Height-Weight Relationships of Idaho Fescue in the Big Horn Mountains

Jon G. Siddoway
Jeff Powell
Larry C. Munn
William A. Laycock

Agricultural Experiment Station
College of Agriculture
SM-54

UNIVERSITY OF WYOMING

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Editor: Diana Marie Hill-Chavez

James J. Jacobs, Director, Agricultural Experiment Station, University of Wyoming, Box 3354, Laramie, WY 82071.

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Abstract

Height-weight relationships were developed for Idaho fescue (*Festuca idahoensis* Elmer) in 1985 and 1986 in the Burgess Junction area of the northern Big Horn Mountains of Wyoming on six sites, three each on sedimentary and granitic soils at variable depths. Vegetative plants and seeded plants were collected during the high boot/hard dough phenological stage, but only seeded plants were collected during the mature phenological stage.

Very few plants produced seed stalks in 1985 except on the two most productive sedimentary soils, even though only minor weather differences occurred in 1985 and 1986. Plant stress in 1984 may have reduced seed production in 1985. The two deeper sedimentary sites had taller, heavier plants with a more uniform height-weight distribution along the total leaf length than the four less productive sites. Regression analyses indicated the normal growth curve accounted for 75 to 90% of the variation in weight distribution. Height-weight curves were developed and presented for vegetative and seeded plants on all sites and for different collection periods during the summer and fall.

Introduction

Height-weight relationships of various grasses used to determine the degree of utilization have been studied extensively in the western United States and, to some extent, in other parts of the world. The use of these relationships, however, has been more qualitative than quantitative. Individual species have different height-weight relationships, and these relationships often vary under different environmental conditions.

Idaho fescue (*Festuca idahoensis* Elmer) is a key forage species for many domestic and wild ungulates on a variety of soil types within upland areas of montane, open grassland communities. Because of its high ecological amplitude, Idaho fescue is the single most important forage species in terms of cover, production, abundance, frequency, and constancy (Beetle 1956, Hurd and Pond 1958, Fichtner 1959, Hurd 1961, and Despain 1973) on soils derived from granitic and sedimentary parent materials in the higher grassland communities of the Big Horn Mountains. Idaho fescue is an important component of elk (*Cervis canadensis*) and cattle diets in the Big Horn Mountains (Hurd and Pond 1958, Probasco 1968, Todd 1969, and Kufeld 1973).

The height-weight method is often used for determining utilization because it relies on recorded measurements. It also has been used extensively in research and management.

The height-weight relationships of Idaho fescue on granitic and sedimentary soils of variable depths within the northern third of the Big Horn Mountains were determined near Burgess Junction, Wyoming. The area of study was chosen primarily because of the wealth of previous research conducted on the Big Horn Mountains grasslands.

Height-weight curves relating percent of height removed to percent of weight removed also should be determined for Idaho fescue at varying soil depths on granitic and sedimentary soils and at different phenological stages because of the grazing management implications under these different conditions. Weather and growing conditions fluctuate annually and greatly influence the grazing behavior of large herbivores and their impacts on Idaho fescue and other major forage plants.

Therefore, the objectives of the study were to develop the height-weight relationships for Idaho fescue on two parent materials at three depths and three collection/phenological stages over a two-year period and develop height-weight regression equations that can be used by grazing managers to determine both utilization and grazing residue under a variety of conditions.

Literature Review

Utilization is defined as the proportion of the current year's forage production consumed or destroyed by grazing animals (SRM 1974). Methods for measuring utilization have been reviewed by Campbell (1943), Cook and Stubbendieck (1986), Heady (1949), Humphrey (1949), Jasmer and Holechek (1984), Pechanec and Pickford (1937), Pieper (1978), Risser (1984), and Stoddart, Smith and Box (1975). The review by Pechanec and Pickford (1937) did not include the height-weight method (or stubble height converted to weight removed method) because the method was developed after 1937.

Common estimation techniques include general reconnaissance, ocular estimate by plot and by the average number of plants, visual estimation of residue and the primary forage plant methods. The height-weight, stem count, cage comparison, clipping before and after grazing, weight, and regression methods are common measurement techniques, which have had a role in measuring utilization on western rangelands. Measurement techniques require more time than estimation techniques and are more suited to research than management because they are based on recorded measurements rather than on ocular estimation.

The height-weight relationship for measuring utilization is the concept of the weight of plant material relative to certain height increment intervals (Heady 1950). This utilization method was developed by Lomasson and Jensen (1938, 1943) in western Montana.

This method is relatively accurate, rapid, and simple (Heady 1950, Das et. al. 1964, McDougald and Platt 1976, and Rai et. al. 1980). The technique has been used extensively in research and management (Pieper 1978, Jasmer and Holechek 1984). The height-weight relationships can be adjusted from year to year to compensate for different growing season conditions in a certain locality (Heady 1950), and exclosures are not necessary to compare grazed and ungrazed areas.

This method is relevant in view of its value as a teaching aid. It shows the distribution of weight for a particular grass species relative to height (Heady 1950, Das et. al. 1964, and Rai et. al. 1980) and the plant material or stubble, which remains above the ground (residue) following grazing relative to the requirements of a plant to retain its productivity from one growing season to another (Collins and Hurtt 1943, Heady 1950, Hyder 1954, and Bement 1969).

Special considerations concerning the height-weight method must be addressed for proper interpretation of utilization results. To evaluate utilization of a particular species in a given community, it is necessary to develop height-weight tables for plants with seed stalks or reproductive culms and plants without seed stalks; weight distribution will differ along the entire length of a plant depending on the presence or absence of seed stalks (Heady 1949). Heady (1950) also stated the significance of including the proportion of plants with or without seed stalks when computing utilization levels for a certain area.

A particular grass species may exhibit different growth forms in different environments and between years. This can be influenced by such factors as elevation, soil, moisture conditions, and temperature (Clark 1945, Heady 1950, Shankarnarayan et. al. 1970, and Rai et. al. 1980). The accuracy of determining utilization with the height-weight method on rangelands depends on the amount of knowledge acquired about a particular plant species within a particular locality over time (Heady 1950).

Different methods of expressing height-weight relationships for range grasses and the use of these relationships are employed to determine utilization. For example, Lommasson and Jensen (1938) developed height-weight tables for grass species in western Montana after obtaining the percent weight relative to 1 inch height increments in a large number of plants to obtain adequate averages.

Variations in height increment length depend on the grass species and the person preparing height-weight relationships. Lomasson and Jensen (1938) developed a utilization gauge that uses a logarithmic scale for the conversion of stubble height remaining into the percent volume (weight) utilization.

Valentine (1946) in New Mexico used scales placed on a heavy card that showed use percentage for black grama (*Bouteloua eriopoda*) at a certain stubble height when placed beside the plant. This eliminated calculating percent use based on a certain stubble height.

Examples of utilization research of range grasses based on percent height removed or height of stubble relative to percent weight removed were conducted in Arizona and New Mexico by Crafts (1938), in the Wallowa Mountains of the Pacific Northwest by Reid and Pickford (1941), in eastern Montana by Collins and Hurtt (1943), in western Montana by Heady (1950), in Texas by McArthur (1951), in southwestern Colorado by Bartel and Davis (1973), in northern California by McDougald and Platt (1976), and in India by Das et. al. (1964), Shankarnarayan et. al. (1970), and Rai et. al. (1980).

Study Area

The Big Horn Mountains are located in north central Wyoming. The Pryor Mountains in Montana are on the north, the Owl Mountains are southwest, the Big Horn River Basin is on the west, and the Powder River Basin is on the east.

The Big Horn Mountains are approximately 30 to 50 km wide and about 190 km long. Situated in a northwest to southwest direction, they are bounded by longitudes 107 and 108 and latitudes 44 and 45. The Burgess Junction (junction of state highway 14 and 14A) study site area lies about 35 km west of Sheridan, Wyoming.

Geology and Topography

The Big Horn Mountains rise from the valley basins to a maximum elevation at Cloud Peak of 4016 m. The east and west basins range from 900 to 1200 m, respectively. The mountains are a broad, simple, asymmetric, anticlinal fold with a core of Precambrian granite.

The range is naturally divided into northern, middle, and southern segments. During mountain formation, the middle segment was thrust to the east and the northern and southern segments were shoved to the west. The middle segment contains the exposed core of Precambrian granites, which form the highest peaks in the mountain range. The northern and southern segments are over-arched by sedimentary rock that forms elevated plateaus.

During Quaternary times numerous glacial epochs occurred in an area of approximately 63 km by 43 km and involved 800 square km of moving ice. The ice originated at 3000 to 3500 m in elevation while the glacial termini ranged from 1900 to 3200 m. The less eroded and unglaciated front ranges are still covered by sedimentary rocks such as shales, sandstones, limestones, and dolomites (Darton 1906, Love and Christiansen 1985, Richmond and Fullerton 1986).

The Tongue, Powder, and Big Horn Rivers originate in the central segment of the mountains and flow north into the Yellowstone River in Montana. The study area in the northern portion of the Big Horn Mountains near Burgess Junction is near the North Fork of the Tongue and is characterized by gentle slopes with open grassland where summer grazing occurs adjacent to timbered stands (Beetle 1956).

Climate

The climate characteristic of the Big Horn Mountains is affected by air masses from Canada, which during the winter months cause strong northerly and northwesterly winds, snow, and low temperatures. Moderation in temperature occurs when winds from the southwest and west follow the passage of the cold fronts.

On the eastern side of the range, upslope conditions can produce precipitation during the winter and spring months. Local thunderstorms, which are fairly common in the summer months, move in a northeasterly direction (Nesser 1982).

Mean annual precipitation varies from about 380 mm at 1524 m elevation in the *Pinus ponderosa* zone to about 630 mm at 2744 m elevation in the *Picea engelmanii - Abies lasiocarpa* zone. Precipitation is equally distributed throughout the year with a major proportion falling as snow in the higher elevations. Most of the precipitation in the lower elevations falls as rain during the months of April through September.

In the *Pinus ponderosa* zone the mean annual air temperature is about 7 degrees C with a maximum range of -40 degrees C to 43 degrees C. In the *Picea engelmanii - Abies lasiocarpa* forest zone, the mean annual temperature is approximately 2 degrees C with a range of -46 degrees C to about 32 degrees C (Hoffman and Alexander 1976).

Burgess Junction (elevation 2500 m) has the most complete records (1961 to the present) for precipitation, temperature, snowfall, and snow depth. At Burgess Junction the mean annual precipitation is 528 mm with recorded droughts in the 1960s and wet periods in the 1970s (Figure 1).

Approximately 40% of the annual precipitation occurs in April, May, and June; the least precipitation occurs in July and August. The most consistent months of precipitation are September, October, and November (Figure 2).

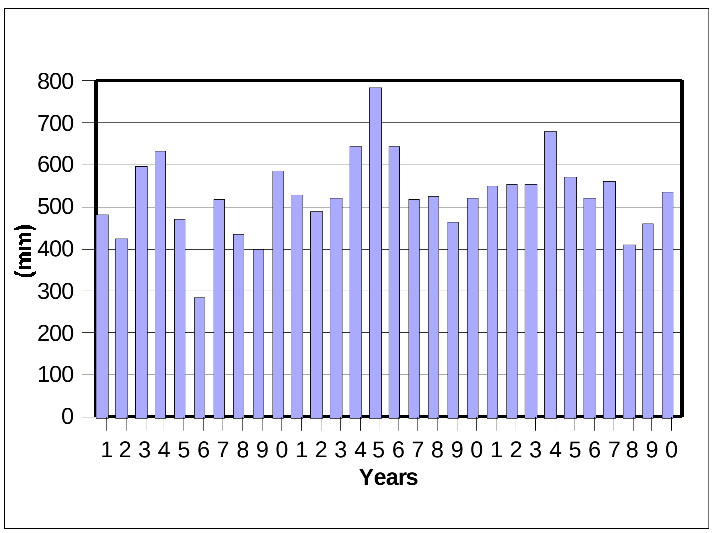

Figure 1. Annual study area precipitation (mm).

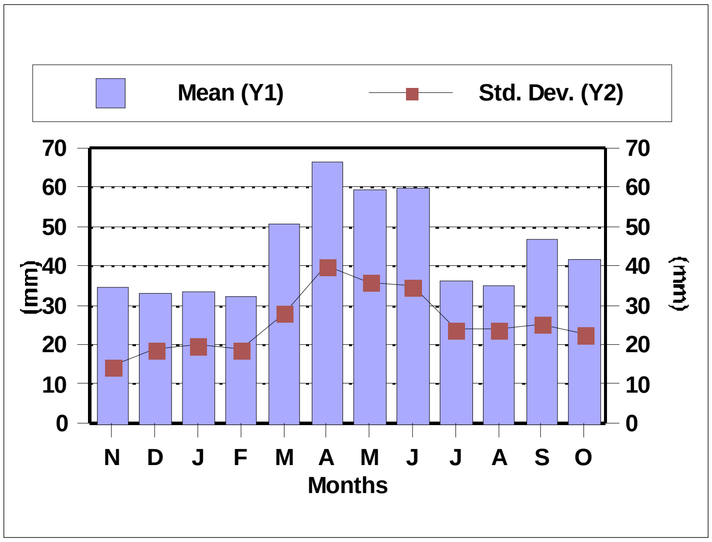

Figure 2. Annual study area monthly precipitation (mm).

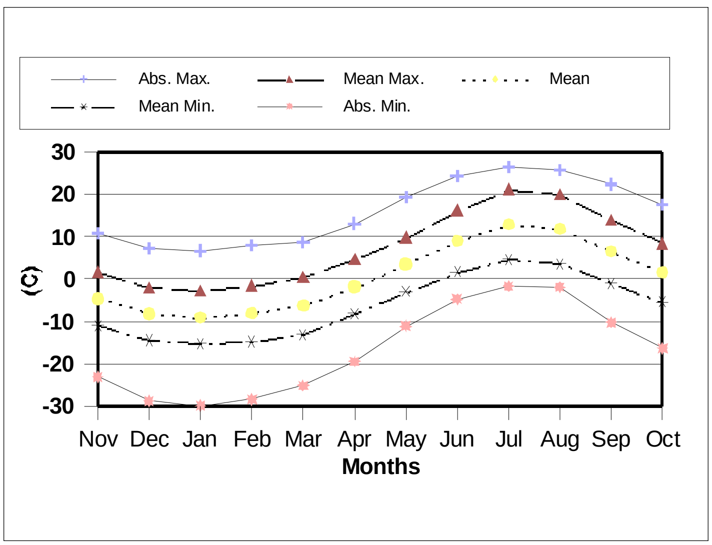

Figure 3. Average study area temperatures.

In general, Burgess Junction is very cold in the winter, wet and cool in the spring, and warm and dry in July and August. A comparison of the mean, mean maximum and minimum, and absolute maximum and minimum temperatures shows a relatively smooth transition of mean temperatures from one month to the next (Figure 3). It is important to note, however, from the standpoint of moose (*Alces alces*) and other animals that may stay on top, that the average absolute minimum temperature is less than -25 degrees C from December through March. At the other extreme, the average absolute maximum temperatures are only about 5 degrees C higher than the average maximum and 15 degrees C higher than the mean temperatures during the summer. It gets very cold in the winter but not very hot in the summer.

Monthly snowfall is relatively consistent from November through February, high in March and April and highly variable in May (Figure 4). Snowfall may occur any month of the year and averages from 10 to 20 cm in June and September.

Average snow depth increases uniformly from September to about 90 cm in March and then decreases to zero in July (Figure 5). Average snow depth may vary +30 cm or -30 cm any month between December and May. The mean and standard deviation of 32 ± 28 cm of snow depth in May indicates the high potential for either “early” (no snow) or “late” (deep snow) springs.

Soils and Vegetation

Nesser (1982) described 39 soil series and seven variants within the Big Horn National Forest. The common soils derived from granitic parent material found in the Burgess study area include the Lucky, Burgess, and Hazton series.

The Lucky series is classified as a fine-loamy, mixed Argic Cryoboroll. It is a moderately deep, well drained soil formed in residuum derived from granite, on slopes of 2 to 30%. Idaho fescue and sedge (*Carex* spp.) is the common plant association on this soil. Potential annual herbage production on this soil is about 1680 to 2020 kg per hectare.

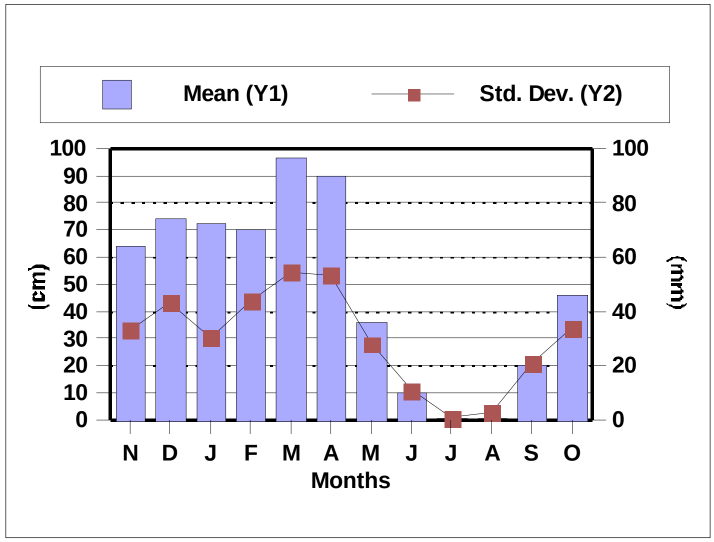

Figure 4. Average study area snowfall (cm).

The Burgess series is classified as a course-loamy, mixed Argic Cryoboroll. It is a moderately deep, well drained soil that formed in residuum from granite on slopes of 2 to 30%. Idaho fescue and sedge is the common plant association with about 1680 to 2020 kg of herbage per hectare.

The Hazton series is classified as a loamy, mixed Lithic Cryoboroll. It is a shallow, well drained soil formed in residuum from granite on slopes of 2 to 30%. Idaho fescue and sedge is the predominant plant association with production of approximately 670 to 900 kg per hectare.

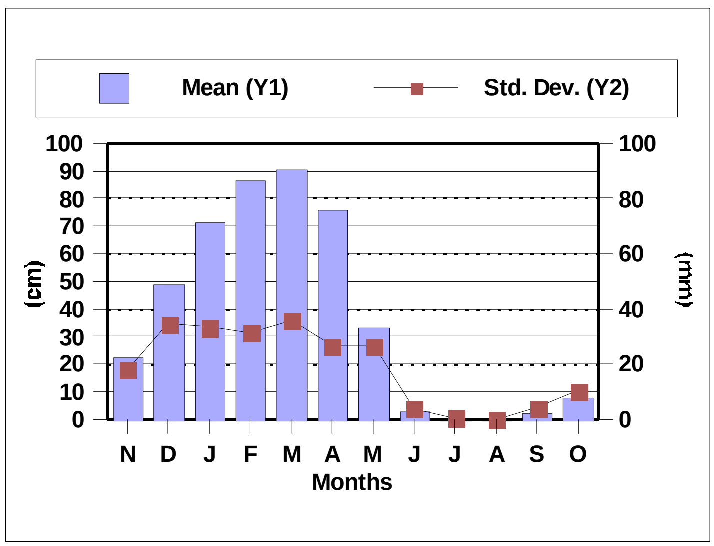

Figure 5. Average study area snow depth (cm).

The common soils derived from sedimentary parent material found in the Burgess area include the Owen Creek, Echemoor, and Neilson. The Owen Creek series is classified as a fine-loamy, montmorillonitic Argic Cryboroll. It is a moderately deep, well drained soil that formed in colluvium derived from interbedded shale and limestone on slopes of 2 to 35%. The common plant association is Idaho fescue and silky lupine (*Lupinus sericeus*) with herbage production between 1790 and 2690 kg per hectare.

The Echemoor series is classified as a Fine-loamy, mixed Argic Pachic Cryoboroll. It is a moderately deep, well drained soil found on slopes of 10 to 30% and formed in residuum derived from calcareous shale and limestone. The predominant plant association is big sagebrush (*Artemisia tridentata*) and Idaho fescue with herbage production about 3360 to 3920 kg per hectare. The Nielsen series is classified as a Loamy-skeletal, mixed Argic Lithic Cryoboroll. This series consists of soils that are shallow and well drained and were derived form calcareous sandstone. The plant association characteristic of this series is Idaho fescue and silky lupine on slopes between 5 to 20%. Potential production on this series varies between 1340 to 1900 kg per hectare. The Big Horn Mountains contain all of the major forest types common to Wyoming, such as lodgepole pine (*Pinus contorta*), subalpine fir-Engelmann spruce, Douglas fir (*Pseudotsuga menziesii*), ponderosa pine, and communities of pinyon-juniper species (Choate 1963). The ponderosa pine belt lies along a narrow strip at elevations ranging from 1524 m to 2134 m. On the drier western slope, juniper, mountain mahogany (*Cercocarpus montanus*) and sagebrush form the major communities. The ponderosa pine on the eastern slope mixes with the lodgepole pine forest type, which dominates the broad top of the mountain from 2287 m to 2900 m. The many broad, open areas between these lodgepole pine stands are represented by an Idaho fescue association (Beetle 1951 and Despain 1973).

Soils developed over sedimentary rock in the northern portion of the Big Horns support such species as *Agropyron caninum, Poa canbyi, Poa ampla, Bromus marginatus, Lupinus sericeus, Geum triflorum, Achillea millefolium, Galium boreale*, and *Phlox multiflora* as well as Idaho fescue. The more common species on granitic soils include *Phlox hoodii, Antennaria rosea, Selaginella densa,* and *Carex* sp. in addition to the common dominant, Idaho fescue (Beetle 1956 and Despain 1973).

The sagebrush community on the higher portion of the mountain range chiefly has the same floristic composition as the Idaho fescue community (Pond and Smith 1971). The sagebrush is found on the deeper sedimentary and granitic soils.

Plant Phenology

Pond and Smith (1971) found that initial spring growth of Idaho fescue was affected by the local climate, which is a reflection of elevation influences. At 2900 m leaf length of Idaho fescue averaged only 58% of maximum on June 20, while at 2200 m, leaf length had reached 69% of maximum by the end of May.

Once growth commenced, however, the plants at higher elevations grew more rapidly than those at lower elevations. Culms and leaves of Idaho fescue at similar elevations reached maximum length near the same date, even though culms were 15 to 23 days behind leaves in reaching 90% of maximum length. Maximum leaf height and culm height were achieved at higher elevations (2600 to 2900 m) between the end of July and August 10. Flower stalks required much less time than leaves to complete the final 10% of their maximum height.

Methods

Experimental Design

The project used six blocks, one block each on a shallow, a moderately deep, and a deep sedimentary soil and on a shallow, a moderately deep, and a deep granitic soil. The temporal distribution included collection of Idaho fescue in 1985 and 1986 during two different collection periods. The first collection period was between the middle of July through the middle of August for plants that only produced leaves ("vegetative") and plants that produced leaves and seed stalks in the high boot to hard dough stage ("dough"). Heady (1950) emphasized the importance of differentiating between plants that did and did not produce seed stalks in the population to accurately determine utilization levels.

The second collection period was from late August through the middle of September for Idaho fescue plants, which were in a later than hard dough stage—beginning of seed shatter through senescence ("mature"). An individual Idaho fescue plant constituted an experimental unit.

Site Selection and Soil Descriptions

Soil survey data, photographs, and information were provided by soil scientist John Nesser of the Big Horn National Forest Supervisor's Office. These materials provided a good starting point to begin looking for prospective sites.

Approximately 100 soil pits were dug at various locations within the Burgess Junction area to select the best sites on sedimentary and granitic soils at the various depths. Soil sampling continued from early June to mid-August, 1985, when specific sites were selected for study.

The criterion for determining what constituted a shallow, moderately deep, or deep soil in both parent materials was based on the information gathered from the numerous soil pit excavations. Granitic soil depth categories were divided into "shallow" if the soil was less than 15 cm deep to bedrock, "moderately deep" if the soil was between 15 cm to 30 cm deep to bedrock, and "deep" if the soil had a depth greater than 30 cm to bedrock.

Sedimentary soils were divided into shallow soils if less than 40 cm to the bedrock layer, moderately deep if the soil was between 40 cm and 127 cm deep to bedrock, and deep if that soil was deeper than 127 cm to bedrock.

Those sites that fit a particular parent material X depth criteria were then used for sampling Idaho fescue plants. The soils sampled were primarily within sections of Township 54 North Range 88 West, Township 55 North Range 88 and 89 West, and

Township 56 North Range 88 and 89 West. A description of excavated soil pits on the six selected sites is found in Appendix A as well as soil lab analysis results in Appendix B.

Plant Collection

Prior to collecting individual, ungrazed plants on a specific parent material X depth site, a direction of travel was determined by arbitrarily choosing a three-digit number from a random numbers table and then using the same random numbers table to select a number that determined the distance between plant collections (the number of steps between plants). Each Idaho fescue plant was collected by clipping at ground level. Each clipped plant was tied tightly near the base with string to discourage slippage of individual leaves within a plant. After air-drying to a constant weight, each plant was measured for total leaf length, clipped at 2-centimeter increments, and each 2-centimeter increment weighed to determine weight per total plant and weight per 2-centimeter increment.

At least 20 Idaho fescue vegetative plants were collected on each parent material X soil depth site in 1985 and 1986. More than 20 vegetative plants were collected on the shallow granitic and shallow sedimentary sites in 1985 because these two sites were more uniform over a broader expanse than the other four sites.

Observation also indicated a greater variety of vegetative plant size because relatively few plants on the shallow granitic and shallow sedimentary sites produced seed stalks in 1985. Plants with seed stalks were collected in 1985 only on the moderately deep sedimentary and the deep sedimentary sites because of the sparse production of seed stalks on the remaining sites. In 1986 at least 20 vegetative and 20 seeded plants were collected on all six sites during the dough stage of the seeded plants, and 20 seeded plants were collected during the mature stage of the seeded plants.

In both 1985 and 1986, seed stalks were separated from leaves, banded, dried, measured for length, cut at each 2-centimeter increment, and each 2-centimeter increment weighed separately for total weight and incremental weights.

Weather

Weather records (NOAA 1990) from the Burgess Junction Ranger Station were used to compare the study period (1985-86) weather with the long-term (1961-90) means for precipitation, temperatures, snowfall, and snow depth.

Statistical Analyses

Analyses of variance (General Linear Models) and regression analysis (PROC REG) were conducted using the Statistical Analysis System software for personal computers

(SAS Institute 1985). Source of variation main effects included sites, years, and kinds of plants (vegetative versus seeded) or phenological stage (dough versus mature). Interactions included site X year, site X collection (kind of plant or phenological stage), and collection X year. Dependent variables included average plant total dry weight (mg) and leaf length (mm); individual, 2-centimeter-increment percentages of plant weights and actual weights per increment; and accumulative percentages of plant weights and accumulative weights (mg).

All differences discussed are statistically significant at the 5% level of significance unless otherwise stated. Statistically significant, but relatively small (i.e., less than 5%), differences between percentages of total plant weight within a plant height increment were considered biologically unimportant and, therefore, not discussed. The analysis of variance statistics (i.e., variables, source of variation, number of observations, degrees of freedom, and means) for each analysis are presented in tables 1 through 6. Average plant weights (mg) and leaf lengths (mm) are expressed as mean ± standard error (SE).

Regression curves were developed for each site X collection X year set of data using leaf length (percent) and accumulative percentage of total leaf weight per individual plant. The model used was the normal growth curve: $WTPC = b_0 + (1 - e^{-b1\ LL})$ when $b_0 = 0$; WTPC is the independent variable, accumulative percentage of total leaf weight; and LL = (accumulative leaf length/total leaf length) per 2-centimeter increments of leaf length.

For example, for a plant with a total leaf length of 140 mm, the 0- to 20-millimeter (14% of total leaf length) increments may contain 50% of the total leaf weight, the 0- to 40-millimeter (29%) increments may contain 73%, the 0- to 60-millimeter (43%) increments may contain 90%, etc. up to the 100% of total leaf length and 100% of total leaf weight. The regression coefficient, standard error for the regression coefficient, and coefficient of determination (R^2) were determined for each regression equation.

Figure 6. View of the shallow granitic site.

Results And Discussion

Sites

The shallow (i.e., less than 15 cm to bedrock) granitic site (Figure 6) is located at an elevation of about 2615 m on a 10% slope facing mostly south at an aspect of 172 degrees.

Figure 7. View of the moderately deep granitic site.

Just east of the shallow granitic site, the moderately deep (i.e., 15 to 30 cm to bedrock) granitic site (Figure 7) is located at

Figure 8. View of the deep granitic site.

Figure 9. View of the shallow sedimentary site.

Figure 10. View of the moderately deep sedimentary site.

Figure 11. View of the deep sedimentary site.

the same elevation but on a more normal 3% slope, facing mostly south at 162 degrees. These two sites are represented by the Hazton series, which is classified as a Loamy, mixed Lithic Cryoboroll.

The deep (i.e., more than 30 cm to bedrock) granitic site (Figure 8) is situated on a 9% slope, facing south at 181 degrees at approximately 2736 m above sea level. The soil is classified as a Fine-loamy, mixed Argic Cryboroll, the Lucky series. This was the only site that had a sagebrush component in the present plant community.

The shallow (i.e., less than 40 cm to bedrock) sedimentary site (Figure 9), whose soil is classified as a Loamy-skeletal, mixed Argic Lithic Cryoboroll (Neilsen series) lies mostly south at 174 degrees at an elevation of 2450 m on a slope of 8%.

Approximately 2 km east of this site is the moderately deep (i.e., 40 to 130 cm to bedrock) sedimentary site (Figure 10) in which it is located at 2450 m of elevation on an 8% slope facing 171 degrees.

Located within 200 m and east of the deep granitic site is the deep (i.e., greater than 130 cm to bedrock) sedimentary site (Figure 11), which is situated at an elevation of about 2750 m on a slope of 11% on a south aspect measuring 176 degrees. Both the moderately deep and deep sedimentary sites are represented by the Echemoor series, a fine-loamy, mixed Argic Pachic Cryboroll.

Weather

Precipitation

The accumulative precipitation for plant years (November to October) 1985 and 1986 were very similar and not greatly different from the long-term average (Figure 12). The accumulative precipitation in plant year 1984, the year prior to the first year's data collection was much above average. The additional precipitation was primarily from above average snowfall in March, April, and May, 1984.

Temperature

The mean temperature was much lower in January, February, and March of 1985 than in the winter of 1986 (Figure 13). April mean temperatures were about the same in both years. The mean temperature was higher in May but lower in June 1985 than in 1986.

The mean maximum temperatures (Figure 14) showed similar differences. The relatively warm months of April and May 1985 may have caused rapid snow melt and more rapid spring growth.

Snowfall

Although the monthly snowfall amounts for 1985 and 1986 were very different (Figure 15), the accumulative snowfall amounts were similar until snowfall in May 1986 (50 cm) was much higher than that in 1985 (5 cm).

Snow depth

Since the accumulative snowfall amounts were similar in 1985 and 1986 until May, the colder temperatures in the winter of 1985 appear to have maintained a greater snow depth in March and April 1985 (Figure 16). The warmer 1986 mean and maximum temperatures in April and May melted the accumulated snow rapidly. Although no runoff records are available for the Burgess Junction area, much of the snow melt may not have gone into the soils, especially if the soil surface in April to early May was still frozen. Apparently May 1986 was also warm enough to melt all the snowfall received in that month because the average snow depth in June 1986 was 0 cm.

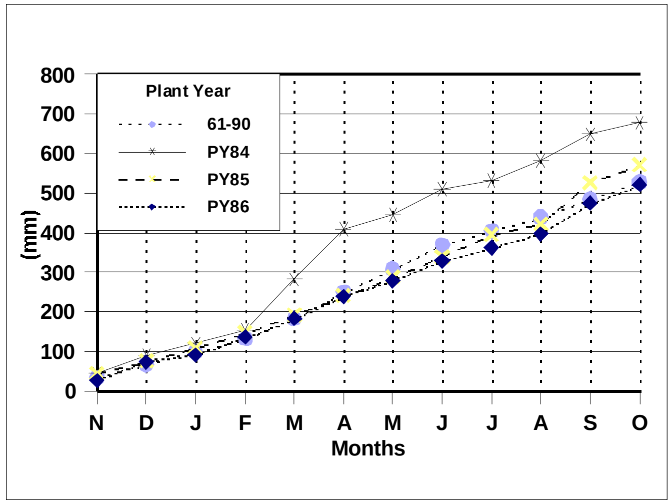

Figure 12. Longterm and study period precipitation (mm).

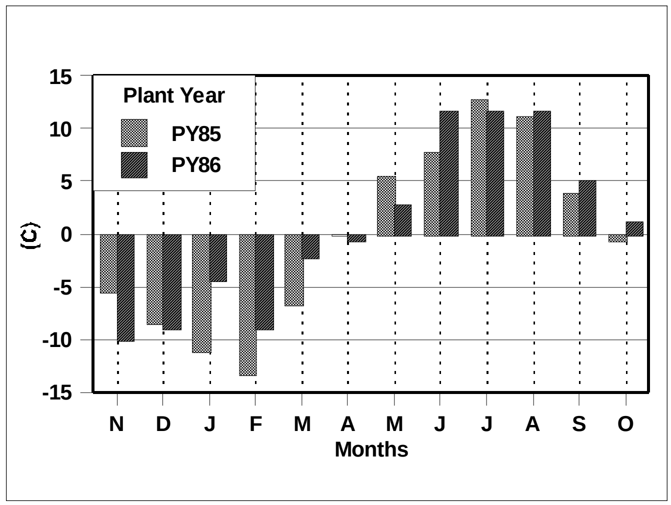

Figure 13. Mean temperatures (C) in 1985 and 1986.

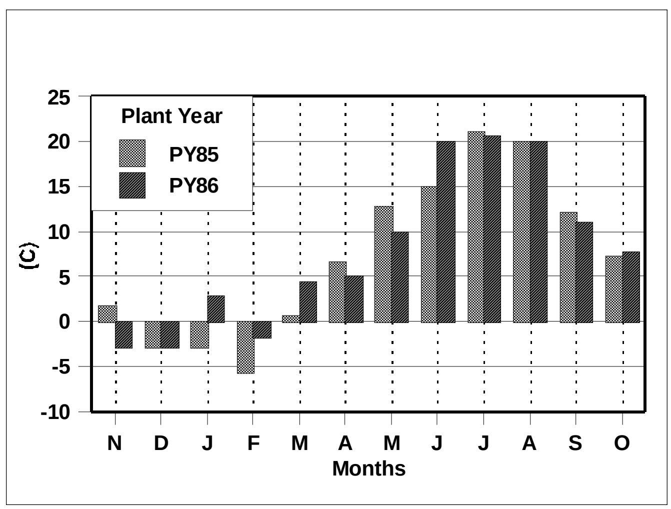

Figure 14. Mean maximum temperatures (C) in 1985 and 1986.

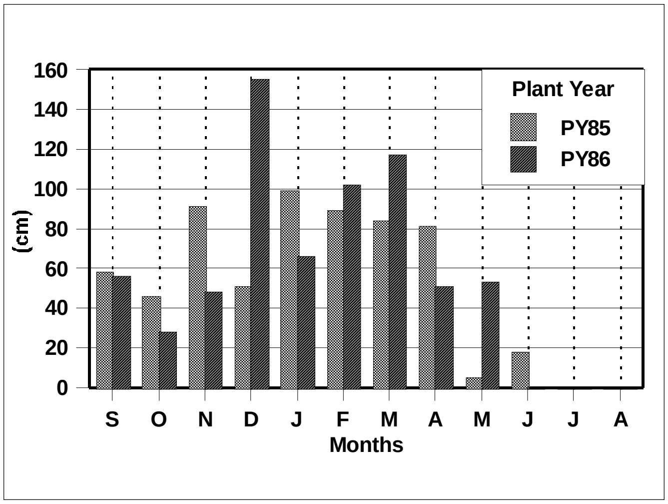

Figure 15. Snowfall (cm) in 1985 and 1986.

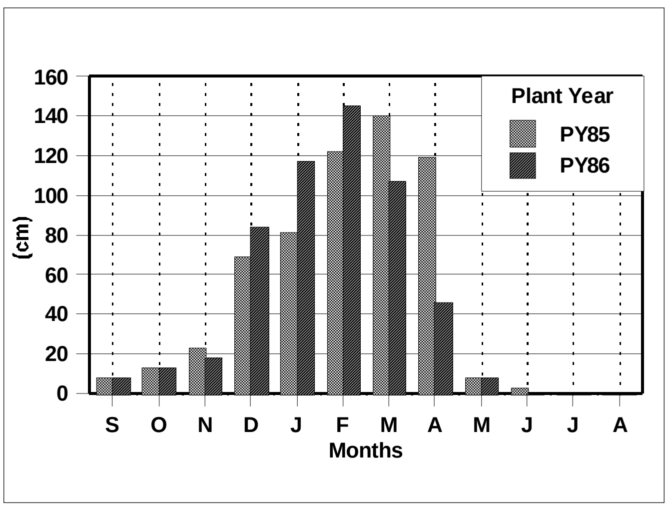

Figure 16. Average monthly snowdepth (cm) for 1985 and 1986.

Vegetative Height-Weight Relationships

Vegetative plants

Ungrazed Idaho fescue vegetative plants were collected both years on all six sites. Vegetative plants were those plants that did not produce seed stalks during the growing season. The proportion of plants producing seedstalks in 1985 was much smaller than in 1986 on the shallow granitic, moderate granitic, deep granitic, and shallow sedimentary sites—so small, in fact, there were not enough plants with seedstalks to collect an adequate sample on these four sites. In general, vegetative plants were of smaller stature and younger than seeded plants in the dough and mature stages or plants. The average weight of 293 vegetative Idaho fescue plants collected on all six sites over both years was 588±38 mg (Table 1). About half of the plant weight was in the 0- to 20-mm increment, 78% in the 0- to 40-mm increment and 91% of the total plant weight was located in the 0- to 60-mm increment. Only 9% of the total weight was above 60 mm.

Vegetative plants on the moderate sedimentary site had the highest average weight (1267±168 mg) and were 44% heavier than those on the deep sedimentary site (886±112 mg). Vegetative plants on these two sites were noticeably larger than those on the shallow (264±24 mg), moderate (565±57 mg), and deep granitic (468±68 mg), and shallow sedimentary (345±40 mg) sites.

Consistent with the plants being larger and taller on the moderate and deep sedimentary sites (159±7 mm and 166±7 mm, respectively), the plant height-weight distributions were well below the overall mean distribution with 35% at the 0 to 20 mm increment, 61% of the total weight within 0 to 40 mm for both sites and 79% of the weight in the 0 to 60 mm increment.

The proportions of leaf weight on plants on the shallow and moderate granitic and shallow sedimentary sites were greater than that for the overall mean through the 40 to 60 mm increment, while the deep granitic plants approximated the mean height-

Table 1. *Average total weight (WT, mean±SE) and length (LTH, mean±SE) of leaves, and percentage of total weight per length increment (e.g., I100 = percentage of total weight within the 80- to 100-mm increment) for Idaho fescue plants collected on shallow granitic (SG), moderately deep granitic (MG), deep granitic (DG), shallow sedimentary (SS), moderately deep sedimentary (MS), and deep sedimentary (DS) sites during the vegetative (V) stage collection period in 1985 and 1986. Those values within the same column and for the same source of variation (SOV) followed by a different letter are significantly different at the 5% level. N = number of samples. S*Y = site X year interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	LTH
			(mg)	%							(mm)
	MEAN	293	588±38	48.6	29.5	13.2	5.2	2.1	0.9	0.3	112±3
SITE	SG	63	264±24c	57a	31a	10c	2c	0c	0b	0b	81±2c
	MG	44	565±57bc	58a	31a	9c	2c	0c	0b	0b	90±3c
	DG	41	468±68bc	46b	29a	16b	6b	2b	1b	0b	109±5b
	SS	61	345±40c	54a	32a	12c	2c	0c	0b	0a	90±3c
	MS	42	1267±168a	35c	26b	18a	11a	6a	3a	1a	159±7a
	DS	42	886±112b	35c	26b	18ab	11a	6a	3a	1a	166±7a
YEAR	85	173	669±48a	45b	31a	15a	6a	2a	1a	0a	111±3a
	86	120	471±63b	54a	27b	11	5b	2a	1a	0a	112±5a
S*Y	SG85	43	286±27c	53c	33ab	12c	3ef	0de	0e	0b	83±3c
	SG86	20	219±49c	66a	27c	5d	1f	0e	0e	0b	77±4c
	MG85	24	598±73bc	51c	33a	12bc	3ef	1de	0e	0b	94±5bc
	MG86	20	526±91bc	66a	27c	6d	1f	0e	0e	0b	86±4c
	DG85	21	632±108b	39de	32ab	19a	8d	2d	1e	0b	120±7b
	DG86	20	295±63c	55bc	26c	12bc	4e	2de	1de	0d	97±5bc
	SS85	41	378±47c	50c	33ab	13bc	3ef	1de	0e	0d	92±6c
	SS86	20	277±75c	62ab	29bc	8d	2f	0de	0e	0d	87±6c
	MS85	22	1505±157a	35de	28c	18a	11bc	5b	2cd	1ab	148±7ab
	MS86	20	1005±302ab	34ef	25c	18a	12ab	6ab	3ab	1ab	170±12a
	DS85	22	1235±154a	28f	25c	19a	13a	8a	4a	2a	175±11a
	DS86	20	503±115bc	42d	26c	16ab	8cd	4c	2bc	1ab	156±11a

weight distribution throughout their length and were taller than plants on the shallow and moderate granitic and shallow sedimentary sites. This indicates that depth as well as substrate may be important as determinants for height, weight, and height-weight distribution. There was little variability between sites after the 60- to 80-mm increment.

This study did not address the productive potential of each site as it relates to the nutrients found in each soil. However, there were differences between sites with respect to soil fertility, especially between the two deeper sedimentary sites and the remaining sites (Appendix B).

A small, but significant, difference between years for average total weight (669±48 mg in 1985 and 471±63 mg in 1986) was found. Perhaps older, larger plants that

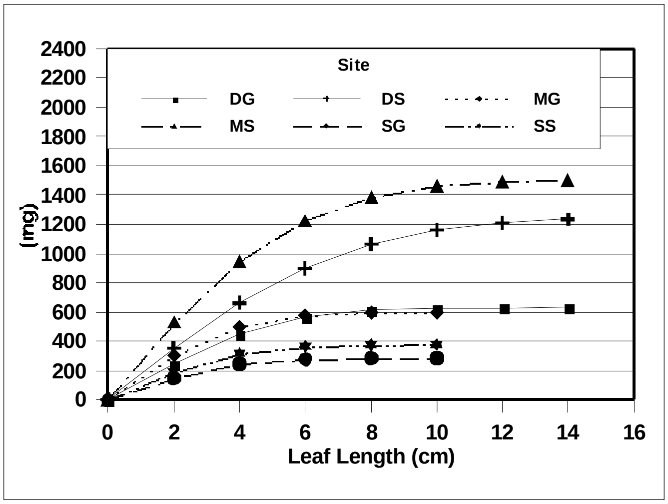

Figure 17. Accumulative leaf weights (mg) for vegetative plants on all sites in 1985.

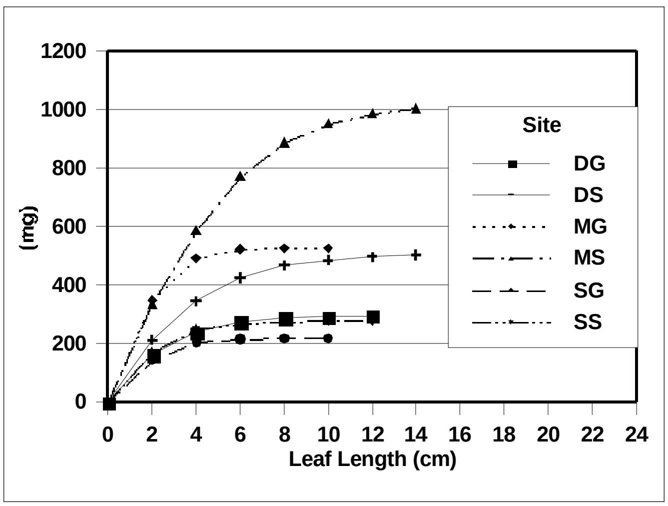

Figure 18. Accumulative leaf weight (mg) for vegetative plants on all sites in 1986.

normally would have produced seedstalks during favorable seed-producing growing conditions did not produce seedstalks in 1985 on four of the sites and were included among the vegetative plants sampled. Growing condition appears to be a factor more likely to affect seed production than grazing intensity in this study because in 1985, plants on the deep sedimentary site produced seeds while plants on the deep granitic site 200 m away in the same allotment did not produce seeds. Smaller plants were the majority of the population of vegetative plants sampled on the same four sites in 1986.

The 1985 plants were the same height as the 1986 plants (111±3 m and 112±5 mm, respectively). There was, however, a difference in height-weight distribution between years because of a greater proportion of the weight in the 0 to 20 cm increment in 1986.

Significant differences occurred due to site and year main effects, but the interpretation of these differences is influenced by the site X year interaction. In general, deeper sites had higher weights with 1985 weights (Figure 17) consistently higher than 1986 weights (Figure 18).

The major differences within a site between years occurred on the moderate sedimentary site, where plants in 1985 (1505±157 mg) were 50% heavier than the plants collected in 1986 (1005±302 mg). Deep sedimentary plants in 1985 (1235±154 mg) were 140% heavier than similar plants in 1986 (503±115 mg). No differences in leaf weights between years for plants on the shallow, moderate, deep granitic, and shallow sedimentary sites were found.

In 1985, conditions may have been more favorable (i.e., earlier because of warmer April and May temperatures; see Figure 14) for vegetative growth than in 1986, which may also explain the higher vegetative plant weights in 1985 than in 1986. Soil temperatures were not determined either year on any sites.

Another contributing factor is the low weights (503±115 mg) for plants on the deep sedimentary site in 1986. Effects of the elevation difference on growing conditions for moderate and deep sedimentary sites may have been more pronounced in 1986 than in 1985 if environmental conditions retarded growth on the deep sedimentary site at the higher elevation in 1986.

Differences in height-weight distribution due to site X year interactions (Table 1) were found. The percentages of weight in the 0 to 20 cm increment were greater in 1986 than in 1985 for plants on all sites except the moderate sedimentary site. However, the percentages of weight in the 20 to 40 cm increment were less in 1986 than in 1985 for plants on all three granitic sites, but not for plants on the three sedimentary sites.

Differences in height-weight distribution at or near the base of these plants on the same site may indicate differences in the partitioning of resources within plants in response to different annual environmental stimuli. There was no difference in height-weight distributions for the moderate sedimentary site in 1985 and 1986 even though there was more weight in 1985 than in 1986.

The major height differences were consistent with the differences in the site main effect for weight. Plants on the granitic sites and the shallow sedimentary site were noticeably shorter than those on both the moderate and deep sedimentary sites.

Moderately Deep and Deep Sedimentary Sites

Sites, years, and phenological stages

Idaho fescue vegetative and seeded plant height-weight data for both 1985 and 1986 and three phenological stages were collected on only the moderate and deep sedimentary sites. The average weight of leaf material for 250 plants collected on both sites, two years and three collections was 2487±147 mg. About one-third of the total plant weight was in the 0 to 20 mm increment, 56% in the 0 to 40 mm increment, 73% in the 0 to 60 mm increment, and only 27% of the total plant weight is above 60 mm (Table 2).

The average weight of plants from all collections in 1985 and 1986 on the moderate sedimentary site (2869±232 mg) was 40% greater than the average weight of plants collected at similar times on the deep sedimentary site (2123±177 mg). Any effect of the difference in soil depth was probably negated by the fact the moderately deep sedimentary site was 300 mm lower in elevation than the deep sedimentary site. The plant height-weight distributions on both the moderate and deep sedimentary sites were similar to that for the overall mean distribution.

Weight differences between years were less than those between sites and not significant at the 5% level. The average weight of plants collected on both sites was 2722±161 mg in 1986 and 2270±161 mg in 1985. However, there was a site X year

Table 2. *Average total weight (WT, mean±SE) and length (LTH, mean±SE) of leaves and percentage of total weight per length increment (e.g., I160 = percentage of total weight within the 40 - 60-mm increment) for Idaho fescue plants collected on moderately deep (MS) and deep (DS) sedimentary sites during the vegetative (V), dough (D), and mature (M) phenological stages in 1985 and 1986. Those values within the same column and for the same source of variation (SOV) followed by a different letter are signigicantly different at the 5% level. N = number of samples. S*Y = site X year interaction. S*P = site X phenological stage interaction. P*Y = phenological stage X year interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	I160	I200	I280	LTH
			(mg)	%										(mm)
MEAN		250	2487±147	31.9	23.7	17.4	11.8	7.4	4.2	2.1	0.9	1.5	1.5	176±3a
SITE	MS	122	2869±232a	31b	24a	18a	12a	8a	4a	2a	1a	1a	1a	178±4a
	DS	128	2123±177b	33a	24a	17b	12a	7a	4a	2a	1a	2a	2a	174±4a
YEAR	85	130	2270±161a	29b	25a	19a	13a	8a	4a	2a	1a	1a	1a	165±4b
	86	120	2722±249a	35a	22b	16b	11b	7a	4a	2a	1a	2a	2a	189±4a
PHEN	V	84	1077±103b	35a	26a	18a	11b	6b	3b	1b	0b	0b	0b	162±5b
	D	86	3092±280a	29c	24b	18a	12a	8a	5a	2a	1a	2a	2a	177±5a
	M	80	3318±263a	32b	21c	16b	12a	8a	5a	3a	1a	2a	2a	190±5a
S*Y	MS85	62	2224±203b	30bc	25a	19a	12a	7ab	4b	2b	1b	1c	1c	156±4b
	MS86	60	3536±407a	31b	22b	17b	12a	8a	5a	3a	1a	2a	3a	193±6a
	DS85	68	2312±249b	28c	25a	19a	13a	8a	4ab	2ab	1ab	2ab	2ab	173±6ab
	DS86	60	1908±250b	39a	22b	15c	10b	6b	4ab	2b	1b	1bc	1bc	184±6a
S*P	MSV	42	1267±168c	35a	26a	18a	11b	6c	3c	1c	0c	0b	0b	159±7b
	DSV	42	886±112c	35a	26a	18a	11b	6c	3c	1bc	0bc	0b	0b	166±7b
	MSD	40	4055±468a	26b	22b	17a	13a	9a	6a	3a	2a	3a	3a	189±7a
	DSD	46	2254±279bc	32a	25a	18a	12ab	7bc	4bc	2bc	1bc	1b	1b	170±7b
	MSM	40	3366±383ab	31a	23b	17a	13a	8ab	5ab	2b	1b	1b	1b	176±6b
	DSM	40	3269±365ab	32a	20c	15b	12ab	9a	6a	3a	2a	3a	3a	203±7a
P*Y	V85	44	1370±110b	32b	26a	19ab	12b	7c	3c	1c	0d	0d	0d	162±6bc
	V86	40	754±165b	38a	26a	17c	10c	5d	3c	1c	0d	0d	1cd	163±8bc
	D85	46	2535±296ab	29bc	26a	19a	12ab	7c	4bc	2bc	1cd	1cd	1cd	155±6c
	D86	40	3733±481a	30b	21b	16d	12ab	9ab	6a	3a	3a	3a	3a	203±6a
	M85	40	2956±335a	26c	22b	18bc	13a	9a	6a	3a	3ab	3ab	3ab	181±6bc
	M86	40	3679±401a	37a	20c	15d	11bc	8bc	5ab	2ab	2bc	2bc	2bc	199±5a

interaction. Plant weights on the moderate sedimentary site in 1986 (3536±407 mg) were 59% greater than those on the same site in 1985. Average plant heights on the moderate sedimentary site in 1986 (193±6 mm) were also 20% greater than in 1985 (156±4 mm). Plant weights and heights on the deep sedimentary site were similar in both years. Plants collected in 1986 had a greater percentage of weight in the 0 to 20 mm (35%) increment than those collected in 1985 (29%), but the height-weight distribution was relatively similar above 20 mm.

The greatest differences in weights were for kinds of plants and phenological stages. Average leaf weights of plants collected during the mature (3318±263 mg) and dough phenological stages (3092±280 mg) were both much greater than weights for vegetative plants (1077±103 mg) collected during the dough phenological stage of seeded plants.

Vegetative plant leaves were shorter (162±5 mm) than seeded plant leaves collected in the dough (177±5 mm) and mature (190±5 mm) stages and had over 60% of their total weight in the lower 40 mm of height. In general, the longer seeded plants seemed to have their weights more equally distributed from the base to the tips of the leaves. Above 100 mm, plants had similar percentages of total weight per 20 mm increment for all three kinds of plants and phenological stages.

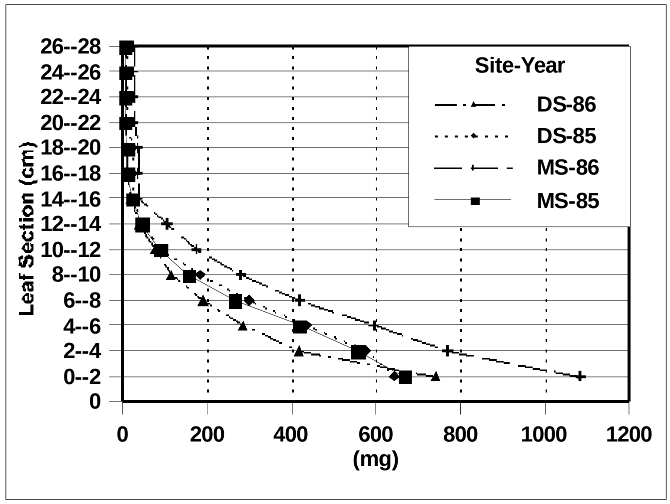

Figure 19. Average leaf length-weight distribution for all plants collected on moderately deep (MS) and deep sedimentary (DS) sites in 1985 and 1986.

Although significant differences occurred due to site and collection periods, the interpretation of these differences is influenced greatly by significant site X year, site X collection, and year X collection interactions. Relatively few differences were found among the total plant weights for Idaho fescue plants (i.e., both vegetative and seeded plants) collected on the deep sedimentary site in 1985 (2312±249 mg) or in 1986 (1908±250 mg) or on the moderate sedimentary site in 1985 (2224±203 mg) (Figure 19).

Although the total height and weight of plants collected on the moderate sedimentary site in 1986 was greater than that in 1985, the height-weight distribution was relatively similar. Plants on the deep sedimentary site in 1986, however, were lighter (1900 mg) and had a greater proportion (39%, 61%, and 77%) of the total weight in the 0 to 20 mm, 0- to 40-mm, 0- to 60-mm increments, respectively, than those on the same site in 1985 (2300 g, 28%, 52%, and 71%, respectively).

Heights for plants on the deep sedimentary site in 1985 and 1986 were similar, but lighter total weights and a greater concentration of weight at the lower increments in 1986 indicates a greater percentage of relatively short leaves on plants in 1986. The height-weight distribution above 60 mm was relatively similar for plants on both sites and years. The greater leaf productivity in 1986 on the moderate sedimentary site than leaf productivity on the deep sedimentary site indicates differences in physiological responses to site and environmental factors.

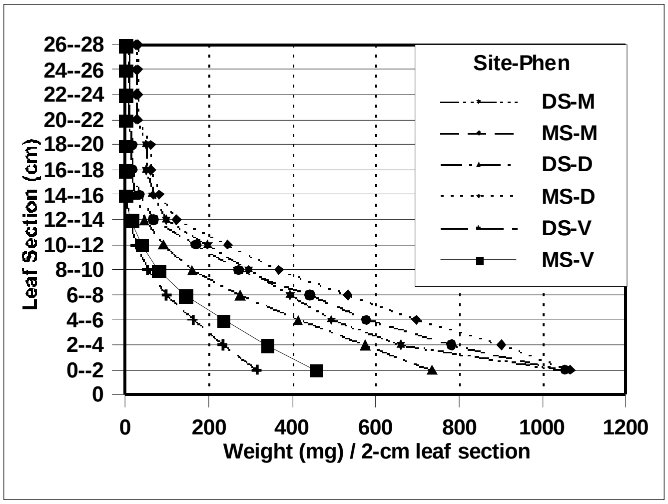

Figure 20. Average leaf length-weight distribution for vegetative (V) and seeded plants (SD & SM stages) collected on moderately deep (MS) and deep sedimentary (DS) sites.

Relatively little difference in leaf weights or height-weight distribution on different sites for vegetative plants or for mature seeded plants was found. However, during the dough phenological stage, leaf weights on the moderate sedimentary site (4055±468 mg) were 78% higher than those on the deep sedimentary site (2250±280 mg) (Figure 20).

Although lighter in weight but of similar heights, plants on the higher elevation deep site had a greater concentration of weight at the lower levels. Plants on the deep site had 87% of total weight in the lower third of their height, whereas plants on the lower elevation and more productive, moderate site had 79% of total plant weight within the same height. With more biomass the plants on the moderate sedimentary site had their weights more equally distributed along the entire length of a particular plant.

Leaf weights for vegetative plants on both the deep and moderate sites were only one-third as much as those of seeded plants at either phenological stage. Leaf weights of seeded plants on the moderate sedimentary site were only slightly greater during the dough phenological stage than at maturity, whereas leaf weights of seeded plants on the deep sedimentary site were greatest at maturity.

This apparent rapid growth rate at higher elevations is similar to the results of Pond and Smith (1971). They studied Idaho fescue plants at 2600 m and 2900 m, and we compared plants at 2450 m and 2750 m in elevation. Idaho fescue leaves reached maximum length near the same date at the different elevations in their study. However, in our study leaf length of plants on the deep sedimentary site continued to increase from 166±7 mm in the vegetative stage to 203±7 mm in the mature stage, whereas leaf length of plants on the moderately deep site increased from 159±7 mm in the vegetative stage to 189±7 mm in the dough stage and then decreased to 176±6 mm in the mature stage. Plants on the moderately deep sedimentary site increased leaf length approximately 30 mm only between the vegetative and dough stages, whereas plants on the deep sedimentary site showed little increase in leaf length between the vegetative and dough stages but 33 mm between the dough and mature stages.

During the dough stage seeded plants on the moderate sedimentary site had their leaf weights more equally distributed along the entire length of a particular plant than similar plants on the deep site. At maturity leaf weights on the two sites were distributed similarly from the base to the tips of the leaves with a concurrent increase in leaf biomass on the deep sedimentary site between the dough stage and maturity.

Plants on the deep sedimentary site from the dough to the mature stage may be more susceptible to grazing due to the increase of growth during this time period. Although beyond the scope of this study, physiological questions for Idaho fescue need to be addressed as they relate to differential growth rates on these sites to determine the effects of utilization during the growing season.

This knowledge would be valuable to resource managers responsible for maintaining productive stands of grass where pastures occur at different elevations in mountain grasslands. Plant heights on the two sites were similar for vegetative plants and for dough phenological stage plants but significantly taller on the deep site during the late phenological stage.

In both 1985 and 1986 leaf weights of seeded plants were greater than those of vegetative plants at the same time; however, the greater weight difference occurred in 1986 (Figure 21). The greatest difference in leaf weights occurred in 1986 between vegetative plants (754±165 mg) and seeded plants in the dough stage (373±481 mg), and the greatest difference between years was during the dough phenological stage when plant weights averaged 2535±296 mg in 1985 and 3733±296 mg in 1986.

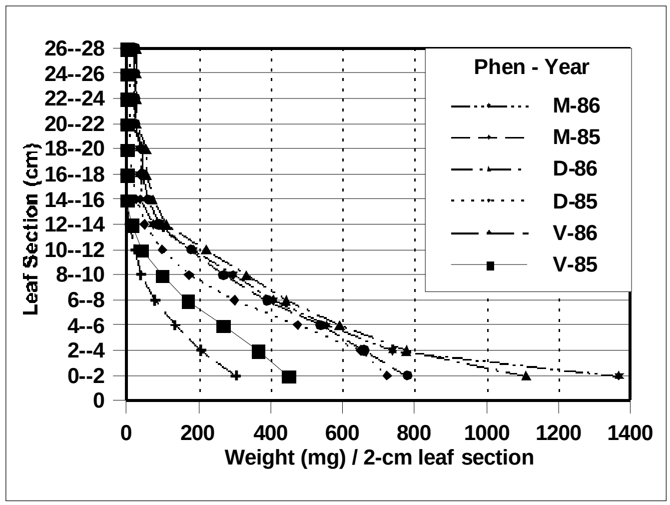

Figure 21. Average leaf length-weight distribution for vegetative (V) and seeded plants (SD & SM) collected on 2 sites in 1985 and 1986.

In 1985, seeded plants during the dough and mature phenological stages on the moderately deep and deep sedimentary sites had about the same leaf length, and the height-weight relationships were similar during both phenological stages. In 1986, seeded plants during the dough and mature phenological stages also had the same leaf length, but the leaf weights were proportionally greater at the base of the plant during the mature phenological stage.

The differences in height-weight relationships in 1985 and 1986 may indicate differences in the beginning rate and duration of good growing conditions; senescence and weight loss of older and longer leaves; and the proportion of younger, shorter leaves and older, longer leaves. Idaho fescue growth appears to have started earlier but lasted a shorter period in 1985 than in 1986 and with fewer, if any, new leaves being produced later in the season. In contrast, Idaho fescue plants appear to have begun growth later in 1986 but sustained growth later into the season with new leaves being produced during the mid-phenological stage.

Sites and phenological stages for 1985

The average total weight for 130 plants on the moderately deep and deep sedimentary sites in the vegetative, dough, and mature phenological stages for 1985 was 2270±166 mg (Table 3). There was 29%, 54%, and 73% of the total plant weight in the 0 to 20 mm increment, 0 to 40 mm increment, and 0 to 60 mm increments, respectively. Only 27 % of the total plant weight was above 60 mm.

Table 3. *Average total weight (WT, mean±SE) and length (LTH, mean±SE) of leaves, and percentage of total weight per length increment (e.g., I100 = percentage of total weight within the 80- to 100-mm increment) for Idaho fescue plants collected on moderately deep (MS) and deep (DS) sedimentary sites during the vegetative (V), dough (D), and mature (M) phenological stages (PHEN) in 1985. Those values within the same column and for the same source of variation (SOV) followed by a different letter are significantly different at the 5% level. N = number of samples. S*P = site X phenological stage interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	I160	I200	LTH
			(mg)					%					(mm)
MEAN		130	2270±166	29	25	19	13	7	4	2	1	0.3	165±4
SITE	MS	62	2224203a	30a	25a	19a	13a	8a	4a	2a	1a	0.5a	156±4b
	DS	68	2312±249a	28b	25a	19a	12a	7a	4a	2a	1a	0.2b	173±6a
PHEN	V	44	1370±111b	32a	26a	19a	12b	7b	3b	1b	0.2b	0.0b	162±6ab
	D	46	2534±296a	29b	26a	19a	12b	7b	4b	2ab	0.7ab	0.2b	155±6b
	M	40	2956±335a	26c	22b	18b	13a	9a	6a	3a	1.4a	0.8a	181±8a
S*P	MSV	22	1504±157b	35a	28a	18ab	11b	5c	2c	1c	0b	0b	148±7b
	DSV	22	1235±154b	28bc	25ab	19a	13a	8abc	4bc	2bc	0b	0c	175±9ab
	MSD	20	2909±531a	26bc	24abc	19a	13a	9ab	5ab	2ab	1b	0b	168±9b
	DSD	26	2247±327ab	30ab	28a	19a	12ab	6bc	3bc	1bc	0b	0b	145±7b
	MSM	20	2330±207ab	29bc	24bc	19a	13a	9ab	4ab	2bc	0b	0b	153±6b
	DSM	20	3581±614a	23d	21c	17b	13a	10a	7a	4a	2a	1a	208±12a

No differences due to site for total weight, average leaf length/height, or for height-weight distribution were found; however, there were differences between stages. Average plant weight in the dough stage (2530±300 mg) was 80% greater than in the vegetative stage (1370±110 mg). Though the 0 to 120 mm increment for height-weight distribution a trend led to the vegetative and dough stages being slightly higher than the mean. Those in the mature stage were consistently much lower than the mean through the same 0 to 120 mm increment. Weights of mature Idaho fescue plants were more evenly distributed through the same length as compared to those in the dough stage. Significant differences in weight-per-length ratios for plants in the dough and mature stages for the 0 to 40 mm increment, the 0 to 60 mm increment, and the 0 to 80 mm increment were found.

Large differences also were found for total average weight and height-weight distribution among phenological stages for the two sites. Average plant weights on the deep sedimentary site were lower than those on the moderately deep sedimentary site during the vegetative and dough stages but higher during the mature stage. Apparently, plants on the deep sedimentary site peaked in weight and height or leaf length at the later than hard dough stage because of their higher elevation (shorter growing season), whereas plants on the moderately deep site at a lower elevation peaked earlier in the high boot to hard dough stage.

Differences in growth patterns between plants on the two sites also are shown in the leaf length and in the height-weight distributions during different phenological stages. Plants on the moderately deep site were longer ($P < 0.10$) in the dough stage than in the vegetative or mature stage, whereas plants on the deep site were shorter in the dough stage than in the vegetative or mature stage. In addition, plants on the deep site had a slightlly greater concentration of plant weight in the 0 to 40 mm increment during the dough stage than plants on the moderately deep site but not during the vegetative or mature stages. This implies that plants on the deep site (higher elevation) may withstand a greater degree of grazing in the dough stage than plants on the lower elevation, moderately deep site at the same time.

Sites and Phenological Stages for 1986

The overall mean leaf weight for 362 plants from all six sites and three plant kinds or stages in 1986 was 1440±100 mg (Table 4). Research indicated there was 48%, 75%, and 87% of the total weight distributed within the 0 to 20 mm, 0 to 40 mm, and 0 to 60 mm increments, respectively, with only 13% of the total plant weight above 60 mm.

Substantial variation occurred among plant weights on different sites, with plants on the granitic and shallow sedimentary sites being lighter than those on the two deeper sedimentary sites (Figure 22). Plants on the moderate sedimentary site had 84% greater leaf weight than those on the deep sedimentary site (3540±410 mg and 1908±250 mg, respectively.).

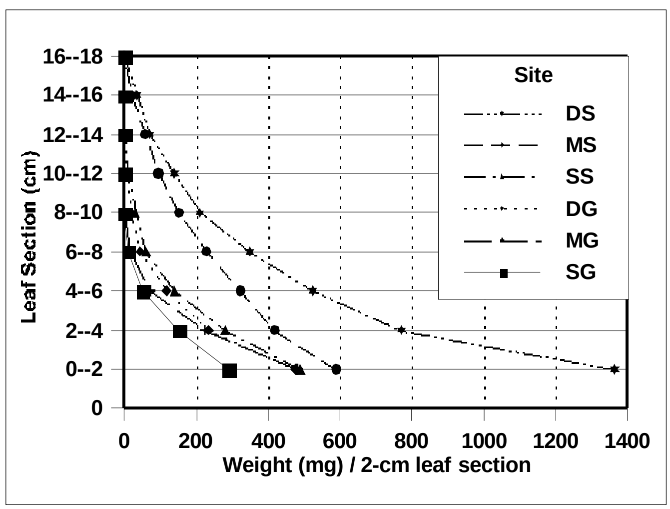

Figure 22. Average leaf weights (mg) per 2-cm increment for plants on all sites in 1986.

Table 4. *Average total weight (WT, mean±SE) and length (LTH, mean±SE) of leaves, and percentage of total weight per length increment (e.g., I160 = percentage of total weight within the 140- to 160-mm increment) for Idaho fescue plants collected on shallow granitic (SG), moderately deep granitic (MG), deep granitic (DG), shallow sedimentary (SS), moderately deep sedimentary (MS), and deep sedimentary (DS) sites during the vegetative (V), dough (D), and mature (M) phenological stages in 1986. Those values within the same column and for the same source of variation (SOV) followed by a different letter are significantly different at the 5% level. N = number of samples. S*P = site X phenological stage interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	I160	LTH
			(mg)	%								(mm)
MEAN		362	1436±101	48.3	26.2	12.9	6.2	3.3	1.8	0.8	0.4	134±3
SITE	SG	61	471±61d	58a	30a	10d	2d	0d	0d	0c	0c	94±3c
	MG	60	781±83cd	60a	28ab	9d	2d	0d	0d	0c	0c	99±3c
	DG	60	911±108cd	53b	26b	13c	5c	2c	1cd	0c	0c	119±5b
	SS	61	1031±131c	49c	28ab	14bc	6c	3c	1c	0c	0c	118±5b
	MS	60	3536±407a	31e	22c	17a	12a	8a	5a	3a	1a	193±6a
	DS	60	1908±250b	39d	22c	15ab	10b	6b	4b	2b	1b	184±6a
PHEN	V	120	471±63b	54a	27a	11c	5b	2b	1b	0b	0c	112±5b
	D	121	1887±204a	43c	26a	15a	7a	4a	2a	1a	1a	146±5a
	M	121	1942±187a	47b	26a	13b	7a	4a	2a	1a	0b	144±5a
S*P	SGV	20	219±49d	66a	27bc	5i	1ij	0g	0f	0e	0c	77±4a
	SGD	21	572±125d	52cd	33a	13cdef	2ij	0fg	0f	0e	0c	97±3a
	SGM	20	619±105d	54bcd	31ab	11fg	3ghij	1efg	0f	0e	0c	107±4a
	MGV	20	526±91d	66a	27bc	6hi	1j	0g	0f	0e	0c	86±4a
	MGD	20	794±146c	55bcd	29abc	12ef	3ghi	1fg	0f	0e	0c	105±4a
	MGM	20	1022±169c	60abc	29abc	9gh	2hij	0fg	0f	0e	0c	105±4a
	DGV	20	295±63d	55bcd	26bc	12ef	4fgh	2efg	1ef	0e	0c	97±5a
	DGD	20	1164±164c	50d	27bc	14def	6def	2de	1ef	0de	0c	135±8a
	DGM	20	1274±218c	53cd	26bc	13def	5efg	2ef	1ef	0de	0c	126±8a
	SSV	20	277±75d	62ab	29abc	8hi	2ij	0fg	0f	0e	0c	87±6a
	SSD	20	1166±157cd	42e	28bc	17ab	9bc	4d	1def	0de	0c	134±8a
	SSM	21	1622±275c	43e	28bc	16abc	8cde	4d	1de	0de	0c	131±9a
	MSV	20	1005±302cd	34f	25cd	18a	12a	6c	3c	1c	0c	170±12a
	MSD	20	5201±693a	27f	20e	16abc	13a	9a	7a	4a	3a	211±9a
	MSM	20	4401±668ab	33f	21de	16abc	12a	8abc	5b	3b	1b	199±7a
	DSV	20	502±115d	42e	26bc	16abc	8bcd	4d	2d	1cd	0c	156±11a
	DSD	20	2263±492c	34f	21de	16abc	12a	8ab	5b	2b	1b	196±8a
	DSM	20	2957±398bc	42e	19e	14cdef	10ab	7bc	5b	2b	1b	199±a

Plant weights on the shallow, moderate, and deep granitic and shallow sedimentary sites varied only 560 mg among sites and averaged 470±60 mg, 780±80 mg, 910±110 mg, and 1030±130 mg, respectively. The combination of soil depth and available soil nutrients on a given site impacts the differences between deep sedimentary and moderate sedimentary site plant weights compared with the granitic and shallow sedimentary sites.

Consistent trends occurred in height-weight distribution below 80 mm for plants on different sites. In this range, shallow and moderate granitic site plant weight percentages were well above the mean, while those for deep granitic and shallow sedimentary sites were slightly above the mean, and those for moderate and deep sedimentary sites were well below the mean and different from each other (moderate sedimentary site plants having a consistently lower percentage of the total weight through the first 80 mm).

This is in agreement with the leaf lengths for various sites that were 94±3 mm, 99±3 mm, 119±5 mm, 118±5 mm, 193±6 mm, and 184±6 mm for shallow granitic, moderate granitic, deep granitic, shallow sedimentary, moderate sedimentary, and deep sedimentary sites, respectively. Although moderate and deep sedimentary site plants had the same height, the greater weight of leafy material on the moderate sedimentary plants for the same height was distributed more equally along the length of the moderate sedimentary plants relative to the deep sedimentary plants.

At different collection periods, the average weight of seeded plants in the dough stage was 280% greater than that of vegetative plants collected at the same time (1890±200 mg and 470±60 mg, respectively). This is consistent with the previously discussed analysis where larger, taller seeded plants were larger and taller in the dough stage (146±5 mm) than the relatively lighter, shorter vegetative plants (112±5 mm).

This difference was also reflected in the height-weight distribution below 80 mm. Vegetative plant weight percentages for leaf increments less than 80 mm were much higher than the overall mean and plant weight percentages for seeded plants in the dough stage. No differences in plant weight percentages above 60 mm between stages were found.

No differences within sites for all three kinds or stages for all three granitic sites occurred. However, differences for plant weights and weight distribution on the three sedimentary sites were found.

Large differences in total leaf weights of seeded plants in the dough stage and in the mature stage on the moderately deep sedimentary site in 1985 and 1986 were found (Figure 23). Moderate sedimentary plants in the dough stage were 80% heavier in 1986 than in 1985, while mature moderate sedimentary plants had 90% more leaf biomass in 1986 than in 1985. Apparently, the growing conditions were much more

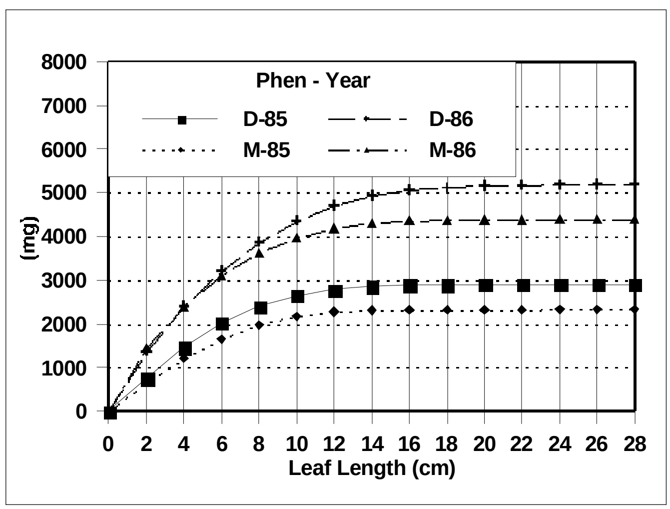

Figure 23. Accumulative leaf weights of seeded plants in 1985 and 1986 on the moderately deep sedimentary site.

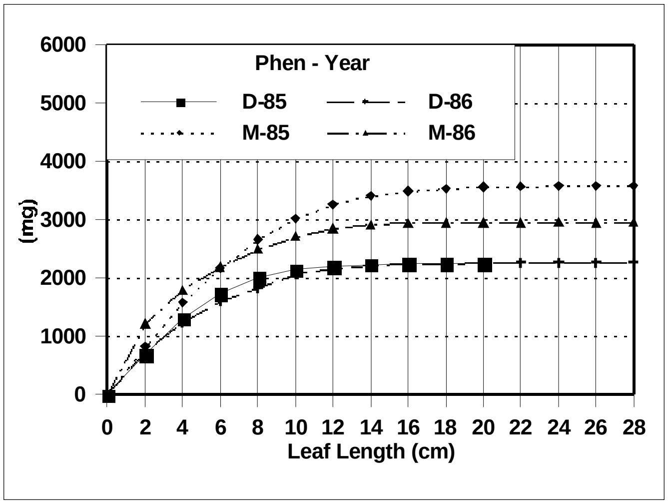

Figure 24. Accumulative leaf weights of seeded plants in 1985 and 1986 on the deep sedimentary site.

conducive to leaf growth in 1986 than in 1985 on the moderate sedimentary site.

Figures 23 and 24 show the height-weight relationships for seeded plants in the dough and mature stages on moderate and deep sedimentary sites, respectively. There was a noticeable increase in total average weight from 1985 to 1986 and a corresponding decrease in weight from the dough to the mature stage for plants on the moderate sedimentary site, while there is little difference between years and an increase in weight from the dough to the mature stage on the deep sedimentary site.

Figure 25 shows the height-weight relationships for the shallow sedimentary, the shallow, moderate, and the deep granitic sites during the dough

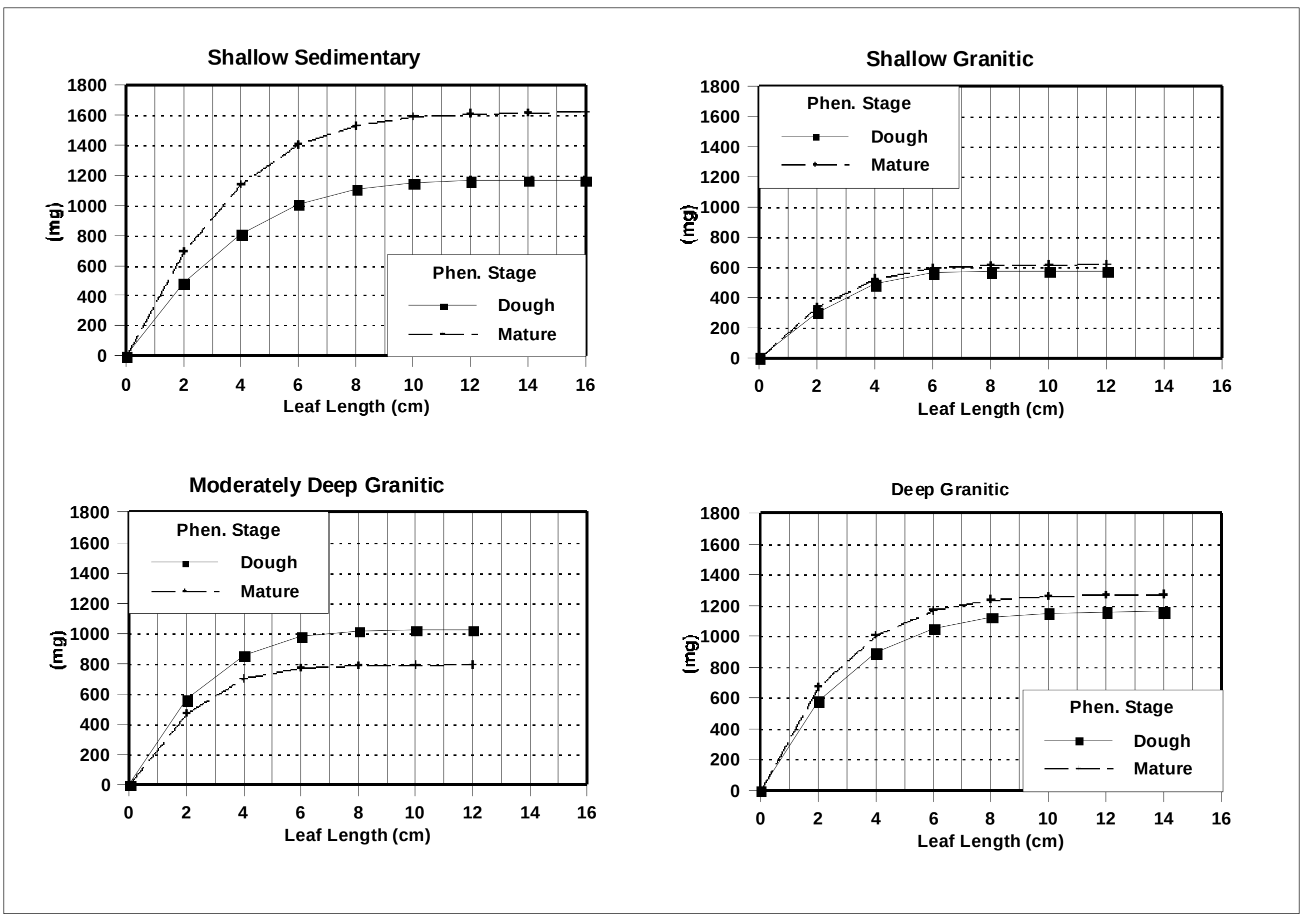

Figure 25. Accumulative leaf weights of seeded plants in 1986 on the less productive sites.

and mature stages in 1986. A 400 milligram difference in plant weights between the dough and mature stages for plants on the shallow sedimentary site was evident, but there were no significant differences between stages on any of the granitic sites.

On all sites, the percentages of weight in the 0 to 20 mm increment for vegetative plants were much higher that those for seeded plants on the same sites in either the dough or mature stage. This difference exists below 60 mm especially for plants on the shallow and moderate granitic sites because of the short stature of the plants on these sites.

Deeper sites, such as the moderate and deep sedimentary, have taller plants (weight is distributed more equally along the entire length of the plants), and this difference in plant weight distribution between stages is expressed as far up as the 100 to120 mm increment on the moderate sedimentary site.

Within a particular stage, no differences in vegetative plant weight distribution for shallow and moderate granitic or for shallow sedimentary plants were found. Vegetative plants on the deep granitic site had a lower percentage than those on the three previously mentioned sites but were well above the overall mean for percentage of total weight through the 0 to 80 mm increment.

The dough stage incremental weight percentages for moderate and deep sedimentary plants were much lower than the mean percentage of the total weight and were different from each other. The larger moderate sedimentary plants had the lowest mean percentage of the total weight through the 0- to-80 mm increment for all three stages. The dough and mature stages for shallow and moderate granitic plants were similar throughout all increments.

Shallow sedimentary plants in the dough and mature stages had lower incremental percentages than those on the deep granitic site through the 0- to 6-mm increment even though vegetative stage incremental percentages for deep granitic plants were lower than those for shallow sedimentary plants. Apparently, even though the total average weight and height are similar for the shallow sedimentary and deep granitic plants at all stages, shallow sedimentary plants are distributing their weights more evenly throughout their lengths in the dough and mature stages (with seedstalks) than deep granitic plants, whereas deep granitic plants are distributing their weights more equally from base to tip in the vegetative stage (without seedstalks). Deep granitic plants had the most consistently similar values per increment between stages. Values for deep granitic and shallow sedimentary plants were intermediate for percentage of total weight for the dough and mature stages through the 0- to 80-mm increment.

Consistent with the height-weight distribution and the average total weight figures, the shallow and moderate granitic plants were shorter than deep granitic and shallow sedimentary plants, which were shorter than moderate and deep sedimentary plants.

Leaf lengths were similar during all stages for shallow and moderate granitic plants, about 100 mm. Length was not similar for deep granitic, shallow sedimentary, moderate sedimentary, and deep sedimentary plants when comparing leaf lenghts during the vegetative and dough stages.

Seedstalk Height-Weight Relationships

Sites, years, and phenological stages

Idaho fescue seedstalk plant height-weight data were collected in the dough and mature phenological stages in 1985 and 1986 on the moderate and deep sedimentary sites. The average weight of Idaho fescue seedstalks collected on the two sites, two stages, and over a two-year period was 2990±500 mg (Table 5).

Table 5. *Average total weight (WT, mean±SE) and length (LTH, mean±SE) of seedstalks, and percentage of total seedstalk weight per length increment (e.g., I160 = percentage of the total weight within the 140- to 160-mm increment) for Idaho fescue plants collected on moderately deep (MS) and deep (DS) sedimentary sites during the dough (D) and mature (M) phenological stages (PHEN) in 1985 and 1986. Those values within the same column and for the same source of variation (SOV) followed by a different letter are significantly different at the 5% level. N = number of samples. S*Y = site X year interaction. S*P = site X phenological stage interaction. P*Y = phenological state X year interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	I160	I180	I200	I300	I400	I500	I600	LTH
			(mg)	%														(mm)
MEAN		32	2990±497	8.5	8.2	8.4	8.1	7.9	7.1	6.7	5.8	5.0	4.4	16.3	9.7	3.5	0.4	578±12
SITE	MS	16	2035±607b	10a	9a	9a	9a	8a	8a	7a	6a	5a	4a	15a	7b	2b	0b	556±17b
	DS	16	3943±572a	7b	7b	8b	7b	7b	7b	6b	5a	5a	4a	17a	13a	5a	1a	600±15a
YEAR	85	16	1627±345b	9a	9a	9a	8a	8a	7a	7a	6a	5a	4b	15a	9a	4a	1a	581±21a
	86	16	4351±672a	8	8a	8a	8a	8b	7a	7a	6a	6a	5a	18a	10a	3a	0b	575±11b
PHEN	D	16	3047±655a	7b	7b	7b	8a	7b	7a	6b	6a	5a	5a	18a	13a	4a	0a	569±14a
	M	16	2932±623a	10a	9a	10a	8a	8a	7a	7a	6a	5a	4a	14b	6b	3a	1a	587±20a
S*Y	MS85	8	780±268c	12a	11a	11a	10a	9a	8a	8a	6a	4b	4b	13b	5b	1b	0b	537±30b
	MS86	8	3291±103ab	7b	8b	8ab	8b	8a	8a	7ab	6a	6a	5a	18a	8ab	2b	0b	575±16ab
	DS85	8	2475±482bc	7b	7b	7b	7c	7b	6b	6b	5a	5ab	4ab	18a	14a	7a	2a	625±23a
	DS86	8	5412±74a	8b	8b	8b	8b	8ab	7ab	6ab	6a	5ab	5ab	17ab	12a	4b	0b	575±16ab
S*P	MSD	8	2418±1122a	7b	7b	8b	8ab	8b	7ab	6b	6a	6a	5a	19a	11a	3ab	0b	563±23a
	DSD	8	3676±681a	7b	7b	7b	7b	7b	6b	6b	5a	5a	4a	17a	15a	5a	0ab	575±16a
	MSM	8	1653±530a	13a	11a	11a	10a	9a	8a	8a	7a	5a	4a	12b	2b	0b	0b	550±27a
	DSM	8	4211±975a	7b	8b	8b	7b	7b	7b	6b	6a	5a	5a	17a	11a	5a	1a	625±23a
P*Y	D85	8	1941±571bc	8b	8a	7b	8a	7a	7a	6b	5a	5a	4ab	17a	14a	5a	0ab	563±23a
	D86	8	4153±1077ab	7b	7b	7b	8a	8a	7a	6b	6a	5a	5a	19a	12a	3a	0b	575±16a
	M85	8	1313±393c	11a	10a	10a	9a	8a	7a	8a	6a	4a	4b	13b	5b	3a	1a	600±37a
	M86	8	4551±873a	8b	9a	9ab	8a	8a	8a	7ab	6a	6a	5a	16ab	8ab	2a	0b	575±16a

About 25% of the total plant weight existed in the 0- to 60-mm increment, almost 50 % in the 0- to 120-mm increment and 70% in the 0- to 200-mm increment.

The climatic variation between the fall of 1984 and the spring of 1986 may partly explain why there was such a disparity between seedstalk production between 1985 and 1986. Temperatures during the summer of 1984 were much higher than average for the early to middle part of the growing season and may have increased the evapotranspiration rate. Temperatures for the same period in 1985 were about average.

Less moisture occurred in the fall of 1984 than in the fall of 1985, although levels in both years were about average for that time of year. Snow accumulation amounts for the winters of 1984 to 1985 and 1985 to 1986 were similar, but snow depth was much less in late spring 1985 than for the same period in 1986. This may be due to the warmer days that occurred in early May 1985, which melted snow at a faster rate.

A high snow-melt rate and subsequent increased overland flow would decrease water infiltration and soil profile recharge. So the possibility of overland flow in 1985 as well as higher evapotranspiration during the summer of 1984 and less moisture than average during the fall of 1984 may have stressed the plants on the shallow and moderate sedimentary and on the shallow and moderate granitic sites (sites near the Burgess Junction weather station and at much lower elevation than the deep sedimentary and granitic sites) to the point that less energy was put into seedstalk production. Although this scenario may be part of the answer, the question arises; how do environmental factors (including grazing pressure in previous years) on a particular site affect the differentiation of buds to produce vegetative or floral primordia in Idaho fescue.

Seedstalk weights differed considerably between plants on the two sites with moderate sedimentary plants (2030±610 mg) being much lighter than deep sedimentary plants (3940±570 mg). This is in contrast to moderate sedimentary vegetative plant weights (2870±230 mg) being much heavier than those on the deep sedimentary site (2120±180 mg). Apparently, deep sedimentary plants are expending more energy toward seed production than for vegetative growth, while the reverse seems to be true for moderate sedimentary plants.

Consistent with the relatively large differences in weights for plants on the two sites, a corresponding disparity between the height-weight distribution from the 0- to 60-mm increment and the 0- to 300-mm increment occurred. Deep sedimentary plants had a lower percentage of the total weight within this incremental range and had taller seedstalks (600±15 mm) than moderate sedimentary plants (556+17 mm). Deep sedimentary seedstalk weights were distributed more equally along the entire length of the stalks, producing relatively lower percentages of the total weight within the 0- to 60-mm through the 0- to 300-mm increment.

Seedstalk weights were more than 2X greater in 1986 (4350±670 mg) than in 1985 (1630±350 mg). This difference may have been because of more favorable conditions for seedstalk formation in 1986.

No difference occurred between years for height-weight distributions along the entire length of the sampled plants. Average seedstalk heights were similar (581 and 575 mm) during both years. Seedstalk weights or heights did not differ between stages, but height-weight distributions for the 0- to 40-mm through the 0- to 300-mm increments were different. Differences in height-weight distribution probably occurred during the growing season when the plant was using many of its resources for seed production rather than after the hard dough stage when seeds were shattering, and energy within the seedstalks was being translocated downward toward the crown of the plant.

Although there were differences due to site and year, the interpretation of these differences is notably influenced by significant site X year, site X collection period, and collection period X year interactions. In 1986 seedstalks on the moderate sedimentary site were 313% heavier than in 1985, and seedstalks on the deep sedimentary site were 116% heavier than in 1985 (Figure 26).

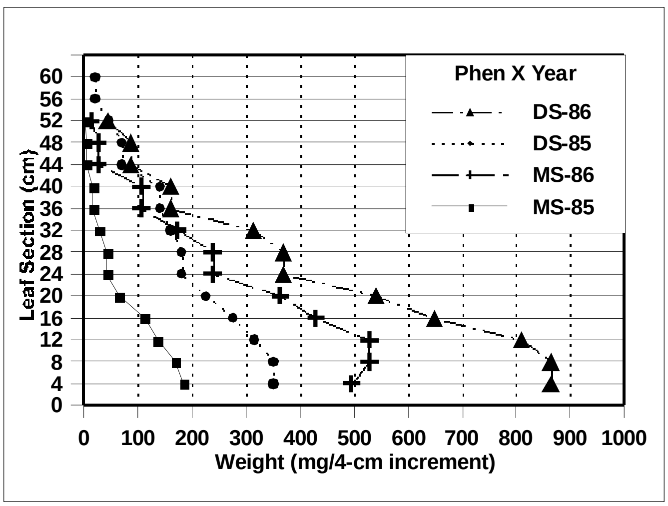

Figure 26. Seedstalk height-weight relationships for plants on the moderately deep (MS) and deep (DS) sedimentary site in 1985 and 1986.

Seedstalk weights did not differ between the two sites in 1985, but seedstalk weights on deep sedimentary plants were 64% heavier than those on moderate sedimentary plants in 1986. The general trend for the height-weight distribution was for the incremental weights in 1985 for moderate sedimentary plants to be well above the mean through the 0- to 180-mm increment while the incremental weights in 1986 on the same site, and for the deep sedimentary plants were somewhat below the mean in 1985 and 1986. This was because seedstalks collected in 1985 from moderate sedimentary plants were shorter (537±30 mm) than those for the deep sedimentary in 1985 (625±23 mm).

No difference in seedstalk weights for the site X collection period combinations was found (Figure 27). Mature plant seedstalks on the moderate sedimentary site had consistently more of their weight at the base than plants on the moderate and deep sedimentary sites in the dough stage and mature plants on the deep sedimentary site. Mature stage seedstalks on the moderate sedimentary site (550±27 mm) were shorter than mature stage seedstalks on the deep sedimentary site (625±23 mm), and slightly shorter than dough stage seedstalks (563±23 mm) on the moderate sedimentary site. Therefore, the apparent discrepancy in height-weight distribution was probably due to the differences in physiology between the two phenological stages as well as the increase in seed shatter during the mature stage.

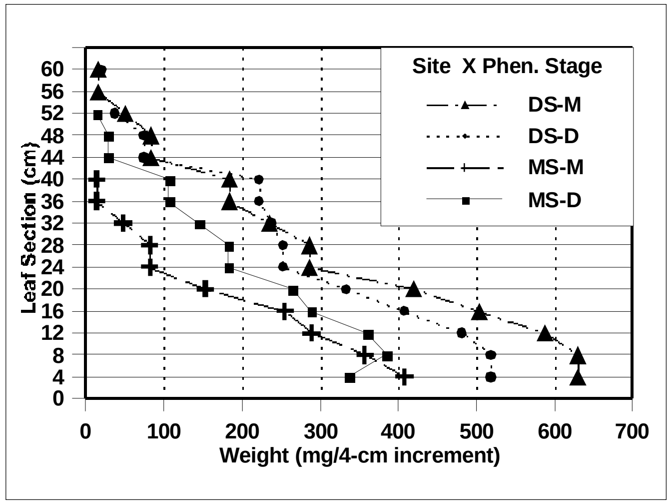

Figure 27. Seedstalk height-weight relationships for plants in the dough (SD) and mature (SM) stages on moderately deep (MS) and deep (DS) sedimentary sites.

The difference between mature stage seedstalk weights on moderate and deep sedimentary plants caused the taller, mature stage, deep sedimentary seedstalks to distribute their weight more equally from the base to the tip of the seedstalk. The variability between moderate and deep sedimentary seedstalks in the mature stage may have occurred because plants on the moderate sedimentary site cured earlier than plants on the deep sedimentary site.

Apparently, in contrast to the additional leaf growth (i.e., increased leaf weight and length increases) between the high boot, hard dough, and mature stages on the deep sedimentary site, there was no additional increase in weight of seedstalks during the same time. The plants evidently switched their resource allocation to leaf growth after seedstalks formed seed. Regardless of the phenological stage, the 1986 seedstalks (4150±1080 mg and 4550±880 mg, 1986 dough and mature, respectively) weighed considerably more than the 1985 seedstalks (1940±570 mg and 1310±390 mg, 1985 dough and mature, respectively) (Figure 28). Mature seedstalks in 1986 were 254 % larger than the mature seedstalks in 1985. Growing conditions in 1986 were either conducive for seedstalk production or plants were reacting (compensating) for the lack of seedstalk production in 1985.

The dough stage seedstalks tended to have their weight more equally distributed along their length than the mature stage seedstalks due to physiological differences and less seed shattering. This relationship was different for plants in the dough and mature stages in 1985, but there was no difference between seedstalk height-weight relationships during the dough and mature stages in 1986.

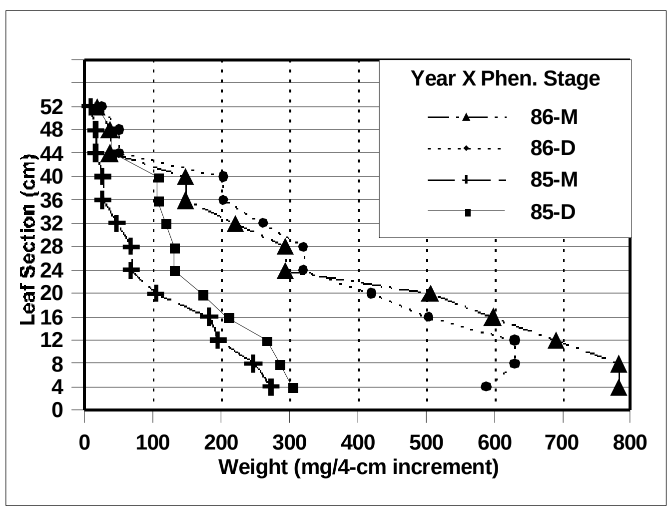

Figure 28. Seedstalk height-weight relationships for plants in the dough (SD) and mature (SM) stages in 1985 and 1986.

Sites and phenological stages for seedstalks in 1986

Mean seedstalk weight and height averages for six sites during the dough and mature phenological stages in 1986 were 2000±350 mg for seedstalk weights and 500±13 mm for leaf length (Table 6). The shallow sites (shallow and moderate granitic and shallow sedimentary) had similar average seedstalk weights (169±48 mg, 566±146 mg, and 592±12 mg, respectively) and all of these were much less than those on the moderate and deep sedimentary sites (3290±1030 mg and 5410±740 mg, respectively). Seedstalk weights on the deep granitic site (1990±650 mg) were intermediate.

Table 6. *Average total seedstalk weight (WT, mean±SE) and length (LTH, mean±SE), and percentage of total seedstalk weight per length increment (e.g., I160 = percentage of total weight within the 140- to 160-mm increment) for Idaho fescue plants collected on shallow granitic (SG), moderately deep granitic (MG), deep granitic (DG), shallow sedimentary (SS), moderately deep sedimentary (MS), and deep sedimentary (DS) sites during the dough (D) and mature (M) phenological stages (PHEN) in 1986. Those values within the same column and for the same source of variation (SOV) followed by a different letter are significantly different at the 5% level. N = number of samples. S*P = site X phenological stage interaction.*

SOV	EFFECT	N	WT	I20	I40	I60	I80	I100	I120	I140	I160	I180	I200	I300	I400	LTH
			(mg)	%												(mm)
MEAN		48	2004±354	12.3	12.0	12.2	9.8	8.6	7.5	6.2	5.1	4.0	3.6	11.8	5.3	500±13
SITE	SG	8	169±48c	21a	19a	19a	11ab	9a	5b	3c	3b	2c	2c	6b	2cd	413±18b
	MG	8	566±146c	15b	15ab	14ab	12a	8a	8a	6b	5ab	4b	3bc	9b	0d	387±18b
	DG	8	1993±655bc	12bc	13b	13bc	10ab	9a	8ab	6b	5a	4b	4ab	10b	5bc	512±26a
	SS	8	592±12c	11bc	10bc	12bc	10ab	10a	9a	9a	5a	4b	3c	10b	5bcd	537±23a
	MS	8	3291±1029ab	7c	8c	8c	8b	8a	8ab	7ab	6a	6a	5a	18a	8b	575±16a
	DS	8	5412±744ab	8c	8c	8c	8b	8a	7ab	6b	6a	5ab	5a	17a	12a	575±16a
PHEN	D	24	1946±486a	11a	10a	11a	9b	8a	7b	6b	5a	5a	4a	15a	7a	508±19a
	M	24	2062±524a	14a	14b	13a	11a	9a	8a	7a	5a	3b	3b	8b	4b	492±19a
S*P	SGD	4	1397±85b	21a	17ab	20a	9b	8a	3c	3d	3c	3de	3cd	9cde	2bc	400±29cd
	MGD	4	723±253b	12abc	10bcd	11bc	9b	8a	8ab	6bc	6ab	6ab	6a	17ab	1bc	425±25bcd
	DGD	4	1703±252b	10bc	11bcd	11bc	9b	9a	7ab	6bc	5abc	4cd	5ab	13bcd	7abc	525±48abc
	SSD	4	803±105b	10bc	10bcd	11bc	9b	9a	8ab	6bcd	5abc	4bcd	3bcd	15abc	7ab	550±41ab
	MSD	4	4115±1985ab	6c	6d	7c	8b	7a	7b	6bc	6ab	6abc	5ab	21a	12a	575±25a
	DSD	4	4190±1214ab	7c	7d	8c	8b	8a	7ab	6bc	6abc	5abc	5ab	17ab	12a	575±25a
	SGM	4	1975±55b	20a	20a	17ab	12ab	9a	8ab	4cd	4abc	1e	1e	2ef	1bc	425±25bcd
	MGM	4	408±136b	18ab	19a	18ab	16a	8a	9ab	7bc	3bc	1e	0e	1f	0c	350±0d
	DGM	4	2283±1373ab	14abc	15abc	14abc	11ab	10a	8ab	5bcd	5abc	3cd	4abcd	7def	4bc	500±29abc
	SSM	4	382±157b	13abc	11bcd	13abc	10b	11a	11a	12a	5abc	4cd	2de	5ef	2bc	525±25abc
	MSM	4	2467±742b	9c	9cd	10bc	9b	9a	9ab	8b	7a	7a	5a	16abc	3bc	575±25a
	DSM	4	6634±339a	8c	9dc	8c	8b	7a	7b	6bc	6abc	5abcd	5abc	16abc	12a	575±25a

This weight variation probably reflects the net effect of a combination of soil depth (water-holding capacity), soil fertility, and annual growing conditions. Differences in height-weight distribution among the six sites were consistent with the differences that persist for the mean height for each site.

Seedstalk heights on shallow granitic (413±18 mm) and moderate granitic (387±18 mm) sites were shorter than on the other four sites. In general, there is a larger percentage of the total weight in the lower increments for the shallower sites and more even distribution throughout the length of the seedstalks on the deeper sites. Seedstalk lengths were similar for the two collection periods, and seedstalks weights were only slightly greater in the mature stage (2060±520 mg) than in the dough stage (1950±490 mg).

Seedstalk height-weight relationships between 40- and 300-mm showed that, before seed shatter, less of the total weight was in this region and more was above 300 mm. After seed shatter, the upper weight loss shifted a higher proportion of the remaining weight into the 40- to 300-mm region. This was consistent with previous discussions concerning differences between seedstalk height-weight distributions due to physiological variability and degree of seed shatter.

A significant site X phenological stage interaction occurred because seedstalk weights on the deep sedimentary site were greater on other sites in the mature stage but not in the dough stage.The major difference in seedstalk height for both stages was that seedstalks on the shallow and moderate granitic sites were consistently shorter than those on the other four sites. In contrast, seedstalk weights for plants on the shallow sedimentary sight were relatively low compared to their heights.

Much of the variation due to phenological stage in the 0- to 40-mm through the 0- to 300-mm increment can be explained by the difference that exists between the dough and mature stages for the moderate granitic site (this difference is inclusive from the 0- to 40-mm through the 0- to 200-mm increment), the disparity between the dough and mature stages for the shallow sedimentary site (from the 0- to 120-mm through the 0- to 200-mm increment) and the variation between the dough and mature stages for moderate sedimentary (inclusive between the 0- to 140-mm through the 0- to 300-mm increment.

These three sites showed the greatest variation between the dough and mature stages during 1986. With the exception of the shallow granitic site, which had very low seedstalk productivity and no difference between stages. The three sites showing the variability between stages were all at lower elevations where the curing process started earlier in the growing season. This may have been the factor that resulted in the disparity between the dough and mature stages.

Consistent differences occurred between the deeper, more fertile sites (deep granitic, moderate, and deep sedimentary) and the shallower, less fertile sites (shallow and moderate granitic and shallow sedimentary) within both stages, which were consistent with the main effect differences.

Height-Weight Models

The model for a normal growth curve (WTPC (%) = 1 - e^{-b1LL}), transformed as Y = (LOG(1 - WTPC)) / -10, accounted for 75 to 90 % of the variation in percentage of total leaf weight for 28 different sets of Idaho fescue leaf length-weight distribution data (Table 7). From 20 to 40 plants were used in each data set, but R^2 values were not increased by using more than 20 plants per data set.

Table 7. *Regression equation statistics for vegetative (V) plants and seeded plants in the dough (D) or mature (M) phenological stage (PHEN) on different sites in 1985 and 1986.*

SITE[1]	YEAR	PHEN	WT[2]	LL[3]	b_1	SE b_1	R^2
			(mg)	(mm)			
SG	1985	V	286	120	0.103	0.0027	0.83
MG			598	120	0.101	0.0035	0.83
DG			632	160	0.104	0.0035	0.82
SS			378	120	0.97	0.0027	0.82
MS			1505	160	0.094	0.0032	0.81
DS			1235	200	0.093	0.0029	0.83
SG	1986	V	219	100	0.096	0.0042	0.82
MG			526	100	0.096	0.0031	0.89
DG			295	160	0.101	0.0040	0.78
SS			277	120	0.097	0.0042	0.80
MS			1005	280	0.108	0.0042	0.75
DS			503	280	0.104	0.0039	0.77
MS	1985	D	2909	280	0.107	0.0038	0.78
DS			2247	200	0.100	0.0036	0.75
MS	1985	M	2331	280	0.109	0.0034	0.83
DS			3581	280	0.101	0.0033	0.81
SG	1986	D	572	120	0.100	0.0029	0.89
MG			1022	120	0.096	0.0033	0.86
DG			1164	160	0.096	0.0034	0.82
SS			1166	160	0.098	0.0039	0.78
MS			5202	280	0.100	0.0024	0.83
DS			2264	280	0.105	0.0029	0.85
SG	1986	M	619	140	0.097	0.0030	0.87
MG			794	120	0.091	0.0030	0.87
DG			1274	160	0.094	0.0033	0.82
SS			1622	160	0.095	0.0040	0.75
MS			4401	280	0.103	0.0024	0.89
DS			2957	280	0.105	0.0029	0.86

[1] SG - shallow granitic; MG - moderately deep granitic; DG - deep granitic; SS - shallow sedimentary; MS - moderately deep sedimentary; DS - deep sedimentary.
[2] Average total leaf weight per plant.
[3] Maximum leaf length yielding highest R^2 values.

The regression coefficients ranged from 0.09 to 0.11 when the accumulative percentage of total plant weight (mg) was regressed against the accumulative percentage of total leaf length (mm). The narrow range in regression coefficients and relatively small (3 to 4%) standard errors for regression coefficients indicate that the same regression equation can be used with confidence across a wide range of conditions to predict the percentage of weight removed or left as residue.

Although the average plant weights varied widely (220 to 5200 mg), as did average plant heights (100 to 280 mm), the height-weight relationships on a percentage of height and percentage of length remained the same. Taller plants were bigger in about the same proportion as shorter, lighter plants. It should be remembered that height-weight relationships for seeded plants were determined for leaf weights after the seedstalks were removed.

A graphic presentation of the tabular data in Table 7 does raise a question as to whether the mathematical model is the “best” model to be determined or whether R^2 values of 0.75 to 0.90 are adequate to predict with confidence significant differences in the percentage of accumulative weight at a particular leaf length.

Figure 29 shows the height-weight relationships for vegetative plants on all sites in 1985 and 1986. The relationships for a particular site do not differ between 1985 and 1986. The two sets of curves for the two years do, however, indicate rather large differences among curves for plants on different sites.

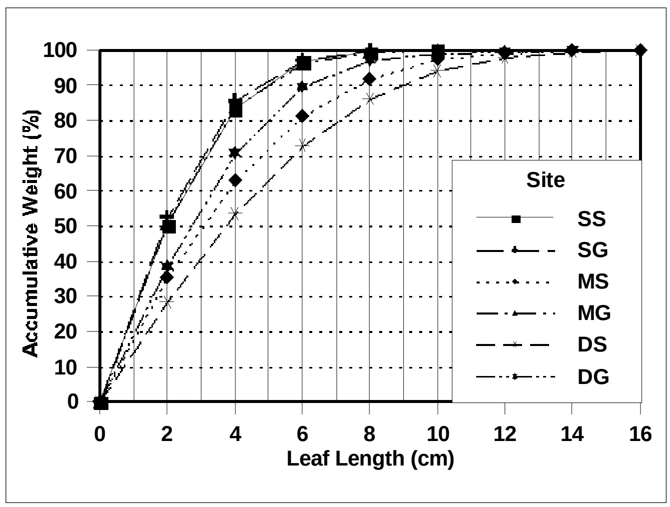

Figure 29. Height-weight curves for vegetative plants on all sites in 1985 and 1986.

Little difference in the curves for plants on the shallow and moderate granitic and the shallow sedimentary sites was detected, but the differences among the moderate and deep sedimentary and the deep granitic and between these three curves and those for plants on the shallow and moderate granitic and shallow sedimentary sites are very important from a management standpoint.

For example, using the curves for vegetative plants and a grazing stubble height of 4 cm, the predicted grazing residue levels are more than 80% on shallow and moderate granitic, and shallow sedimentary sites, but only 70% on the deep granitic site, 62% on the moderate sedimentary site, and about 55% on the deep sedimentary site. A comparison of the tabular data in Table 7 does not show the same pattern as in Figure 29.

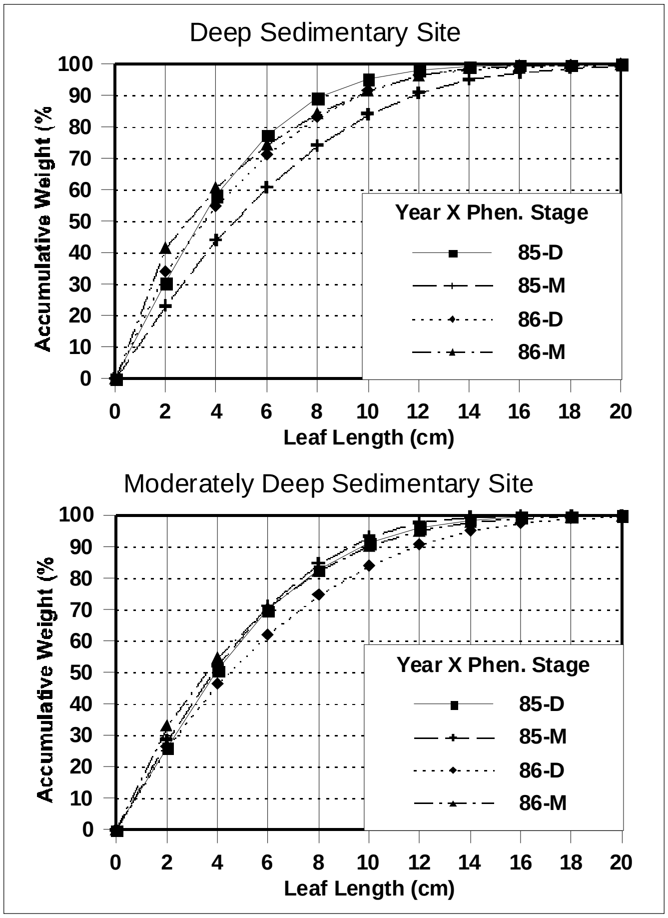

Figure 30. Height-weight curves for leaves of seeded plants on the moderately deep and deep sedimentary sites during the dough and mature phenological stages.

A comparison of the height-weight curves for seeded plants during the dough and mature phenological stages on the moderate and deep sedimentary sites indicates the height-weight relationships for plants on the same site tend to be similar under different conditions (Figure 30). In both sets of curves, the maximum deviation of one curve from another was about 10%.

In the case of the least productive sites, the curves for seeded plants on a particular site during two different phenological stages in 1986 were almost identical (Figure 31).

Summary And Conclusions

The study of Idaho fescue height-weight relationships during three collection periods (vegetative, dough, and mature) in 1985 and 1986 on granitic and sedimentary soils near Burgess Junction in the Big Horn Mountains of Wyoming revealed plant-soil relationships and concepts that should be beneficial to managing Idaho fescue plant communities.

A mosaic of granitic and sedimentary soils of variable depths that all have Idaho fescue as an important component of the plant community exists within the open grasslands of the study area. While a few Idaho fescue plants produced seedstalks during the growing season, others did not, especially in 1985. Because of only minor weather differences in 1985 and 1986, it appears that vegetative (i.e., non-seeded) plants did not produce seedstalks in 1985 because of plant stress due to drier conditions in 1984.

Although there was more total leaf production for all sites in the vegetative stage in 1985 than in 1986, larger, more mature plants did not produce seedstalks in 1985 but were sampled as vegetative plants. In 1986 more seedstalk production occurred on all sites, so many of the vegetative plants collected in 1986 were younger, smaller plants with less biomass.

In general, plants on the moderate and deep sedimentary sites have longer leaves and seedstalks and have more biomass than plants on the shallow, moderate, and deep granitic and shallow sedimentary sites. Shallow sedimentary and deep granitic plants

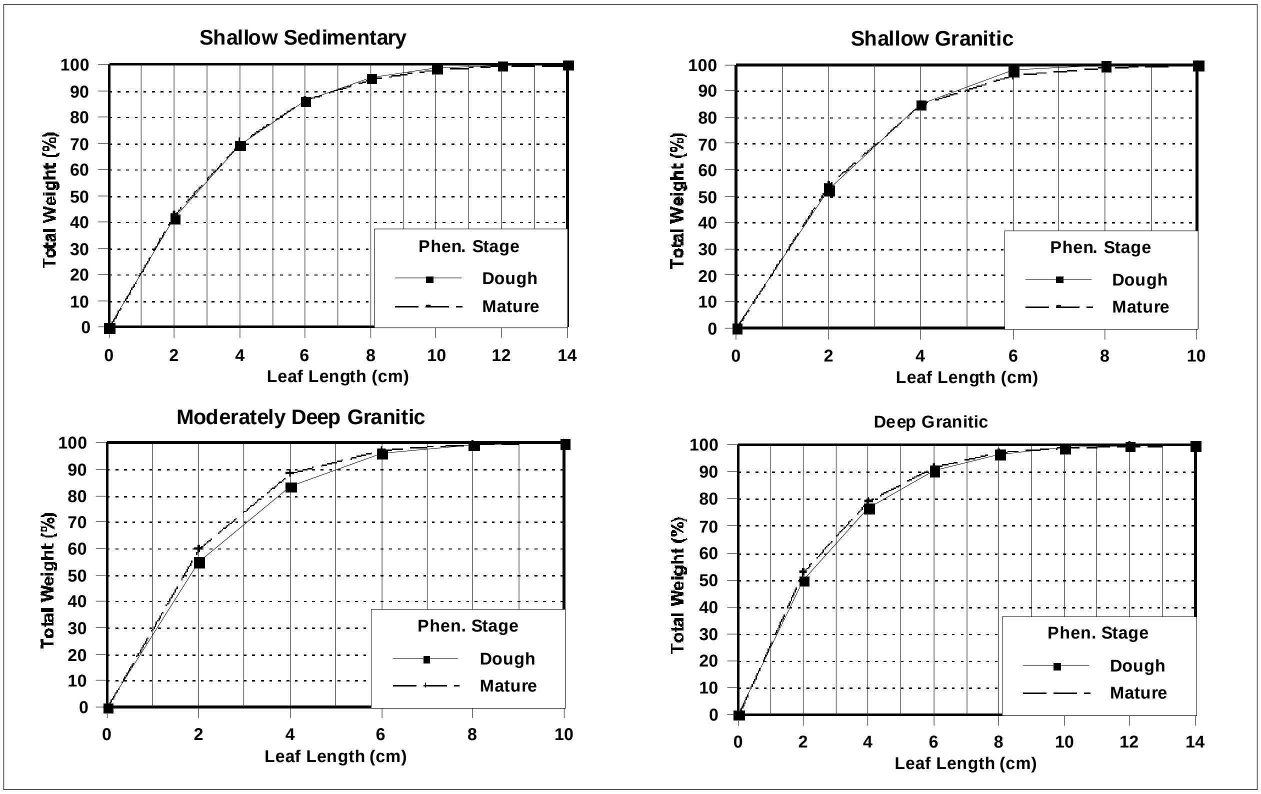

Figure 31. Height-weight curves for leaves of seeded plants on the 4 least productive sites during the dough and mature phenological stages.

tend to be intermediate with regard to weight, height, and height-weight distribution. Plants on shallow and moderate granitic sites were the lightest and shortest. In general, taller and larger plants, relative to height-weight distribution, tend to distribute weight more equally along the entire length of leaves and seedstalks.

The distribution of weight in the leafy plant material is concentrated near the base of the plant where at least 70% of the weight, regardless of site, is in the first 60 mm. Weight distribution is more equal on the moderate and deep sedimentary sites. The weight is distributed more evenly in the seedstalks, but in 1986 when all sites were sampled with seedstalks, almost 75% of the weight was in the first 160 mm from the base.

Although there was more total leaf production for all sites in the vegetative stage in 1985 than in 1986, this is a distorted fact because the difference was due to more weight on plants on the moderate and deep sedimentary sites in 1985 than in 1986. The other four sites had similar vegetative plant weights in both years.

Vegetative plants averaged considerably lighter than seeded plants in the dough stage over both years for the moderate and deep sedimentary sites. Vegetative plant heights were considerably less than those for seeded plants in the dough and mature stages on these two deeper sedimentary sites but appreciably greater than for plants on the other four sites regardless of kind of plant or phenological stage for seeded plants.

In 1986 when seedstalks were collected on all the sites, virtually no difference between collection period/stages for average seedstalk weights on shallow, moderate, and deep granitic, and shallow sedimentary sites, although there were differences in height between the vegetative and the dough stages for the deep granitic and the shallow sedimentary sites (the dough stage having taller plants).

Some interesting differences occurred between the dough and the mature phenological stages in 1985 and 1986 for the moderate and deep sedimentary plants due to elevational difference. Deep sedimentary site plants (at a higher elevation than the moderate sedimentary plants) increased weight from the dough to the mature stage, while the opposite was true for moderately deep sedimentary site plants. Although seedstalk growth had ceased, apparently leaves were still growing after the dough stage on the deep sedimentary site, while leaf and seedstalk growth had stopped on the moderate sedimentary site.

In 1986 leaf weights of plants on the moderately deep sedimentary site were much higher than those on the deep sedimentary site; however, plants on the deep sedimentary site were producing much more biomass the same year in seedstalk production than plants on the moderately deep sedimentary site. Apparently, the plants on the deeper sedimentary site were responding physiologically by producing more floral primordia relative to the moderate sedimentary site due to environmental and climatic differences that existed between the two sites. Total biomass (leaves and seedstalks) was greater in 1986 than 1985 due to a combination of climatic factors.

The moderate and deep sedimentary sites are much more productive than the other four sites as a result of soil nutrient levels, soil development, and the ability to hold moisture in the soil profile (availability to roots). Because the remaining sites do not have either the nutrient levels, depth, and/or moisture-holding capacity found on the two deeper sedimentary sites, they tend to be more consistent from year to year and between phenological stages in regard to leaf biomass. Vegetative plant leaf biomass did not differ between 1985 and 1986, and no difference between collection period or stages in 1986 for the shallow, moderate, and deep granitic, and shallow sedimentary sites was evident, but seedstalk production was variable from year to year. It would be best to develop accurate, dependable height-weight relationships on these sites for several years because of the variable climatic conditions that differ from season to season and from year to year as well as the stresses that occur through disease, competition, and grazing.

Regression analysis for the leaves on each site, stage, and year was completed using leaf length as the independent variable and percentage of total weight as the dependent variable. The natural growth curve model proved to fit the data satisfactorily with R^2 values ranging from 0.75 to 0.89. Regression coefficients ranged from 0.091 on the moderate granitic mature seeded plants in 1986 to 0.109 on the moderate sedimentary mature seeded plants in 1985.

Although average plant height and plant weight varied widely across site and collection stages, the height-weight relationships on a percentage of weight and percentage of length remained the same. Taller plants were larger in about the same proportion as were shorter, lighter plants. Care must be taken if managers are applying the curves to determine utilization levels on the different sites. If management plans call for certain grazing residue levels (stubble height) to remain on a given pasture, there can be a large difference between sites regarding the percentage of residue that remains for a given stubble height after grazing due to the height and weight differential that exists between Idaho fescue plants on different substrates and depths. Minimum grazing green leaf biomass residue for different range sites is, therefore, a more appropriate measurement of proper utilization than is stubble height.

This study should enable range resource professionals to improve the management of the plant communities in this area. The soil survey in use in this part of the Big Horns map areas are based on certain soil associations. These associations are made up of two or more soil series. Within these associations is the potential to include shallow, moderate, and deep sites that all have varying production and height-weight distributions. Within a series there can also be similar significant differences due to elevation (Echemoor—moderate and deep sedimentary sites). The moderate and deep sedimentary sites would generally be classified as the same range or ecological site. It may be best for the resource to further divide, where necessary, the range or ecological site guidelines on an elevational basis within and between designated pastures so timing of grazing and utilization levels can be better manipulated.

Recognition of site differences also can aid in placing physical practices, such as fences, in the best possible locations on the landscape. In contrast to the Echemoor series (moderate and deep sedimentary sites), the two sites within the Hazton series (shallow and moderate granitic sites) could be managed similarly, at least at similar elevations.

The height-weight relationships of other important montane range grasses, such as beardless wheatgrass, mountain brome, big bluegrass, and Canby bluegrass, would also be valuable information for the resource manager. More ecophysiological research to determine the effects of site and weather conditions on plant growth will be worthwhile.

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APPENDICES

Appendix A. Bighorn Soil Horizon Morphological Descriptions

Site[1]	Hor.	Thickness (cm)	Texture	Structure	Consistence		Boundary	Clay films	Salts/ $CaCO_3$	Course fragments	Roots
					Dry	Wet					
SGR	A1	1	sl	SAB	Friable	Firm	Gradual	No	No	Small rock	Abundant
SGR	B1	8	cl	SAB to crumbly	Friable	Coarse	Gradual	No	No	Stones 1-12"	Abundant
SGR	C							No	No		Rare
MGR	A1	1	1	Wk SAB			Clr/Smooth	No	No	No	Abundant
MGR	B1	19	1	Wk SAB to crumbly			Shp/Smooth	No	No	Small 1--1-1/4"	Abundant
MGR	C						Clr/Smooth	No	No	Small-Large	Rare
DGR	A11	1	sil	Fine SAB			Gradual	No	No	Rocky	Abundant
DGR	A12	37	sil	Fine SAB			Gradual	No	No	Rocky	Common
DGR	B1	18		Crumbly			Gradual			Rocky	Rare
DGR	B2	43		Crumbly-FSAB		Firm				Rocky	Rare
SSE	A1	3	sil	Weak, Fine SAB			Smooth/Grad.	No	No	Infreq.	Abundant
SSE	B1	25	1	Weak SAB			Smooth/Sharp	No	No	Abundant	Abundant
SSE	C									Rock	Infrequent
MSE	A11	3	1	Fine SAB	Friable	Loose	Smooth/Grad.	No	No	So	Abundant
MSE	A12	28	1	SAB			Smooth/Sharp	No	No	Small Rock	Abundant
MSE	B21t	48	cl	Crumbly			Smooth/Grad.	Weak	No	Small Rock	Abundant
MSE	B22t	18	c	Weakly Prismatic			Smooth/Grad.	Weak	No	Small Rock	Common
MSE	C								No	Rock	Rare
DSE	A11	1	1	SAB-Crumbly	Friable	Firm	Irreg./Wavy	No	No	Very Few	Abundant
DSE	A12	27	cl	SAB-Crumbly	Friable		Irreg./Wavy	No	No	Very Few	Abundant
DSE	B21t	10	c	Blocky	Hard		Smooth/Irreg.	Yes	No	Few	Common
DSE	B22t	49	c	Blocky	Hard		Smooth/Sharp	Yes	No	Small-1/2"	Infrequent
DSE	C1	28		Granular	Loose		Sharp	No	No	Rock	No
DSE	C2			Granular	Loose			No	No	Loose Rock	No

[1] SGR- Shallow Granitic, MGR - Moderately Deep Granitic, DGR - Deep Granitic, SSE - Shallow Sedimentary, MSE - Moderately Deep Sedimentary, DSE - Deep Sedimentary

Appendix B. Soil Horizon Laboratory Analyses

Site[1]	Hor	Thck.	pH	OM	P	N	Na	K	Mg	Ca	WTRO3	WTR15	Sand	Silt	Clay
SGR	A1	1	5.9	8.9	11	6	0.40	2.02	1.94	9.81	18.5	13.8	70	18	12
SGR	B1	8	5.4	5.5	4	5	0.12	0.24	1.58	7.02	17.7	8.5			
MGR	A1	1	5.2	14.6	17	29	0.22	1.64	2.53	12.20	27.0	23.8	48	36	17
MGR	B1	19	5.2	6.3	8	2	0.22	0.49	1.45	6.07	17.9	10.3	49	35	17
DGR	A11	1	5.4	17.7	42	17	0.11	4.07	3.68	19.56	37.1	31.0	26	52	22
DGR	A12	37	5	6.2	17	0	0.20	1.26	1.49	5.50	27.1	13.1	24	53	22
DGR	B1	18	4.8	1.3	17	0	0.15	1.04	1.04	2.33	21.0	9.5			
DGR	B2	43	4.7	0.6	10	0	0.08	1.41	1.41	5.38	18.1	9.3			
SSE	A1	3	6.6	21.6	24	11	0.29	3.05	4.42	33.81	49.6	45.1	29	61	11
SSE	B1	25	6.9	8.6	8	4	0.20	1.39	4.87	14.17	35.5	29.3	32	40	28
SSE	C	13											34	35	30
MSE	A11	3	6.2	25.6	32	24	0.14	6.63	7.46	39.17	63.4	48.7	40	40	20
MSE	A12	28	5.9	8.3	12	7	0.12	6.00	3.22	17.80	27.4	16.6	42	28	30
MSE	B21t	48	5.5	1.1	15	0	0.10	0.24	3.18	15.85	19.1	10.2	47	31	22
MSE	B22t	18											50	27	23
DSE	A11	1	5.1	18.3	66	115	0.09	4.71	3.40	30.10	44.0	37.8	28	45	28
DSE	A12	27	5.4	7.0	17	17	0.23	1.13	1.87	20.14	27.4	28.4	21	45	34
DSE	B21t	10	5.2	1.2	21	2	0.05	0.75	1.95	23.68	25.3	15.4	22	39	39
DSE	B22t	41	5.3	0.9	33	0	0.06	1.00	1.86	23.80	27.5	18.1	19	32	50
DSE	C1	8	5.8	0.5	16	0	0.11	0.49	0.88	14.40	18.0	12.2			
DSE	C2	28	6.2	0.3	16	0	0.07	0.49	0.71	14.70	14.4	9.8			

[1] SGR- Shallow Granitic, MGR - Moderately Deep Granitic, DGR - Deep Granitic, SSE - Shallow Sedimentary, MSE - Moderately Deep Sedimentary, DSE - Deep Sedimentary