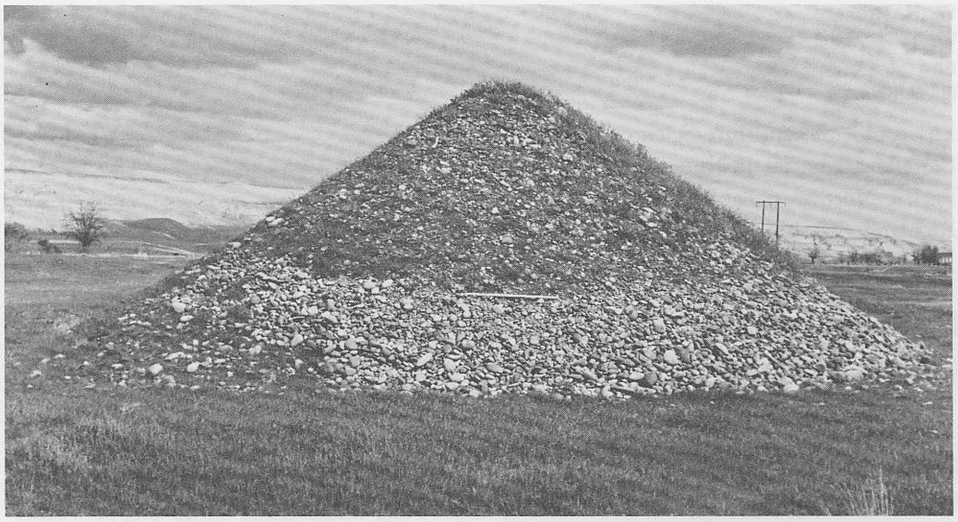

Figure 1. Photograph of an earth mound in April. The south-facing slope is on the right. A meter stick is shown for scale.

same three mounds giving a total of six harvested plots per week. Late in the season only the north-facing slopes of another three mounds were harvested yielding three plots per week, *i.e.*, one plot per mound per week.

Plucking plants by hand proved to be the most practical method of plant harvest on the irregular surface. A small portion of the root system was usually attached to each plant as it was pulled and this was included as harvest yield. Plants were collected according to species and placed in paper bags for transport to the laboratory where they were oven dried at 60 C. Biomass is expressed as grams of dry plant material per square foot and also as an average weight per plant.

Continuous records of total incoming solar radiation were made by two clock-driven pyranometers, one on each contrasting slope. The instruments were tilted to approximate the 36° slope angle. Air temperatures were measured near ground level by two thermographs, one on each slope exposure. The instruments were shielded to prevent sunlight from striking the sensing elements directly.

Soil temperatures were made weekly from thermocouples buried four decimeters deep. Soil-moisture determinations were considered but these were impractical to obtain considering the stoniness of the mounds.

Laboratory tests to determine seed germinability were conducted using five lots of 25 seeds each from north and south exposures. Petri dishes were fitted with a disk of filter paper upon which the seeds were placed. The dishes were kept in thermostatically controlled incubators at temperature regimes of 15 and 20 C. After wetting, seeds were kept in the dark except when taken out of the incubators for tallying germinated seeds.

## Observations

The 1968-69 growing season throughout the region was marked by an unusually luxuriant growth of winter annuals. The weather during the growth year was characterized by above average monthly precipitation in October and November which promoted the early establishment of seedlings (Table 1). April also brought greater than average precipitation at a critical stage of growth. Although total precipitation averaged greater than normal the winter temperatures were much colder. January was especially cold with an average temperature of 9.8°F below normal (Table 1).

TABLE 1. Summary of climatic conditions at Pacific Northwest laboratory meterological station during the 1968-69 growing season.

| | Avg. temp. °F | Departure from normal | Total monthly ppt. | Departure from normal |
|---|---|---|---|---|
| 1968 Sept. | 66.8 | +1.0 | 0.25 | −0.09 |
| Oct. | 50.3 | −3.1 | 0.93 | +0.20 |
| Nov. | 41.7 | +2.1 | 1.23 | +0.46 |
| Dec. | 30.6 | −3.3 | 1.25 | +0.38 |
| 1969 Jan. | 19.8 | −9.8 | 1.24 | +0.26 |
| Feb. | 31.7 | −3.8 | 0.54 | −0.12 |
| March | 45.8 | +1.4 | 0.10 | −0.38 |
| April | 52.2 | −1.2 | 1.22 | +0.85 |
| May | 64.6 | +2.5 | 0.51 | +0.01 |
| Total ppt. | | | 7.27 | +1.57 |

Station Location: Latitude 46° 34′ N, Long. 119° 35′ W, ground elevation 733 feet.

The weekly change in harvest yields from contrasting north- and south-facing slopes throughout the most active parts of the growth season is shown in Table 2.

TABLE 2. Plant biomass grams per square foot, on contrasting slopes of earth mounds during the spring of 1969.

| Harvest date | Dry wt. in grams | | | Mean ± S.E.* | Per cent forbs |
|---|---|---|---|---|---|
| | North slope | | | | |
| 3/18 | .99 | .49 | 1.06 | .85 ± 0.18 | 0 |
| 3/25 | 2.29 | .30 | .87 | 1.15 ± 0.59 | 21 |
| 4/2 | 1.88 | .76 | .77 | 1.13 ± 0.37 | 25 |
| 4/9 | 2.83 | .87 | 2.70 | 2.03 ± 0.63 | 12 |
| 4/16 | 3.27 | 1.35 | 1.70 | 2.10 ± 0.59 | 24 |
| 4/23 | 3.91 | 2.63 | 1.63 | 2.72 ± 0.69 | 6 |
| 4/30 | 5.35 | 1.50 | 6.84 | 4.56 ± 1.14 | 22 |
| 5/8 | 5.47 | 5.20 | 6.97 | 5.88 ± 0.08 | 20 |
| 5/19 | 13.67 | 6.10 | 7.95 | 9.24 ± 2.28 | 8 |
| | South slope | | | | |
| 3/18 | 8.97 | 5.35 | 3.97 | 6.10 ± 1.49 | 15 |
| 3/25 | 7.04 | 9.48 | 1.71 | 6.08 ± 2.29 | 12 |
| 4/2 | 15.81 | 5.62 | 3.14 | 8.19 ± 3.88 | 12 |
| 4/9 | 11.53 | 16.80 | 4.62 | 10.98 ± 3.53 | 21 |
| 4/16 | 21.46 | 11.34 | 8.30 | 13.70 ± 3.98 | 19 |

* S.E.=Standard Error

Cheatgrass provided most of the biomass, tumble mustard contributed between 12 and 21 per cent of the total biomass on the south-facing slopes, while *Holosteum* contributed mostly to the forb biomass on the north-facing slopes.

At the beginning of the spring growing season in mid-March, the average cheatgrass plant on the south exposures weighed much more than those on the north exposures (Table 3). This indicates that the autumn environment was more salubrious on the south exposure. The cheatgrass plants on the south exposures also flowered and matured earlier. By early April at least half of the cheatgrass plants in each harvested plot on the south-facing slope had flowering culms. A similar stage of development was not attained by the north-facing slope plants until early May. By mid-April cheatgrass

TABLE 3. Mean density of cheatgrass plants per square foot and the average weight of individual plants on contrasting slopes of earth mounds during the spring 1969.

| Harvest date | Average density/ft$^2$ $\pm$ S.E. | Average wt. per plant (mg) |
|---|---|---|
| | North slope | |
| 3/18 | 80.7 $\pm$ 16.9 | 10 |
| 3/25 | 94.7 $\pm$ 34.5 | 9 |
| 4/2 | 91.7 $\pm$ 31.2 | 8 |
| 4/9 | 129.0 $\pm$ 26.8 | 14 |
| 4/16 | 86.7 $\pm$ 14.7 | 18 |
| 4/23 | 88.3 $\pm$ 15.5 | 31 |
| 4/30 | 144.0 $\pm$ 34.1 | 25 |
| 5/8 | 118.7 $\pm$ 18.8 | 39 |
| 5/19 | 108.7 $\pm$ 13.3 | 78 |
| AVERAGE | 104.7 $\pm$ 7.8 | — |
| | South slope | |
| 3/18 | 48.3 $\pm$ 8.8 | 215 |
| 3/25 | 39.7 $\pm$ 15.4 | 133 |
| 4/2 | 51.3 $\pm$ 20.1 | 141 |
| 4/9 | 30.3 $\pm$ 3.5 | 287 |
| 4/16 | 34.0 $\pm$ 2.1 | 387 |
| AVERAGE | 40.7 $\pm$ 5.1 | |

plants on the south side had matured and were brown in color indicating that soil moisture was exhausted. However, plants on the north-facing slope continued to grow and remained green throughout April and into May.

When the average total biomass on the contrasting slopes was compared for each harvest day using t tests, the tests were not significant (except for 3/18/69 and 4/16/69) due to the large variability in biomass between plots on a given harvest day. However, a regression analysis described in the next section resulted in statistically significant differences in yields on the two slopes.

Although the growing season was extended several weeks on the north exposures, the terminal average biomass on the south exposure (13.70 gms/ft$^2$) was about 25 per cent greater than that on the north (9.24 gms/ft$^2$). However, the difference of 4.46 grams with standard error 4.58 was not statistically significant. A significant result may have been obtained if considerably more than three plots per day per slope had been harvested. We have estimated that approximately 26 plots on each slope would be required to be 80 per cent sure of obtaining a statistical significant result for a true mean difference in yield of 4.5 gm/ft$^2$.

Total incoming radiation measured on the contrasting slopes showed that south-facing slopes received considerably more solar radiation than north-facing slopes (Table 4). From the first of March until cheatgrass maturation in mid-April the

TABLE 4. Weekly accumulative solar radiation (langleys) on contrasting slopes of a small earth mound measured during the spring of 1969.

| Date | North | South |
|---|---|---|
| 3/18 | 1,100 | 2,800 |
| 3/25 | 2,200 | 7,700 |
| 4/2 | 4,200 | *12,000 |
| 4/9 | 6,300 | 15,900 |
| 4/16 | 8,400 | 19,900 |
| 4/23 | 10,800 | |
| 4/30 | *13,300 | |
| 5/8 | 16,900 | |
| 5/19 | 22,400 | |

* Flowering of cheatgrass.

south-facing slope received 19,900 langleys. At the same time the north-facing slope had received only 8,400 langleys. However, the north-facing slope had accumulated a total input of approximately 22,000 langleys at cheatgrass maturity in May.

The higher input of solar energy to the south exposure resulted in higher soil temperatures, and daytime air temperatures (Fig. 2). Nighttime air temperatures on the south slope also averaged slightly higher, but the contrasts were not so apparent as were the daytime temperatures.

The large variations observed in the harvested biomass between plots on a given day appeared to be due to two factors. First, the slope surfaces had exposed stones, some quite large, which determined the amount of surface available for plant rooting. There also was a great deal of observed variation in the sizes of individual plants. This became increasingly apparent as the growing season progressed. Some cheatgrass plants at maturity had culms 3-4 dm tall with numerous basal leaves and several flowering culms, each with dozens of florets. Other plants were very small, 3-4 cm tall, with only a pair of basal leaves and a single flowering culm with only a few florets. The large differences in plant sizes are presumably due in part to the volume of soil and concomitant moisture-storage volume available to the roots of each plant as determined by the arrangement and amount of rock and the amount of competition from neighboring plants.

The north slopes averaged more plants per square foot than did the south slopes (Table 3). In studies concerning competition among weedy species, Palmblad (1968) showed that the seeds of greenhouse-grown cheatgrass under high stand density conditions averaged less in weight as compared to seeds produced under low density. It was expected that the more dense stands of cheatgrass would produce small plants with smaller seeds.

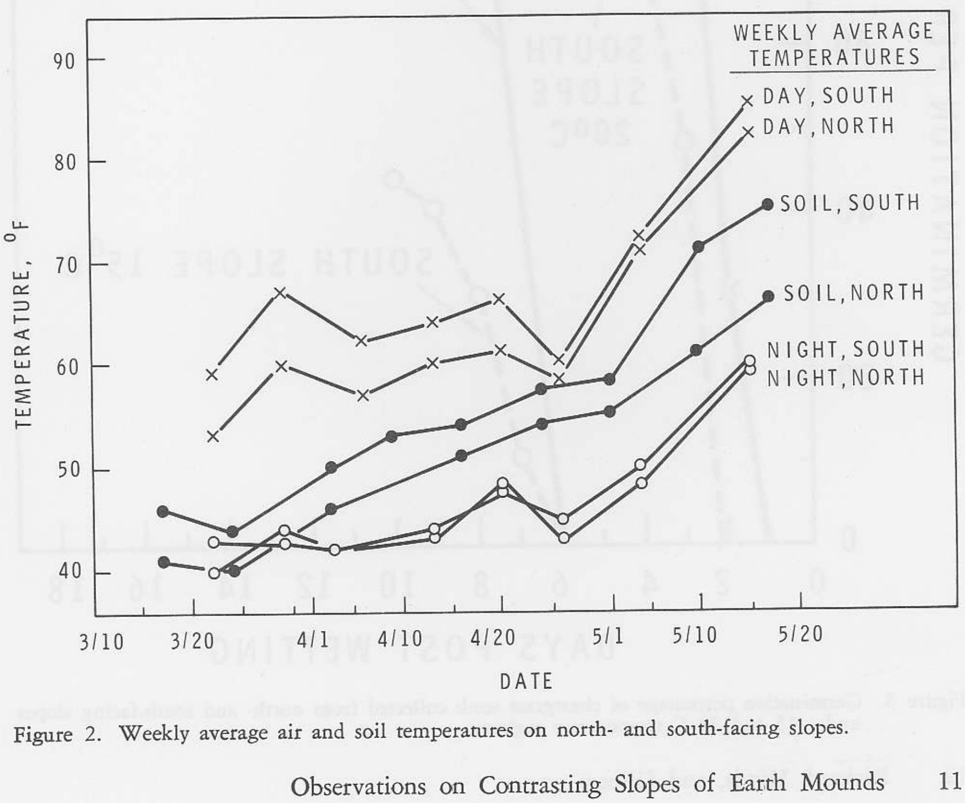


Figure 2. Weekly average air and soil temperatures on north- and south-facing slopes.

However, the average weights of five lots of 25 seeds each from the north and south slope were 0.0586 and 0.0600, respectively. This difference in average weight of 0.0014 grams with pooled standard error of .000842 was not statistically significant at the .05 level.

Palmblad (1968) reported germination percentages ranging between 84-87 per cent for laboratory-grown cheatgrass seeds produced under different stand densities. Germinability of cheatgrass seeds from the earth mound was also high but the south slope seeds did not germinate so promptly as did the north slope seeds, especially under the cooler temperature regime (Fig. 3). Similar results have been reported previously (Rickard and Hinds, 1969). The significance of delayed germination is not clear but it may be important to the successful establishment of seedlings on the more xeric south slopes. Seeds that do not readily germinate early in autumn would appear to have a better chance to avoid drought than prompt germinators because of the greater likelihood of increased frequency and intensity of precipitation associated with the approach of winter.

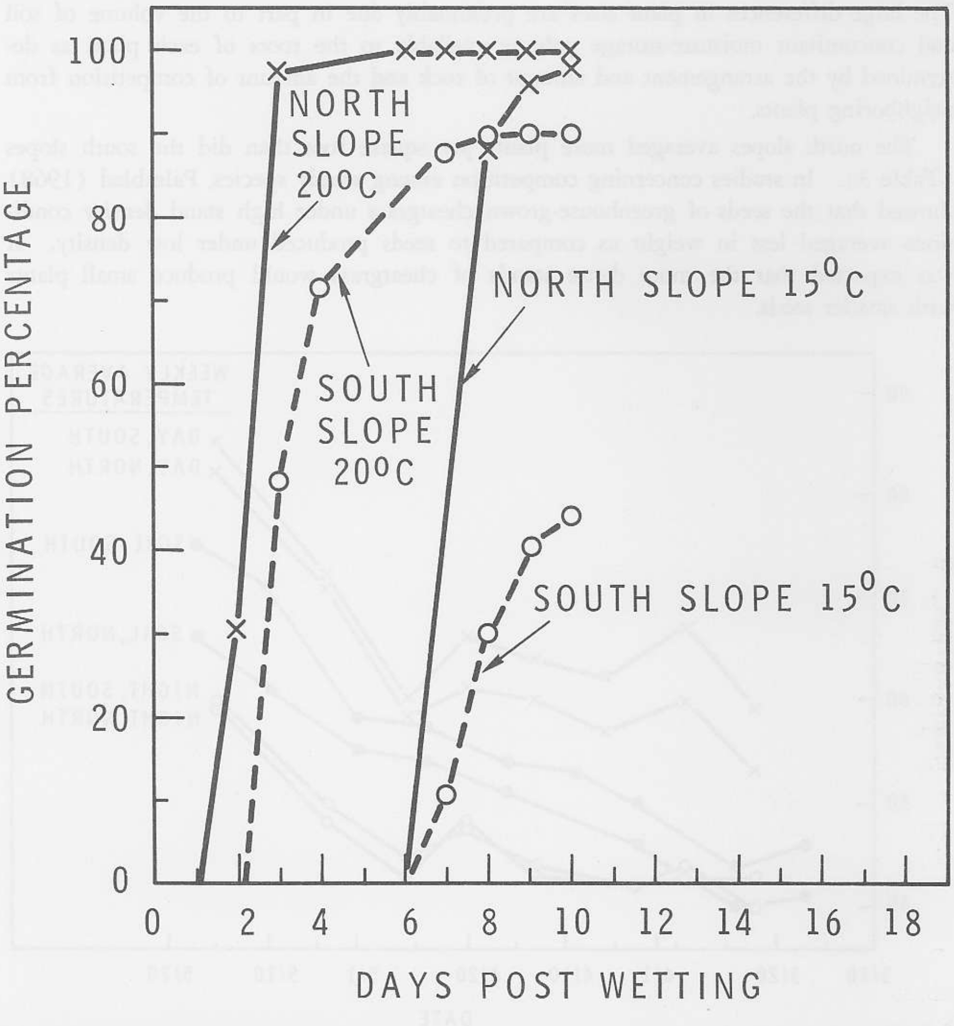


Figure 3. Germination percentage of cheatgrass seeds collected from north- and south-facing slopes under 15 and 20 C temperature regimes.

One way to employ effectively the different microclimates of contrasting slope exposures for biologic and environmental observations, without the high degree of variability associated with a heterogeneous substrate, is to construct purposefully mounds of rock-free soil. Such mounds would permit meaningful measurements of soil moisture, which is of special significance to winter annuals since growth terminates with the spring depletion of soil moisture.

### Biomass—Time Models

A plot of the average biomass $G_i$ harvested on day i against the cumulative number of days since the first harvest day $X_i$, suggests that the J-shaped exponential growth model

$$G_i = Ae^{cX_i} \qquad (1)$$

may fit both the north and south slope data over the time period for which harvests were made ($i = 1, \ldots, 5$ – south data: $i = 1, \ldots, 9$ – north data), where A is the biomass on the first day, and c is the overall population growth rate under unlimited environmental conditions (Odum, 1959, p. 178). In our study

$$G_i = \frac{1}{3} \sum_{j=1}^{3} G_{ij}$$

where $G_{ij}$ is the biomass harvested from the $j^{th}$ plot on day i. Rather than estimate A and c under the exponential model above, which would require the solution of non-linear equations in A and c by successive approximations, we have taken the simpler route of transforming equation (1) by taking $\log_e$ of both sides. Our model is thus

$$Y_i = \log_e G_i = \log_e A + cX_i + \varepsilon_i \qquad (2)$$

or

$$Y_i = \alpha + cX_i + \varepsilon_i \qquad (3)$$

where $\alpha = \log_e A$ and the residuals $\varepsilon_i$ are assumed to be normally and independently distributed with a mean of zero and variance $\sigma^2$.

Under the linear form given in equation 3 the least squares estimates $\hat{\alpha}$, $\hat{c}$, and $\hat{\sigma}^2$ as well as tests of significance and confidence limits on c are readily available. These estimates and the resulting fitted models in both the linear and exponential forms are given in Tables 5, 6, and 7 and Figures 4 and 5. Tests of significance in Table 7 in-

TABLE 5. Observed and expected biomass under the model $\log \hat{G}_i = \hat{\alpha} + \hat{c} X_i$.

| X | North slope Observed | North slope Expected | South slope Observed | South slope Expected |
|---|---|---|---|---|
| 0 | –.1625 | –.252 | 1.8077 | 1.7033 |
| 7 | .1398 | .273 | 1.8045 | 1.9133 |
| 15 | .1222 | .333 | 2.1029 | 2.1533 |
| 22 | .7080 | .606 | 2.3961 | 2.3633 |
| 29 | .7419 | .879 | 2.6174 | 2.5733 |
| 36 | 1.0006 | 1.152 | — | — |
| 43 | 1.5173 | 1.425 | — | — |
| 51 | 1.7716 | 1.737 | — | — |
| 62 | 2.2235 | 2.166 | — | — |

TABLE 6. Observed and expected biomass under the model $\hat{G}_i = \hat{A}e^{\hat{c}X_i}$

| X | North slope Observed | North slope Expected | South slope Observed | South slope Expected |
|---|---|---|---|---|
| 0 | .85 | .777 | 6.10 | 5.492 |
| 7 | 1.15 | 1.021 | 6.08 | 6.775 |
| 15 | 1.13 | 1.395 | 8.19 | 8.613 |
| 22 | 2.03 | 1.833 | 10.98 | 10.626 |
| 29 | 2.10 | 2.408 | 13.70 | 13.109 |
| 36 | 2.72 | 3.164 | — | — |
| 43 | 4.56 | 4.157 | — | — |
| 51 | 5.88 | 5.678 | — | — |
| 62 | 9.24 | 8.721 | — | — |

TABLE 7. Estimated parameters for the linear and exponential models of the relationship between time and total biomass.

| | North slope | South slope |
|---|---|---|
| $\hat{c}$ | 0.039 | 0.030 |
| $\hat{\alpha}$ | −0.252 | 1.704 |
| $\hat{\sigma}^2$ | 0.0188 | 0.00938 |
| $\hat{\sigma}_c$ | 0.00236 | 0.00420 |
| t test on c | t=16.54 (d.f.=7)* | t=7.223 (d.f.=3)* |
| 95% conf. limits on c | .033, .045 | .017, .044 |
| Linear model | $\log_e \hat{G}_i = -.252 + .039\,X_i$ | $\log_e \hat{G}_i = 1.704 + .03\,X_i$ |
| $e^{\hat{\alpha}} = \hat{A}$ | 0.777 | 5.493 |
| Expon. model | $\hat{G}_i = .777\,e^{.039\,X_i}$ | $\hat{G}_i = 5.493\,e^{.03\,X_i}$ |

* Statistically significant at $\alpha = .05$ level

dicate the $c > 0$ for both north and south slopes. $\hat{A}$ was obtained from $\hat{\alpha}$ as $\hat{A} = e^{\hat{\alpha}}$. These parameters were estimated assuming the linear model given in equation 3; hence, strictly speaking, they are not the least squares estimators under the exponential model. The data are seen to fit quite well both the linear and exponential forms.

TABLE 8. Comparison of the estimated linear regression lines for total biomass on north and south slopes.

| | d.f. | $\Sigma x^2$ | $\Sigma xy$* | $\Sigma y^2$ | $\hat{c}$ | Deviations from regression d.f. | S.S. | M.S. |
|---|---|---|---|---|---|---|---|---|
| Within | | | | | | | | |
| North | 8 | 3386.222 | 131.9839 | 5.2760 | .039 | 7 | .131702 | .0188 |
| South | 4 | 533.2 | 16.1562 | 0.5177 | .030 | 3 | .028147 | .00938 |
| | | | | | | 10 | .159249 | .01598 |
| Pooled | 12 | 3919.422 | 148.1401 | 5.7937 | .0378 | 11 | .194525 | .01768 |
| Difference between slopes | | | | | | 1 | .034676 | .034676 |
| Between | 1 | 708.292 | −59.6380 | 5.0215 | | | | |
| Pooled + Between | 13 | 4627.714 | 88.5021 | 10.8152 | | 12 | 9.12265 | |
| Between adjusted means | | | | | | 1 | 8.92813 | 8.92813 |

Comparison of residual variances: F=.0188/.00938=2.00 (d.f.=7, 3) N.S.
Comparison of slopes: F=.034676/.0159849=2.169 (d.f.=1, 10) N.S.
Comparison of elevations: F=8.92813/.017684=504.87 (d.f.=1, 11), highly significant.
* $x = X_i - \overline{X}$, $y = Y_i - \overline{Y}$

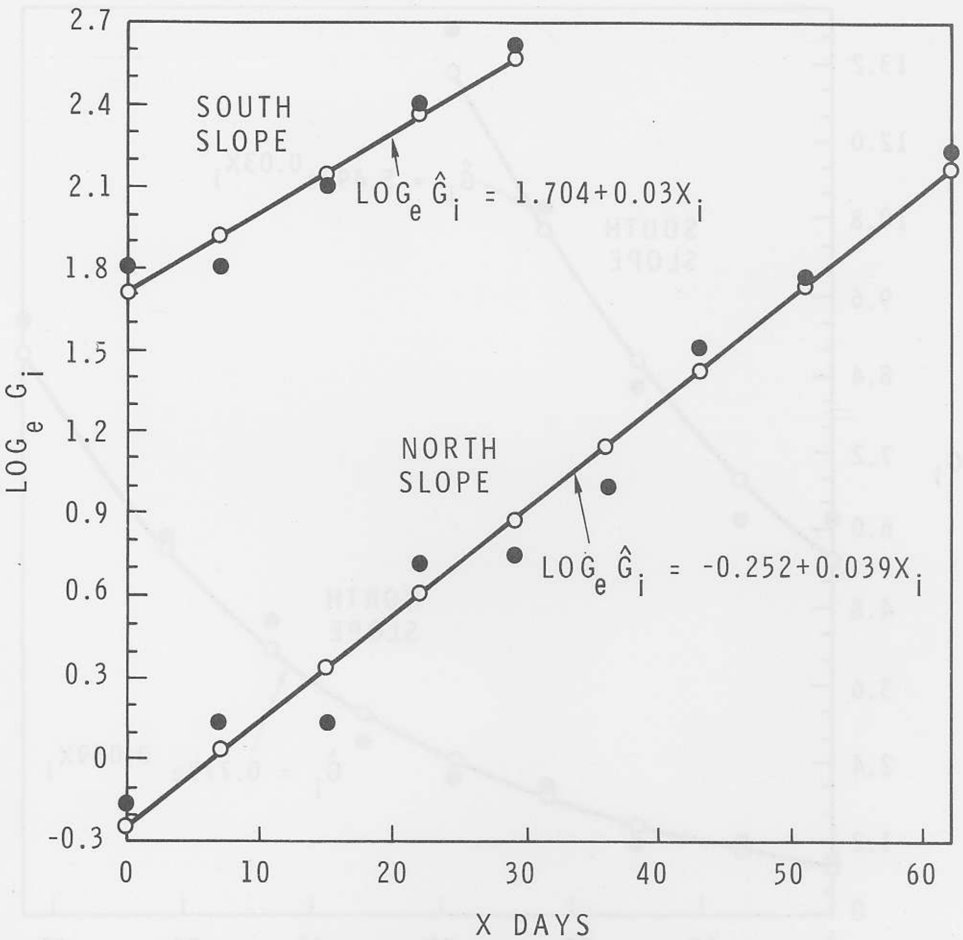


Figure 4. Fitting transformed north- and south-facing slope biomass means $\log_e G_i$ to the straight line $\log_e \hat{G}_i = \hat{\alpha} + \hat{c} X_i$

In Table 8 we follow the format given in Snedecor and Cochran (1967, p. 435) for comparing the north and south exposure linear regression lines with respect to residual variation $\sigma^2$, slope c, and elevation $\alpha$ above the abcissa. The test results indicate that neither the residual variance nor the slopes of the two regression curves are significantly different. However, the F test of the difference in elevations of the two curves is statistically significant. These results point to the conclusion that in the transformed scale log $G_i$, the relative rate of increase in biomass per unit of time is approximately the same for the north and south slopes during the spring growing season, but that the amount of biomass measured on a given day during the harvest period studied is substantially greater on the south slope. We recall that this could not be established for most given harvest days by using individual t tests because of the large variability between plot to plot biomass.

An attempt was also made to fit the linear model to the three individual biomass samples per day over the harvest period (Table 2). However, due to the large variability between plots on a given day, the fit was much less satisfactory. For the north slope c was estimated to be .039 with variance $\sigma^2_{\hat{c}} = .0000251$, and 95 per cent confidence limits of (.029, .049). For the south side $\hat{c}$ was .031 with variance $\sigma^2_{\hat{c}} =$

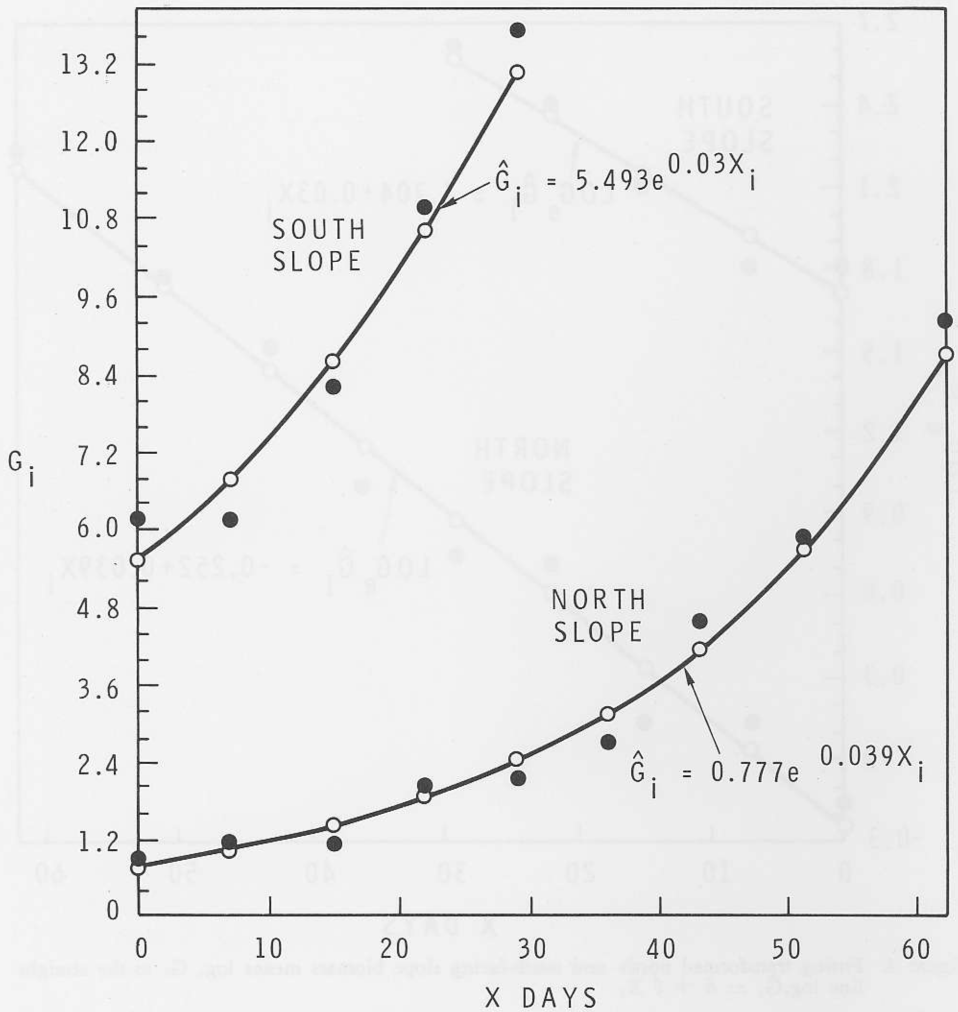


Figure 5. Fitting the north- and south-facing slope biomass means $G_i$ with the curve $\hat{G}_i = \hat{A}e^{\hat{c}X_i}$.

.000241 so that the t test of $H_o$: c = o was nonsignificant, *i.e.*, the variability was so great on the south side that even though the data show the biomass to be increasing, the statistical test showed no significance. Clearly, when considering individual harvest plots rather than the mean of plots on a given day, many samples are required to obtain a relatively precise estimate of c.

**Field Considerations**

Phenological criteria have been frequently used in field studies to relate the responses of natural plant communities and the environments of steep slopes and contrasting exposures. In a study of eastern North American deciduous forest herbs, Jackson (1966) reported a maximum variation at time of flowering of 11 days for *Phacelia bipinnatifida* growing on contrasting north and south slopes. In our study cheatgrass was delayed 3 weeks in flowering on the north slope. This lag is indicative of the strong influence that the abiotic environment has upon the phenological response of plants in a shrub steppe region. Biotic factors also play an important role in determining the floristic composition of plant communities. Since the introduction of Eurasian weeds to Western North America about 100 years ago, cheatgrass has become an integral part of the flora of disturbed habitats, thereby changing the species composition and general appearance of the shrub steppe communities of southeastern Washington. Under undisturbed conditions the native Sandberg bluegrass occurs on all slope angles and exposures. The apparent inability of Sandberg bluegrass to colonize the south-facing slopes of the earth mounds after approximately 15 years suggests that a combination of factors, *i.e.,* cheatgrass competition and a warmer and drier microclimate on steep south-facing slopes are deterrents to bluegrass establishment. Other evidence that cheatgrass and south-facing slopes are effective deterrents to perennial grass establishment is provided by Dillon (1967). After 64 years of non-grazing use, the south exposure of an earthfill supporting a railroad track in southeastern Washington was vegetatively dominated by winter annuals, especially cheatgrass. The north-facing slope, however, supported the typical dominants of climax communities, especially bluebunch wheatgrass *Agropyron spicatum* and *Poa secunda.* Harris (1967) showed laboratory and field experiments that seedlings of cheatgrass are more competitive than those of bluebunch wheatgrass.

Artificial earth mounds purposefully constructed of rock-free soil would appear as a way to minimize substrate variability and to produce a variety of field environments for study at relatively low cost. The opportunity to alter outdoor environments by the expeditious designing of slope angles and exposures would seem to be useful in the system-oriented research advocated by the International Biological Program projects in the desert and grassland biomes.

## Summary

A series of simple biologic and environmental observations were made on small cone-shaped earth mounds in the shrub steppe region of Washington in the Spring of 1969. The environment on contrasting north- and south-facing slopes was marked by high solar radiation inputs on the south-facing slopes which resulted in higher soil and air temperatures throughout the spring growth period of winter annuals. There was a marked difference in time of onset of flowering in cheatgrass, *Bromus tectorum,* on the contrasting slopes. Flowering was delayed about three weeks on the north-facing slope. North slope stands were more dense than south slope stands. Seeds from the south slope did not germinate so quickly under laboratory conditions as north slope seeds. This was especially marked under a colder temperature regime.

The mean biomass of plant material produced on the south-facing slope substantially exceeded that of the north-facing slope on a given harvest day. This difference in yield was statistically significant when the linear relationship between average biomass harvested and time since first harvest day was taken into account. The north and south linear regression lines appear to have the same slope, which implies that both north and south exposures may have the same relative rate of growth, at least over the period of time observed in this study.

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