



Effect of precipitation on mixed grass plant communities of southeastern Montana and its implications for grazing intensity
by Kenneth Clark Olson

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Range Science
Montana State University
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Abstract:

Data were compiled for a grazing study over a 24 year period between 1932 and 1956 at the Livestock and Range Research Station, Miles City, Montana. Previous research based on these data suggests that climate is the major controlling factor of range condition and production.

The objectives of this study were: (1) to investigate the correlation between plant community composition and precipitation, (2) to examine the effect of grazing intensity on the correlation between plant community composition and amount of precipitation, and (3) to examine management alternatives that maximize desirable plant communities for livestock production under variable climatic conditions.

Basal cover data were collected annually from permanent meter square chart quadrats by using the pantograph method. Data analysis employed multiple regression techniques with basal cover as the dependent variable and precipitation parameters as independent variables. A series of predictive equations were obtained to evaluate relationships among factors such as annual precipitation, preceding annual precipitation, cumulative precipitation, and growing season precipitation. A total of 142 species were recorded from 1932 to 1956. Of these, predictive equations were developed with a coefficient of determination (r^2) of 0.70 or greater for twelve species. These included western yarrow, western wheatgrass, fringed sagewort, red threeawn, blue grama, buffalograss, threadleaf sedge, needleleaf sedge, tumblegrass, scarlet globemallow, needle-and-thread, and green needlegrass.

Predictive equations were developed for three grazing intensities, for exclosures, and for all quadrats combined. Cover was predicted for several precipitation regimes using each predictive equation. These predicted cover values were then used to develop three dimensional graphs, which were used to examine the precipitation regime that determines cover for a particular species. The response of each species to precipitation is discussed. Each species responds to a different precipitation regime, indicating that fluctuations in the precipitation regime will cause fluctuations in species composition of the plant community. By comparing graphs for the same species under different grazing intensities, the effect of grazing upon plant cover is also discussed. Moderate grazing (.92 ha or 2.3 acres/AUM) was recommended as the optimum for maintaining a composition most conducive to livestock production.

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EFFECT OF PRECIPITATION ON MIXED GRASS PLANT COMMUNITIES
OF SOUTHEASTERN MONTANA AND ITS IMPLICATIONS FOR
GRAZING INTENSITY

by

KENNETH CLARK OLSON

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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in

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ABSTRACT

Data were compiled for a grazing study over a 24 year period between 1932 and 1956 at the Livestock and Range Research Station, Miles City, Montana. Previous research based on these data suggests that climate is the major controlling factor of range condition and production.

The objectives of this study were: (1) to investigate the correlation between plant community composition and precipitation, (2) to examine the effect of grazing intensity on the correlation between plant community composition and amount of precipitation, and (3) to examine management alternatives that maximize desirable plant communities for livestock production under variable climatic conditions.

Basal cover data were collected annually from permanent meter square chart quadrats by using the pantograph method. Data analysis employed multiple regression techniques with basal cover as the dependent variable and precipitation parameters as independent variables. A series of predictive equations were obtained to evaluate relationships among factors such as annual precipitation, preceding annual precipitation, cumulative precipitation, and growing season precipitation. A total of 142 species were recorded from 1932 to 1956. Of these, predictive equations were developed with a coefficient of determination (r^2) of 0.70 or greater for twelve species. These included western yarrow, western wheatgrass, fringed sagewort, red threeawn, blue grama, buffalograss, threadleaf sedge, needleleaf sedge, tumblegrass, scarlet globemallow, needle-and-thread, and green needlegrass.

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INTRODUCTION

Climate appears to be the major controlling factor of plant growth in the Great Plains. Reed and Peterson (1961) and Hurtt (1951) stated that major trends in vegetation characteristics are determined by fluctuations in climatic conditions, and that changes within these major trends are influenced by grazing intensity.

At the present time, there are generalized ideas of the influence of precipitation and grazing intensity on rangeland plant communities, but little effort has been made to quantitatively describe changes in these plant communities as influenced by fluctuating precipitation regimes. Researchers have developed models to predict or estimate forage production, but literature has not been found which attempts to predict plant cover under fluctuating precipitation regimes. Predictions of forage production are very useful for determining stocking rates. However, by determining changes in basal cover of the plant species present, a more concise understanding of the changing ecological roles of the species can be achieved, and hence a better understanding of community dynamics of the range ecosystem can be realized.

The purpose of this thesis is to quantitatively describe changes in basal cover of vegetation in response to variation in precipitation and grazing intensity.

The specific objectives of this study were:

1. To investigate the relationship between plant community composition and amount of precipitation.
2. To examine the effect of grazing intensity on the relationship between plant community composition and amount of precipitation.
3. To examine management alternatives that maximize desirable plant communities for livestock production under variable climatic conditions.

LITERATURE REVIEW

Factors Controlling Vegetation Growth

Climate appears to be the major factor controlling plant growth in the Great Plains. Reed and Peterson (1961), Hurtt (1951), and Clark, Tisdale and Skoglund (1943) stated that major trends in vegetation characteristics are determined by major changes in climatic conditions and that changes within these major trends are influenced by grazing intensity. Whitman, Hanson and Peterson (1943) stated that drought is the primary influence of vegetational change. Forage production may decrease due to abnormal climatic conditions and increased grazing intensity (Albertson, Riegel and Launchbaugh 1953). Climatic conditions greatly affect the quantity, quality, and availability of forage (Clark et al. 1943).

Soil moisture content has also been considered the major factor controlling plant growth, whether it be biomass production or tillering, which increases basal area (Clark et al. 1943; Schumacher 1974; Coupland 1958). However, fluctuation in soil moisture is due to variation in precipitation (Schumacher 1974). Therefore, precipitation, which is an element of climate, appears to be a major controlling factor of plant growth. There is a direct relationship between the amount of precipitation and forage production (Albertson, Tomanek and Riegel 1957).

Other climatic factors have been reported in the literature as

limiting vegetational growth. These include high temperature, low humidity, high winds, and burial by dust, along with low soil moisture (Weaver and Albertson 1936). Clark et al. (1943) stated that temperature is a controlling factor in the early spring, insofar as determining when plant growth begins. This is also a period when soil moisture is usually plentiful. It appears that other climatic factors also affect availability of moisture and the plant's ability to use it, so available moisture remains the major controlling factor.

Several authors have discussed soil related factors that control plant growth. Young (1956) stated that plant death loss due to drought can be related to soil type and land management. Ballard and Ryerson (1973) stated that forage production varies more due to range site and condition than precipitation. They reported that, in northern Montana, only four of ten grass species showed a significant relationship between forage production and precipitation using regression and correlation techniques. When considering sandy soils, Herbel, Ares and Wright (1972) reported a direct relationship between drought damage and depth of soil. They stated that a shallow soil is better because it holds moisture closer to plant roots, where it is more readily available. Cook and Sims (1975) stated that soil type and past grazing use determine changes in species composition, with dry years emphasizing these changes. In contrast, Abel, Rosenfield

and Stephens (1962) refute this, stating that precipitation has the major influence on plant growth, with other climatic factors, soil type, topography, ecological factors, and management practices, such as stocking rate or breeding programs, having less influence. Weaver, Stoddart and Noll (1935) reported similar findings, stating that* drought effects are mostly due to reduced soil moisture, with little effect from low humidity or high temperature.

Only two researchers, Johnson (1981) and Craddock and Forsling* (1938) stated that grazing effects have a greater influence on the range ecosystem than does climate. Craddock and Forsling (1938) discussed use of spring-fall sheep range in southern Idaho, which may not be comparable to summer cattle use in southeastern Montana.

Effects of drought can also be increased by other factors which occur as a result of the drought conditions. These factors usually intensify adverse effects of drought. Grasshoppers are influential in the deterioration of rangeland during drought (Cook and Sims 1975; Reed and Peterson 1961). Whitman et al. (1943) reported that grasshoppers increased during drought, which greatly increased their use of grasses. Litter cover is also lost from the soil surface* during drought by unknown means (B.W. Sindelar, personal communication). Therefore, the insulating and reflective qualities of the litter cover are lost, allowing increased evaporation of soil moisture and heating of the soil profile. Organic matter content of

the soil profile is also decreased because less litter is available to be incorporated into the soil.

Precipitation Regime of the Northern Great Plains

Climate of the Great Plains ranges from sub-humid to semi-arid (Coupland 1958). At Miles City, Montana, where this study is located, the climate is semi-arid. Hurtt (1951) reported that average annual precipitation is approximately 325 mm (13 inches), of which 70% typically falls between April first and September 30th. Throughout the Great Plains, precipitation on a monthly or an annual basis varies widely from the long term mean (Clark et al. 1943; Cook and Sims 1975; Craddock and Forsling 1938). Extended periods of drought are common (Cook and Sims 1975). By the same token, extended periods of above average precipitation can also occur. Smoliak et al. (1976) stated * that wet or dry years tend to occur in sequence. Thus, drought periods and periods of normal or high precipitation alternate regularly over time to develop weather cycles (Cook and Sims 1975). Vegetation of the short and mixed grass prairie has evolved to react in a relative equilibrium which changes continuously in relation to climatic fluctuations (Clark et al. 1943; Newbauer et al. 1980). Thus, different plants will react differently during wet or dry cycles (Cook and Sims 1975).

Precipitation fluctuations below normal are termed drought (Reynolds 1954). Various definitions have been given for drought.

The USDA Weather Bureau defined drought as a period when precipitation is 30% of the average for 21 days or longer (Ryerson unpublished; Cook and Sims 1975). Another definition is: a period when annual precipitation is 70% of normal or monthly precipitation is 60% of normal (Cook and Sims 1975). The Society for Range Management uses the definition: "prolonged dry weather, generally when precipitation is less than 75% of the average annual" (Bedell and Ganskopp 1980). Hurtt (1951), reporting on drought in southeast Montana, defined it as being when total precipitation is less than 70% of the 229.5 mm (9.18 inch) spring-summer average for the area. This would be less than 160 mm (6.4 inches) of precipitation. He also stated that a serious moisture deficiency in the first four months of the growing season will result in greatly retarded plant growth.

One of the greatest problems with drought is that its occurrence cannot be reliably predicted (Ryerson unpublished; Cook and Sims 1975; Schumacher 1974). The probability of drought can be estimated (Schumacher 1974). The probability of drought in southeast Montana is one year out of every five (Hurtt 1951) and in southern Alberta it is one year out of every four (Johnson 1981). However, the sequence cannot be predicted (Hurtt 1951). Because of this, it has been difficult to manage rangeland for fluctuating climatic conditions (Cook and Sims 1975).

Drought has a deleterious effect on the economy of the ranching

industry. Livestock gains are greatly reduced during drought (Reed and Peterson 1961), resulting in lower total production. This has the effect of lowering income. At the same time, in many cases, livestock have to be removed from the range. They may be sold, moved to a region that has not been affected by drought conditions, or fed hay or other supplements. All of these alternatives are costly and incur large economic losses for ranchers. Because of this, drought has received considerable attention, with many reports written on its effects (Newbauer et al. 1980; Coupland 1958). Most of these studies were initiated to investigate the effects of grazing on range, but the effects of climate were superimposed on them (Coupland 1958). In contrast, relatively few reports are available on the effects of above average precipitation on range (Newbauer et al. 1980; Coupland 1958). Recent interest has been shown in above average precipitation to determine the effects of weather modification on the Great Plains range ecosystem (Newbauer et al. 1980). Also, above average precipitation needs to be better understood to make full use of the increased growth that usually occurs with increased precipitation, without lowering range condition.

A comprehensive understanding of the responses of the range ecosystem to weather and grazing is desirable to improve management (Reed and Peterson 1961). As of now, drought cannot be controlled, but its impact can be lessened by proper livestock management. To do

this, actual changes in plant communities need to be known so that the effects of drought on the range can be better understood.

Vegetation Response to Climate

Abrupt and fundamental changes in the amount and kind of living plant crown area may result from severe drought and last longer than ordinarily supposed (Reed and Peterson 1961). The frequency and duration of drought are both important in determining the severity of the effect of climate on vegetation (Ryerson unpublished; Cook and Sims 1975; Herbel et al. 1972). There is a close relationship between* the time and amount of precipitation and plant growth (Albertson et al. 1953). One wet or dry year will affect production, but two or more wet or dry years are required to change the basal cover (Ryerson unpublished; Smoliak et al. 1976). The magnitude of change will depend upon grazing pressure, fire, small herbivores, and insects (Ryerson unpublished).

Effects of drought years can be carried over into non-drought* years, especially in severe droughts. Sarvis (1941) reported that in the drought of the 1930's, 1934 and 1936 were the only true drought years. However, drought effects were recorded throughout the entire period of the 1930's. Also, recovery does not occur immediately after a drought breaks. Coupland (1958) and Cook and Sims (1975) reported two major reasons for this: first, it takes time to produce seed crops and have ideal conditions for seed to germinate and establish; and

second, after plants have been dormant for a long time, it may take* two years to break dormancy, due to low vigor. Albertson et al. (1957) reported that in 1940, a normal precipitation year which followed a prolonged drought, deterioration continued throughout the summer. In northern Montana, during a drought in the early 1960's, basal cover continued to decrease in 1962, even though it was a year of normal precipitation (Ryerson unpublished). Ellison and Woolfolk* (1937) reported that the effect of drought on plant vigor extends into the year following drought.

Native vegetation has developed under conditions of wide climatic variation (Albertson et al. 1957). Marked changes in botanical composition occur, but the plant populations are not destroyed (Cook and Sims 1975). These changes are slow, whether for better or worse (Sarvis 1941). Native grass species will remain dominant in prairies unless they are severely overgrazed or buried by dust (Cook and Sims 1975; Schumacher 1974; Albertson et al. 1957). Reed and Peterson (1961) reported that in southeast Montana, perennial grasses continued to make up most of the plant cover throughout all climatic conditions or grazing intensities. Cover did not deteriorate to weeds or unpalatable grasses. There was no elimination of any component or total destruction of range cover during drought in northern Montana (Ryerson unpublished). Ryerson further stated that composition was comprised of species that can tolerate drought conditions. This

indicated high tolerance of such range to adverse conditions. Mixed grass prairie in western North Dakota is highly stable during fluctuating moisture conditions (Whitman et al. 1943). Studies from various areas of the western rangeland indicate that forage production, basal area cover, and species composition may be changed drastically by major weather fluctuations, but usually the dominant species are not completely lost from the stand (Cook and Sims 1975). A few species are temporarily completely killed, but they recover after drought from seed or vegetative spread. Only two reports contradict these statements. Hurtt (1951) stated that a small decline in annual precipitation may result in reduced growth or even in total failure of all but the most drought resistant species. Albertson and Weaver (1946) reported that drought and dust, unaided by grazing, had reduced an area of mixed grass prairie to a disclimax of short grasses. However, it appears that these authors considered only the immediate effects during the very severe drought of the 1930's, and did not consider post drought recovery.

Drought effects range from reduction in vigor, or size, including height growth, basal diameter, and root length, to actual death of the plant (Ryerson unpublished; Cook and Sims 1975). Thus, drought causes a reduction in basal cover by mortality of parts or all of individual plants (Pieper and Donart 1975; Cook and Sims 1975).

Different species have different drought tolerances and therefore

significantly different mortality rates (Chamrad and Box 1965). Strategies used to increase drought tolerance include deep rooting, spread by stolons and rhizomes, making maximum use of light showers, greater lateral distribution of roots, or reduced palatability, which will reduce grazing stress during drought stress (Chamrad and Box 1965; Weaver and Albertson 1939; Weaver et al. 1935). Because of inherent differences in drought tolerances, species react and change in different amounts during and following drought (Cook and Sims 1975).

There are several general responses that vegetation undergoes during drought. The earliest response of vegetation is a reduction in forage yield (Weaver and Albertson 1944). Young and shallow rooted plants die first (Coupland 1958). Decrease in cover is more rapid in early years (Albertson and Weaver 1942). If drought persists for an extended period, cover may actually increase slightly due to spread into bare areas by more drought resistant species. During drought, losses of cover seem to be greatest on more densely covered areas (Coupland 1958). However, dominant species that decrease most rapidly during drought appear to increase most rapidly following drought (Cook and Sims 1975).

Vegetation response during drought recovery proceeded through definite seres of secondary succession (Coupland 1958). The initial sere depended upon the amount of deterioration that had occurred. The

order of the seres was: annual forbs, annual grasses with perennial forbs, early perennial grasses, and late perennial grasses. Rate of recovery depended on several factors:

1. predrought cover
2. degree of depletion of vegetation during drought
3. plant species remaining
4. dust burial damage
5. grazing intensity before, during, and after drought
6. trampling after drought
7. amount and distribution of precipitation after drought

(Coupland 1958; Ryerson unpublished).

Drought generally causes a decline in basal cover, with species composition shifting toward short grasses (Newbauer et al. 1980). Reed and Peterson (1961) reported on the effects of the 1930's drought in southeast Montana. In 1933, prior to the drought, basal cover of all grasses was 28%, but by 1937, it was reduced to 2%. Most major grass species cover declined, but one, Sandberg bluegrass (Poa sandbergii¹), which increased during the drought period. Recovery to the original amount of basal cover of grasses was completed by 1944. Houston and Woodward (1966) reported on a different phase of the same study between 1945 and 1956. During this period, total basal cover declined. Precipitation was below average for most of this period.

¹Nomenclature taken from USDA Soil Conservation Service (1982)

This decline included most species, with the only species increasing cover being Sandberg bluegrass, threadleaf sedge (Carex filifolia), and big sagebrush (Artemisia tridentata). Ryerson (unpublished) reported on a drought occurring from 1960 to 1962 in northern Montana. Total basal cover was reduced from 14.5% in 1960 to 6.7% in 1962, with grass and sedge basal cover reduced from 11.4 to 6.2%. Whitman et al. (1943) reported on the effects of drought in western North Dakota. The effects in North Dakota were not as severe as in Montana. Basal cover decreased from 30% in 1933 to 13% in 1936. Recovery was relatively rapid, with many species attaining greater basal cover than previous to drought. In eastern Wyoming, basal cover decreases of 50% or more can be expected when wet years are followed by dry years (Lange 1945). In southern Alberta, basal cover declined throughout the drought of the 1930's, with a similar amount of decrease in basal cover occurring whether the vegetation was grazed or protected (Clark et al. 1943). Several reports have been written about the effects of drought in the Central Great Plains, mostly in Nebraska and Kansas. By 1936, at the height of the drought, perennial grass basal cover had declined by 20% (Weaver, Robertson and Fowler 1940). By 1939, perennial grass cover had increased to twice what it had been in 1936. Annual grasses increased basal cover profusely (564% increase) immediately after 1936, but had decreased by 96% of this increase by 1939. Weaver and Robertson (1940) reported that basal cover was

reduced by two thirds to one half of the original basal cover during drought. Weaver and Albertson (1939) also reported that the major dominant grasses suffered the most loss in basal cover and were also slow to recover. Meanwhile, other perennial grasses that weren't dominant prior to the drought, but had xeric qualities, increased and became dominant during the drought. The fact that these species had increased was evident by the age class structure being characterized by young, newly established plants. Annual grasses increased rapidly during drought, but were replaced rapidly following drought. In mixed grass prairie of the Central Great Plains, midgrasses were lost and the shortgrass blue grama (Bouteloua gracilis) dominated (Coupland 1958). Craddock and Forsling (1938) reported that total basal area decreased 19% from 1923 to 1932 due to drought in southern Idaho. Pechanec, Pickford and Stewart (1937) stated that basal cover of grasses decreased by 60% at the same site during drought.

Coupland (1958) reported that during long periods of above average moisture, which occurred during the 1940's and 1950's in Alberta and Saskatchewan, succession moved toward more mesic communities. This included increased total basal cover and a compositional shift toward midgrasses with proportionately less short grass cover. In southern Canada, total basal cover increased 23% during the previously mentioned period (Coupland 1958). In southeastern Montana, total basal cover increased 61% and composition

shifted toward more midgrasses during a 13 year period of above average precipitation (Newbauer et al. 1980).

Response of Individual Species to Climate

Compositional changes due to fluctuating precipitation varied due to location in the Great Plains and type of grass cover (Coupland 1958). Western wheatgrass (Agropyron smithii) basal cover decreased drastically during extended severe drought in southeastern Montana, losing 87.9% of its cover from 1933 to 1937 (Hurt 1951; Reed and Peterson 1961). In contrast, western wheatgrass increased to be the dominant species during the same period in North Dakota (Coupland 1958), Nebraska, and Kansas (Weaver and Albertson 1940; Weaver and Albertson 1939; Weaver and Albertson 1936). Recovery of western wheatgrass to the pre-drought level of basal cover was slow in southeast Montana (Reed and Peterson 1961). They reported that complete recovery from the 1930's drought had not yet been reached by 1945. Recovery of western wheatgrass was also slow in western North Dakota (Whitman et al. 1943), but it made rapid increases in basal cover following drought in central North Dakota (Sarvis 1941).

Most wheatgrasses (Agropyron spp.) generally increased basal cover during periods of above average precipitation throughout the Great Plains (Coupland 1958). Newbauer et al. (1980) reported similar results during a period of above average precipitation in southeast Montana.

Blue grama basal cover decreased more rapidly during drought in southeast Montana than did midgrasses (Coupland 1958). Blue grama is a warm season species, while most midgrasses are cool season species. Consequently, midgrasses probably had the advantage of using available moisture before blue grama initiated growth. Ellison and Woolfolk (1937) and Reed and Peterson (1961) reported high death losses of blue grama in southeast Montana as a result of drought. Hurtt (1951) reported that blue grama actually lost 95.5% of its basal cover between 1933 and 1937. In northern Montana, basal cover of blue grama decreased from 6.2 to 4.1% over a two year drought period (Ryerson unpublished). In central North Dakota, on range dominated by blue grama, basal cover of blue grama decreased little during drought and recovered quickly (Sarvis 1941). This response was attributed to an ability to respond to light rain showers, making it possible to use any available moisture. In the eastern part of the Central Great Plains, blue grama colonized bare areas that were previously occupied by taller species (Weaver and Albertson 1939; Albertson and Tomanek 1965). Further west in Kansas, where the effects of drought were more severe; even blue grama basal cover decreased (Weaver and Albertson 1940). Blue grama was slow to recover to pre-drought cover levels where it had suffered large losses (Reed and Peterson 1961; Whitman et al. 1943). Pre-drought basal cover of blue grama had not been reached by 1945 in southeast Montana (Reed and Peterson 1961). Newbauer et

al. (1980) stated that blue grama appeared to be one of the most drought tolerant species when considering the entire Northern Great Plains.

Under above average precipitation, blue grama basal cover tended to decrease in southeast Montana and southern Canada (Newbauer et al. 1980; Coupland 1958). However, this response varied, depending on the range site being considered.

In southeast Montana, buffalograss (Buchloe dactyloides) lost as much basal cover during drought as blue grama. It was reduced by 95.9% of its cover from 1933 to 1937 (Hurt 1951; Reed and Peterson 1961; Ellison and Woolfolk 1937). After the drought, buffalograss increased basal cover rapidly. It reached pre-drought amounts of cover by 1942, and achieved 50% greater cover than pre-drought amounts by 1945 (Reed and Peterson 1961). Studies in the Central Great Plains reported various responses of buffalograss to drought. Some studies reported that buffalograss decreased during drought (Coupland 1958; Weaver and Albertson 1940; Albertson and Tomanek 1965). These reports stated that buffalograss generally decreased more than blue grama. These authors also stated that buffalograss increased rapidly following drought. In contrast, Weaver and Albertson (1939) reported that buffalograss increased during drought.

Newbauer et al. (1980) classified threadleaf sedge as one of the most drought tolerant species throughout the Northern Great Plains.

In southeast Montana, threadleaf sedge basal cover decreased only half as much during drought as blue grama, buffalograss, or needle-and-thread (Stipa comata). It lost 54.7% of its cover from 1933 to 1937 (Reed and Peterson 1961; Hurtt 1951). It had recovered to pre-drought levels by 1942 (Reed and Peterson 1961). Threadleaf sedge tended to react to above average precipitation similar to blue grama, with an increase or decrease in basal cover depending on the range site (Newbauer et al. 1980).

Prairie junegrass (Koeleria pyramidata) basal cover decreased during drought in North Dakota (Sarvis 1941). Prairie junegrass appears to be one of the species on the Northern Great Plains which is least drought tolerant (Newbauer et al. 1980). Prairie junegrass increased its basal cover during above average precipitation in southeast Montana (Newbauer et al. 1980).

Sandberg bluegrass was the only perennial grass species that increased basal cover during drought in southeast Montana (Reed and Peterson 1961; Hurtt 1951; Ellison and Woolfolk 1937). Sandberg bluegrass is a minor species during years of normal precipitation (Lommasson 1939). These authors disagree on the actual amount of increase in basal cover. Hurtt (1951) reported that Sandberg bluegrass basal cover increased 75% from 1933 to 1937, while Reed and Peterson (1961) reported an increase in basal cover of 4.5 times. These increases were especially pronounced on heavily grazed sites and

during extended drought (Lommasson 1939). It increased until it was the dominant species during drought (Hurtt 1951). Several factors were suggested by Lommasson (1939) which allowed Sandberg bluegrass to increase during drought. There is a decrease in competition from other perennial grasses as they die. Also, Sandberg bluegrass develops early in the spring and matures seed before the hot, dry summer intensifies drought. It uses winter moisture before the soil dries up. It completes growth in only 100 to 120 days, so seed is usually mature in June. The plant is then dormant through the summer. Meanwhile, other perennial grasses try to mature seed during the driest season. During recovery, Sandberg bluegrass was reduced to its pre-drought level by 1943 in southeast Montana (Reed and Peterson 1961).

Needle-and-thread basal cover decreased during drought in southeast Montana (Coupland 1958; Reed and Peterson 1961; Hurtt 1951; Ellison and Woolfolk 1937). Basal cover decreased 97.7% from 1933 to 1937 (Hurtt 1951). It had regained its pre-drought basal cover by 1942 (Reed and Peterson 1961). It is among the species that recover from drought most rapidly, through establishment of new seedlings (Ellison and Woolfolk 1937). During a two year drought in northern Montana, basal cover of needle-and-thread was reduced from 2.9 to 0.8% (Ryerson unpublished). Basal cover of needle-and-thread was reduced due to drought in North Dakota also (Sarvis 1941). Newbauer et al.

(1980) classified needle-and-thread as one of the least drought tolerant species in the Northern Great Plains. However, Hurtt (1951) stated that it seemed to be the grass species most able to recover from drought.

Needle-and-thread responded to above average precipitation in southeast Montana by increasing basal cover (Newbauer et al. 1980). However, during a period of above average precipitation in southern Canada, needle-and-thread basal cover decreased (Coupland 1958).

Little bluestem (Schizachyrium scoparium) basal cover decreased during drought in North Dakota (Sarvis 1941) and in the Central Great Plains (Weaver and Albertson 1940; Weaver and Albertson 1939; Albertson and Tomanek 1965; Weaver and Albertson 1936).

Forbs are affected by precipitation fluctuation in a similar manner to grasses. Some are more drought resistant than others. Some species vanish or decrease rapidly, while others may actually increase, at least during the beginning of a drought (Weaver and Albertson 1939). Different species use different strategies to survive drought, such as dormancy or reduced stature (Coupland 1958). Species with fleshy roots or storage organs are often able to persist through drought the best (Weaver and Albertson 1939).

During the drought period from 1933 to 1937 in southeast Montana, total basal cover of forbs decreased by 82.8% (Hurtt 1951). During a two year drought in northern Montana, basal cover of forbs was reduced

from 3.1 to 0.4% (Ryerson unpublished). In the Central Great Plains, forbs generally suffered losses due to drought, with up to a 50% loss in basal cover (Weaver and Albertson 1939). Weaver et al. (1940) reported that perennial forb basal cover decreased by 28%, while Weaver and Albertson (1936) reported a complete disappearance of all native forbs. It appears that forb response to climate is site dependent. In southern Idaho, basal cover of perennial forbs decreased 40%, and annual forbs completely disappeared during drought (Pechanec et al. 1937). The loss of forbs on this site occurred more rapidly than the loss of grasses.

Recovery of forbs also varied following drought. Annual forbs increased immediately following drought, but perennial forbs recovered more slowly (Whitman et al. 1943). The cover of perennial forbs was 128% greater following drought than previous to drought in southern Idaho (Pechanec et al. 1937). Annual forbs appeared immediately after drought and comprised a majority of the cover, but they decreased rapidly as perennials reestablished (Weaver and Albertson 1939; Pechanec et al. 1937; Sarvis 1941).

Annual pepperweed (Lepidium densiflorum) was often the dominant annual forb invading the Great Plains region during and immediately following drought (Sarvis 1941; Weaver and Albertson 1939).

Scarlet globemallow (Sphaeralcea coccinea) basal cover increased during drought (Coupland 1958). After drought, scarlet globemallow

cover decreased to pre-drought levels.

Forb and shrub basal cover response to above average precipitation varied depending on the site being considered (Newbauer et al. 1980).

Plains pricklypear (Opuntia polyacantha) basal cover increased during and immediately following drought (Reed and Peterson 1961; Ellison and Woolfolk 1937; Hurtt 1951). The actual increase in cover in southeast Montana was 108.3% during the period of 1933 to 1937. This made it one of the major constituents of the plant community during drought (Hurtt 1951). It appeared to be favored by hotter and drier weather (Reed and Peterson 1961). There was a decrease of parasites of plains pricklypear during dry conditions (Coupland 1958). Also, it is spread by rhizomes or by distribution of seed and vegetative parts by livestock. As the weather became wetter and cooler, plains pricklypear cover was reduced to pre-drought amounts (Reed and Peterson 1961; Coupland 1958). By 1946, plains pricklypear cover was basically the same as before the drought in southeast Montana (Reed and Peterson 1961).

Sagebrush (Artemisia spp.) was greatly reduced by drought in southeast Montana (Reed and Peterson 1961). Different sagebrush species recovered from drought to different degrees. Silver sagebrush (Artemisia cana) reestablished and recovered rapidly. By 1943, there were about seven times as many plants as prior to the drought (Reed

and Peterson 1961). Big sagebrush did not recover as rapidly following drought or to the extent that silver sagebrush did. Fringed sagewort (Artemisia frigida) increased rapidly following drought, probably due to its ability to invade deteriorated or disturbed sites.

Elements of the Moisture Regime that Determine Vegetation Growth

Coupland (1958) reported that fluctuations in annual precipitation are often less important than distribution of precipitation. When a storm occurs, an area may receive one third of its annual precipitation in that one storm. Different species characterize the aspect of a plant community in succeeding years due to the timing and distribution of precipitation, which will favor various species in successive years (Sarvis 1941). This is because each species responds differently to precipitation at various periods in its growth cycle (Abel et al. 1962).

Different moisture regimes determine forage production in a given year than the moisture regimes that determine plant cover. Plant * cover is more closely related to weather cycles, while production is an indicator of the growing conditions within a single year (Herbel et al. 1972; Ryerson unpublished; Smoliak et al. 1976).

Herbage production and the moisture regime that controls it has been studied by more researchers than has plant cover. Reports have been based in some cases simply on observation, while in other cases, regression and correlation techniques have been used to determine

which factors most strongly affect and determine production. Reed and Peterson (1961) reported that annual forage production usually depends * on spring precipitation. Ballard and Ryerson (1973) used regression and correlation on forage production data from northern Montana. They reported that of ten grass species analyzed, only four species are significantly related to or influenced by precipitation. These are western wheatgrass, green needlegrass (Stipa viridula), needle-and-thread, and needleleaf sedge (Carex eleocharis). Western wheatgrass tends to be influenced by growing season precipitation. April through June precipitation favors cool season grasses, but generally disfavors warm season grasses. Sarvis (1941) reported a high correlation * between April through June precipitation and forage production in North Dakota. Rogler and Haas (1947) studied the correlation between soil moisture or precipitation and forage production in North Dakota. There is a highly significant correlation coefficient (r) between fall soil moisture at certain depths and total forage production the following season. These are $r=.72$ at 1 m (3 feet) and $r=.74$ at 2 m (6 feet). They also stated that $r=.76$ between April through July precipitation and forage production for the same season. Use of all of these variables together further increased the r value. In South * Dakota, correlation was best between the previous September through June precipitation and forage production (Johnson 1981). Johnson further stated that there is a complex interrelationship between

season of precipitation, plant vigor, range condition, and forage production. Therefore, plant vigor and range condition may affect the correlation between precipitation and forage production (Johnson 1981; Weaver and Albertson 1944). In southern Alberta, forage production is related to the precipitation/evaporation ratio (Clark et al. 1943). They also stated that moisture from fall and winter did not appear to be as important as precipitation during the growing season. Smoliak (1956), also working in southern Canada, reported a high correlation ($r=0.86$) between May through June precipitation and forage production. He developed the following regression equation:

$$Y = 27.17 + 78.48 X \quad (r^2=0.74)$$

Y = predicted forage production in lbs. per acre

X = May + June precipitation

He reported that there are negative correlations between forage production and seasonal average temperature, hours of bright sunlight, wind mileage, or seasonal evaporation. Abel et al. (1962) used March through June precipitation plus monthly deviation from average temperature for May and June to predict forage production for the current season in the Northern Great Plains. In the Central Great Plains, amount and distribution of rainfall during the six summer months (April through September) greatly affect growth of grassland vegetation (Albertson et al. 1957). This is especially true of early summer rains, with late summer rain being too late to help plant

growth if early rain was lacking. In western Kansas, forage production shows a stronger relationship with seasonal precipitation than with preseasonal or winter precipitation (Hulett and Tomanek 1969). They hence reported that May and June precipitation is most reliable for predicting forage production. They also stated that production of weedy species is correlated with April precipitation, and short grass production is highly correlated with July precipitation. However, Reinert (1962) stated that early season precipitation influences short grass production in Kansas. In eastern Colorado, annual precipitation from the two previous years and the depth of moist soil on April 15 gave the highest correlation with forage production (Dahl 1963). In southern Idaho, production is correlated ($r=0.944$) with precipitation in the previous winter and current spring (Craddock and Forsling 1938). Sneva and Hyder (1962) developed a regression equation to predict forage production in the northern Intermountain Region:

$$Y = 1.11 X - 10.6$$

Y = yield index

X = precipitation index

These indices are in comparison to the median yield and precipitation for a given location. In northern Nevada, the previous winter and current spring precipitation determines soil moisture, which then determines the length of the growing season and forage production for

that season (Roundy, Eckert and Evans 1979)*

Coupland (1958) reported that basal cover decreases only during prolonged drought. Reed and Peterson (1961) reported that two or more consecutive years of drought are probably necessary for an appreciable kill of plants and extended subsequent effects. In southeast Montana, changes in basal area cover are most closely associated with precipitation of the previous growing season (Reed and Peterson 1961)*. In eastern Wyoming, a relationship exists between basal cover and annual precipitation beginning on the previous September 15th (Lange* 1945). In southern Idaho, basal cover responds to previous annual precipitation (Craddock and Forsling 1938). Nelson (1934) reported similar results for grasses in the desert southwest, and further stated that precipitation during the current summer has little effect on plant basal cover for that year. Herbel et al. (1972) stated that, in the same region, precipitation during the nine months prior to the growing season has the greatest influence on perennial grass basal cover.

Vegetation Response To Grazing

Climate is the major controlling factor of vegetation growth with grazing intensity having proportionately less of an effect (Reed and Peterson 1961; Whitman et al. 1943). Under normal conditions, changes* in vegetation due to grazing occur slowly (Sarvis 1941). In Texas, for example, three years of drought decreased range condition about

the same, regardless of grazing intensity, including changes in exclosures (Osborn 1950). On mixed grass prairie in the Central Great Plains, losses in basal cover during drought occurred throughout all grazing intensities. However, the amount of loss varied (Weaver and Albertson 1936). Losses of basal cover were 50 to 60% under no grazing, 36 to 54% under moderate grazing, and 74 to 91% under heavy grazing during the drought of the 1930's.

It is generally acknowledged that past grazing use affects plant species composition, especially during a drought (Cook and Sims 1975). Because heavy use during wet years may adversely affect plant vigor to the extent that drought effects are more severe, it is unwise to * reduce grazing intensity only during drought (Albertson et al. 1957). Showers received during drought will produce more runoff. However, Whitman et al. (1943) reported that deterioration of heavily stocked rangeland in North Dakota was less than that in other areas, apparently due to removal of livestock during drought. They further stated that grazing under drought conditions would result in heavier utilization due to reduction in available vegetation, even though stocking rate may stay the same. Removal of livestock could limit this and speed recovery.

Heavy grazing adds to the effects of drought (Reed and Peterson 1961). Heavy grazing not only reduces vegetation growth, but also * livestock production (Reed and Peterson 1961; Cook and Sims 1975). It

also results in general deterioration of rangeland, regardless of precipitation (Cook and Sims 1975). Range that is overgrazed prior to drought suffers greater loss in stand, vigor, and carrying capacity* when drought occurs (Schumacher 1974). High plant death losses are usually associated with heavy grazing during drought (Cook and Sims 1975). Albertson et al. (1957) stated that heavily grazed range suffers most from drought and recovers slowest. Heavy grazing can* cause unstable soil, low vigor in surviving plants, decreased revegetation in succeeding wet years, invasion of inferior plants, intensified dry conditions, decreased grazing capacity, and added instability of livestock production (Nelson 1934). While it took five years to recover on moderately grazed range, it took twenty or more years for heavily grazed range to recover from drought in the Central Great Plains (Albertson et al. 1957). It is sometimes difficult for range managers to interpret the impact of heavy grazing, because cover may increase under heavy grazing due to spread of shortgrasses (Albertson et al. 1957). However, after this stage, continued heavy use often results in loss of perennial grass cover along with accelerated erosion. Weedy species can then become prevalent.

Conservative stocking minimizes losses during drought (Hurt 1951). Moderate grazing may actually be better than no grazing (Coupland 1958). It may cause a thinner stand, and reduce competition for moisture. It especially helps short grasses, because they are

usually grazed less. Cover was about the same under either conservative stocking or no grazing (Nelson 1934), and yield on moderately grazed range was greater than when no grazing occurred (Tomanek 1948).

Drought recovery is differentially influenced by grazing intensity. Range should be used lightly following drought to permit rapid recovery (Ellison and Woolfolk 1937; Johnson 1981). Recovery is additionally accelerated by livestock removal (Whitman et al. 1943). Weaver and Hanson (1941) stated that even a single year of protection from grazing greatly increased the regeneration following drought. However, moderate grazing may increase recovery due to trampling effects and removal of excess mulch.

Grasses may produce more immediately after a drought because of reduced cover (Coupland 1958). Yield increase response was quickest on heavily grazed sites, with moderately grazed sites being delayed a year or two (Coupland 1958; Weaver and Albertson 1944). This is probably due to the greater reduction in cover on the heavily grazed site. This increased production from a reduced plant cover can be misleading. A range manager may think that vegetation has recovered, while in reality, plant cover has not yet fully recovered (Sarvis 1941).

Response of different species to grazing varies, just as plant species respond differently to climatic variables. In South Dakota,

Lewis et al. (1956) reported that short grasses dominate under heavy grazing, midgrasses dominate under light grazing, and moderate grazing maintains a proportion of both mid and short grasses. In southeast Montana, the greatest total basal cover occurred under moderate stocking after 25 years (1932-56) of continuous summer grazing (Houston and Woodward 1966). However, in 1945, on the same site, the greatest total basal cover occurred under heavy stocking (Reed and Peterson 1961). This was because of an increase in buffalograss.

The response of several species to grazing has been reported in southeast Montana (Reed and Peterson 1961; Houston and Woodward 1966) and southern Alberta (Clark et al. 1943). The grazing intensity which favors maximum cover for each species is indicated in Table 1. Western wheatgrass response to grazing was variable, being inversely related to buffalograss cover (Reed and Peterson 1961). Blue grama was favored by light grazing during drought (Reed and Peterson 1961). Houston and Woodward (1966) reported that at the end of the study, tumblegrass was only found on the most lightly grazed range. Reed and Peterson (1961) stated that although needle-and-thread had the same amount of basal cover, the cover under heavy grazing consisted of a greater density of smaller, younger plants. With different species showing variable response to grazing depending upon the time period considered, it is further apparent that climate has a greater effect on vegetation change than does grazing.

Table 1. Grazing Intensity Which Favors Maximum Cover of Several Plant Species

species	<u>grazing intensity</u>			no response
	light	moderate	heavy	
western wheatgrass	2			1
red threeawn		1	2	
blue grama		2	1,3	
buffalograss			1,2	
threadleaf sedge		2		1
needleleaf sedge		2		1
inland saltgrass		2		
prairie junegrass				1
false buffalograss			2	
Sandberg bluegrass			1	2
tumblegrass	2		1	
sand dropseed		2	1	
needle-and-thread	3	2		1
green needlegrass	1			2
six weeks grass			1	
plains bahai	1			
Hoods phlox			1	
woolly plantain			2	
American vetch	1			
scarlet globemallow			1	2
silver sagebrush			2	
big sagebrush			2	
fringed sagewort		2		
winterfat		2		
plains pricklypear		2	2	
broom snakeweed			2	

1 (Reed and Peterson 1961)

2 (Houston and Woodward 1966)

3 (Clark et al. 1943)

Recommended Management Practices for Fluctuating Climatic Conditions

Reed and Peterson (1961), Hurtt (1951), Cook and Sims (1975), Ellison and Woolfolk (1937), Albertson et al. (1957), and Whitman et al. (1943) reported that conservative stocking is necessary before, during, and following drought to limit permanent drought damage. Hurtt (1951) stated that conservative stocking will also minimize livestock weight losses. Maintenance of high animal numbers also decreases net $\star$ income during drought because of increased cost and decreased prices for calves (Boykin, Gray and Caton 1962). Therefore, it is best from $\star$ an economic as well as an ecological standpoint to reduce livestock numbers during drought. Reed and Peterson (1961) and Hurtt (1951) stated that a minimum of 12.4 ha (31 acres) per animal unit per year, $\star$ or 1.04 ha (2.6 acres) of good condition range per animal unit month (AUM) are needed in southeast Montana. This is approximately the stocking rate of the intermediate grazing intensity used in the study that they reported. Reed and Peterson (1961) stated that this stocking rate may have shown slow deterioration over a longer period of time. They also stated that this stocking rate should only be used as a guideline or starting point, and that actual stocking for a $\star$ particular range should be based on herbage utilization or range condition and trend. Sarvis (1941) recommended a stocking rate of 1.4 acres per yearling steer per month.

Very few management practices have been developed specifically

for use during drought. Special practices for drought are to cull * early, alter the plan of seasonal use, and restock slowly after drought (Hurtt 1951). However, no indication is given as to actual amount and timing to restock after drought. Protection from grazing during drought kept degeneration of the vegetation to a minimum (Albertson and Weaver 1944). Most recommended management practices are those that range managers should use regardless of drought. These include using early, short breeding season, providing salt and water, and managing for even livestock distribution (Hurtt 1951). Other recommended practices are using complementary pastures, crossfencing, developing water, and using brush control (Fields 1977). Use of rotational grazing was considered essential by Craddock and Forsling (1938).

STUDY SITE DESCRIPTION

Experimental Design

Data for this study were compiled over a 25 year period, from 1932 to 1956, on two areas located on the Livestock and Range Research Station near Miles City, Montana. One area, consisting of 338 ha (845 acres) of level to gently rolling range, was used for spring and summer grazing; while the other area, consisting of 400 ha (1002 acres) of rougher terrain, was used for fall and winter range. This arrangement afforded protection for cattle from winter storms. Each area was used for approximately six months, with movement from one area to the other occurring approximately on May 15 and November 15. The summer and winter ranges were each divided into three pairs of pastures of different sizes radiating from a central well and handling facilities. These central wells were the only source of permanent water on the study areas. This arrangement made it possible to graze six groups of ten cows under three rates of stocking. The stocking rates on the summer range were .76 ha (1.9 acres) per animal unit month (AUM) for heavy grazing, .92 ha (2.3 acres) per AUM for moderate grazing, and 1.24 ha (3.1 acres) per AUM for light grazing. Stocking rates on the winter range were 0.8 ha (2.0 acres), 1.16 ha (2.9 acres), and 1.36 ha (3.4 acres) per AUM for heavy, moderate, and light grazing, respectively.

The experimental pastures were used in the same manner in all

years except the summers of 1932, 1936, and 1937, and the winters of 1934-35 and 1937-38. In these cases, grazing intensity was lightened because the livestock were young or because the range was unable to support livestock due to drought. In addition, supplemental feeding was increased during drought periods. Because of these two factors, the actual adverse effects of drought under continuous grazing regimes were moderated by an inestimable amount.

For further information concerning the character and design of this study, see Reed and Peterson (1961), Hurtt (1951), and Houston and Woodward (1966).

Character of the Range Resource

Vegetation was typical of the mixed grass prairie of the Northern Great Plains. The range had been stocked conservatively and managed well prior to the study, leaving it in good condition. Perennial grasses and sedges comprised the majority of the cover with the remainder being mostly shrubs. Basal cover of all species combined ^{basal} _{cover} ranged from 15 to 80%, and averaged 40% at the beginning of the study. Five grasses and one sedge comprised 65% of the total cover. These were western wheatgrass, needle-and-thread, green needlegrass, blue grama, buffalograss, and threadleaf sedge.

Characteristics of the Climate During the Study

Precipitation data for the study were obtained from Miles City

weather records located about 6.4 km (4 miles) north of the study site. Although individual precipitation events may have varied between the study site and Miles City, it is unlikely that the longer term cumulative precipitation data used for this study were different. Precipitation fluctuated widely throughout the study (Fig. 1). Average annual precipitation over an 80 year period was 323.5 mm (12.94 in.) (Houston and Woodward 1966). Average annual precipitation during the study period, 1932 to 1956, was 314 mm (12.56 in.).

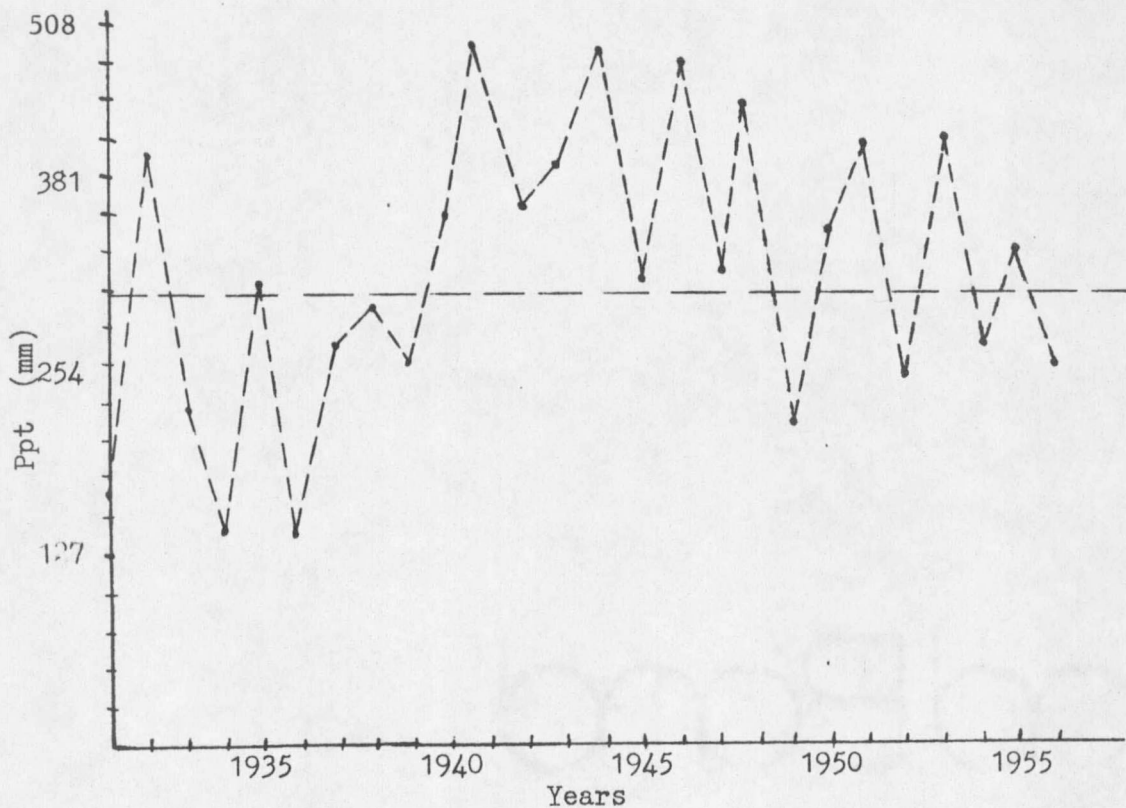


Figure 1. Annual and Average Precipitation (mm), 1931 through 1956

Precipitation was below the long term average between 1930 and 1940, except in 1932. Precipitation was low enough in 1931, 1934, and 1936 for them to be considered drought years. In addition, average monthly temperatures were higher than the long term averages during the 1930's. Precipitation was above average for an extended period following this drought period, lasting from 1940 through 1948, with the exception of the slightly below average years of 1945 and 1947. Temperatures from 1940 to 1948 tended to be closer to the long term average. During the period of 1949 through 1956, precipitation fluctuated above and below average in alternate years, with the last three years all being below average.

METHODS AND PROCEDURES

Data Collection

Basal cover data were collected using the pantograph method (Hill 1920; Weaver and Clements 1938). The pantograph charts were obtained from 57 square meter plots located throughout the summer and winter ranges. Plots were distributed throughout the pastures to monitor each grazing intensity, and were placed in grazing exclosures to determine the response of the range to protection from livestock grazing. Data were not recorded in all years of the study period. Years in which the quadrats were not mapped were 1946, 1947, 1949, and 1951 through 1955. All quadrats were not recorded in all years.

For this study, only data from the summer pastures were evaluated. Growing season grazing had the greatest impact on vegetation, as evidenced by the fact that vegetation changes were much slower on the winter range (Reed and Peterson 1961, Houston and Woodward 1966). Also, grazing impact during the winter was lessened due to supplemental feeding.

Data Analysis

Data from pantograph charts were entered into a file on the computer as area (cm^2) and as density (plants/m^2) of each species in each quadrat. Life form (grass, forb, or shrub) and grazing response (decreaser, increaser, or invader) were also entered for each species. Other information was entered into the data set for each quadrat,

including stocking rate and season of use. Another set containing precipitation data on a daily basis for the entire study period was also used. The computer was used to manipulate the data into the forms needed for analysis and to perform the analysis.

A total of 142 species were recorded on the study area throughout the study. Since many of them were of minor importance, it was first necessary to eliminate those species that showed no relationship between their basal cover and precipitation. This was done to simplify the statistical analysis used later. The first step was to examine the species list and eliminate obscure species which are infrequent in mixed grass plant communities. The number of species was further reduced by using three graphing methods which compared basal cover to precipitation. Graphs were plotted by the computer. The first set of graphs that were examined were of basal cover of each species versus time in years (Appendix A). These graphs were compared to a graph of annual precipitation versus time in years, as shown in Figure 1. This comparison was used to determine those species whose cover fluctuated in direct response to precipitation. Species that showed a definite relationship were retained for more in-depth evaluation and others were discarded.

The next step involved in preliminary species evaluation was to plot the basal cover of the remaining species within each grazing

intensity versus time in years. This included light, moderate, heavy and no grazing. All four lines were plotted on the same graph. This graph was then compared to a graph of precipitation versus time in years. The purpose of this method was to determine if cover of each species was related to certain grazing intensities only, and to identify which grazing intensities were most critical for each species being considered. This method was largely unsuccessful because the number of lines on any one graph made interpretation difficult, and in some cases impossible.

Finally, graphs were plotted with basal cover of each species on one axis and annual precipitation on the other axis (Appendix B). This was done only for those species that showed a definite relationship in the first step. This method plotted points so that the nature of a relationship could be more clearly visualized. These graphs were subsequently used to identify variables that might be used advantageously in multiple regression equations.

Multiple regression techniques were employed on those species that continued to show a relationship in the last graphing method so as to develop predictive equations relating basal cover for each species to precipitation. A variety of equations were evaluated for their potential ability to predict basal cover. The approach used for examining predictive ability and obtaining an acceptable equation was to use the least variables to establish a reasonably high coefficient

of determination (r^2). A value of 0.70 was set as an acceptable r^2 value.

Two multiple regression programs were used to derive predictive equations. The first multiple regression program used did not have the ability to add or delete variables in a stepwise fashion. This proved to be a problem in determining the best combination of variables to use without spending a great deal of time using trial and error. Later, a second multiple regression program with stepwise capabilities was used. This program entered variables in both additive and subtractive modes. However, only the additive mode was used for this study. Because two programs were used, some equations were obtained using the first multiple regression program, and some were derived using the stepwise program. The program used has been identified in the results section.

Two general equations were examined to determine which had the higher r^2 value. The first equation used annual precipitation for both the current and previous year, along with various interactions and transformations of these two variables (Table 2, Equation 1). This equation was used with annual precipitation calculated in two different ways. In one case, precipitation was summed for the calendar year, from January 1 through December 31. In the second case, precipitation was summed from November 1 of the previous year through October 31 of the year being considered. This will be

referred to as the plant year. The second general equation used cumulative precipitation by month during the early growing season. The equation used April, May, and June precipitation, and various interactions and transformations of these three variables (Table 2, Equation 2). This equation was designed to help identify the segment of growing season precipitation that most affected basal cover.

The first set of regression equations was obtained using mean basal cover of each species in all quadrats, regardless of grazing intensity. Mean basal cover was determined for each year by averaging the cover for each species in all quadrats in which the species was encountered. This procedure yielded one value of average cover for each species for each year that the quadrats were mapped. Regression equations were also determined for several groups of species. Groups evaluated included blue grama and buffalograss combined (shortgrasses), all cactus, all perennial grasses, all increaser grasses, all decreaser grasses, all annual grasses, all shrubs, and all increaser shrubs. The cover of all species in each of these groups was summed for each quadrat, and these sums were then averaged for all quadrats in which any member species were encountered for each year. Regression equations were next developed for each species as a function of each grazing intensity. This was done for each year by averaging the cover of each species in the quadrats within each grazing intensity.

Table 2. The Two General Equations Used to Determine Which Precipitation Parameters had the Greatest Predictive Ability

Equation 1:

$$Y = a + b_1x_1 + b_2x_1^2 + b_3x_2 + b_4x_2^2 + b_5x_1x_2 + b_6x_1x_2^2 + b_7x_1^2x_2 + b_8x_1^2x_2^2$$

where: Y = predicted basal cover (cm²)

x_1 = current year annual precipitation (in.)

x_2 = previous year annual precipitation (in.)

a, b_1 - b_8 = constant terms

Equation 2:

$$Y = a + b_1x_1 + b_2x_1^2 + b_3x_2 + b_4x_2^2 + b_5x_3 + b_6x_3^2 + b_7x_1x_2 + b_8x_1x_3 + b_9x_2x_3 + b_{10}x_1x_2x_3$$

where: Y = predicted basal cover (cm²)

x_1 = April precipitation (in.)

x_2 = May precipitation (in.)

x_3 = June precipitation (in.)

a, b_1 - b_{10} = constant terms

The stepwise program was set up to add the aforementioned variables one at a time until an r^2 value of at least 0.70 was obtained. After this was achieved, equations were examined to determine their mathematical validity. If necessary, additional

variables were then added to the original generated equation in order to achieve a more balanced mathematical relationship. For example, if an r^2 value of 0.70 was obtained using variables x_1 , x_2^2 , and $x_1x_2^2$ in the stepwise program, x_2 would then be added to achieve a more balanced equation. This was because the transformation and interaction variables are dependent on both x_1 and x_2 . After equations were examined and modified to yield more balanced mathematical relationships, regression relationships were recalculated using the new combination of variables. In the example, x_1 , x_2 , x_2^2 , $x_1x_2^2$ would then be used. Recalculation was done using the multiple regression program which simply used all variables given to it. This recalculation procedure was done to obtain the final regression equation that was subsequently used for predictive purposes (Appendix C).

Once meaningful regression equations had been developed, the next process was to use the equations to predict basal cover using given levels of precipitation (Appendix D). A total of 25 different combinations of previous and current annual precipitation were examined by using increments of 101.6mm, 203.2mm, 304.8mm, 406.4mm, and 508.0mm (4, 8, 12, 16, and 20 inches, respectively) of annual precipitation. These predicted values were then used to plot three dimensional computer-generated graphs, also called response surfaces (Figures 3-40). These response surfaces can be used to describe the

species response to fluctuating precipitation over a two year period.

RESULTS AND DISCUSSION

Graphing Methods

After preliminary screening, 69 species were subjected to the initial graphing methods as listed in Table 3 (see Appendices A and B for individual graphs). Visual examination of the initial graphs revealed that only 21 species showed a sufficient relationship between cover and precipitation to merit further analysis. These species were therefore subjected to multiple regression procedures.

Multiple Regression

Multiple regression analysis showed that higher r^2 values were generally obtained by using plant year precipitation as opposed to calendar year precipitation. This was readily apparent when only five of the eight variables from the general equation (Table 2, Equation 1) were included. The simplified equation that was used for this determination was:

$$Y = a + b_1x_1 + b_2x_1^2 + b_3x_2 + b_4x_2^2 + b_5x_1x_2$$

where: Y = basal cover (cm^2)

x_1 = current annual precipitation (in.)

x_2 = previous annual precipitation (in.)

$a, b_1 - b_5$ = constant terms

The resulting r^2 values that were associated with both sets of precipitation data are presented in Table 4. With the exception of fringed sagewort, the r^2 values were higher for each of the

Table 3. All Species That Were Subjected to the Initial Graphing Procedures to Determine Which Species Showed a Relationship Between Basal Cover and Precipitation

Common Name	Scientific Name	
western yarrow	<u>Achillea millefolium</u>	0
thickspike wheatgrass	<u>Agropyron dasystachyum</u>	
western wheatgrass	<u>A. smithii</u>	0
bluebunch wheatgrass	<u>A. spicatum</u>	
slender wheatgrass	<u>A. trachycaulum</u>	
western ragweed	<u>Ambrosia psilostachya</u>	
smallflower pussytoes	<u>Antennaria aprica</u>	
red threeawn	<u>Aristida longiseta</u>	0
hoary tansyaster	<u>Aster canescens</u>	
tansyleaf aster	<u>A. tanacetifolius</u>	
threeleaved milkvetch	<u>Astragalus gilviflorus</u>	
slender milkvetch	<u>A. gracilis</u>	
Missouri milkvetch	<u>A. missouriensis</u>	
silver sagebrush	<u>Artemisia cana</u>	0
fringed sagewort	<u>A. frigida</u>	0
big sagebrush	<u>A. tridentata</u>	0
shadscale	<u>Atriplex confertifolia</u>	
Nuttall saltbush	<u>A. gardneri</u>	
blue grama	<u>Bouteloua gracilis</u>	0
Japanese brome	<u>Bromus japonicus</u>	
cheatgrass	<u>B. tectorum</u>	
buffalograss	<u>Buchloe dactyloides</u>	0
prairie sandreed	<u>Calamovilfa longifolia</u>	
threadleaf sedge	<u>Carex filifolia</u>	0
needleleaf sedge	<u>C. eleocharis</u>	0
winterfat	<u>Eurotia lanata</u>	
western tansymustard	<u>Descurainia sophia</u>	
inland saltgrass	<u>Distichlis spicata</u> var. <u>stricta</u>	
snow-on-the-mountain	<u>Euphorbia marginata</u>	
scarlet gaura	<u>Gaura coccinea</u>	
curlycup gumweed	<u>Grindelia squarrosa</u>	
annual sunflower	<u>Helianthus annuus</u>	
prairie sunflower	<u>H. petiolaris</u>	
little barley	<u>Hordeum pusillum</u>	
prairie junegrass	<u>Koeleria pyramidata</u>	

Table 3. (continued)

Common Name	Scientific Name
rush skeletonweed	<u>Lygodesmia juncea</u>
pincushion cactus	<u>Mammillaria missouriensis</u> *
black medic	<u>Medicago lupulina</u>
yellow sweetclover	<u>Melilotus officinalis</u>
false buffalograss	<u>Monroa squarrosa</u>
brittle pricklypear	<u>Opuntia fragilis</u>
plains pricklypear	<u>O. polyacantha</u> *
witchgrass	<u>Panicum capillare</u>
Hoods phlox	<u>Phlox hoodii</u> *
woolly plaintain	<u>Plantago patagonica</u> *
big bluegrass	<u>Poa ampla</u>
Kentucky bluegrass	<u>P. pratensis</u>
Sandberg bluegrass	<u>P. sandbergii</u> *
Douglas knotweed	<u>Polygonum douglasii</u>
russian thistle	<u>Salsola kali</u>
russian thistle	<u>S. pestifer</u>
greasewood	<u>Sarcobatus vermiculatus</u>
tumblegrass	<u>Schedonnardus paniculatus</u> *
little bluestem	<u>Schizachyrium scoparium</u>
bottlebrush squirreltail	<u>Sitanion hystrix</u>
buffalobur	<u>Solanum rostratum</u>
scarlet globemallow	<u>Shaeralea coccinea</u> *
alkali sacaton	<u>Sporobolus airoides</u>
sand dropseed	<u>S. cryptandus</u> *
needle-and-thread	<u>Stipa comata</u> *
green needlegrass	<u>S. viridula</u> *
dandelion	<u>Taraxacum officinale</u>
field pennycress (fanweed)	<u>Thlaspi arvense</u>
salsify	<u>Tragopogon dubius</u>
clover (trefoil)	<u>Trifolium</u> spp.
American vetch	<u>Vicia americana</u>
six weeks grass	<u>Vulpia octoflora</u> *
broom snakeweed	<u>Xanthocephalum sarothrae</u>
meadow death camas	<u>Zigadenus venenosus</u>

* Species that showed a sufficient relationship to justify regression analysis.

Table 4. r^2 Values Obtained Using Calendar Year and Plant Year Annual Precipitation

species or group	calendar year	plant year ¹
western yarrow	.27	
western wheatgrass	.71	.87
red threeawn	.74	.76
silver sagebrush	.18	
fringed sagewort	.66	.62
big sagebrush	.10	
blue grama	.52	
buffalograss	.77	.83
threadleaf sedge	.44	
needleleaf sedge	.50	
six weeks grass	.35	
pincushion cactus	.21	
plains pricklypear	.50	
Hoods phlox	.28	
woolly plantain	.28	
Sandberg bluegrass	.27	
tumblegrass	.62	.79
scarlet globemallow	.73	.76
sand dropseed	.53	.64
needle-and-thread	.77	.80
green needlegrass	.60	.68
shortgrasses	.69	.80
all cactus	.50	
increaser grasses	.63	.60
decreaser grasses	.65	.43
all perennial grasses	.66	.59
annual grasses	.16	
shrubs	.31	
increaser shrubs	.31	
total cover	.17	

¹Calculations of r^2 values for plant year precipitation were undertaken only when r^2 values for calendar year precipitation exceeded 0.60.

individual species when plant year precipitation values were used in the regression equation. When considering groups of species, however, r^2 values were greater when using the calendar year data. Only one exception, the shortgrasses group, was noted. In general, r^2 values were low for all groups, and in only one instance (shortgrasses) was the acceptable level of 0.70 exceeded. It therefore appears that the use of groups of species for predicting cover is not as reliable as the use of individual species. Because calendar year precipitation proved to be of less value than plant year precipitation (November through October), it was eliminated from further consideration.

Cumulative precipitation for April through June was then compared to plant year annual precipitation data using the stepwise multiple regression program (STPWS) and the general equation presented in Table 2 (Equation 2). Resulting r^2 values along with the variables used are presented in Table 5 for the nine species that were evaluated on a plant year precipitation basis. The r^2 values that are shown were obtained when all of the variables listed were included in the regression equation. The "number of variables" column lists the number of variables needed to obtain the r^2 value listed, which include all of the actual precipitation values for the three months. Variables used to reach the r^2 value indicated are also listed according to the order that they were added to the equation. This column has not been completed for those species with an r^2 value of

Table 5. r^2 Values Obtained and Variables Used With Cumulative Early Growing Season Precipitation (Table 2, Equation 2)

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western wheatgrass	.85	10	4	2, 8, 6, 1, 7, 10, 9, 4, 3, 5
red threeawn	.83	10	8	5, 2, 6, 1, 8, 7, 9, 4, 10, 3
fringed sagewort	.71	10	10	9, 8, 4, 5, 6, 7, 3, 2, 10, 1
buffalograss	.59	10		
tumblegrass	.65	10		
scarlet globemallow	.60	10		
sand dropseed	.70	10	10	6, 5, 7, 10, 9, 2, 1, 4, 8, 3
needle-and-thread	.64	10		
green needlegrass	.59	10		

¹Numbers in this list correspond with the order of variables in Equation 2 (Table 2), which are also the same as the subscripts of the b terms.

less than 0.70. In some cases, when actual precipitation variables are last to enter the equation, the number of variables could be decreased to obtain an r^2 value of 0.70. This was done by forcing actual precipitation variables into the equation at the point where 0.70 was first reached. The "least number of variables" column lists the number of variables used when this procedure was followed. Plant year precipitation data gave higher r^2 values for 6 out of 9 species, and it used fewer variables for all except western wheatgrass, than cumulative seasonal precipitation data. Western wheatgrass is a cool season species, so its strong relationship with April through June

precipitation is not surprising. However, red threeawn, needle-and-thread, and green needlegrass are also considered cool season species; and they did not show such a response to early growing season precipitation. Because of these results, plant year precipitation was considered to have the most potential for predicting cover, so additional efforts to predict basal cover concentrated on it.

Although cumulative precipitation was not the best predictor, results could be used to examine how precipitation distribution affects basal cover for each species (Table 5). When using the STPWS program, precipitation variables were added to the equation in their order of ability to improve the prediction of cover, consequently the first precipitation variables entered were those that most strongly affected basal cover, and the last variables entered had the least effect on cover. Using this procedure, variables 1, 3, and 5 are identified as actual April, May, and June precipitation, respectively; while the other variables are transformations or interactions of actual precipitation variables. In this case, cover of only four species was predicted accurately enough that the variables are listed. In most cases, it appeared that interactions are more important than precipitation for individual months. Apparently, precipitation throughout the period is important, and precipitation for individual months does not play an important role, with a few exceptions. June precipitation played an important role for red threeawn, fringed

sagewort, and sand dropseed, while April precipitation was fairly important in predicting cover for western wheatgrass and red threeawn.

The annual precipitation equation (Table 2, Equation 1) was used with the plant year precipitation data in the STPWS program. All 21 species, as indicated with an asterisk in Table 3, were examined with respect to all eight variables. Resulting r^2 values and the variables used are presented in Table 6. The same precipitation data were subsequently used with species cover data separated into grazing intensities. No grazing, light, moderate, and heavy grazing are presented in Tables 7 through 10, respectively. Only 14 of 21 species were considered for regression analysis within grazing intensities. The other seven species had such low r^2 values in the previous analysis that additional evaluation of them was not merited. When basal cover in all quadrats was considered, good r^2 values of at least 0.70 were obtained for nine species using various combinations of variables. When no grazing occurred, as measured in exclosures, high r^2 values (> 0.70) were achieved for six species. Under light grazing, basal cover of eight species yielded good r^2 values. Satisfactory regression equations ($r^2 > 0.70$) were likewise obtained for seven species under moderate grazing, and for nine species under heavy grazing.

The order in which variables entered the equation provided

Table 6. r^2 Values Obtained and Variables Used with Plant Year Annual Precipitation (Table 2, Equation 1), All Quadrats

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.35	8		
western wheatgrass	.91	6	5	1, 7, 4, 2, 8, 3
red threeawn	.80	6	5	1, 2, 7, 4, 6, 3
silver sagebrush	.14	8		
fringed sagewort	.71	8	7	4, 3, 6, 7, 2, 8, 5, 1
big sagebrush	.19	8		
blue grama	.72	5	5	4, 3, 2, 5, 1
buffalograss	.85	7	4	6, 2, 4, 5, 3, 8, 1
threadleaf sedge	.66	8		
needleleaf sedge	.62	8		
six weeks grass	.28	8		
pincushion cactus	.19	8		
plains pricklypear	.18	8		
Hoods phlox	.69	8		
woolly plantain	.34	8		
Sandberg bluegrass	.28	8		
tumblegrass	.98	8	5	4, 3, 6, 7, 2, 8, 5, 1
scarlet globemallow	.73	4	4	6, 3, 8, 1
sand dropseed	.66	8		
needle-and-thread	.84	7	3	5, 8, 4, 1, 6, 2, 3
green needlegrass	.70	6	6	4, 3, 2, 5, 6, 1

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

insight into the relative importance of individual precipitation parameters to basal cover. Upon examination of all tables (6-10), it can be seen that the relative importance of individual variables differs among species. Moreover, the entry sequence of precipitation

Table 7. r^2 Values Obtained and Variables Used With Plant Year Annual Precipitation (Table 2, Equation 1), No Grazing Quadrats

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.81	8	5	4, 3, 2, 5, 6, 8, 7, 1
western wheatgrass	.51	8		
red threeawn	0	0 ²		
fringed sagewort	.59	8		
blue grama	.80	8	7	6, 5, 2, 8, 7, 3, 4, 1
buffalograss	.82	7	6	4, 3, 8, 7, 2, 6, 1
threadleaf sedge	.62	8		
needleleaf sedge	.25	8		
pincushion cactus	.50	8		
tumblegrass	.77	7	7	3, 8, 2, 5, 1, 7, 4
scarlet globemallow	.70	6	6	3, 4, 1, 5, 8, 2
sand dropseed	0	0 ²		
needle-and-thread	.62	8		
green needlegrass	.87	5	4	6, 2, 8, 1, 3

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

²Species with no values recorded were not encountered under this grazing intensity

variables for the same species was different under different grazing intensities. By considering the actual precipitation values for the current and previous years, variables 1 and 3, respectively, some generalities appear. In the majority of cases, 22 of 39 equations, if one of these variables entered early, the other entered late. The reason for this could not be determined. In 25 of 39 equations,

Table 8. r^2 Values Obtained and Variables Used With Plant Year Annual Precipitation (Table 2, Equation 1), Light Grazing Quadrats

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	0	0 ²		
western wheatgrass	.78	6	5	2, 7, 4, 1, 5, 3
red threeawn	.92	8	8	1, 2, 7, 4, 6, 3, 8, 5
fringed sagewort	.84	7	4	4, 3, 7, 6, 2, 5, 1
blue grama	.76	8	8	4, 3, 2, 5, 6, 8, 1, 7
buffalograss	.74	8	6	6, 2, 4, 5, 7, 8, 3, 1
threadleaf sedge	0	0 ²		
needleleaf sedge	.43	8		
pincushion cactus	.34	8		
tumblegrass	.78	7	5	7, 2, 4, 1, 6, 8, 3
scarlet globemallow	.75	6	3	8, 1, 2, 4, 6, 3
sand dropseed	.66	8		
needle-and-thread	.84	8	3	5, 2, 4, 7, 1, 8, 6, 3
green needlegrass	.19	8		

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

²Species with no values recorded were not encountered under this grazing intensity

previous year precipitation entered before current year precipitation. This supported the theories of Reed and Peterson (1961), Craddock and Forsling (1938), and Nelson (1934) who stated that precipitation from the previous year had the greatest influence on basal cover. The remaining 14 equations, in which current year precipitation entered first, supported the theories of Lange (1945) and Herbel et al.

Table 9. r^2 Values Obtained and Variables Used With Plant Year Annual Precipitation (Table 2, Equation 1), Moderate Grazing Quadrats

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.23	8		
western wheatgrass	.97	8	5	3, 4, 2, 5, 7, 8, 6, 1
red threeawn	.81	8	6	5, 8, 4, 7, 6, 1, 2, 3
fringed sagewort	.74	3	3	4, 3, 1
blue grama	.79	5	5	4, 3, 6, 7, 1
buffalograss	.87	6	3	6, 2, 5, 3, 7, 1
threadleaf sedge	.62	8		
needleleaf sedge	.82	8	4	7, 6, 2, 5, 8, 3, 4, 1
pincushion cactus	.29	8		
tumblegrass	.35	8		
scarlet globemallow	.71	5	5	5, 1, 6, 4, 3
sand dropseed	0	0 ²		
needle-and-thread	.60	8		
green needlegrass	.68	8		

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

²Species with no values recorded were not encountered under this grazing intensity

(1972). They stated that precipitation since the previous fall is most important, which corresponds with the current plant year. Therefore, my results support the theory that vegetation response to climate is specific to each species, with each species responding to a different precipitation regime.

Predictive equations were compiled for all species that had a r^2

Table 10. r^2 Values Obtained and Variables Used With Annual Plant Year Precipitation (Table 2, Equation 1), Heavy Grazing Quadrats

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.32	8		
western wheatgrass	.88	8	5	1, 7, 4, 2, 8, 6, 5, 3
red threeawn	.89	8	8	1, 2, 7, 3, 4, 8, 5, 6
fringed sagewort	.69	8		
blue grama	.69	8		
buffalograss	.77	7	6	5, 4, 2, 3, 7, 8, 1
threadleaf sedge	.70	7	7	5, 3, 2, 7, 1, 4, 6
needleleaf sedge	.89	8	5	3, 4, 2, 5, 7, 6, 8, 1
pincushion cactus	.61	8		
tumblegrass	.94	8	5	4, 3, 2, 5, 6, 8, 7, 1
scarlet globemallow	.83	8	4	3, 5, 2, 8, 7, 4, 6, 1
sand dropseed	.53	8		
needle-and-thread	.84	8	3	5, 6, 2, 3, 4, 8, 7, 1
green needlegrass	.73	8	8	4, 6, 2, 1, 8, 3, 5, 7

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

value of 0.70 or higher. This was completed for individual grazing intensity categories, as well as across all quadrats. These equations are presented in Appendix C. An effort was made to limit the number of variables to the least number needed to obtain an r^2 value of 0.70. The actual precipitation variables, if not already included, were added to these equations for better mathematical balance. The resulting r^2 values and the variables used for each category are

presented in Tables 11 through 15. Twelve species were considered in one or more of the categories, including western yarrow, western wheatgrass, red threeawn, fringed sagewort, blue grama, buffalograss, threadleaf sedge, needleleaf sedge, tumblegrass, scarlet globemallow, needle-and-thread, and green needlegrass.

Grazing intensity categories were further analyzed with respect to cumulative early growing season precipitation by using Equation 2 (Table 2). Resulting r^2 values and the variables used are presented in tables 16 through 19. This equation yielded better r^2 values than the annual precipitation equation for only 3 of 11 species (western wheatgrass, fringed sagewort, and threadleaf sedge) when no grazing

Table 11. r^2 Values Obtained And Variables Used For Predictive Equations (Table 2, Equation 1), All Quadrats

species	r^2	no. of variables	list of variables ¹
western wheatgrass	.87	5	1, 2, 3, 4, 7
red threeawn	.75	5	1, 2, 3, 4, 7
fringed sagewort	.71	7	1, 2, 3, 4, 6, 7, 8
blue grama	.72	5	1, 2, 3, 4, 5
buffalograss	.72	4	1, 2, 3, 6
tumblegrass	.85	5	1, 3, 4, 6, 7
scarlet globemallow	.73	4	1, 3, 6, 8
needle-and-thread	.76	3	1, 3, 5
green needlegrass	.70	6	1, 2, 3, 4, 5, 6

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Table 12. r^2 Values Obtained And Variables Used For Predictive Equations (Table 2, Equation 1), No Grazing

species	r^2	no. of variables	list of variables ¹
western yarrow	.72	5	1, 2, 3, 4, 5
blue grama	.75	7	1, 2, 3, 5, 6, 7, 8
buffalograss	.79	6	1, 2, 3, 4, 7, 8
tumblegrass	.77	7	1, 2, 3, 4, 5, 7, 8
scarlet globemallow	.70	6	1, 2, 3, 4, 5, 8
green needlegrass	.82	4	1, 2, 3, 6

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Table 13. r^2 Values Obtained And Variables Used For Predictive Equations (Table 2, Equation 1), Light Grazing

species	r^2	no. of variables	list of variables ¹
western wheatgrass	.78	5	1, 2, 3, 4, 7
red threeawn	.92	8	1, 2, 3, 4, 5, 6, 7, 8
fringed sagewort	.73	4	1, 3, 4, 7
blue grama	.76	8	1, 2, 3, 4, 5, 6, 7, 8
buffalograss	.73	6	1, 2, 3, 4, 5, 6
tumblegrass	.70	5	1, 2, 3, 4, 7
scarlet globemallow	.70	3	1, 2, 8
needle-and-thread	.75	3	1, 3, 5

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Table 14. r^2 Values Obtained And Variables Used For Predictive Equations (Table 2, Equation 1), Moderate Grazing

species	r^2	no. of variables	list of variables ¹
western wheatgrass	.87	5	1, 2, 3, 4, 5
red threeawn	.74	6	1, 3, 4, 5, 7, 8
fringed sagewort	.74	3	1, 3, 4
blue grama	.79	5	1, 3, 4, 6, 7
buffalograss	.78	3	1, 3, 6
needleleaf sedge	.77	4	1, 3, 6, 7
scarlet globemallow	.71	5	1, 3, 4, 5, 6

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Table 15. r^2 Values Obtained And Variables Used For Predictive Equations (Table 2, Equation 1), Heavy Grazing

species	r^2	no. of variables	list of variables ¹
western wheatgrass	.81	5	1, 2, 3, 4, 7
red threeawn	.89	8	1, 2, 3, 4, 5, 6, 7, 8
buffalograss	.70	6	1, 2, 3, 4, 5, 7
threadleaf sedge	.70	7	1, 2, 3, 4, 5, 6, 7
needleleaf sedge	.74	5	1, 2, 3, 4, 5
tumblegrass	.87	5	1, 2, 3, 4, 5
scarlet globemallow	.75	4	1, 2, 3, 5
needle-and-thread	.76	3	1, 3, 5
green needlegrass	.73	8	1, 2, 3, 4, 5, 6, 7, 8

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Table 16. r^2 Values Obtained And Variables Used With Cumulative Precipitation (Table 2, Equation 2), No Grazing

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.50	10		9, 2, 6, 4, 8, 7, 5, 1, 3, 10
western wheatgrass	.74	8	7	3, 10, 7, 9, 2, 5, 4, 1
red threeawn	0	0 ²		
fringed sagewort	.86	8	5	3, 2, 4, 1, 8, 6, 9, 5
blue grama	.74	10	9	6, 1, 9, 2, 10, 4, 7, 8, 3, 5
buffalograss	.71	10	10	9, 8, 6, 2, 10, 1, 5, 4, 7, 3
needleleaf sedge	.71	7	7	4, 7, 3, 1, 6, 8, 5
tumblegrass	.70	10	10	5, 3, 4, 6, 9, 1, 7, 2, 8, 10
scarlet globemallow	.46	10		
needle-and-thread	.66	10		
green needlegrass	.76	9	9	6, 1, 9, 5, 8, 2, 4, 7, 3

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

²Species with no values recorded were not encountered under this grazing intensity

occurred. It provided a better equation for only one of the same 11 species (green needlegrass) in light grazing, but two species (threadleaf sedge and tumblegrass) were more effectively handled by it under moderate grazing. In heavily grazed pastures, cumulative precipitation provided less satisfactory regression relationships than annual precipitation in all cases. Because of these results, annual plant year precipitation was still considered the best overall independent variable to include in a regression equation involving

Table 17. r^2 Values Obtained and Variables Used With Cumulative Precipitation (Table 2, Equation 2), Light Grazing

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	0	0 ²		
western wheatgrass	.65	10		
red threeawn	.78	8	8	5, 1, 8, 10, 6, 3, 9, 7
fringed sagewort	.68	10		
blue grama	.77	10	10	2, 1, 4, 7, 8, 10, 5, 9, 6, 3
buffalograss	.62	10		
needleleaf sedge	.57	10		
tumblegrass	.78	9	9	2, 8, 7, 10, 9, 1, 6, 3, 5
scarlet globemallow	.70	10	10	6, 2, 7, 1, 3, 4, 8, 9, 10, 5
needle-and-thread	.72	10	9	5, 2, 4, 3, 6, 8, 9, 7, 10, 1
green needlegrass	.99	10	5	3, 5, 9, 4, 8, 6, 7, 2, 10, 1

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

²Species with no values recorded were not encountered under this grazing intensity

plant basal cover.

The equations that are summarized in Tables 16 through 19 are similar to other equations that have already been discussed when considering the order in which variables enter and the relative importance of precipitation during each month. Variables do not enter in the same order in any two cases. Only the actual precipitation variables (1, 3, and 5) were considered to determine whether any general similarities appear. When this was done, there appeared to be

Table 18. r^2 Values Obtained and Variables Used With Cumulative Precipitation (Table 2, Equation 2), Moderate Grazing

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.46	10		
western wheatgrass	.94	10	4	2, 8, 6, 3, 10, 7, 9, 4, 5, 1
red threeawn	.82	9	6	5, 2, 6, 1, 8, 7, 10, 9, 3
fringed sagewort	.43	10		
blue grama	.47	10		
buffalograss	.61	10		
needleleaf sedge	.85	9	5	9, 2, 1, 3, 7, 10, 6, 8, 5
tumblegrass	.93	9	6	5, 9, 2, 3, 4, 7, 10, 8, 1
scarlet globemallow	.66	10		
needle-and-thread	.50	10		
green needlegrass	.58	10		

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

an equal distribution of all of the possible orders of variables 1, 3, and 5. This indicated that no particular month was more influential than another with respect to its overall effect on all species or grazing intensities. Therefore, vegetation response to any precipitation regime can still be regarded as specific to each species, and each grazing intensity to which a species is subjected.

Because the groups of species previously considered had not distinguished among grazing intensities, some of the groups were recalculated using the STPWS program under different grazing regimes.

Table 19. r^2 Values Obtained and Variables Used With Cumulative Precipitation (Table 2, Equation 2), Heavy Grazing

species	r^2	no. of variables		order of variables entering ¹
		total	least	
western yarrow	.39	10		
western wheatgrass	.68	10		
red threeawn	.81	9	9	1, 8, 6, 5, 7, 10, 3, 9, 2
fringed sagewort	.51	10		
blue grama	.52	10		
buffalograss	.56	10		
needleleaf sedge	.65	10		
tumblegrass	.64	10		
scarlet globemallow	.51	10		
needle-and-thread	.51	10		
green needlegrass	.72	10	10	7, 8, 6, 1, 5, 10, 2, 9, 4, 3

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

Annual plant year precipitation was used as an independent variable in Equation 1 (Table 2). Resulting r^2 values and the variables used are presented in Table 20. The r^2 values in this table are much higher than those presented for groups across all quadrats (table 5). A partial explanation may be that the values in Table 20 were calculated by including almost all of the eight variables, while the all quadrats results (Table 5) were obtained with only the first 5 variables. In table 20, r^2 values of 0.70 can be obtained using less variables by adding the required variables (1 and 3) sooner. It appears that the

Table 20. r^2 Values Obtained and Variables Used With Plant Year Annual Precipitation (Table 2, Equation 1) On Groups Of Species, By Grazing Intensities

no grazing	r^2	no. of variables		order of variables entering ¹
		total	least	
increaser grasses	.88	8	3	6, 5, 4, 7, 8, 2, 3, 1
decreaser grasses	.77	8	8	3, 2, 7, 5, 4, 6, 8, 1
all perennial grasses	.91	6	3	6, 5, 4, 2, 1, 3
light grazing				
increaser grasses	.70	5	5	4, 2, 5, 3, 1
decreaser grasses	.78	8	5	1, 7, 4, 2, 6, 8, 5, 3
all perennial grasses	.71	5	5	4, 2, 5, 3, 1
moderate grazing				
increaser grasses	.85	7	5	6, 2, 4, 5, 1, 7, 3
decreaser grasses	.93	7	5	3, 4, 2, 5, 7, 8, 1
all perennial grasses	.85	7	5	6, 2, 4, 5, 3, 8, 1
Heavy grazing				
increaser grasses	.74	8	8	4, 3, 2, 5, 6, 7, 8, 1
decreaser grasses	.89	8	5	2, 7, 4, 1, 6, 8, 5, 3
all perennial grasses	.81	5	5	4, 3, 2, 5, 1

¹Numbers in this list correspond with the order of variables in Equation 1 (Table 2), which are also the same as the subscripts of the b terms.

last variables of the equation, those not used in the MTREG program, were important to obtaining a more accurate prediction. This can also be seen by looking at the order of the variables in the list of variables entering in table 20, with variables six and seven often being among the first to be used, and variables one and three being the last to be used to reach an r^2 value of 0.70. Final predictive equations for these groups of species were not calculated, so further analysis could not be performed.

Predicted Basal Cover and Response Curves

After regression relationships were examined and the most appropriate equation determined, values were predicted for each species using annual plant year precipitation as an independent variable and basal cover as a dependent variable. Resulting basal cover values for each species in each category for which a reliable equation ($r^2 > 0.70$) was available are presented in Appendix D. Equations used to predict these values are presented in Appendix C. These values were then used to develop three dimensional graphs, also called response surfaces (Figures 3-40). These response surfaces provided a picture of the overall response of a species to precipitation combinations. By comparing response curves of the same species under different grazing intensities, the response of the species to grazing could also be evaluated.

Each horizontal axis of a three dimensional graph represents

precipitation for a year, with previous year precipitation on the left and current year precipitation on the right. The vertical axis represents the predicted amount of cover (cm^2) generated by the regression equation. As vertical rise increases, there is more predicted basal cover. The vertical legend on the right of the graph indicates the actual height of the vertical axis in inches on the left, and the predicted basal cover of the species in cm^2 on the right. The actual points that were predicted are indicated by stars on the surface of the response curve, and all intermediate values were interpolated by the computer program to create the response surface.

Examination of the response curves indicates that some of them predict a negative amount of basal cover. Obviously, this is impossible in real life, but this situation could result from an artifact of the regression procedure. Negative values sometimes occurred when the precipitation combination being considered was beyond the limits of the data from which the regression equation was derived. For example, consecutive years with 101.6 mm (4 inches) of precipitation never occurred during the study, and the combination might therefore result in a negative cover value if artificially forced into the equation. Figure 2 contrasts actual annual precipitation that occurred during the study with the precipitation regimes for which cover was predicted. Predictions for combinations outside the line around the outer perimeter of the actual

precipitation points may or may not be valid, which cannot be determined from these results. Therefore, for those points in the square that are outside this line, care needs to be taken to consider only the general trend that appears and not the actual values predicted. In the real life situation, there probably would not be any cover under those precipitation regimes for which negative amounts of cover were predicted. Because it is difficult to tell on the surface of the curve how far the negative values dip below the zero level, the thickness of the base is the same as the depth to the lowest negative value.

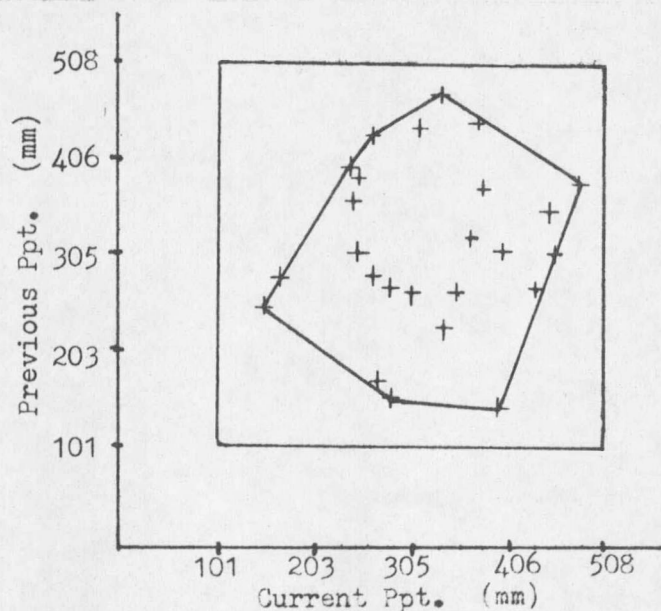


Figure 2. Scatter Diagram of Points Where Actual Precipitation Occurred Over a Two Year Period. The Square Indicates the Outer Limits of the Two Year Precipitation Regimes Used to Predict Cover

Cover greater than the amount possible was likewise predicted. There are 10,000 cm² in a quadrat, and cover values greater than this were predicted on some graphs. This situation also resulted from the predictive equation extrapolating cover for precipitation regimes that were not in the data used to develop the regression equations.

Western Yarrow

Western yarrow could only be predicted accurately for the ungrazed quadrats (Figure 3). Regression equations for other grazing intensities had r^2 values that were too low. Therefore, while response to precipitation could be considered for this species, the response to climate may be much different under other grazing intensities. Basal cover was highest at points where at least one year of precipitation was high. This was especially noticeable on the left and right portion of the graph where precipitation fluctuated considerably from one year to the next. The response was greatest when 508 mm (20 inches) of precipitation was either preceded or followed by 101.6 mm (4 inches) of precipitation. Lowest basal cover was predicted in the middle of the graph, where precipitation was slightly below average for two consecutive years. When precipitation was 101.6 mm (4 inches) in both years, cover actually increased slightly. However, the accuracy of this observation may be suspect because this precipitation combination never actually occurred. The response surface appears to have a dish shape with higher amounts of

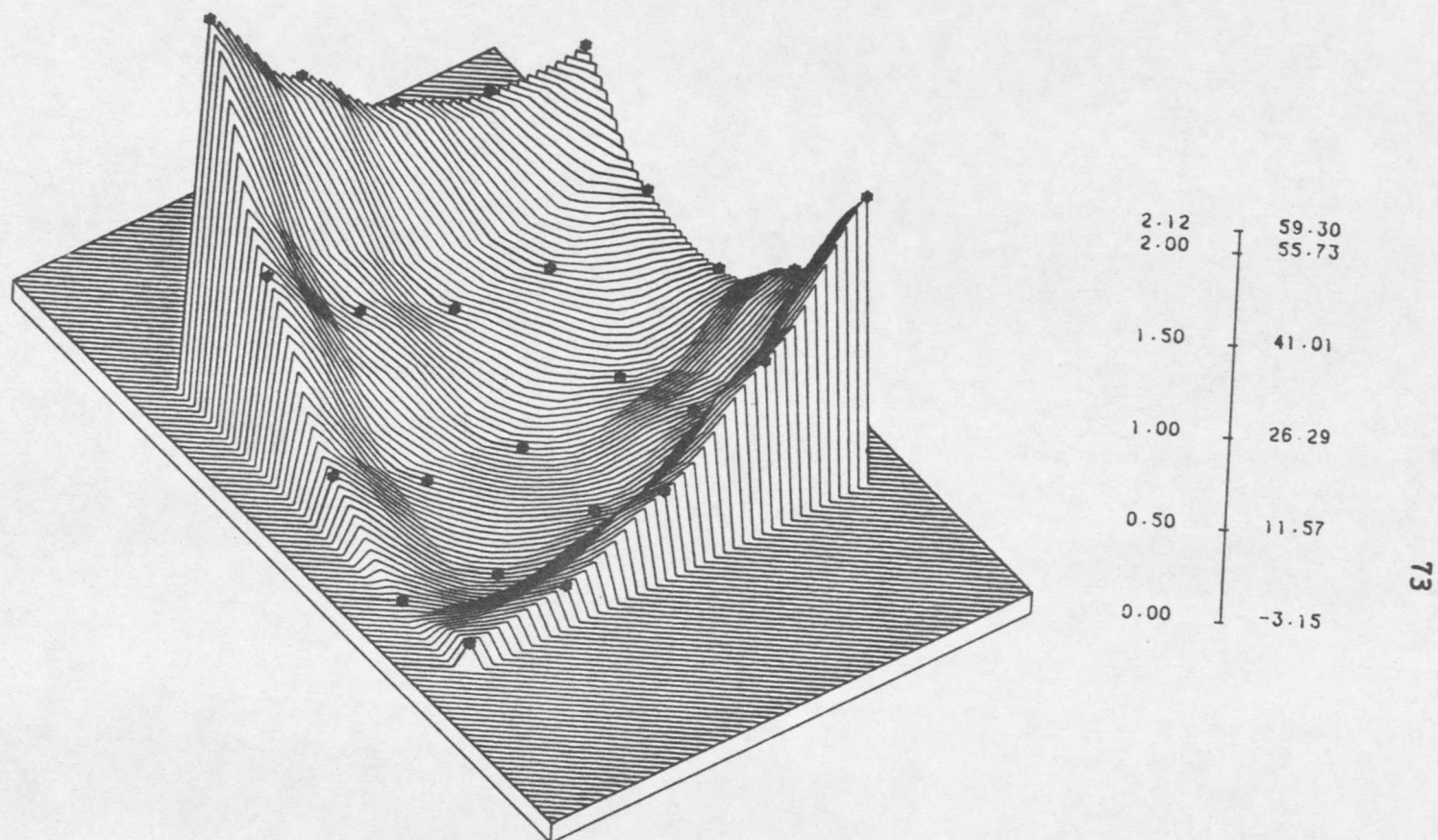


Figure 3. Response of Basal Cover of Western Yarrow to Precipitation, Ungrazed. For Description of Graph, See Page 69.

cover under extreme conditions and lower amounts under more average or normal conditions. It appears that this species may have evolved an ability to respond to year to year fluctuations in precipitation that are common in this region (see Figure 1). Loss of cover under consistent, average rainfall conditions is perhaps due to competition from other species which have a greater ability to take advantage of less extreme precipitation regimes. Possibly, western yarrow has the ability to thrive in areas only when the competitive abilities of other species have been decreased by adverse precipitation conditions.

Western Wheatgrass

Basal cover was predicted for all grazing categories except non-use (Figs. 4-7). All curves show a very similar response under different grazing intensities with the primary differences being in the actual amount of cover predicted. This seemed to indicate that, ultimately, grazing has relatively little effect on the response of western wheatgrass, while precipitation has the major effect. Western wheatgrass also seems to be stimulated by fluctuating precipitation with the greatest amount of cover predicted where the highest year to year fluctuation in precipitation occurs. The lowest amount of cover on the response surface occurs where precipitation is most consistent from year to year. Two consecutive years of above average precipitation appears to cause the most reduced basal cover. It therefore appears that other species may have a competitive advantage

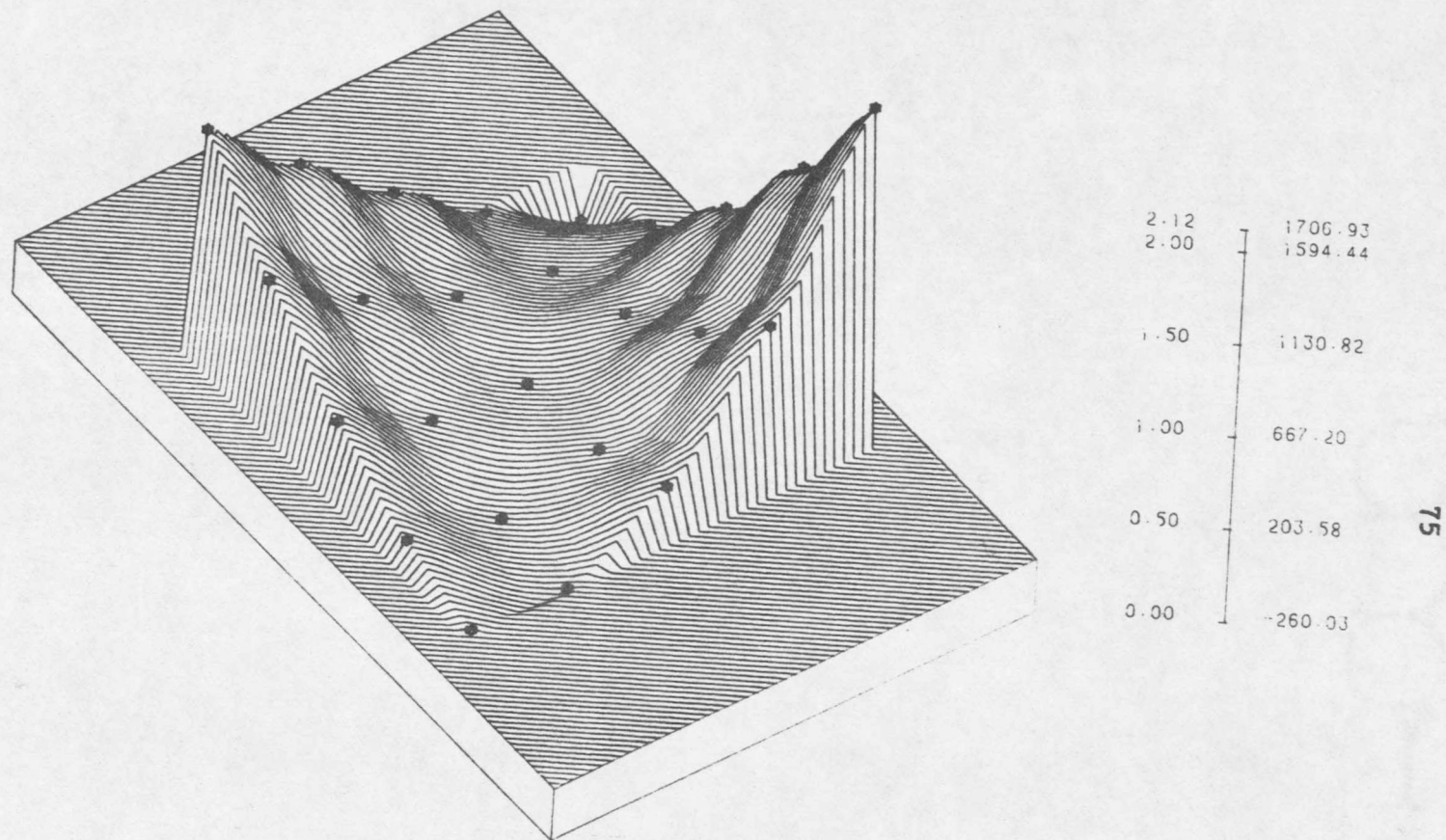


Figure 4. Response of Basal Cover of Western Wheatgrass to Precipitation, All Quadrats. For Description of Graph, See Page 69.

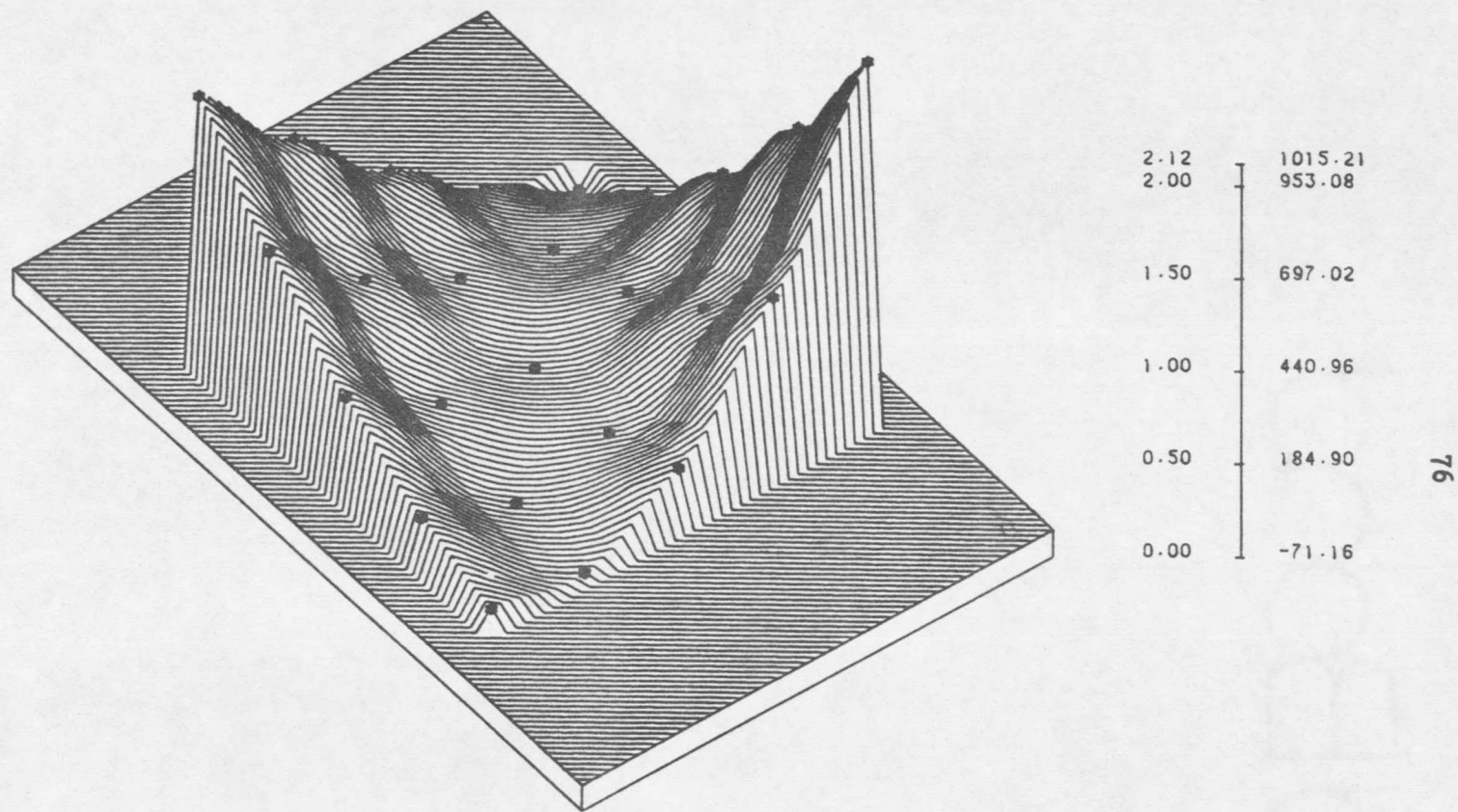


Figure 5. Response of Basal Cover of Western Wheatgrass to Precipitation, Light Grazing. For Description of Graph, See Page 69.

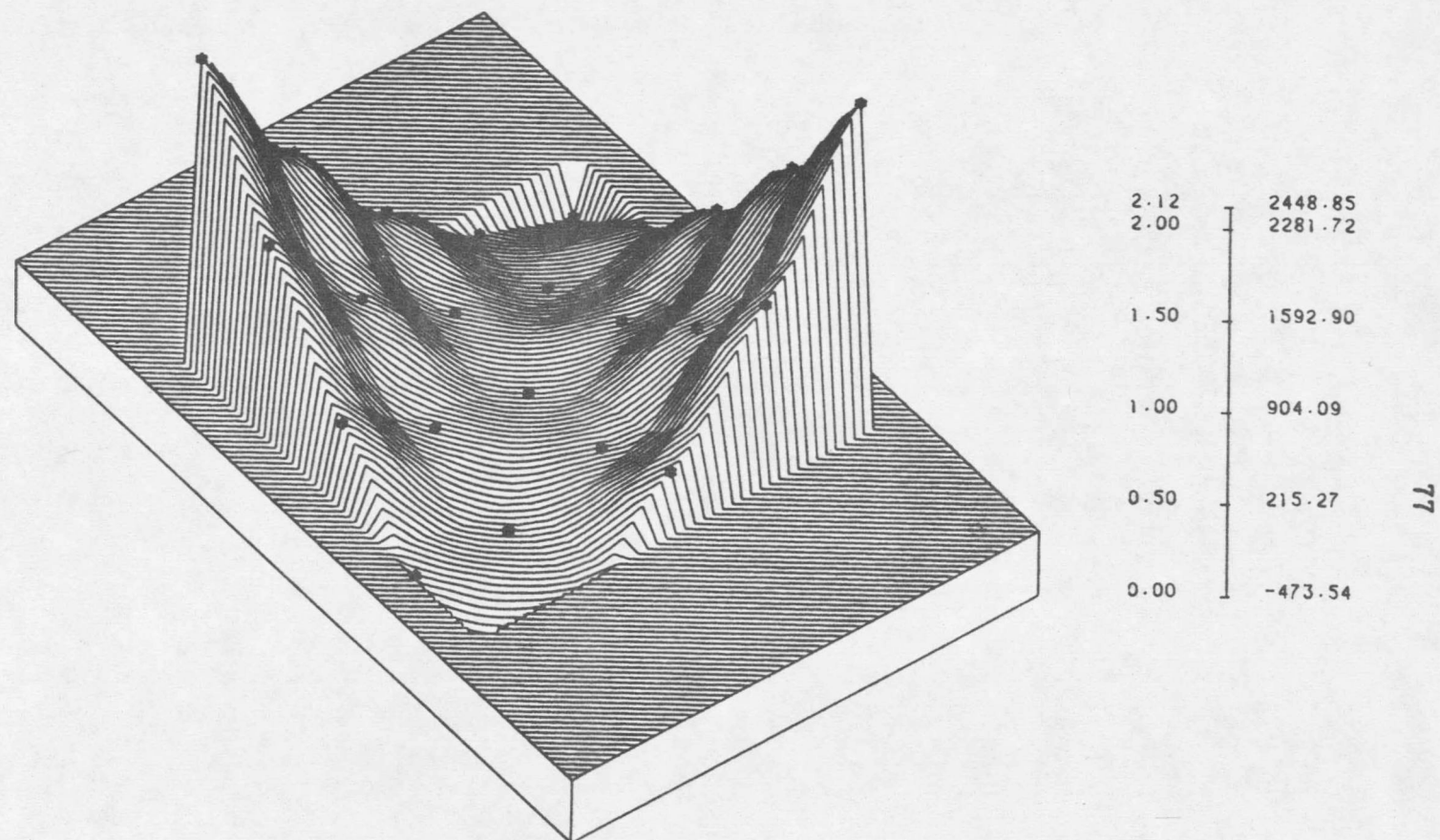


Figure 6. Response of Basal Cover of Western Wheatgrass to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

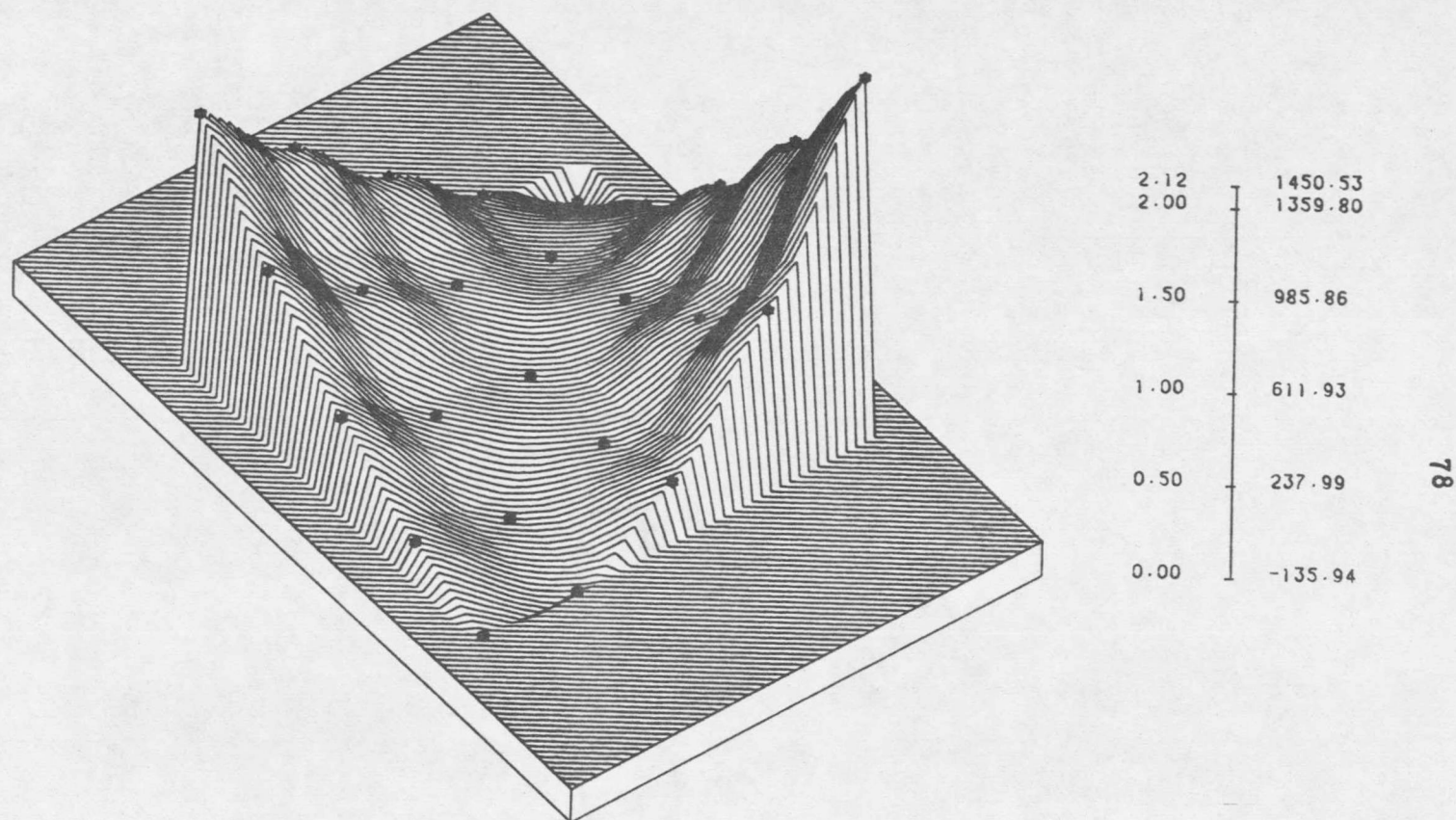


Figure 7. Response of Basal Cover of Western Wheatgrass to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

over western wheatgrass under consistent precipitation conditions, while western wheatgrass has evolved the ability to respond to fluctuating precipitation. Since fluctuating precipitation is characteristic of this region, this may give western wheatgrass a competitive advantage in most years. Reed and Peterson (1961) and Hurtt (1951) stated that western wheatgrass suffered large decreases in cover during prolonged drought. These results are consistent with the predicted cover for consecutive years with low precipitation. Both reports also stated that recovery was slow in the early 1940's, which was a period of consistently above average precipitation. The regression curves likewise provide a possible explanation for this response in that they predicted that cover would be low during consistently high precipitation. However, Coupland (1958) and Newbauer et al. (1980) reported that wheatgrasses generally increase cover during above average precipitation, which contradicted my results. No research information has been found on the effects of fluctuating precipitation on western wheatgrass or any other species.

Moderate grazing appeared to favor western wheatgrass since the greatest amount of cover occurred at this grazing intensity. However, the lowest amounts of cover were also associated with moderate grazing. Heavy grazing ranked second with respect to cover and light grazing had the least amount of predicted cover. However, light grazing also had the smallest negative values. This means that light

grazing will probably result in the least fluctuation in cover and subsequently produce less cyclic fluctuation in the productive capability of the range. Houston and Woodward (1966) also concluded that western wheatgrass was favored by light grazing. Reed and Peterson (1961), however, reported that response to grazing was variable and therefore also depended on other variables. My results also partially agree with them since the curves for each grazing intensity are so similar. It therefore appears that factors other than grazing intensity control cover of western wheatgrass.

Fringed Sagewort

Fringed sagewort was predicted and graphs plotted across all quadrats and at light and moderate grazing intensities (Figs. 8-10). Each graph is different from the others to a certain extent indicating that grazing pressure plays an important role in the response of this species to precipitation. The graph for all quadrats combined does not show any general trends that are readily apparent. Except for a few points, this species responds poorly to fluctuating precipitation, with negative values at points around the edges which indicate extreme fluctuations. In the center, where precipitation fluctuates less from year to year and is near or slightly above average, basal cover appears to be greatest. It is interesting to note that the negative values that were predicted are almost twice as large as the positive values. There does not seem to be any explanation for this, except

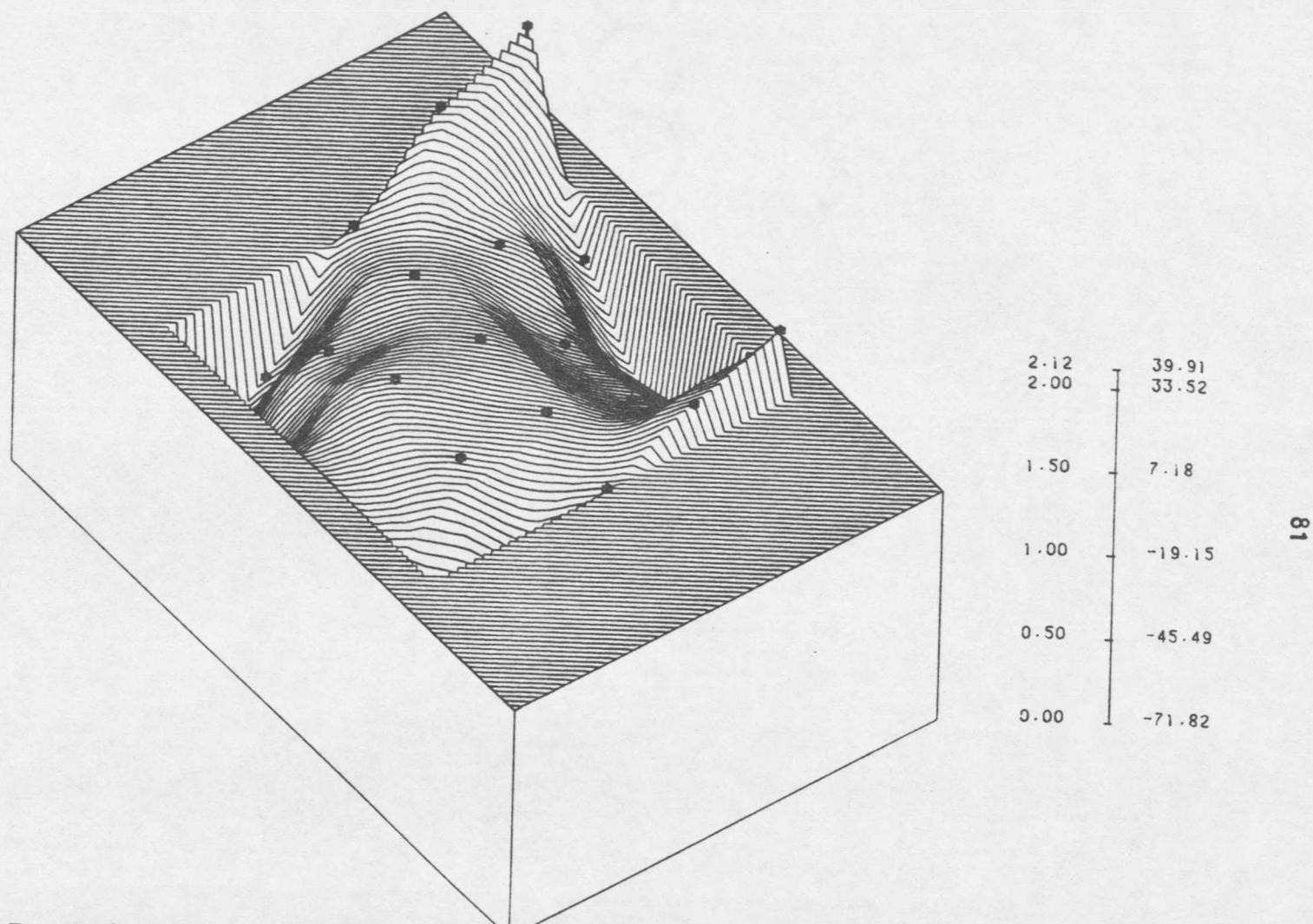


Figure 8. Response of Basal Cover of Fringed Sagewort to Precipitation, All Quadrats. For Description of Graph, See Page 69.

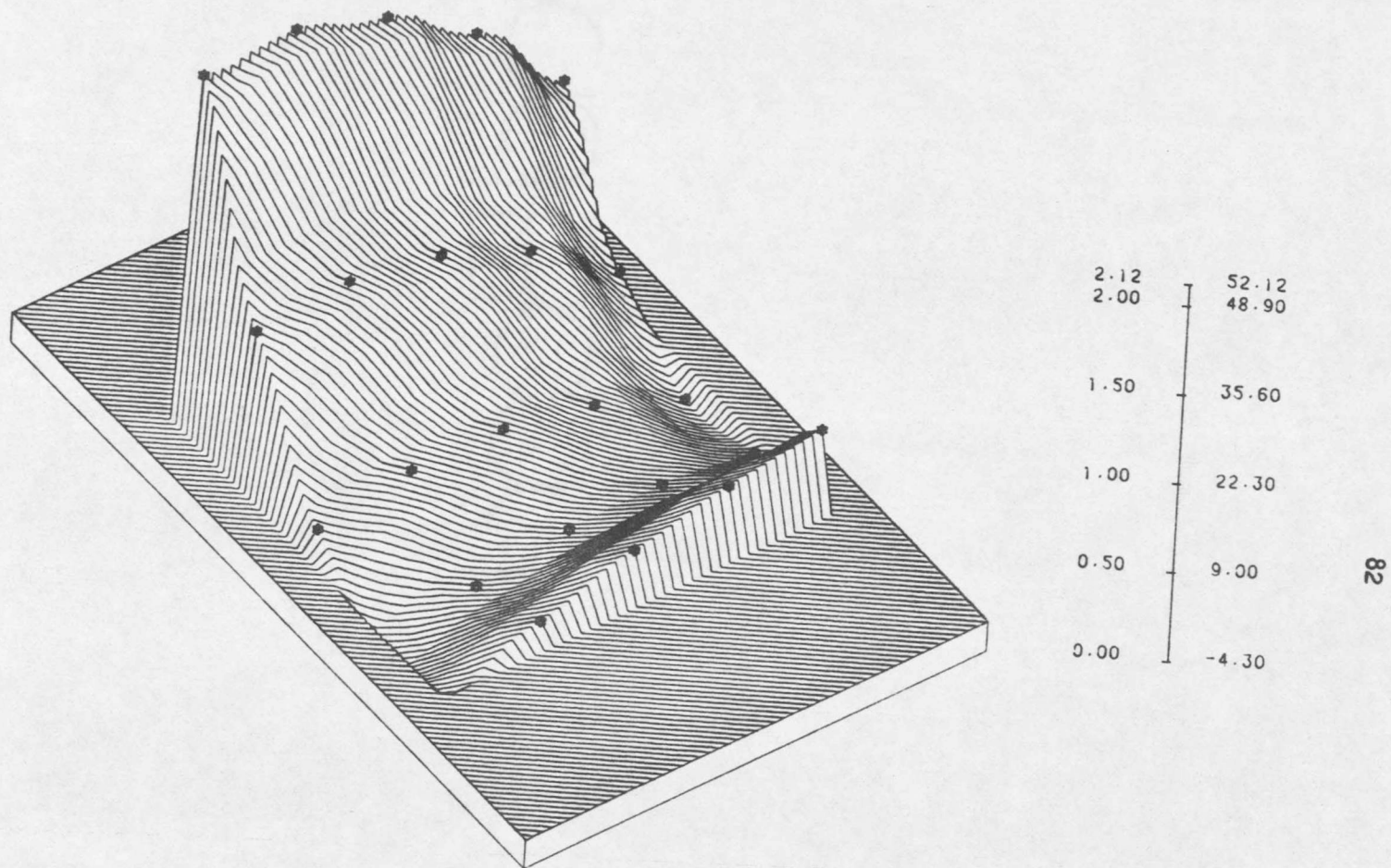


Figure 9. Response of Basal Cover of Fringed Sagewort to Precipitation, Light Grazing. For Description of Graph, See Page 69.

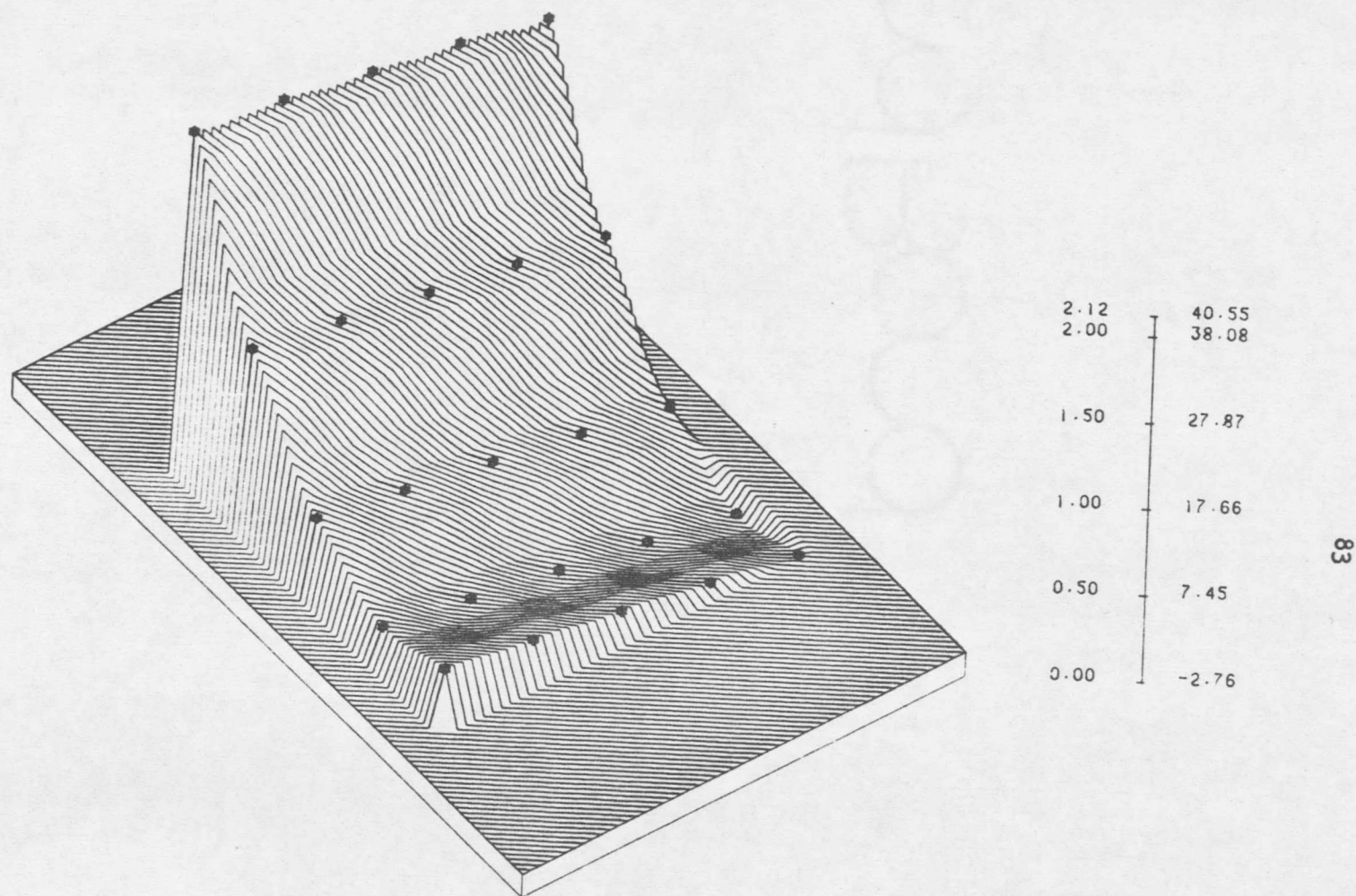


Figure 10. Response of Basal Cover of Fringed Sagewort to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

possibly that this species is simply not favored by the cyclic climate that is common in this region.

The light and moderate grazing intensity graphs are more similar to each other than the graph that combines all quadrats. If other grazing intensities had been separately graphed, it appears their curves would probably have been shaped differently to yield the results seen on the all quadrats curve. It appears that high amounts of precipitation in the previous year are necessary to obtain high amounts of basal cover of fringed sagewort. Current year precipitation has relatively minor effects. Basal cover increases again slightly as precipitation from the previous year becomes extremely low at the 101.6mm (4 inch) level. When precipitation is high in the previous year, the amount of current precipitation appears to have more effect on basal cover under light than under moderate grazing. This tendency showed the greatest response at intermediate values of current year precipitation. In the case of extremely low precipitation during the previous year, high current year precipitation causes the greatest cover response. In contrast to this, the only time that precipitation in the current year affects cover under moderate stocking is at low levels of previous year precipitation. Under these circumstances, cover decreases as current year precipitation increases. For fringed sagewort to increase rapidly following drought, as discussed by Reed and Peterson (1961),

it would need to increase cover when current year precipitation is high and previous year precipitation is low. These curves indicate that a small increase in cover may occur under these circumstances, but not the large increases that might be expected.

Because fringed sagewort is not considered preferred forage for cattle, lowest levels of this species are usually considered optimum. Lowest predicted cover appears to be the result of moderate stocking, although differences are minor between these two grazing intensities. However, Houston and Woodward (1966) contradicted these results when they reported that fringed sagewort was favored by moderate grazing.

Red Threawn

Basal cover response was predicted and plotted for all quadrats combined and for light, moderate, and heavy grazing intensities (Figs. 11-14). All graphs are similar in that cover is low in the middle. This response is characterized by precipitation that is close to the average amount for two consecutive years. Differences among curves, however, were readily apparent at both high and low precipitation values. The curve that combined all quadrats looks very similar to the western wheatgrass curves with the only major difference being the relative amount of predicted cover. Red threawn had only about one tenth as much basal cover as western wheatgrass. Red threawn showed increased cover as fluctuations in precipitation increased.

The shape of the light and heavy grazing intensity curves are

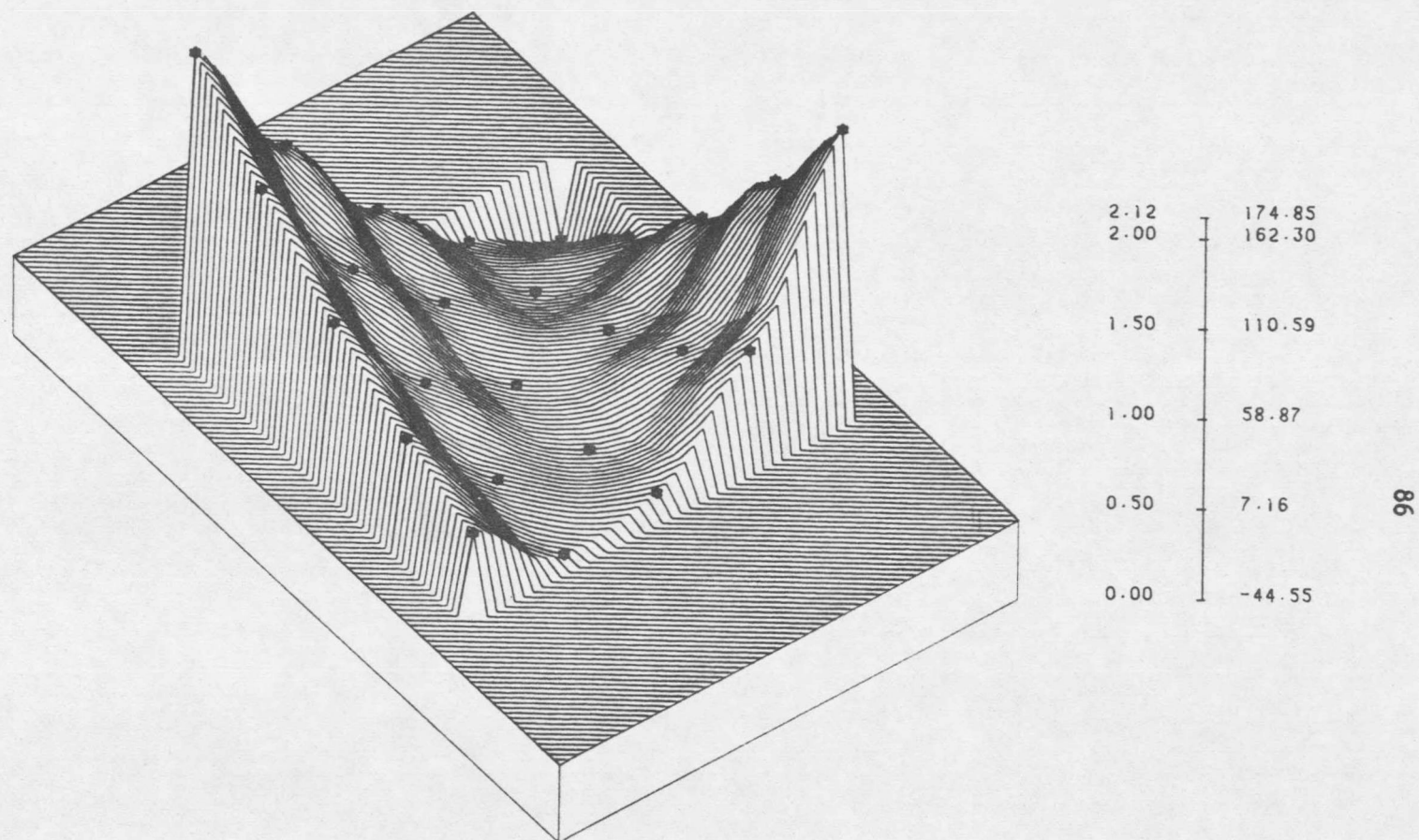


Figure 11. Response of Basal Cover of Red Threawn to Precipitation, All Quadrats. For Description of Graph, See Page 69.

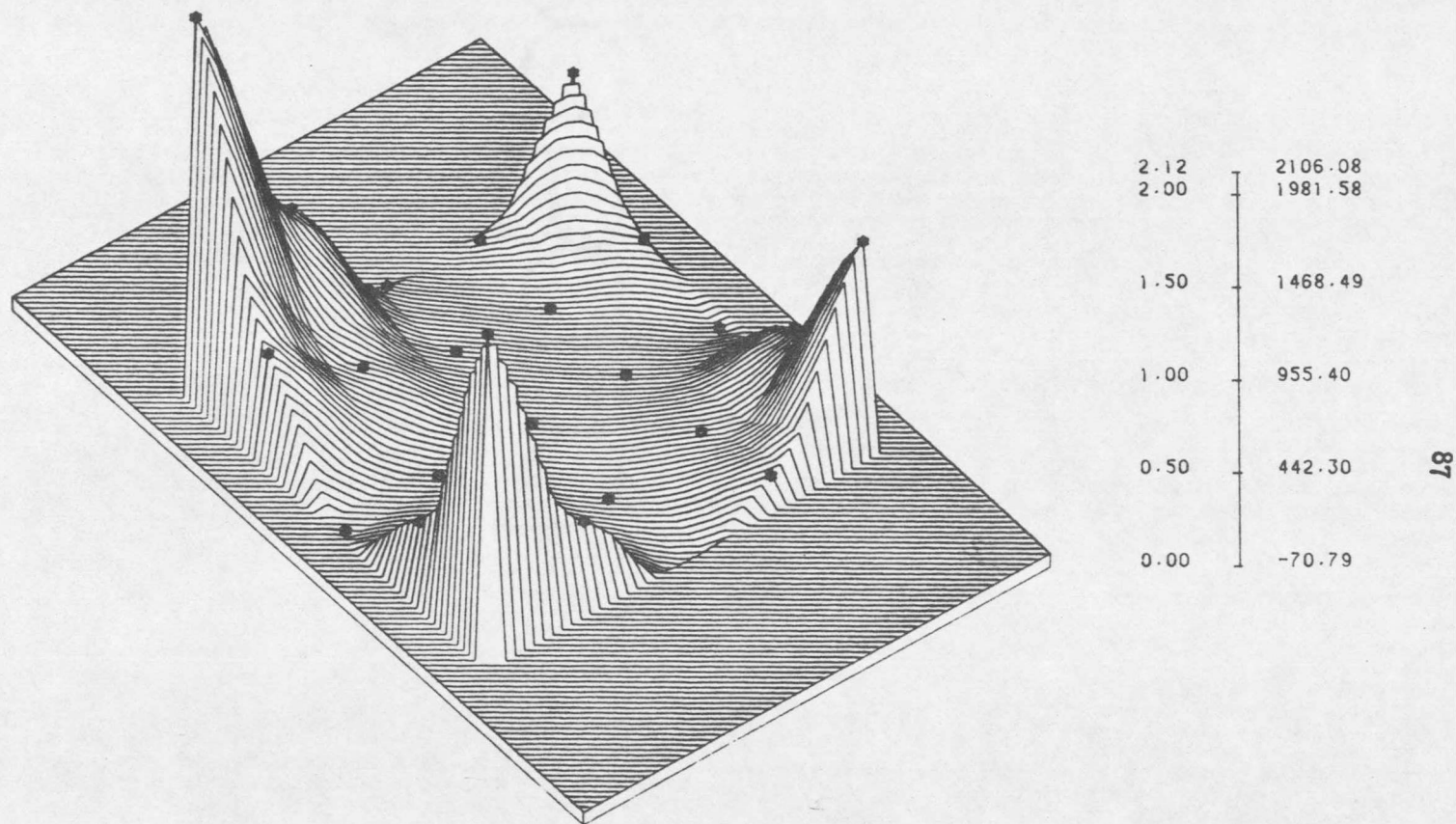


Figure 12. Response of Basal Cover of Red Threeawn to Precipitation, Light Grazing. For Description of Graph, See Page 69.

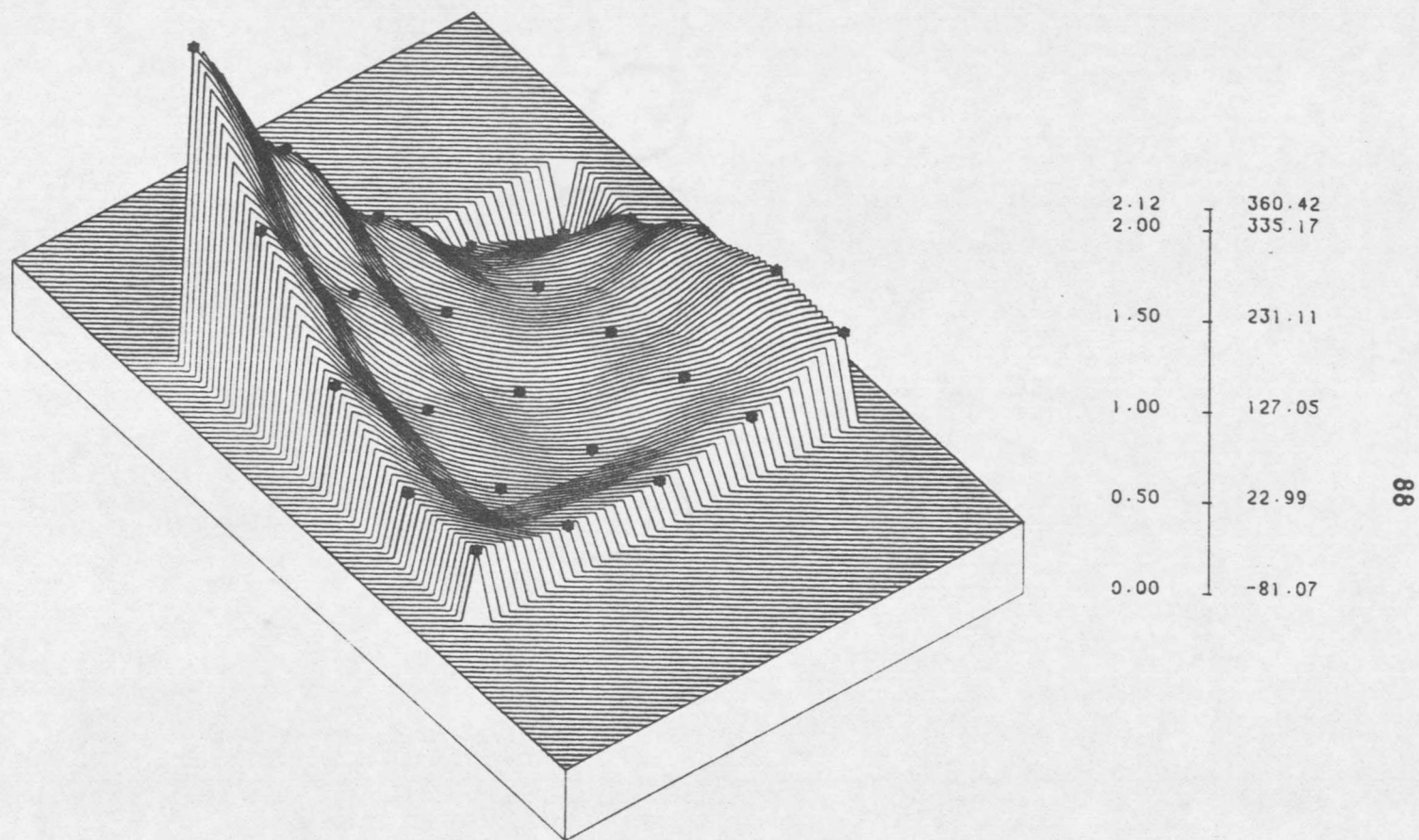


Figure 13. Response of Basal Cover of Red Threeawn to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

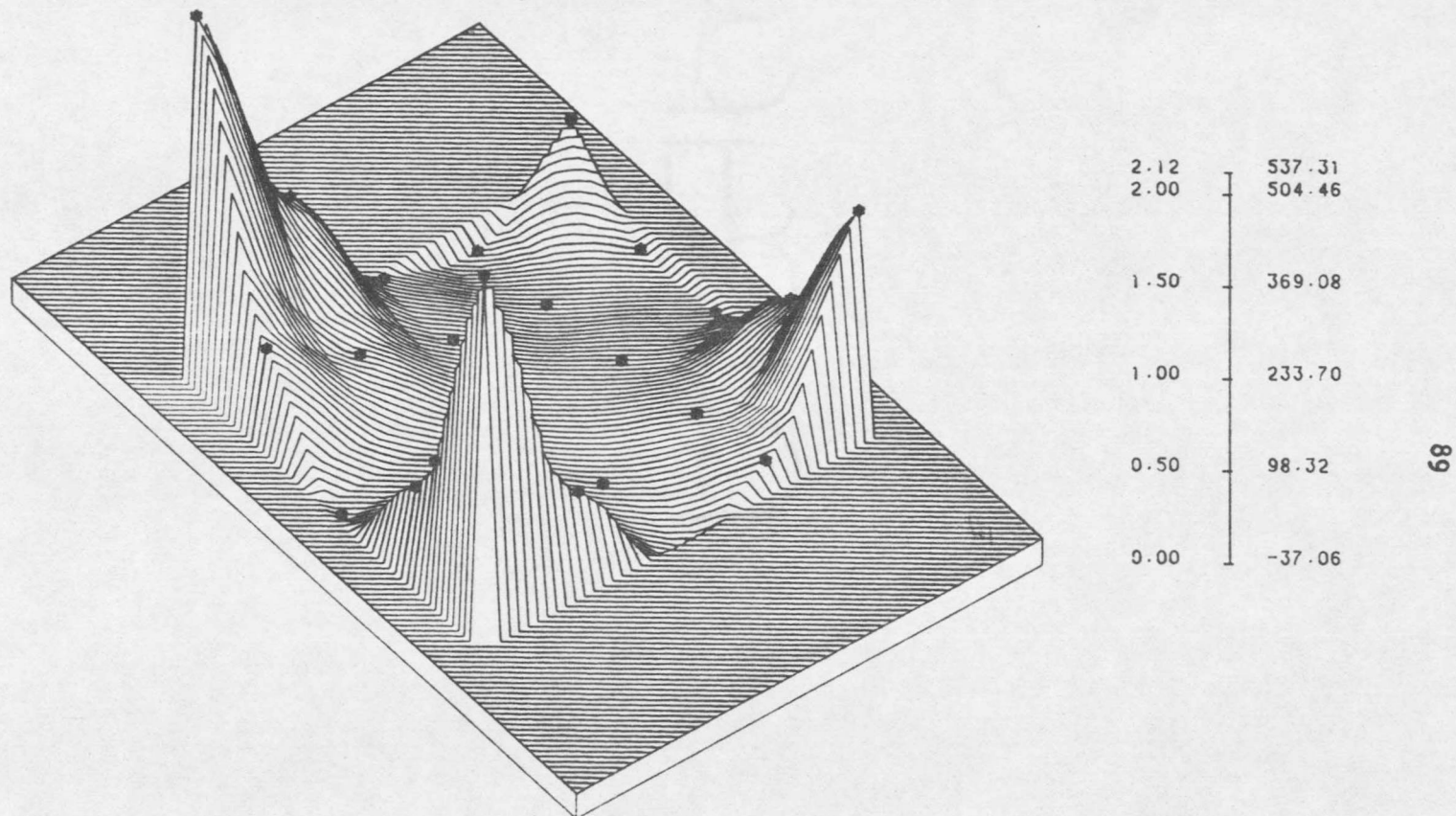


Figure 14. Response of Basal Cover of Red Threawn to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

almost exact replicas, while the moderate grazing intensity curve shows a different response to extreme precipitation conditions (Figs. 12-14). The principle difference between the light and heavy grazing intensity response is that almost four times as much cover is predicted under light grazing. It further appears that red threeawn increases under light or heavy grazing when precipitation conditions are most extreme, whether they vary substantially from year to year or are consecutively high or low for two years. The moderate grazing intensity curve is similar to the curve for all quadrats, except it appears that the relative response to previous precipitation is greater in moderate grazing as opposed to all quadrats. Once again, cover is least after two consecutive years of high precipitation.

Red threeawn is usually considered a strong increaser species on sites which have undergone grazing stress (Reed and Peterson 1961; Houston and Woodward 1966). My results do not support this theory, however, because the greatest amounts of predicted basal cover of red threeawn occurred in the lightest grazed pastures. Since red threeawn is considered an unpalatable species to livestock, it would therefore seem that moderate grazing is the best management practice to use to maintain the lowest level of red threeawn and thereby maintain maximum livestock productivity. In no cases does red threeawn increase to become the dominant species with respect to the amount of basal cover.

Blue Grama

A graph was not constructed for heavy grazing because r^2 values were too low. Figures 15-18 illustrate cover response for other grazing intensities and for all quadrats combined. In each case, the predicted amounts of cover indicate that blue grama is definitely one of the dominant species on this range. The responses found in each category are very similar to those already discussed for red threeawn. It appears that blue grama has thus evolved an ability to thrive under fluctuating precipitation as indicated by higher amounts of cover in association with extreme precipitation values.

It is interesting to note that a negative value of cover was never predicted for all quadrats or moderate grazing, but it is predicted for protected areas or light grazing. This suggests that blue grama has a strong response to grazing pressure as well as climate. Increasing grazing pressure seems to favor the presence of blue grama.

The all quadrats curve (Fig. 15) is similar to the other all quadrats curves previously discussed, in that basal cover is greatest when year to year precipitation fluctuation is greatest. When precipitation is uniform from year to year, predicted basal cover gradually increases as precipitation increases.

The effect of extreme precipitation values on cover depended upon individual grazing intensity. Under protection (Fig. 16), it appeared

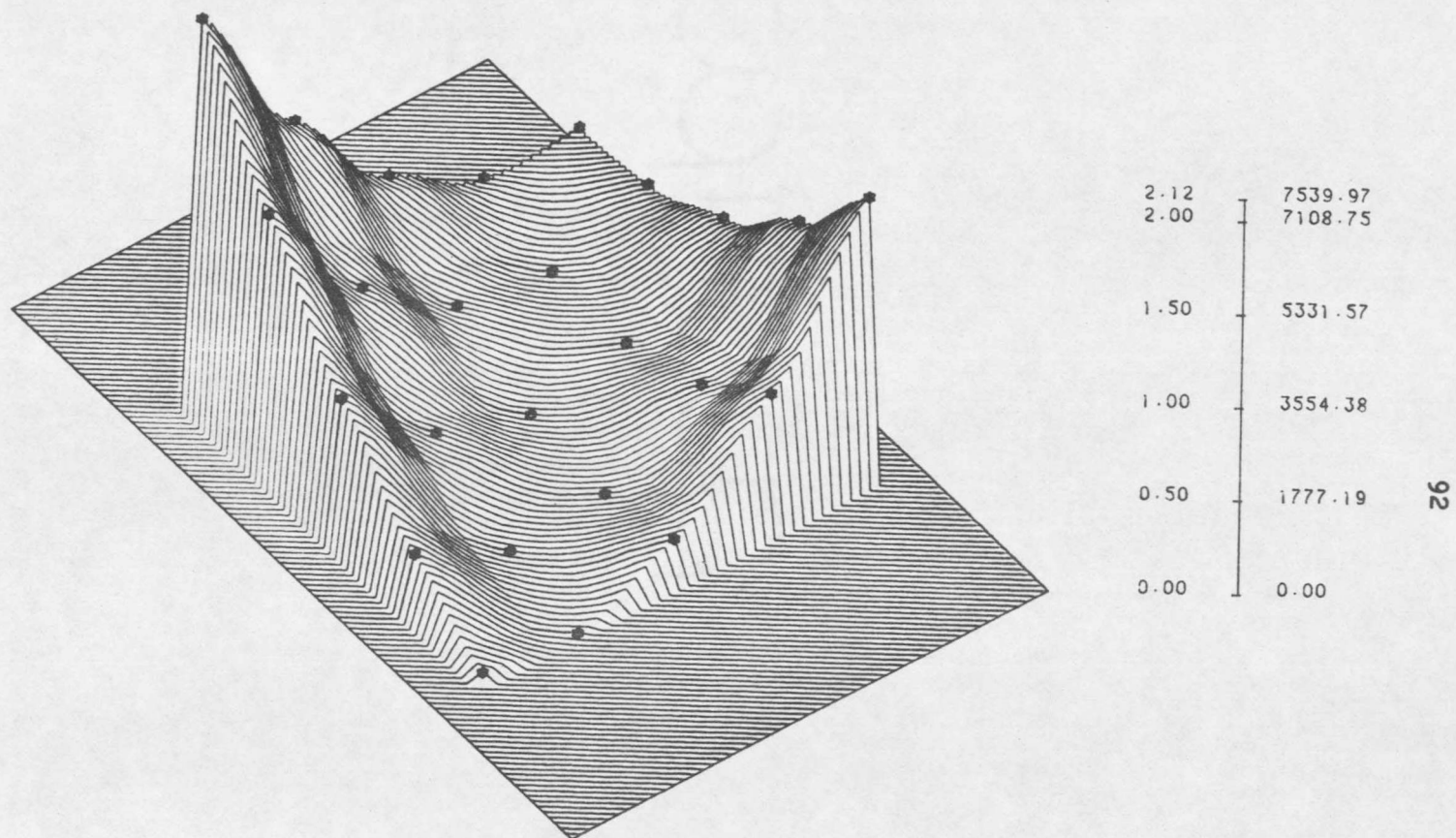


Figure 15. Response of Basal Cover of Blue Grama to Precipitation, All Quadrats. For Description of Graph, See Page 69.

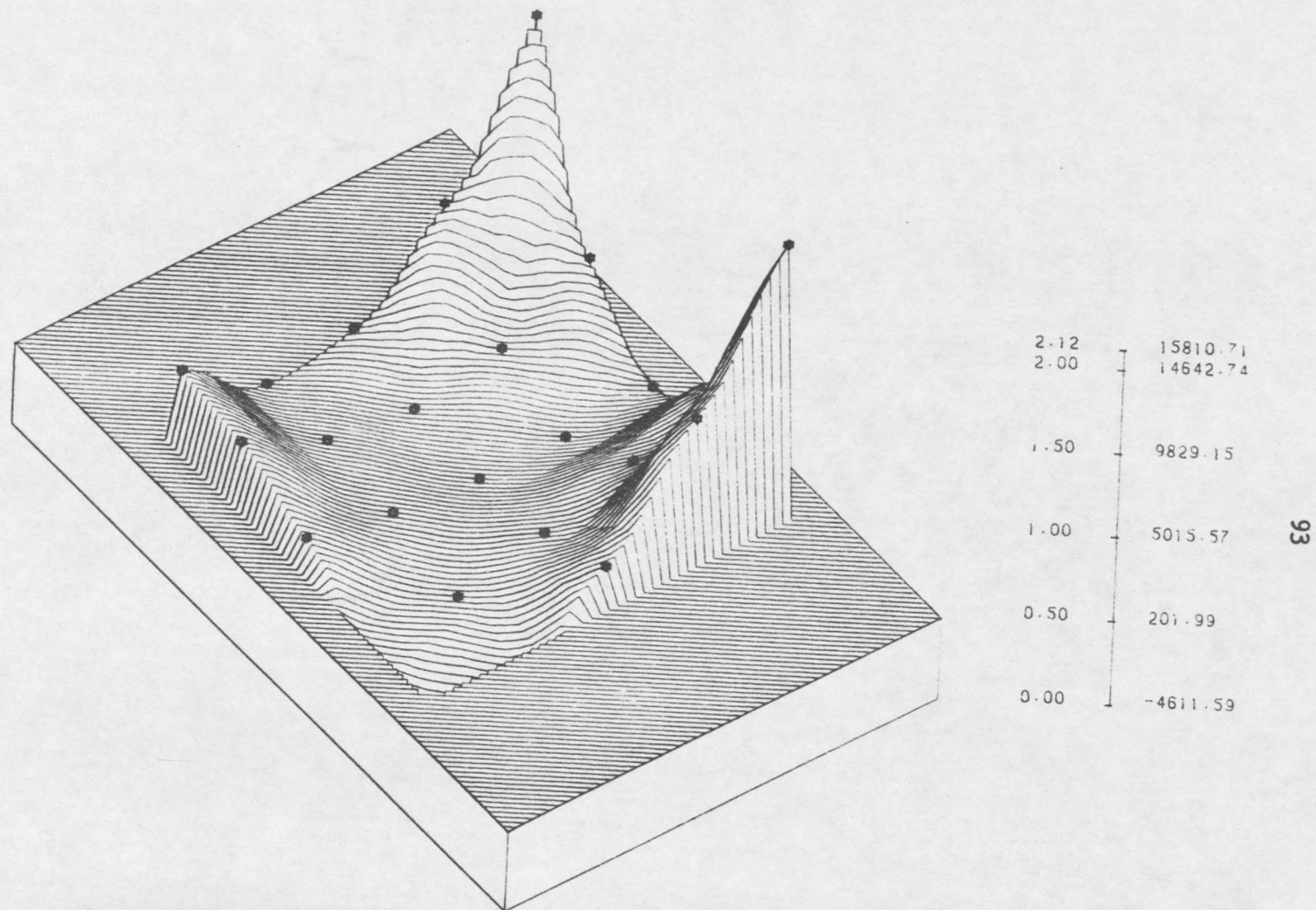


Figure 16. Response of Basal Cover of Blue Grama to Precipitation, No Grazing. For Description of Graph, See Page 69.

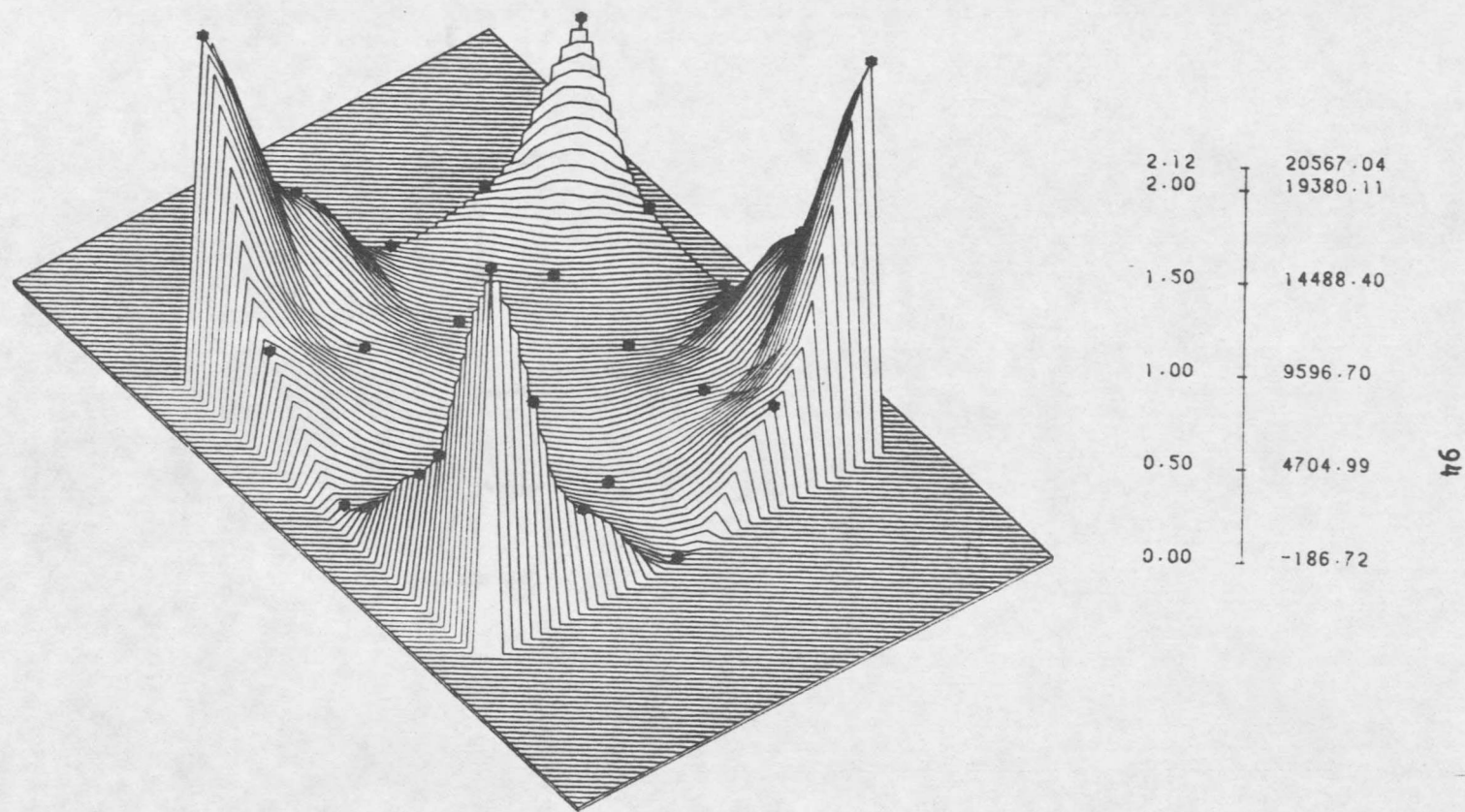


Figure 17. Response of Basal Cover of Blue Grama to Precipitation, Light Grazing. For Description of Graph, See Page 69.

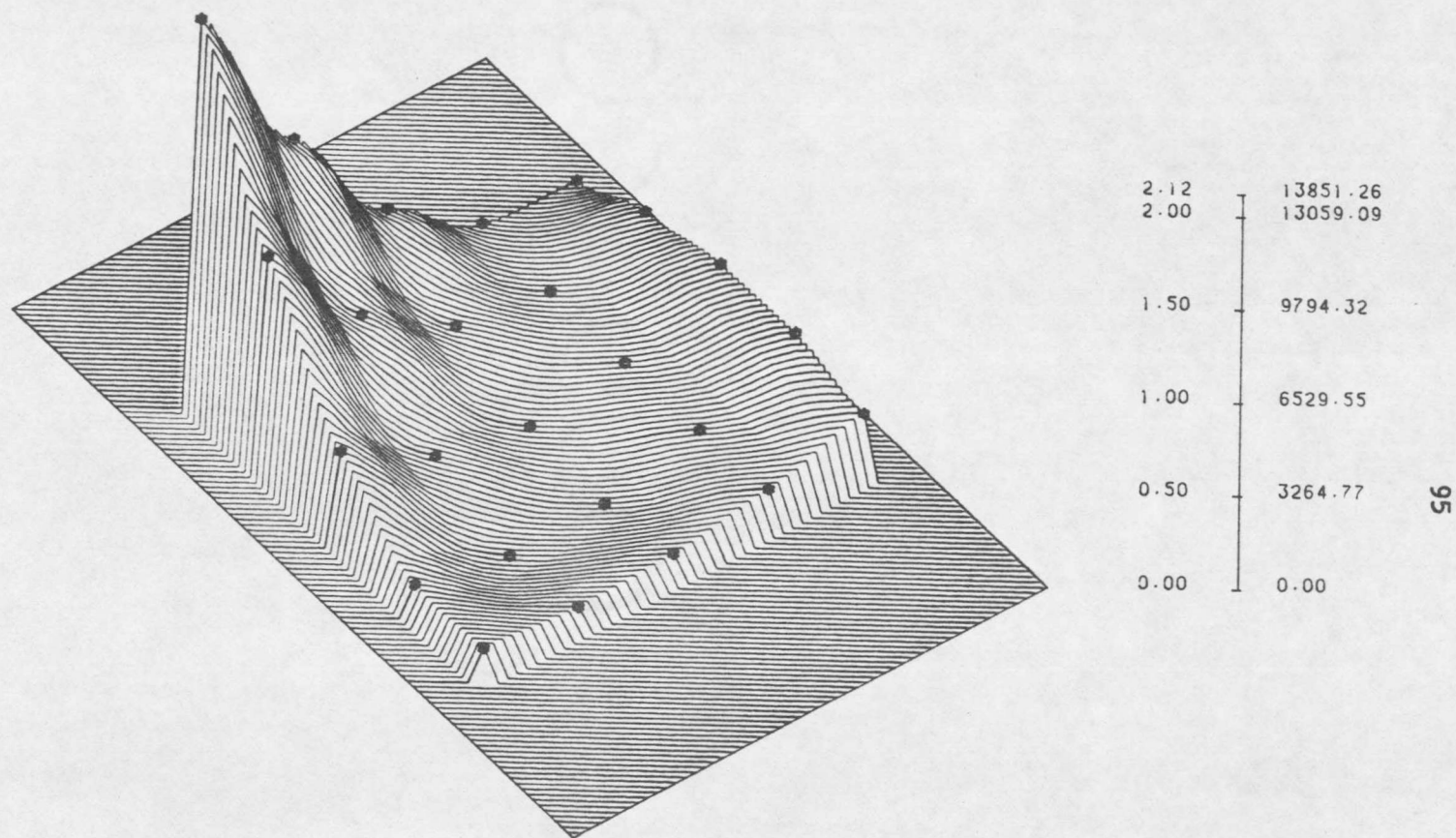


Figure 18. Response of Basal Cover of Blue Grama to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

that current year precipitation was most important because the greatest amount of cover occurred when current year precipitation is highest. This was especially noticeable when previous year precipitation was either extremely low or high. It should be noted that the highest predicted amounts of cover are presented only to illustrate how the species might respond to high precipitation values, because they are greater than the amount possible.

When considering light grazing (Fig. 17), basal cover likewise increased under extreme precipitation regimes. This included both high and low precipitation values that occurred in consecutive years and precipitation fluctuations from year to year. Because the highest predicted amounts were more than twice as much as the amount possible, however, such results were of use only for establishing trends in cover response. In moderate grazing (Fig. 18), the greatest amount of cover appears to occur when previous year precipitation is high and current year precipitation is low. Because my results indicate that blue grama can respond favorably to one or two years of low precipitation, these results therefore do not support the findings of Reed and Peterson (1961) or Hurtt (1951). However, blue grama's response to a longer drought cannot be determined. My results do support Newbauer et al. (1980), who stated that blue grama is a drought tolerant species.

Although blue grama responds differently to precipitation under

different grazing intensities, there is no grazing intensity which strongly favors or penalizes this species. The greatest amount of basal cover appears to occur with light grazing, and the least amount with moderate grazing. However, these values were artificially derived from beyond the limits of the collected data, and so this is probably not a good method to determine which grazing intensity favors cover. Reduced blue grama cover is usually considered an advantage because it is such a low forage producer even though the forage is of good quality and is preferred by livestock. It would therefore seem that moderate stocking might be the best management practice. It also appears that cover is proportionately higher under moderate grazing intensity when average precipitation conditions prevail. This would help to mitigate fluctuations in plant material available from year to year. My results are contrary to those of previous researchers who all indicated that blue grama is generally stimulated by heavier grazing (Reed and Peterson 1961; Houston and Woodward 1966; Clark et al. 1943).

Buffalograss

Buffalograss was predicted and graphed in all categories (Figs. 19-23). High predicted amounts of basal cover confirm that buffalograss is an important species in the mixed grass prairie of this region. As discussed previously, some of the predicted values of cover exceed the amount possible and are useful only to illustrate

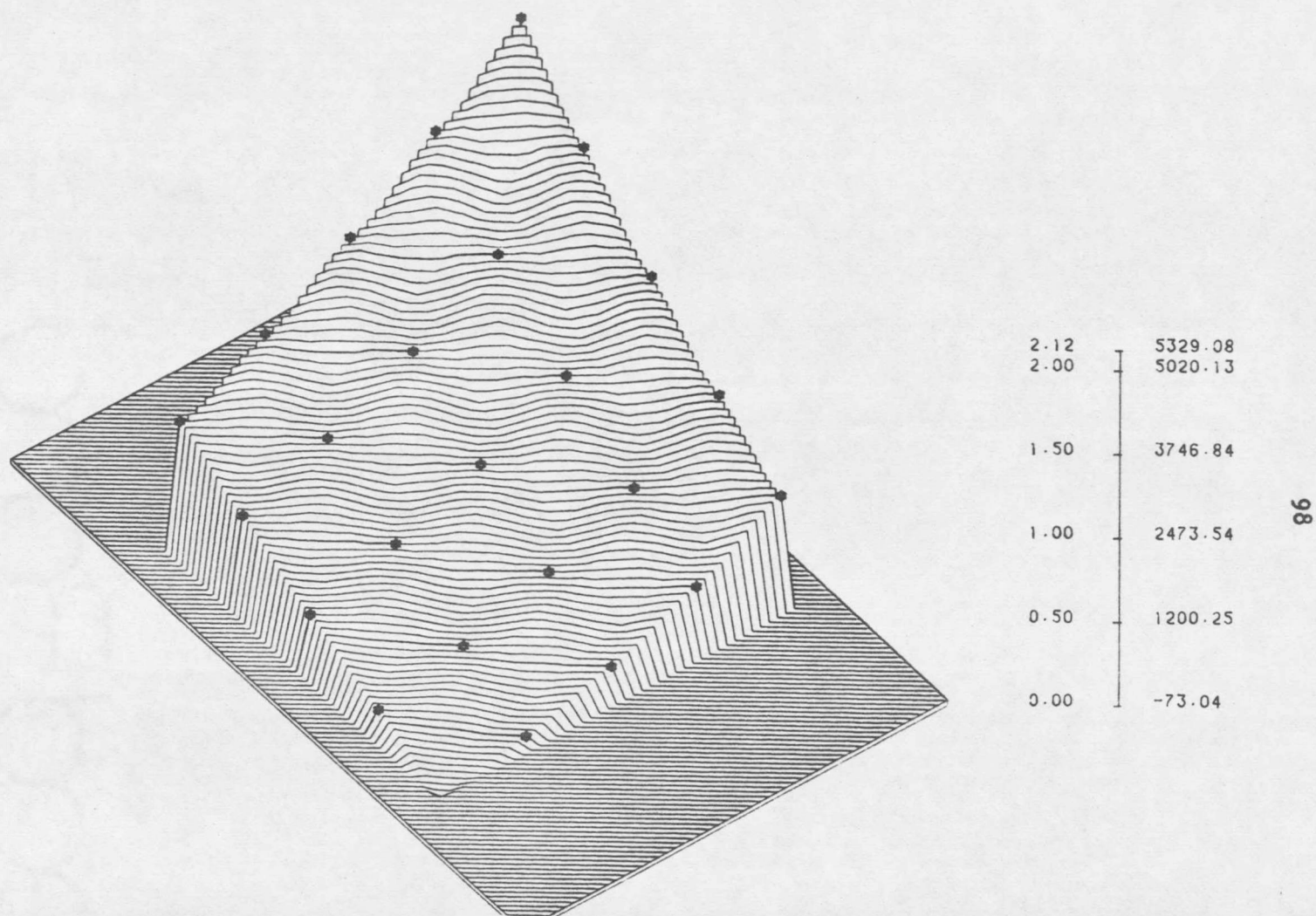


Figure 19. Response of Basal Cover of Buffalograss to Precipitation, All Quadrats. For Description of Graph, See Page 69.

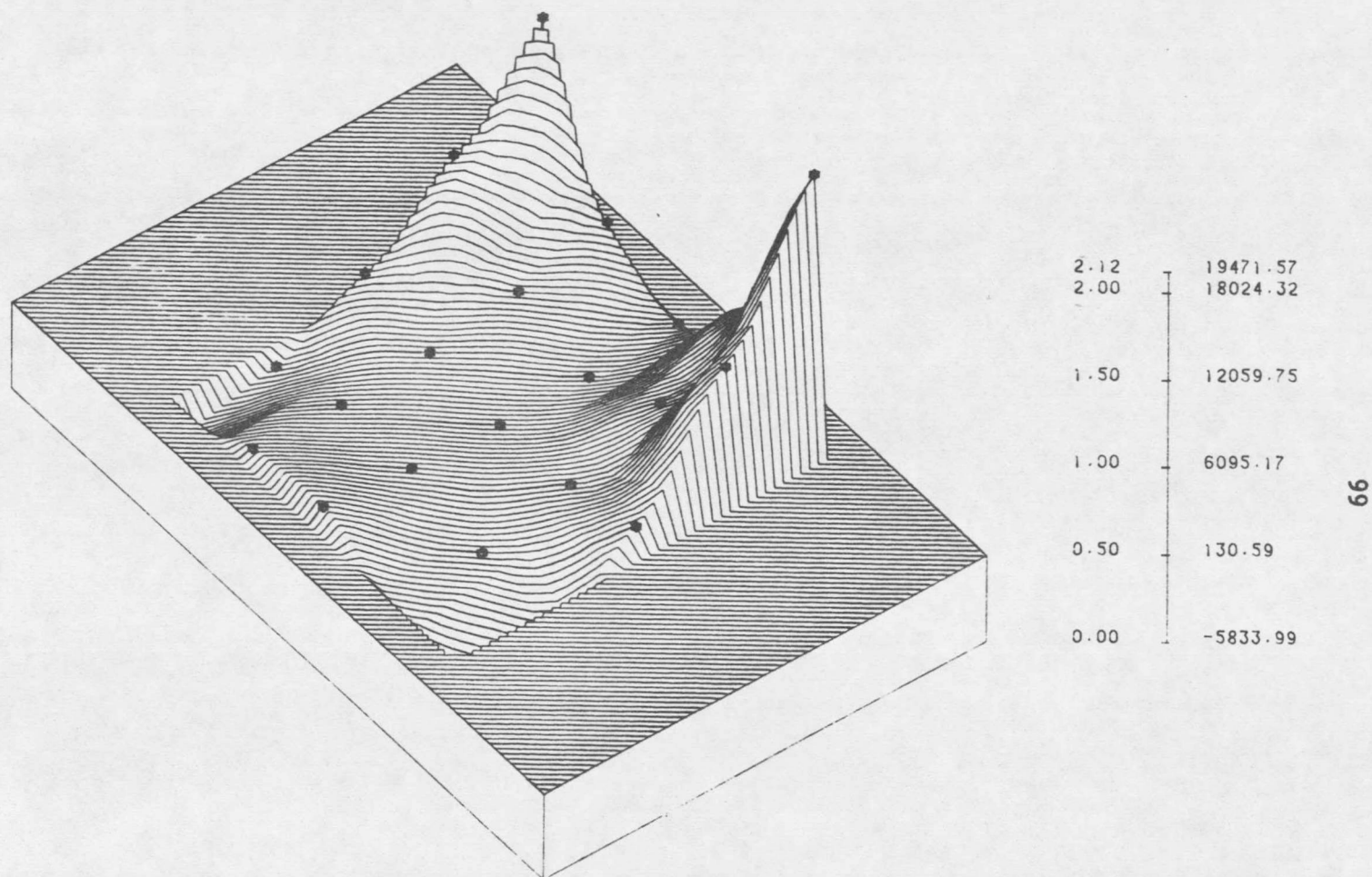


Figure 20. Response of Basal Cover of Buffalograss to Precipitation, No Grazing. For Description of Graph, See Page 69.

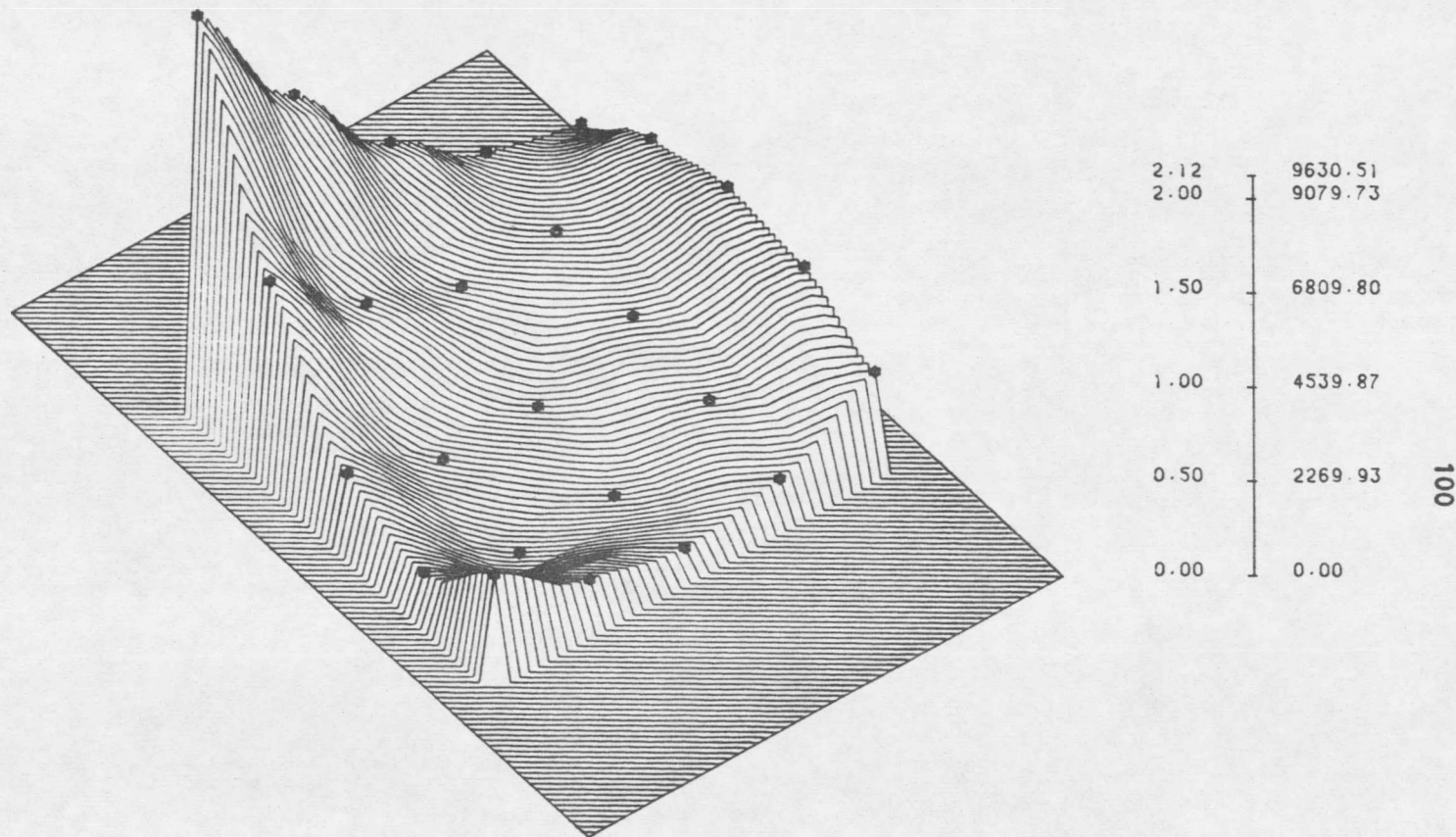


Figure 21. Response of Basal Cover of Buffalograss to Precipitation, Light Grazing. For Description of Graph, See Page 69.

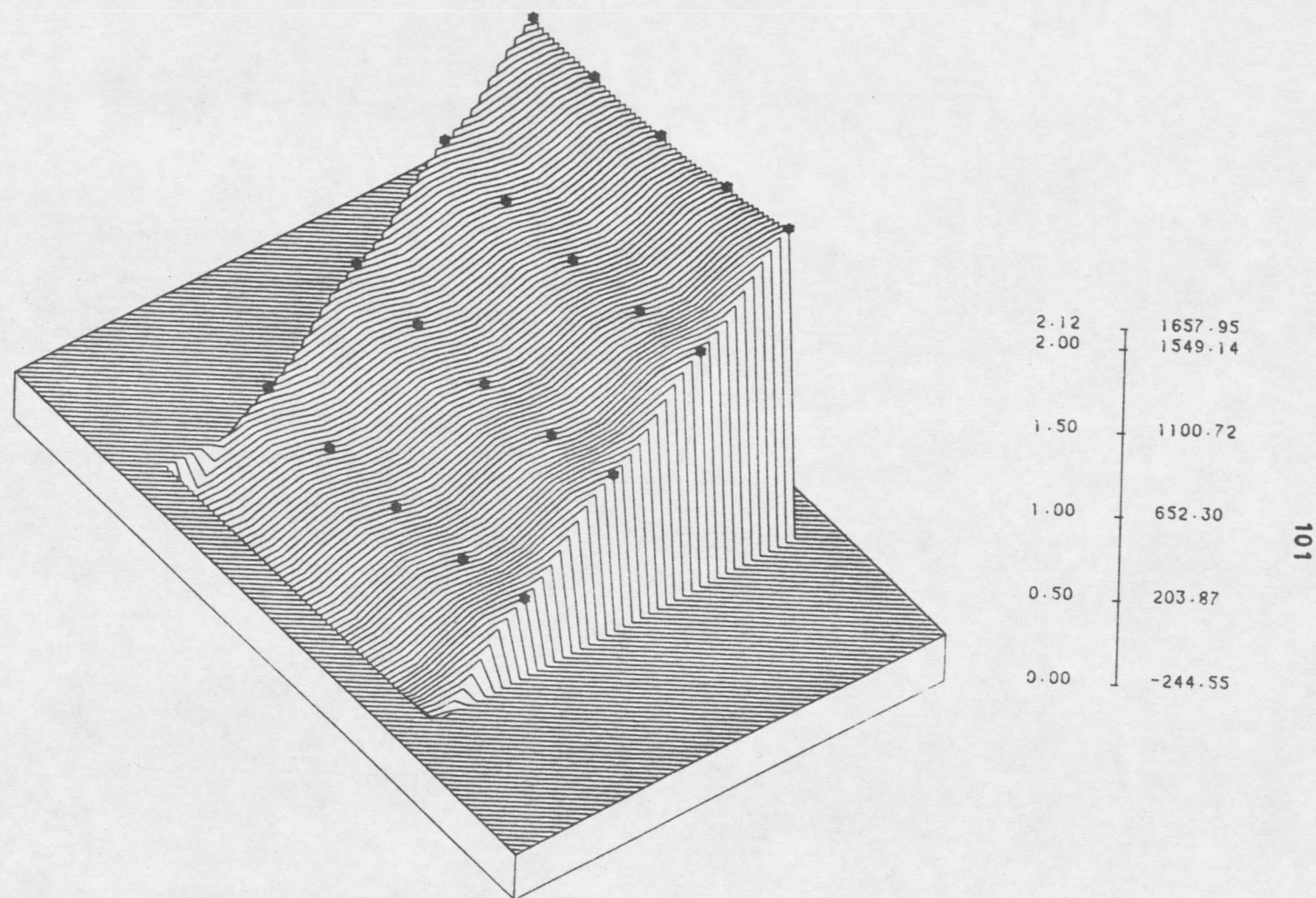


Figure 22. Response of Basal Cover of Buffalograss to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

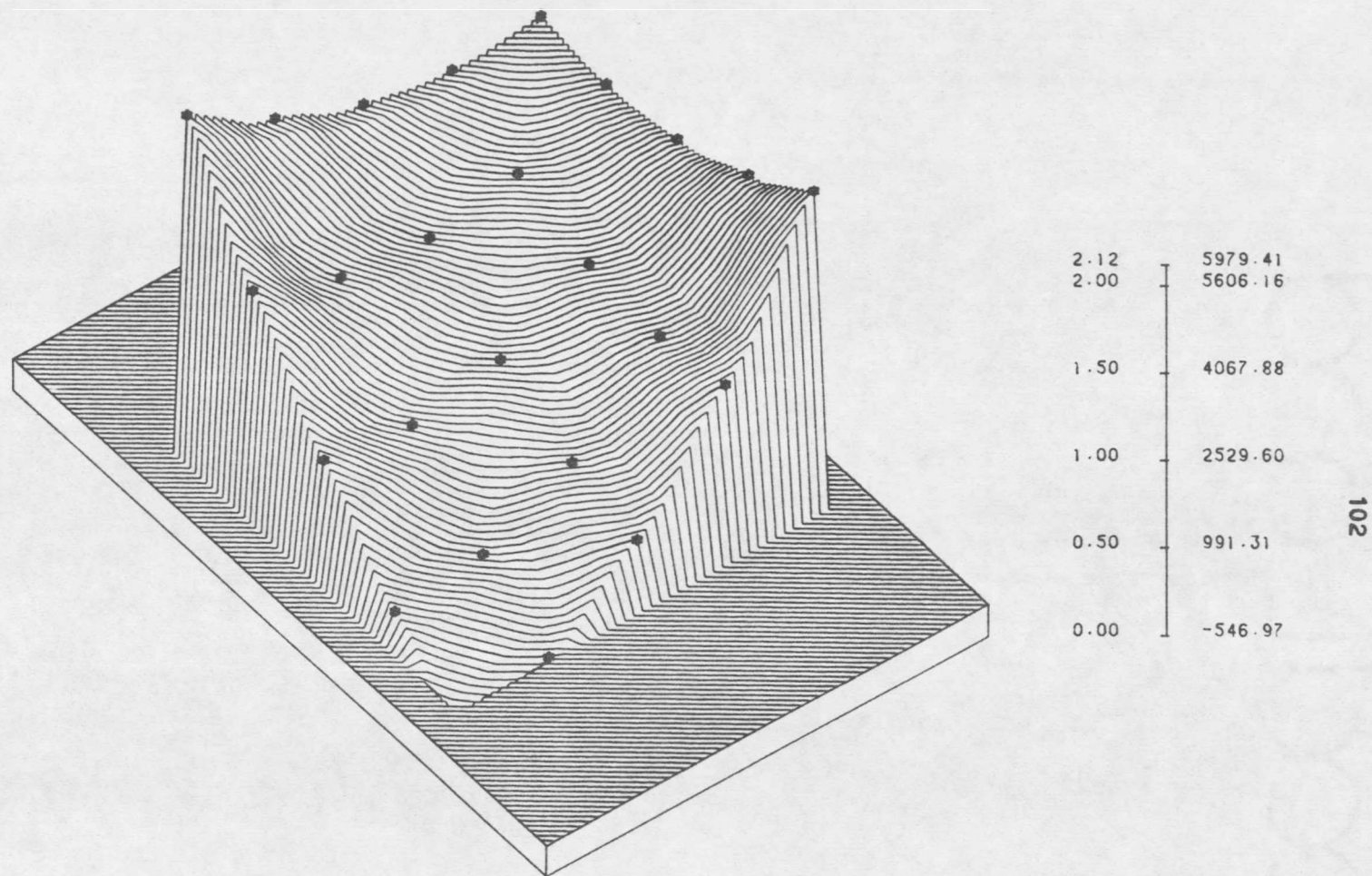


Figure 23. Response of Basal Cover of Buffalograss to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

trends in cover. This situation developed only on the graph for the protected areas (Fig. 20). Response varied a great deal from one grazing intensity to another indicating that grazing pressure played an important role in the response of basal cover to precipitation.

When the overall response to precipitation was considered without regard to grazing intensity, it was apparent that basal cover of buffalograss increased with increased precipitation (Fig. 19). Cover was greatest with two consecutive years of high precipitation with an apparent linear decrease in cover as either previous or current year precipitation decreased. This suggests that the total cumulative precipitation for both years is probably most directly related to basal cover. This hypothesis is further supported by the order in which independent variables entered the buffalograss multiple regression equations. Interaction variables entered early, and hence they seemed more important than individual precipitation variables considered alone. In the case of wide variation in year to year precipitation, response appears to be the same regardless of the relative order of low or high precipitation. The cover of buffalograss has been previously reported to respond inversely with western wheatgrass (Reed and Peterson 1961). This theory is confirmed by my predicted results with cover for buffalograss being highest where western wheatgrass cover is lowest and vice versa.

Buffalograss seemed to respond more to current year precipitation

under nonuse than previous year precipitation (Fig. 20). This was indicated by the greatest amount of cover being predicted when current year precipitation is high. The highest values were predicted when previous year precipitation was either extremely high or low. This may indicate that buffalograss is well adapted to precipitation extremes and fluctuations. The immediate response to high current precipitation that was shown by my regression equations agrees with results presented by previous researchers (Reed and Peterson 1961; Coupland 1958; Weaver and Albertson 1940; Albertson and Tomanek 1965). They reported that buffalograss quickly recovers from drought in a year of high precipitation. These researchers also stated that buffalograss cover decreases drastically during drought, and this is consistent with the low cover that was predicted by my equations at low precipitation values.

Buffalograss responds inversely when under light grazing as opposed to when it is not grazed (Fig. 21). The greatest amount of cover is predicted when previous year precipitation was high and current year precipitation is low. There is also a slight increase in cover as current precipitation increases. This response does not agree with reports of other researchers who reported that buffalograss responds quickly in a year of increased precipitation (Reed and Peterson 1961; Coupland 1958; Weaver and Albertson 1940; Albertson and Tomanek 1965). Why this occurs could not be determined from the

information that was available in my study.

The moderate grazing curve (Fig. 22) is similar to the no grazing curve (Fig. 20), except that cover is high when current year precipitation is high, regardless of precipitation in the previous year. There appears to be a direct linear response between current year precipitation and basal cover. In addition, results from Figure 22 further support the hypothesis that buffalograss cover can increase rapidly in a year of high precipitation even if there was a drought in the previous year.

The heavy grazing response (Fig. 23) is very similar to the response with all quadrats combined (Fig. 19). Cover increased linearly as precipitation increased regardless of the year in which precipitation occurred. However, cover under heavy grazing increased a great deal more when precipitation fluctuated widely than it did on the all quadrats curve. Once again it appeared that, to some extent, buffalograss and western wheatgrass are responding inversely to each other.

Buffalograss is a desirable forage species. However, because it is a relatively low forage producer, it is usually desirable to limit buffalograss cover. This would normally allow more cover of the higher producing western wheatgrass. The greatest cover of buffalograss was obtained with no grazing. Progressively less cover was predicted under light, heavy, and moderate grazing, respectively.

Therefore, it appeared that moderate grazing would be most effective in limiting buffalograss basal cover, and would consequently be best for livestock production. Reed and Peterson (1961) and Houston and Woodward (1966) both stated that buffalograss was favored by heavy grazing, which is not in agreement with my results.

Threadleaf Sedge

Regression equations for threadleaf sedge yielded acceptable r^2 values for only the heavy grazing intensity (Fig. 24). Although grazing intensity might play an important role in the cover response of this species to precipitation, only limited effects of precipitation could be reliably interpreted. It appears that threadleaf sedge may respond more readily to high previous year precipitation during years when current year precipitation is low. When previous year precipitation is not particularly high, cover increased slightly as current year precipitation increased. Threadleaf sedge appeared to be relatively drought tolerant because there was some cover in even the lowest precipitation regimes. This is in agreement with results presented by Reed and Peterson (1961), Hurtt (1951), and Newbauer et al. (1980) who stated that threadleaf sedge is drought tolerant and does not lose as much cover as other species during times of drought.

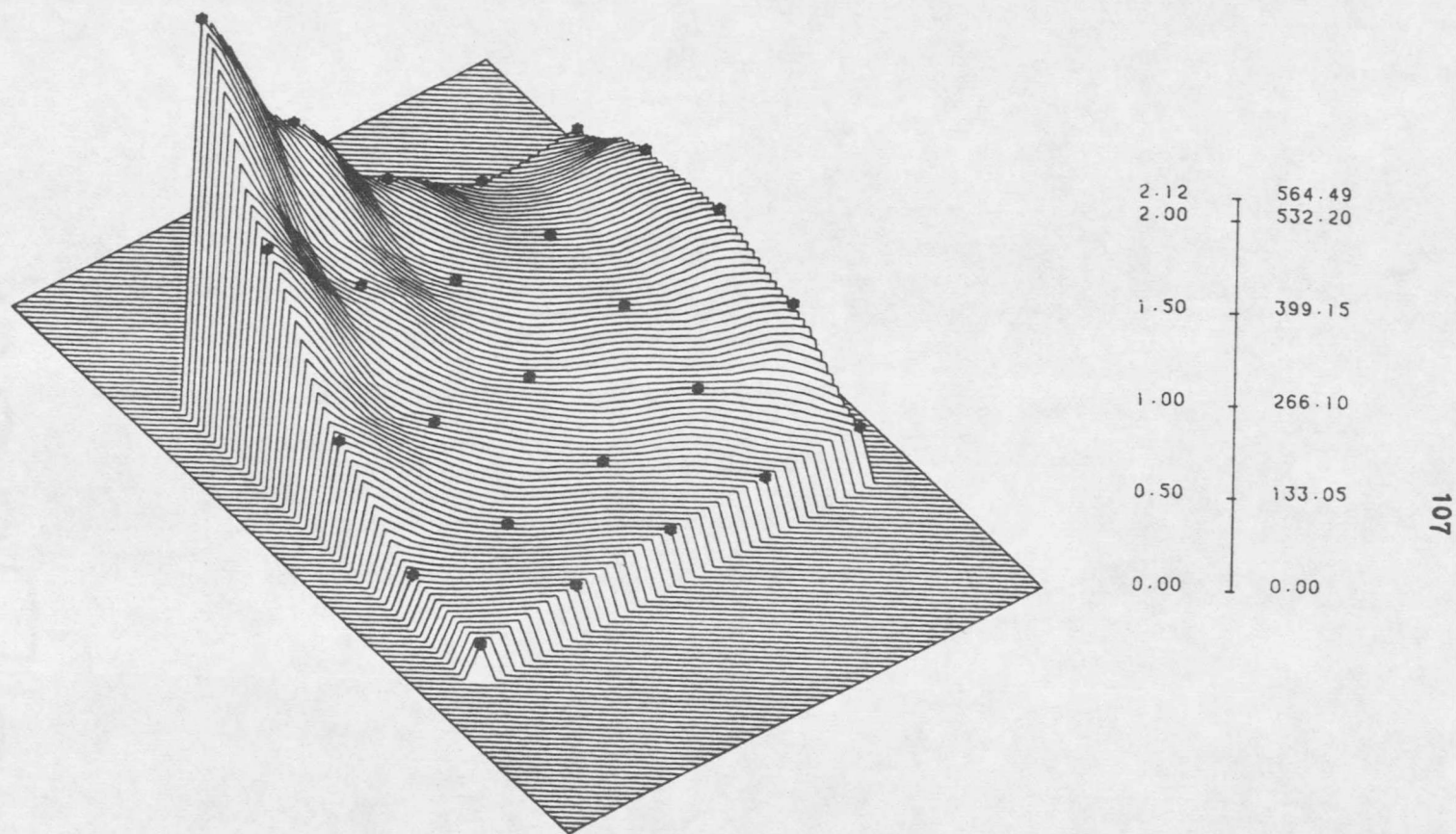


Figure 24. Response of Basal Cover of Threadleaf Sedge to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

Needleleaf Sedge

Needleleaf sedge was graphed at only the moderate and heavy grazing intensities because of low r^2 values at other grazing intensities (Figs. 25 and 26). When considering both graphs, cover appeared to be greatest when precipitation did not vary in consecutive years. The greatest amounts occurred when precipitation was highest.

The moderate grazing curve (Fig. 25) indicates that large amounts of cover were predicted when current year precipitation was high. The greatest response was observed at high current year precipitation in combination with average to above average previous year precipitation. There was also a slight increase in basal cover at low amounts of current year precipitation. Therefore, extremely high or low previous year precipitation seems to disfavor basal cover, while extremely high or low current year precipitation seems to enhance cover.

On the heavy grazing curve, only consistent precipitation allows the presence of this species with year to year fluctuations causing large negative values to be predicted (Fig. 26). Cover was greatest when precipitation was either very high or very low for two consecutive years.

Moderate stocking appears to favor needleleaf sedge with cover being 6.5 times greater under moderate stocking. Houston and Woodward (1966) also stated that needleleaf sedge was favored by moderate grazing, although Reed and Peterson (1961) concluded that there was no

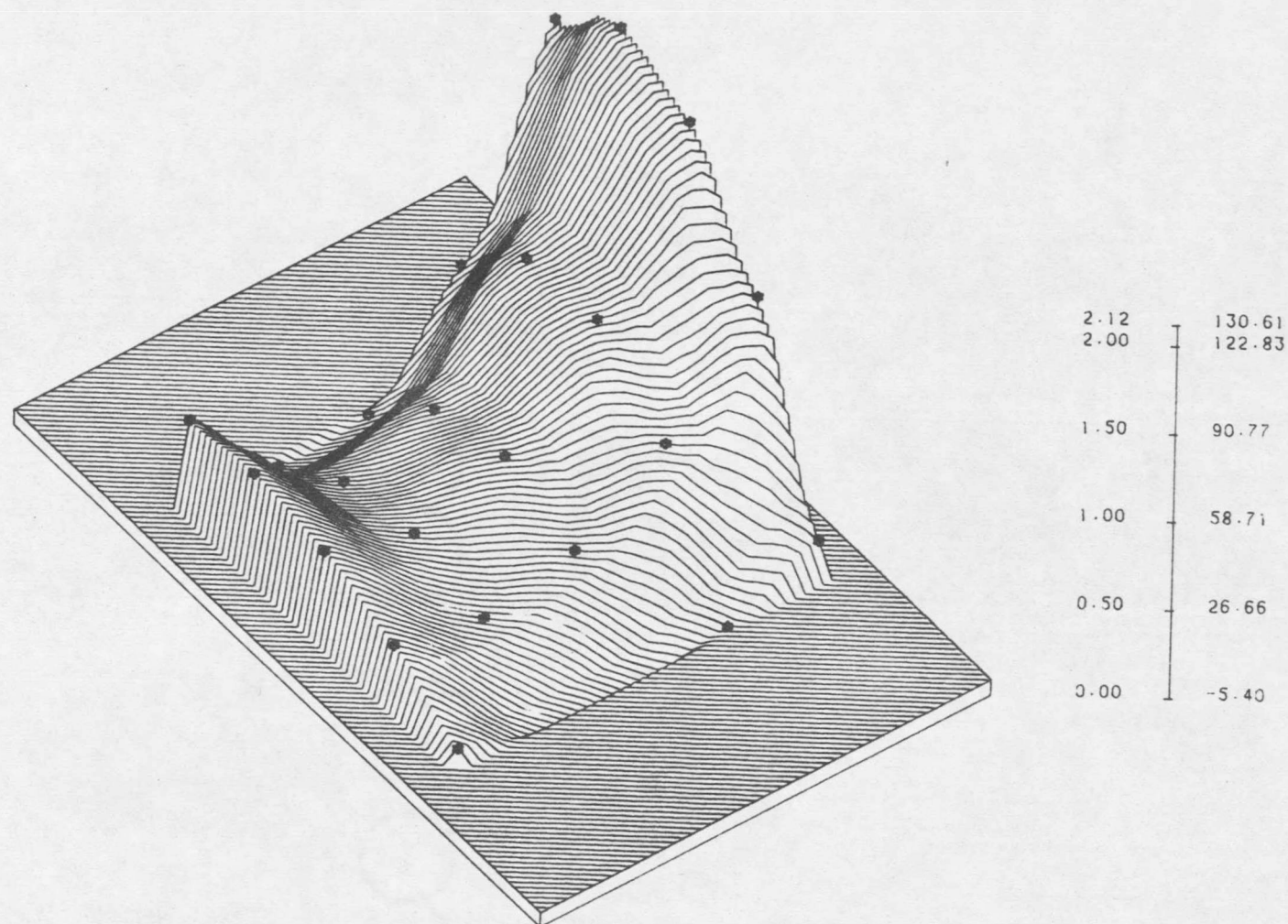


Figure 25. Response of Basal Cover of Needleleaf Sedge to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

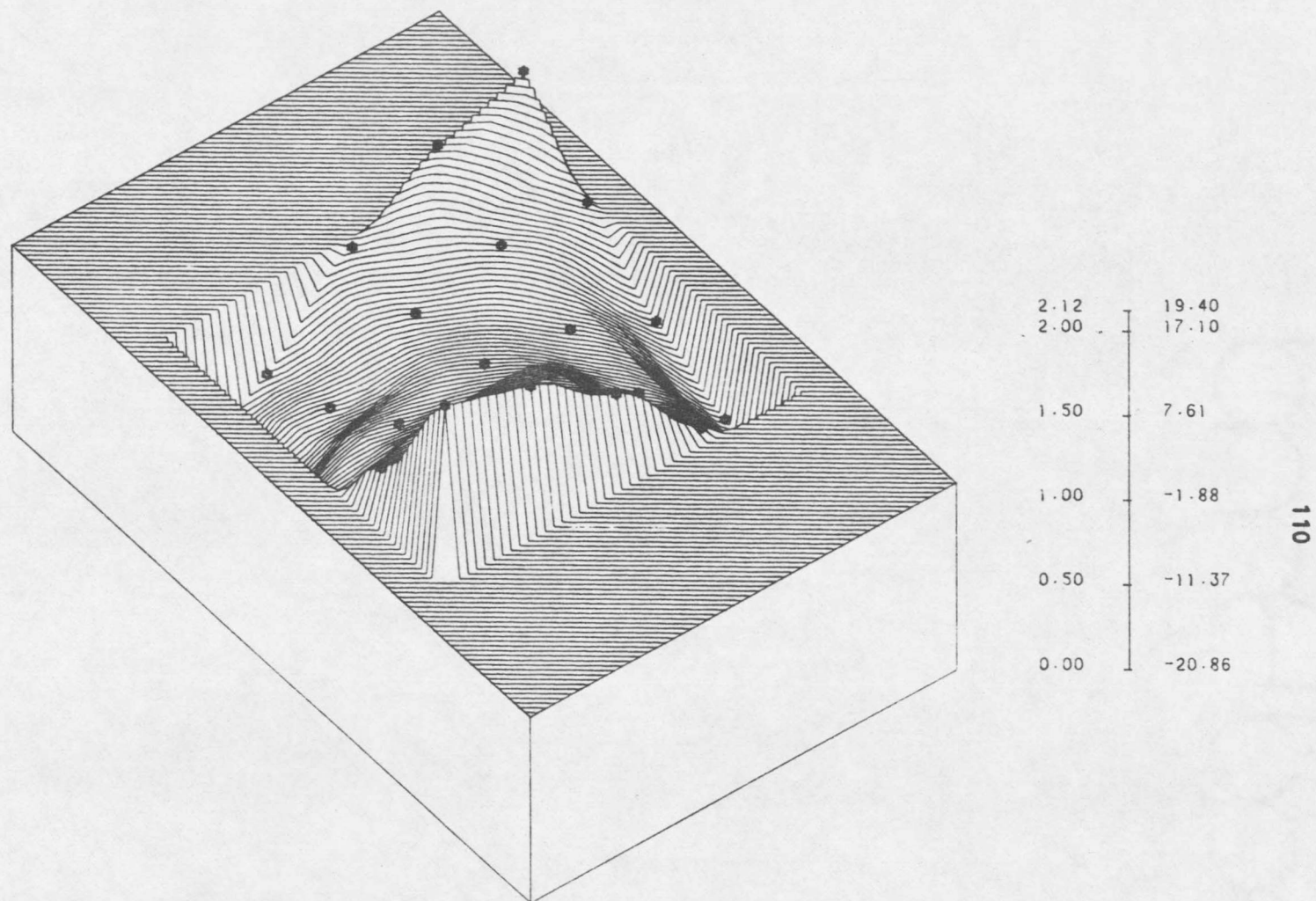


Figure 26. Response of Basal Cover of Needleleaf Sedge to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

response to grazing. Since it is a low producer of forage, needleleaf sedge is not very important for livestock production especially at these relatively low amounts of cover.

Tumblegrass

Cover was graphed for nonuse, light, and heavy grazing (Figs. 27-29). Tumblegrass showed greatest cover under nonuse when previous year precipitation was high and current year precipitation was low (Fig. 27). Cover values were generally very low or even negative for all other precipitation regimes. The graphs for light and heavy grazing are very similar with greater amounts of cover being associated with year to year fluctuation in precipitation (Figs. 28 and 29). The major difference between grazing intensities was that predicted cover under heavy grazing was much greater than that under light grazing, and this would therefore suggest that heavy grazing favors this species. However, a even greater amount of cover was predicted for no grazing, so tumblegrass is apparently also favored by not being grazed. Therefore, these results agree with those of Reed and Peterson (1961), as long as the no grazing category is considered.

Scarlet Globemallow

Good r^2 values were obtained for scarlet globemallow and cover was therefore graphed for all categories considered (Figs. 30-34). When combining all quadrats (Fig. 30), cover is greatest with consistently high precipitation, and it decreases gradually as

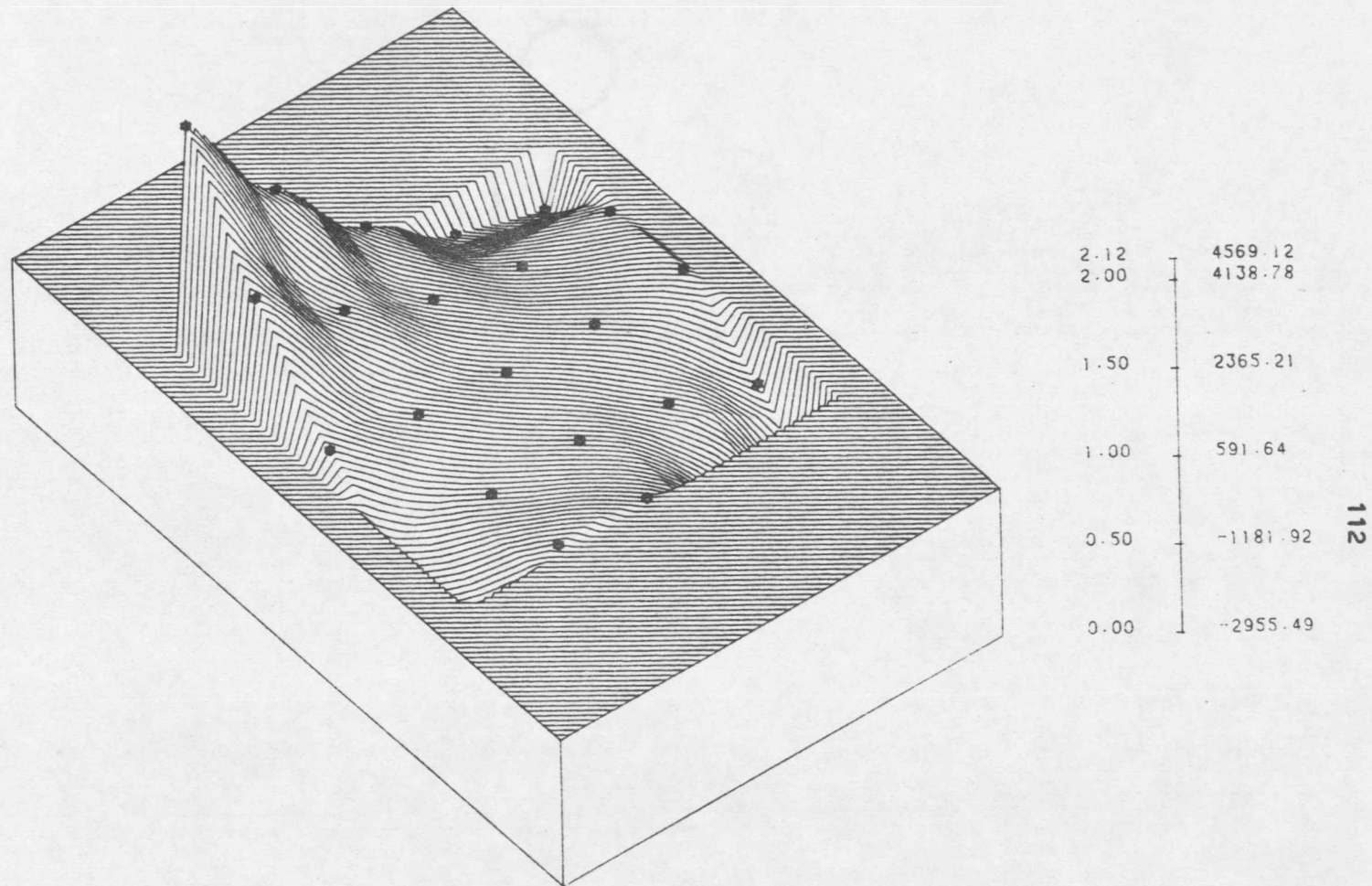


Figure 27. Response of Basal Cover of Tumblegrass to Precipitation, No Grazing. For Description of Graph, See Page 69.

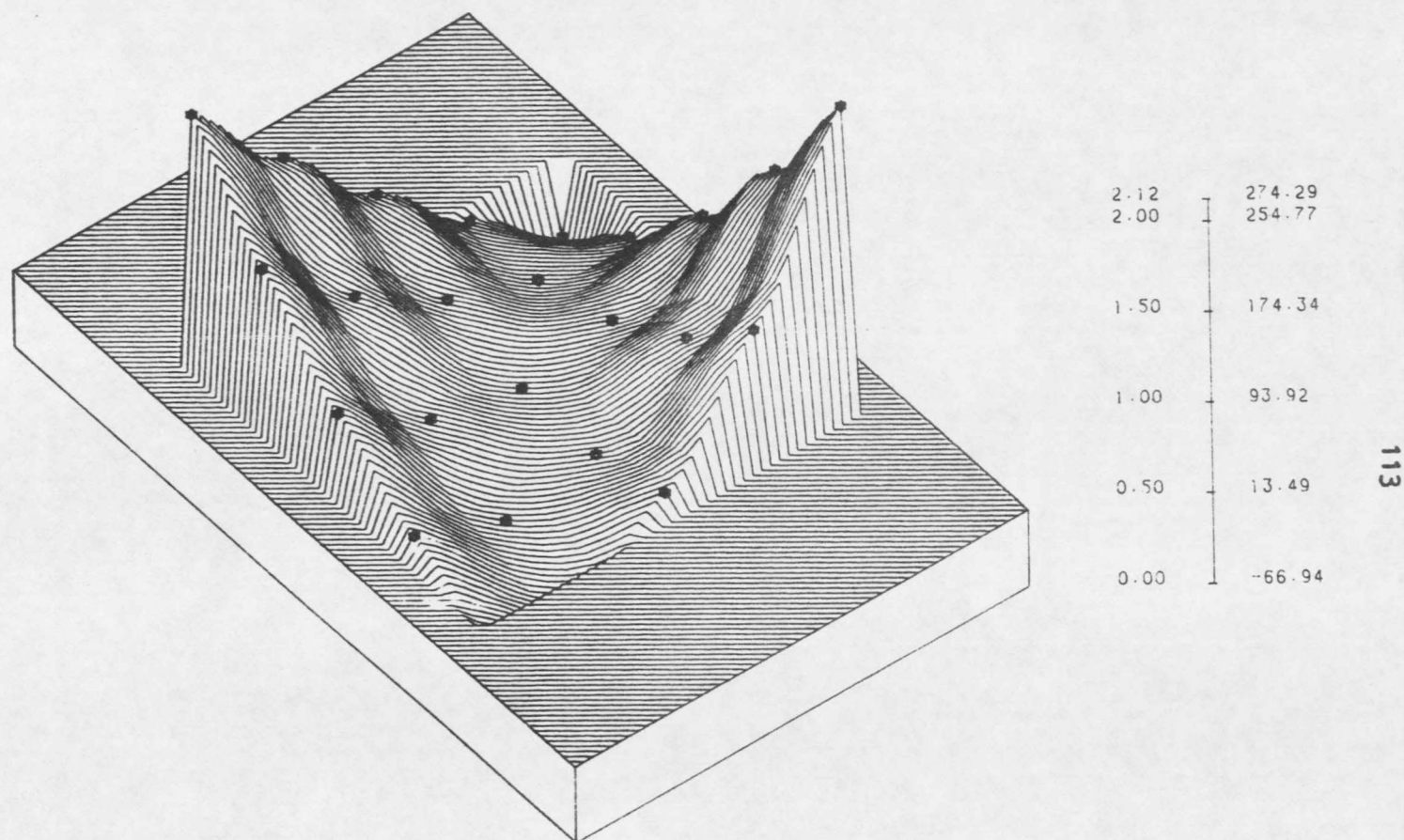


Figure 28. Response of Basal Cover of Tumblegrass to Precipitation, Light Grazing. For Description of Graph, See Page 69.

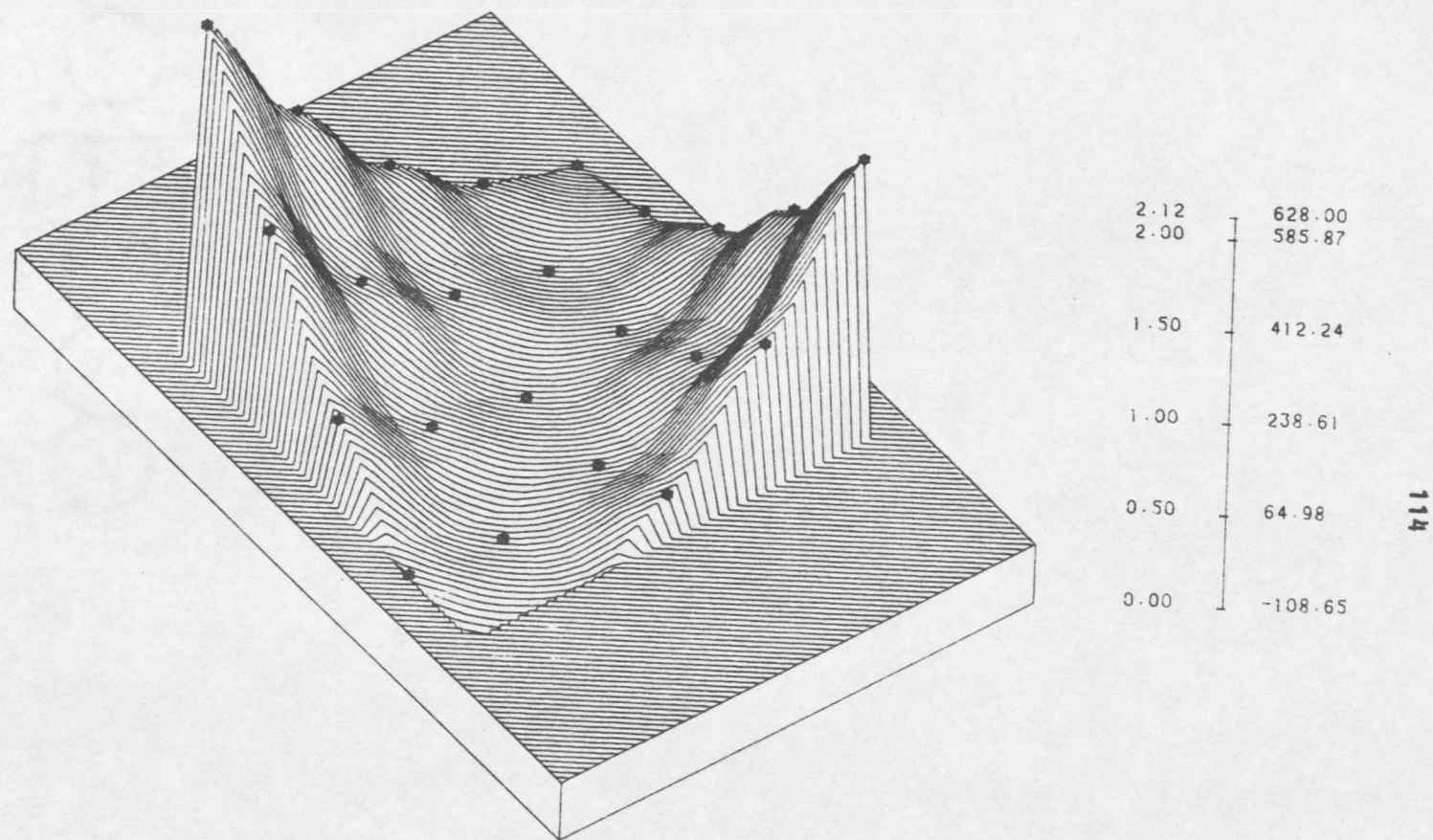


Figure 29. Response of Basal Cover of Tumblegrass to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

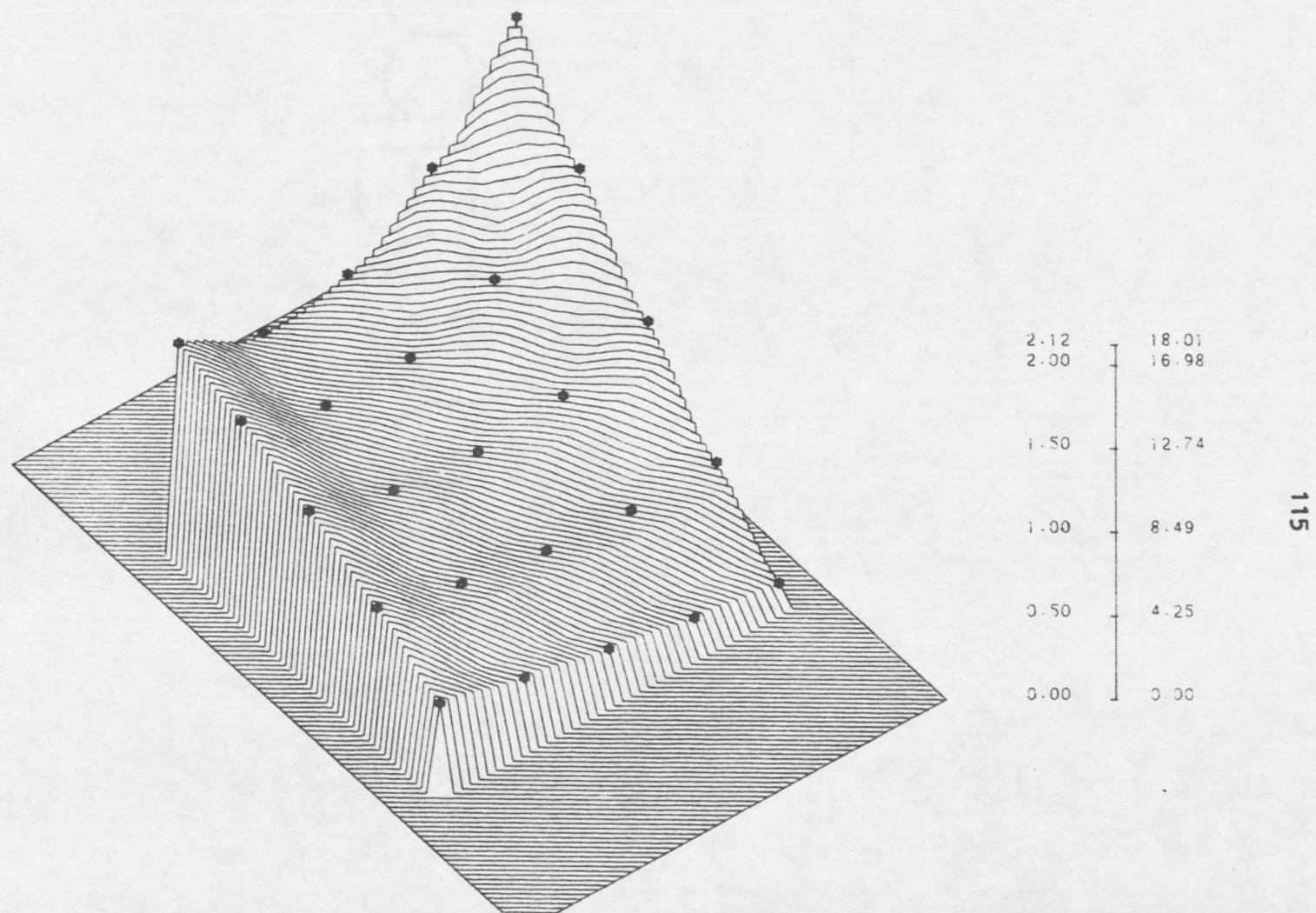


Figure 30. Response of Basal Cover of Scarlet Globemallow to Precipitation, All Quadrats. For Description of Graph, See Page 69.

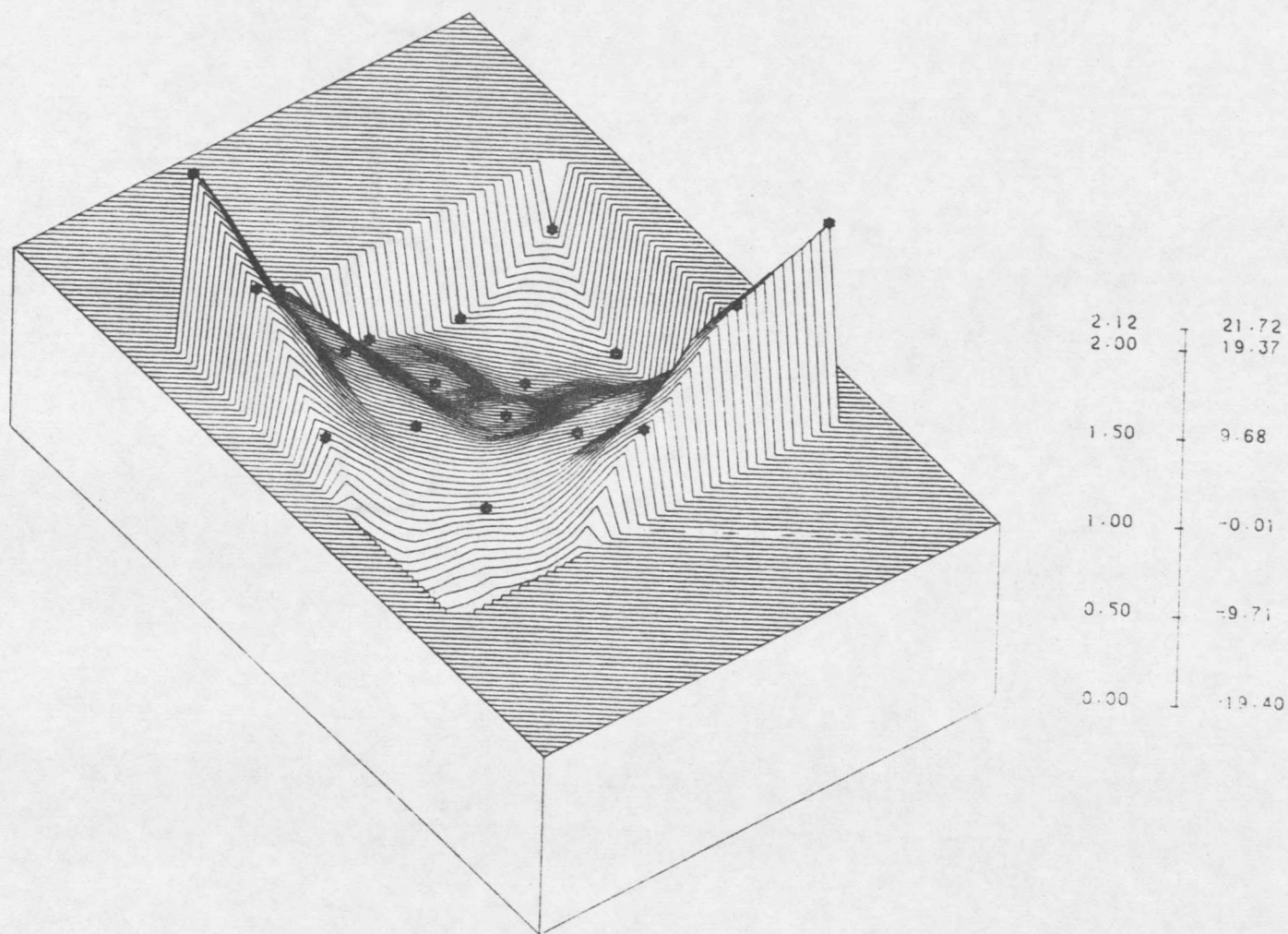


Figure 31. Response of Basal Cover of Scarlet Globemallow to Precipitation, No Grazing. For Description of Graph, See Page 69.

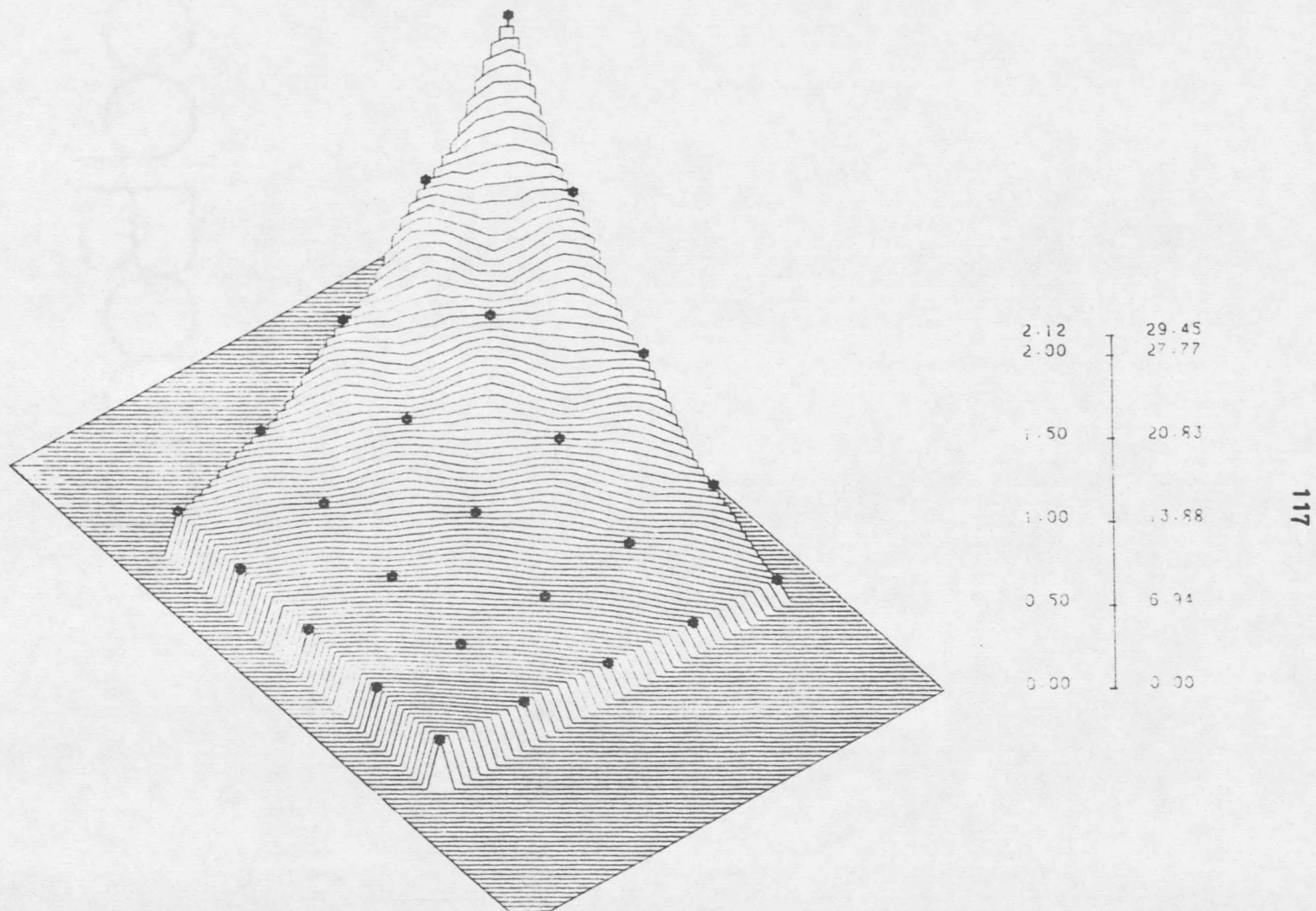


Figure 32. Response of Basal Cover of Scarlet Globemallow to Precipitation, Light Grazing. For Description of Graph, See Page 69.

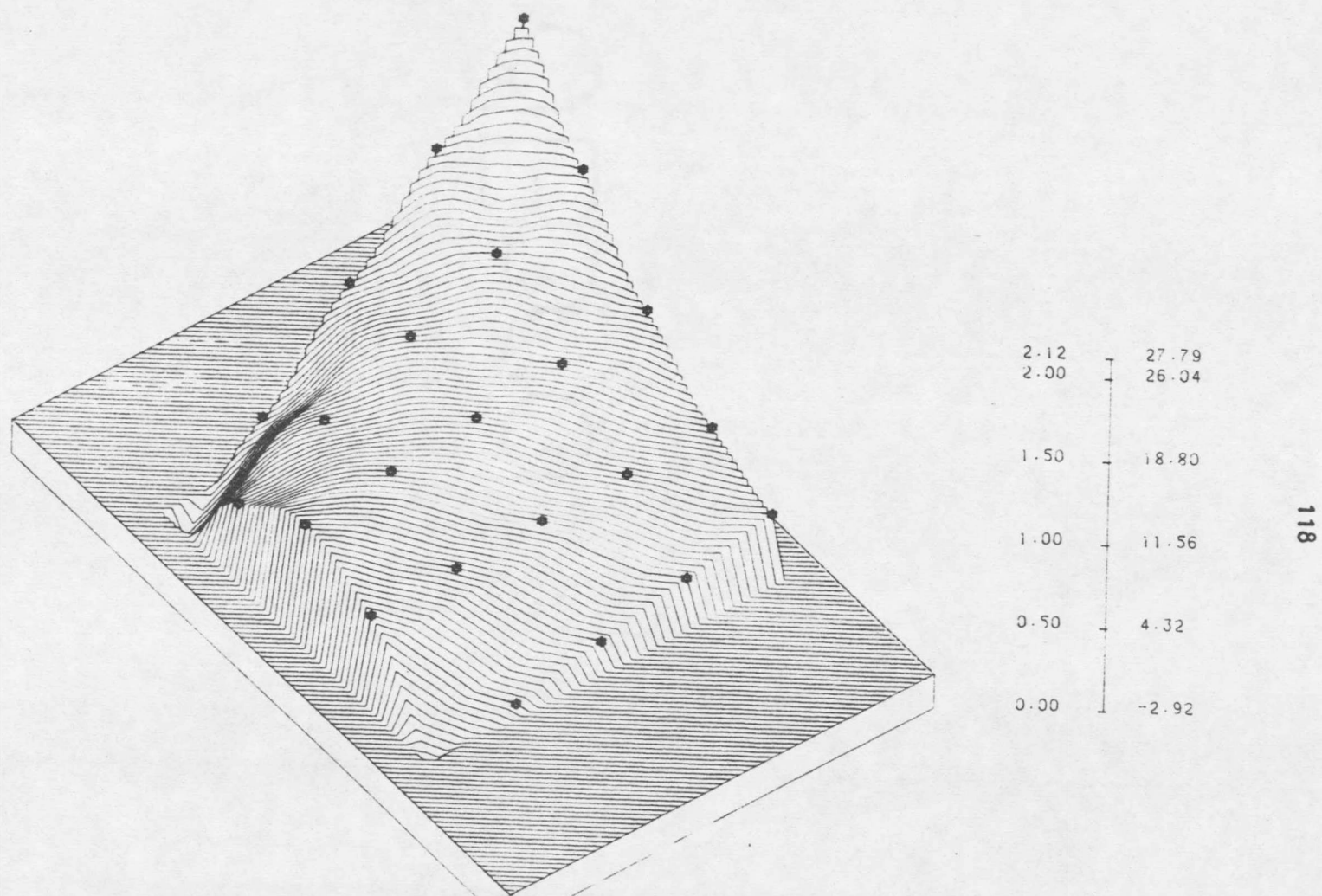


Figure 33. Response of Basal Cover of Scarlet Globemallow to Precipitation, Moderate Grazing. For Description of Graph, See Page 69.

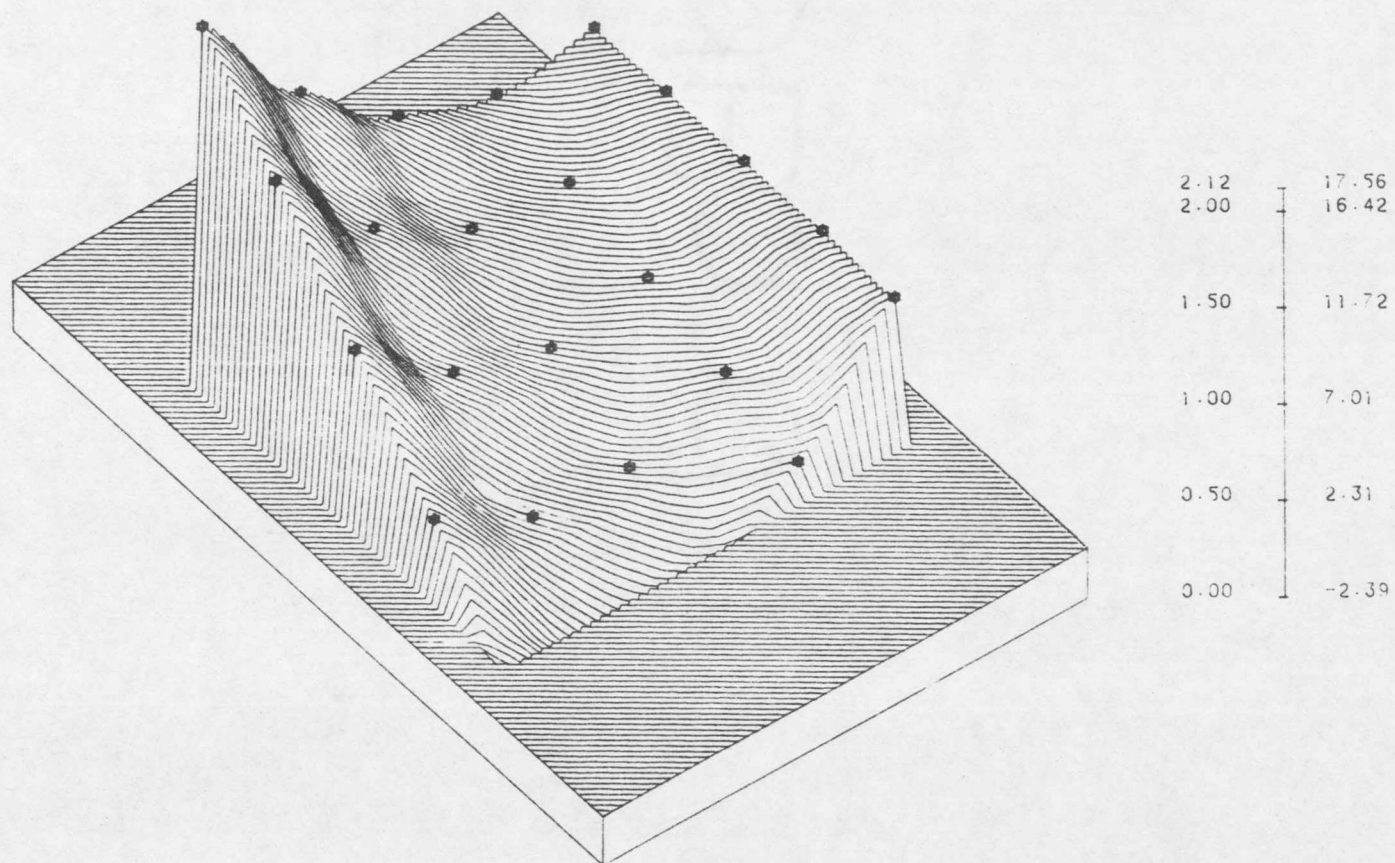


Figure 34. Response of Basal Cover of Scarlet Globemallow to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

precipitation decreases in the current year. However, cover does not decline as rapidly when previous year precipitation declines, indicating that precipitation in the previous year may be more important than current year precipitation for enhancing cover. This species appears to be fairly drought tolerant, because no negative values were predicted. This may indicate that it would not be eliminated by drought or any other precipitation regime that was considered.

Scarlet globemallow apparently needs a certain amount of grazing pressure to remain in the stand. When cover response from ungrazed quadrats was examined, most predicted cover values were negative (Fig. 31). The results were just opposite to those obtained for the species when grazing occurred. Scarlet globemallow persisted under nonuse only when the amount of precipitation fluctuated widely from year to year. The greatest amount of cover occurred during the most extreme fluctuations.

The light and moderate grazing intensity curves (Figs. 32 and 33) are almost identical with the primary differences occurring at low levels of precipitation. Both curves are also very similar to the all quadrats combined curve (Fig. 30). The greatest cover occurred when precipitation was high for two consecutive years. Under light grazing, the cover decreased linearly as both previous and current annual precipitation declined. The same response occurred on the

moderate grazing curve except at lower levels of current year precipitation. When this occurred with low levels of previous year precipitation, cover tended to increase gradually as current annual precipitation increased. When it occurred at high levels of previous year precipitation, predicted cover values became negative. Cover was consequently highest under low current year precipitation when previous year precipitation was average.

Cover was highest under heavy grazing when previous year precipitation was highest, and current year precipitation was lowest (Fig. 34). At low levels of previous year precipitation, however, cover increased as current year precipitation increased. In this respect, the curve was similar to curves associated with other grazing intensities. However, previous year precipitation and precipitation fluctuations between years appeared to play a greater role in determining basal cover at heavy grazing intensities.

Coupland (1958) reported that cover increased during drought. However, my results indicate that cover will decrease with low precipitation except if not grazed.

Scarlet globemallow is considered to be of low value as forage for cattle. A reduction in cover of this species is consequently desirable for livestock production. Since heavy grazing resulted in the lowest amount of predicted cover, this appears to be the best grazing intensity to use to regulate scarlet globemallow. My results

are in direct conflict with those of Reed and Peterson (1961). They stated that the species responded favorably to heavy grazing. However, my results indicated that curves are similar at all grazing intensities and that there is actually little difference in the amount of cover predicted. This agrees closely with the results of Houston and Woodward (1966) who stated that there was no different response between grazing intensities. It should be noted that the cover of scarlet globemallow is so low in all cases that it seldom presents a problem on this range.

Needle-and-Thread

Acceptable r^2 values were obtained and cover was graphed for all quadrats combined, light, and heavy grazing (Figs. 35-37). All curves are very similar with the highest amount of cover occurring when precipitation is consistently high for two years. Cover decreased linearly as precipitation decreased, regardless of the year in which the precipitation occurred. Negative values of cover were never predicted except under heavy grazing when precipitation is extremely low for two consecutive years. In this case the plants were severely stressed by both drought and heavy grazing pressure. This indicated that this species is highly drought tolerant as long as it is not overgrazed. The actual amount of cover is much greater when all quadrats are combined than under either light or heavy grazing intensities. This probably indicates that the predicted cover would

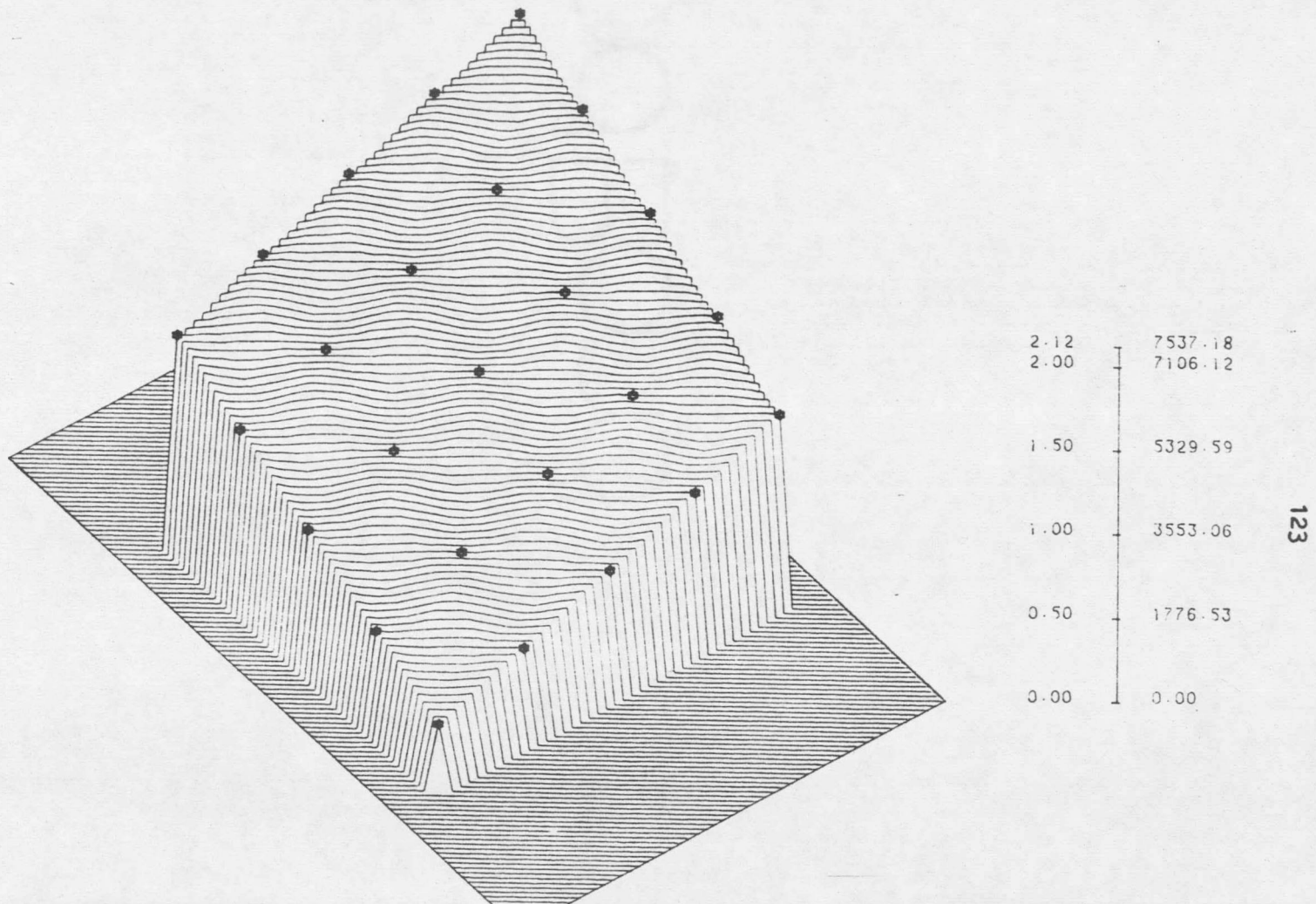


Figure 35. Response of Basal Cover of Needle-and-Thread to Precipitation, All Quadrats. For Description of Graph, See Page 69.

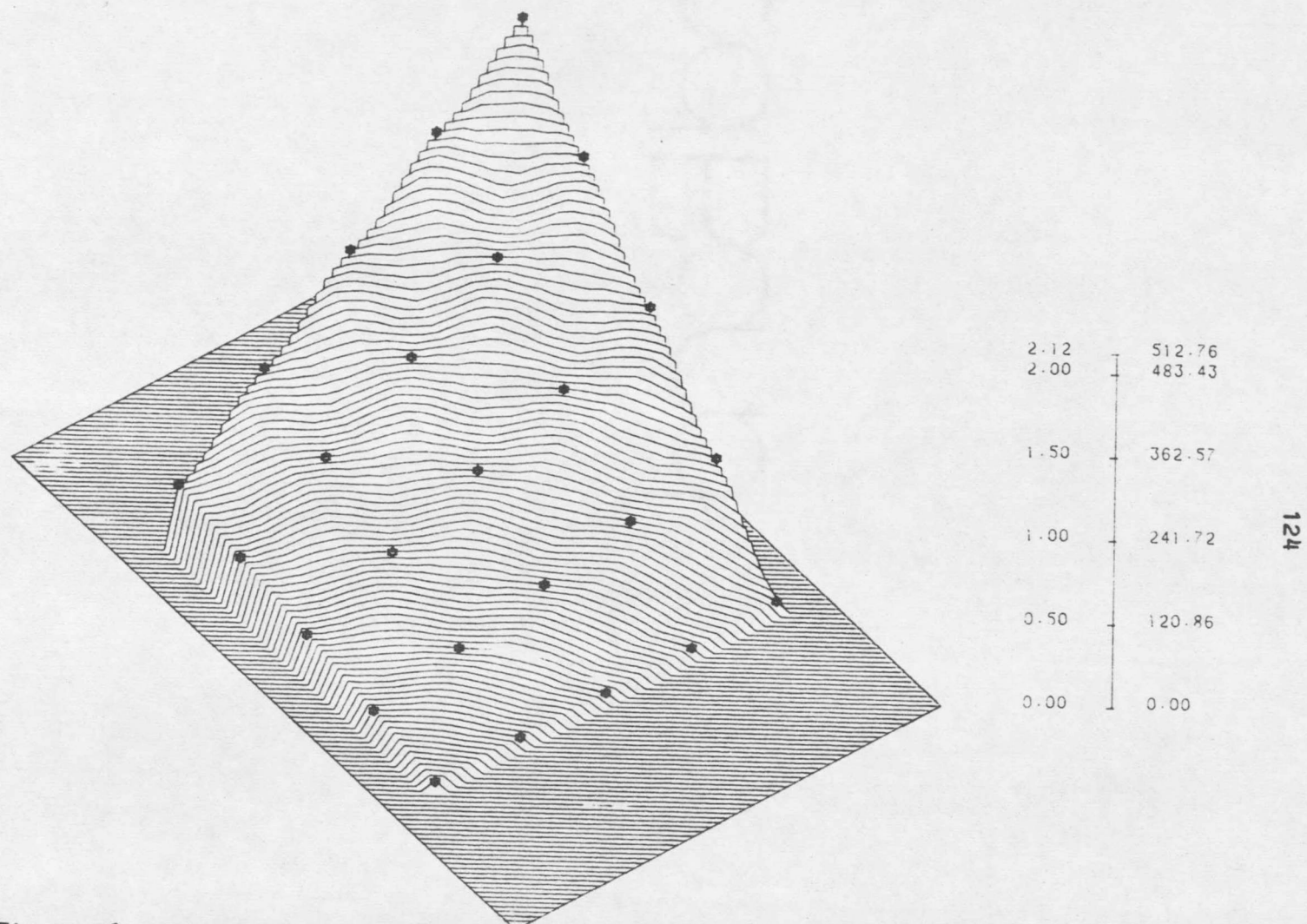


Figure 36. Response of Basal Cover of Needle-and-Thread to Precipitation, Light Grazing. For Description of Graph, See Page 69.

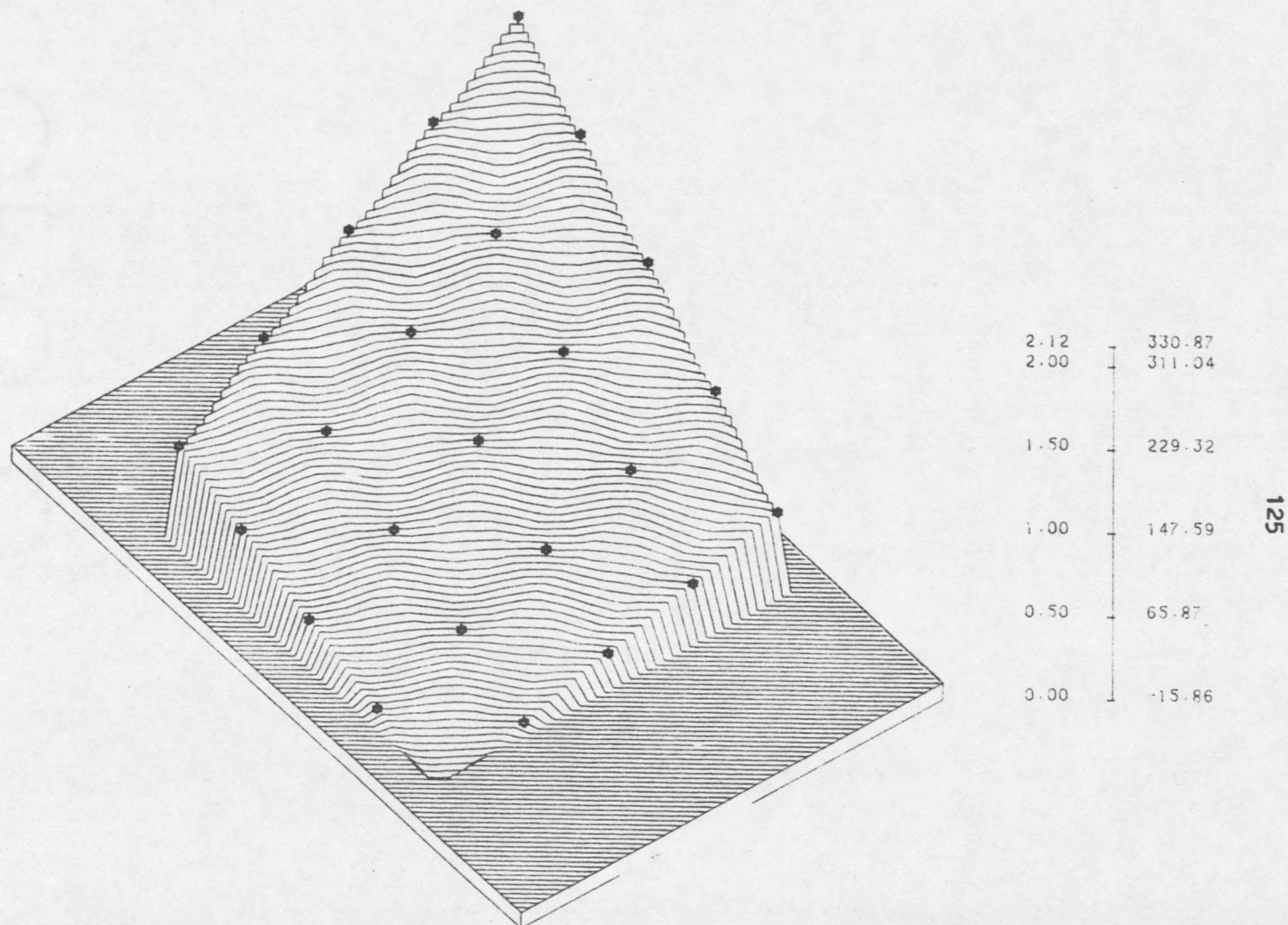


Figure 37. Response of Basal Cover of Needle-and-Thread to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

be considerably higher on either nonuse or moderate stocking. Based on the grazing intensities that were graphed, it appears that light grazing promotes more cover than heavy grazing. The difference in amount is not very substantial, however. Light stocking is therefore more advantageous for livestock production because needle-and-thread is considered a desirable forage species. Based on the information available, these results do not appear to differ from those of Reed and Peterson (1961), Houston and Woodward (1966), or Clark et al. (1943).

Green Needlegrass

Acceptable r^2 values were obtained and cover was graphed for all quadrats combined, nonuse, and heavy grazing (Figs. 38-40). The only portion in common among the three graphs is the center where precipitation is consistent between years and near average. In this case the resulting predicted cover is low. Each curve shows a different response to extreme precipitation values.

On the all quadrats curve (Fig. 38), cover is high when precipitation is either high for two consecutive years or varies greatly from year to year with at least one high precipitation year. Current year precipitation appears to affect cover more because cover is greater when it is high and previous year precipitation is low.

On the nonuse curve (Fig. 39), basal cover is greatest when precipitation is high in both years. There is also a slight increase

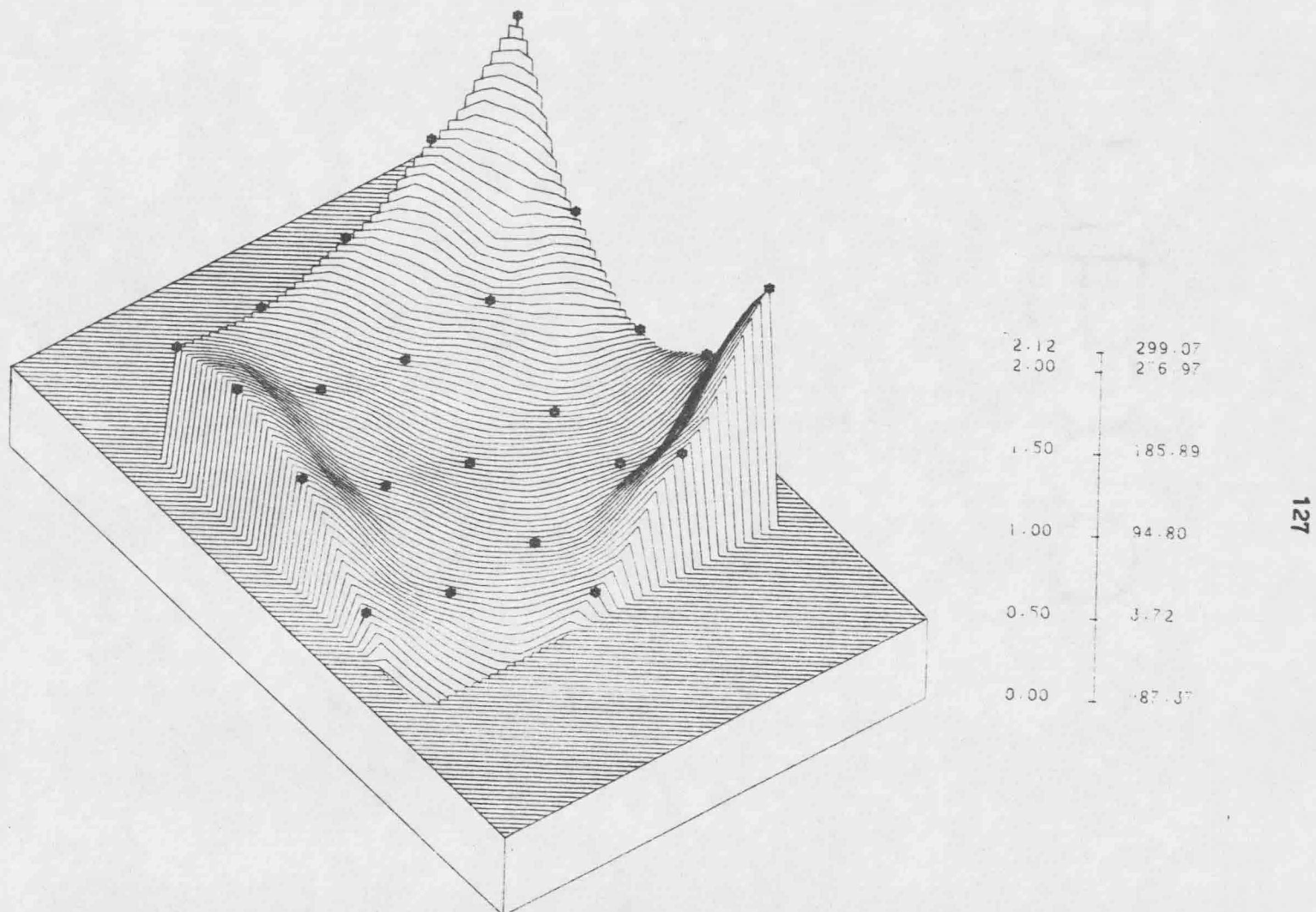


Figure 38. Response of Basal Cover of Green Needlegrass to Precipitation, All Quadrats. For Description of Graph, See Page 69.

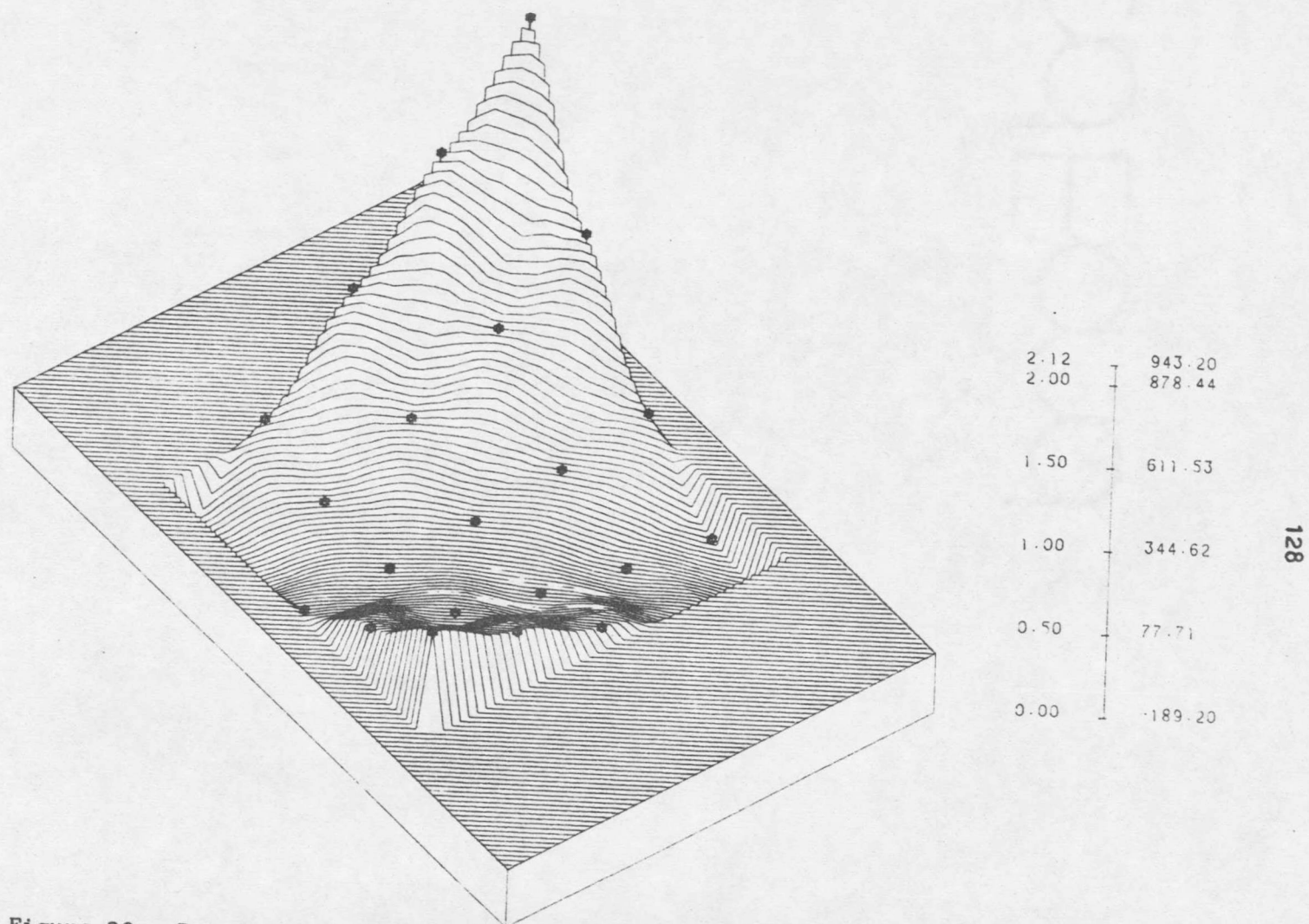


Figure 39. Response of Basal Cover of Green Needlegrass to Precipitation, No Grazing. For Description of Graph, See Page 69.

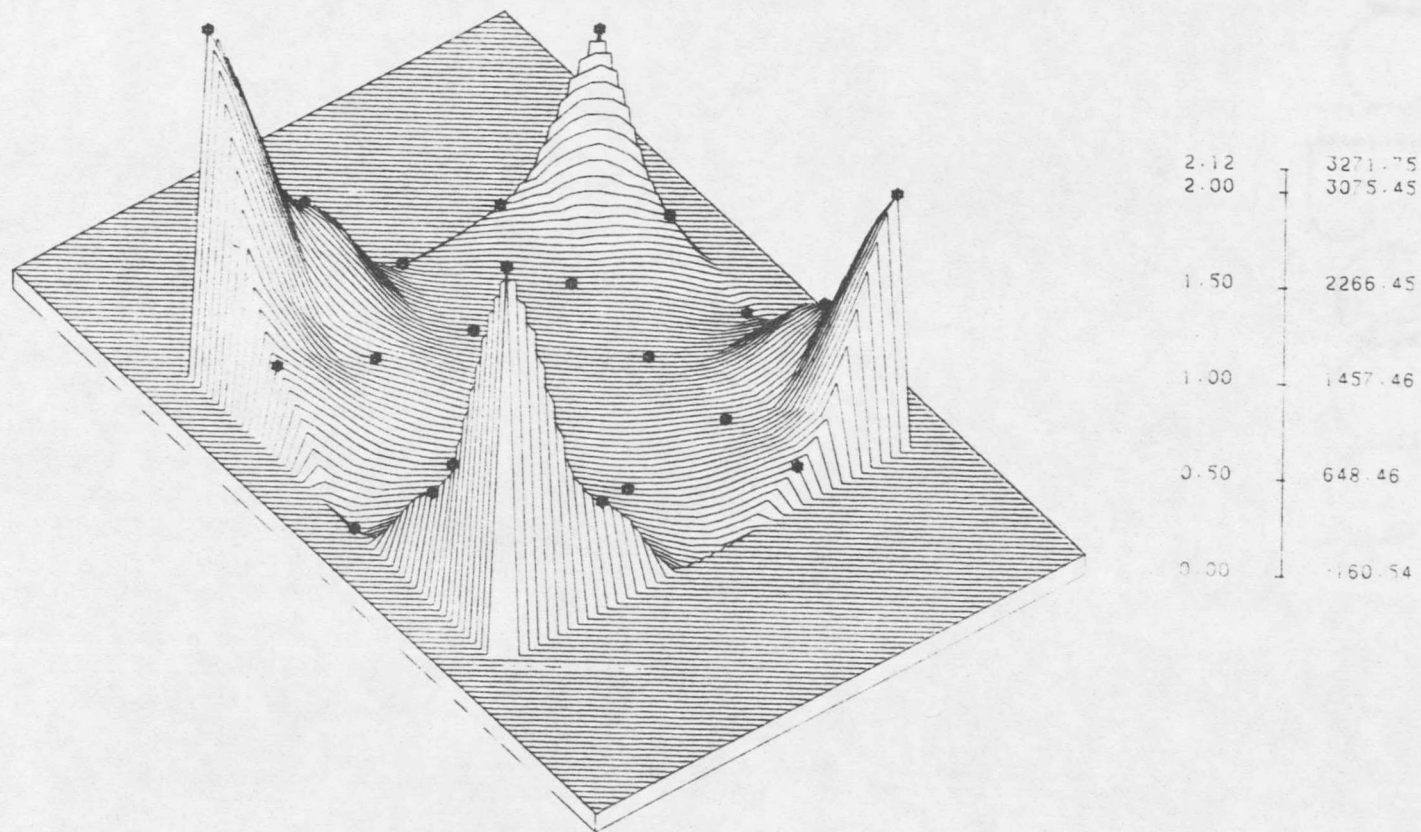


Figure 40. Response of Basal Cover of Green Needlegrass to Precipitation, Heavy Grazing. For Description of Graph, See Page 69.

in cover when precipitation is consistently low. The lowest amount of cover occurred when precipitation fluctuated from year to year. Green needlegrass is often associated with western wheatgrass, and under nonuse, its cover appears to have an inverse relationship with western wheatgrass cover. As discussed earlier, a similar response was observed with buffalograss.

With heavy grazing, green needlegrass had high cover values under any extreme precipitation regime (Fig. 40). This was observed when precipitation amounts were consistently high, consistently low, or fluctuated between years. In this respect, it appeared to respond in a similar manner as red threeawn.

Green needlegrass is usually considered to be a highly productive and desirable forage species that decreases rapidly under grazing pressure. However, my data seem to indicate that this hypothesis may not be valid. The greatest amount of cover was predicted for heavy grazing. Furthermore, green needlegrass tended to increase cover under more precipitation regimes under heavy grazing than under protection from grazing. These results do not agree with those of Reed and Peterson (1961) or Houston and Woodward (1966) who stated that there is either no response to grazing or a favorable response to light grazing or nonuse.

SUMMARY AND CONCLUSIONS

The purpose of this study was to quantitatively describe changes in basal cover of vegetation in response to variation in precipitation and grazing intensity. The objectives were:

1. To investigate the relationship between plant community composition and amount of precipitation.
2. To examine the effect of grazing intensity on the relationship between plant community composition and amount of precipitation.
3. To examine management alternatives that maximize desirable plant communities for livestock production under variable climatic conditions.

Basal cover data of 142 species compiled over a 24 year period between 1932 and 1956 at the Livestock and Range Research Station near Miles City, Montana were analyzed in this study to determine which species showed a relationship between basal cover and annual precipitation. Several plotting techniques were used to visualize the relationship between cover and precipitation. Based on these techniques, 21 species were selected for further data analysis which employed multiple regression techniques with basal cover as the dependent variable and precipitation parameters as the independent variables. Basal cover under several grazing treatments was predicted using annual plant year precipitation for two consecutive years or

cumulative early growing season precipitation. These grazing treatments included three different stocking rates, no grazing, and all grazing intensities combined. Basal cover of twelve species that are constituents of the mixed grass prairie of southeast Montana were reliably estimated based on annual plant year precipitation for two consecutive years. All of these species are common constituents of most plant communities in this region, and some of them are the most abundant species in many plant communities. It appeared that cover relationships of other species could also be established by using similar regression techniques and by introducing other independent variables.

After examining the predicted cover of each species, it was apparent that each species reacts to precipitation regimes and grazing treatments in a unique manner. A species may respond differently to the same precipitation regime when subjected to different grazing intensities. Because of this, it is difficult, if not impossible, to predict how cover of the entire plant community will respond to a given precipitation regime. Because each species has its own response to precipitation, constant changes can be expected in the composition of the plant community as the precipitation regime changes. The species that are favored and disfavored will likewise change in accordance with prevailing precipitation. My results are therefore

supportive of those of past researchers such as Cook and Sims (1975). For management purposes, the dominant species in the plant community need to be identified, and then consideration can be given to how precipitation regimes affect the cover of those species. In the event that the precipitation regime changes, however, it should be realized that another species might become dominant. This might then have an effect on management decisions.

It is also apparent that many species have evolved an ability to respond to fluctuations and extremes in precipitation that are commonly a part of the climate of the Northern Great Plains. They may have evolved the ability to obtain maximum cover when fluctuations and extremes occur, as western wheatgrass or red threeawn do; or may have the ability to respond quickly to any increases in precipitation, as buffalograss or needle-and-thread do.

For the twelve species considered in detail, moderate grazing is the most conducive to the optimum amount of cover desired for more species than any other grazing intensity. Species with optimum cover under moderate stocking included western wheatgrass, red threeawn, fringed sagewort, blue grama, buffalograss, and needleleaf sedge. Two species (scarlet globemallow and green needlegrass) reached optimum cover under heavy grazing, while needle-and-thread obtained optimum cover under light grazing. The optimum grazing intensity could not be determined for two species (western yarrow and threadleaf sedge)

because only one grazing intensity was studied. These conclusions agree with those of Reed and Peterson (1961) and Hurtt (1951), who also recommended the moderate grazing intensity on this range. It therefore appears that moderate stocking of .92 ha (2.3 acres) per AUM, or 5.52 ha (13.8 acres) per animal unit for the entire six months of summer grazing would provide conditions for optimum development of plant cover. Because the cover of all species fluctuated from none or very little to the maximum amount due to changes in the precipitation regime, it is also apparent that stocking rate needs to be adjusted to coincide with the forage available. Although basal cover is not a direct measurement of the forage available for livestock, it provides a reliable index to the amount of plant basal material available to produce forage. My results therefore support the recommendations of Reed and Peterson (1961) and Hurtt (1951) that actual stocking rates for a site need to be set and adjusted based on forage utilization or range condition.

APPENDICES

APPENDIX A

Included are graphs of 48 species. For an explanation of these graphs, see page 41. The species from Table 1 that do not have graphs in appendix A showed such a poor relationship that no graph was printed for them. In most of these cases, cover was only recorded in one or two years throughout the study period. Therefore, a relationship could not be determined between cover and precipitation for these species.

The vertical axis represents basal cover (cm^2) of the species being considered and the horizontal axis represents years from 1931 through 1968. Data from the period after 1956 was not considered because of inconsistencies in the methodology of recording quadrats.

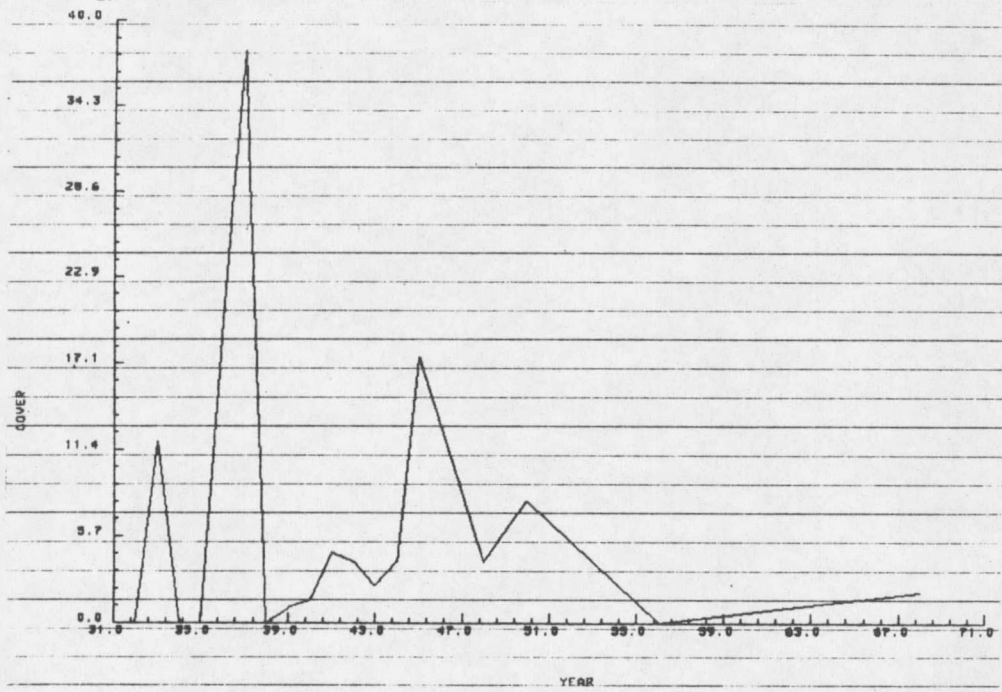


Figure A1. Basal Cover (cm²) of Western Yarrow by Years

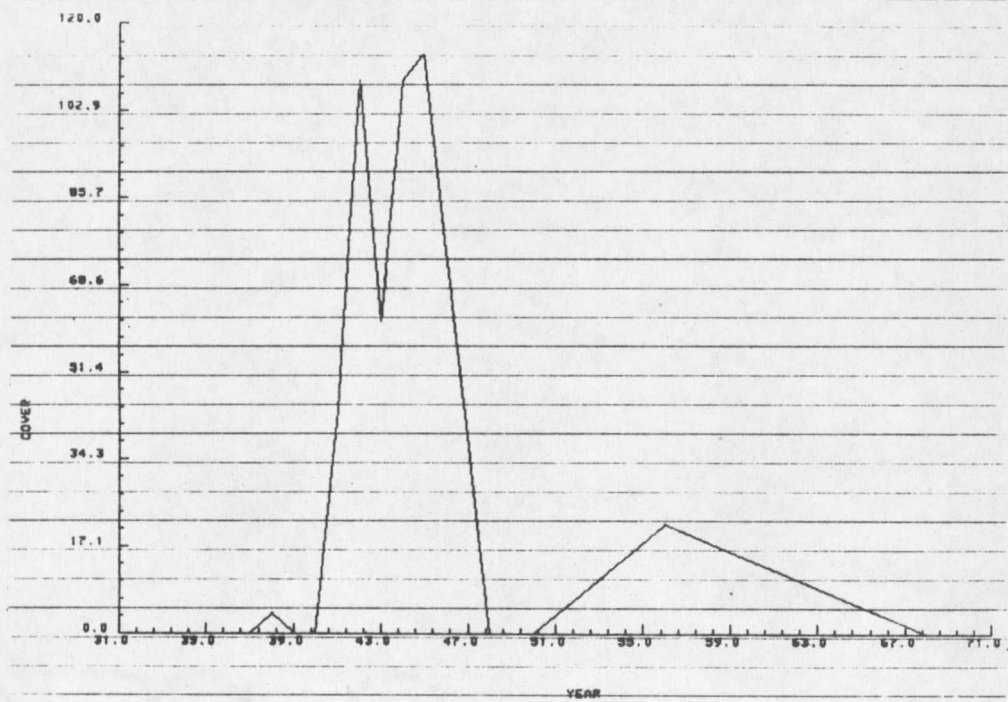


Figure A2. Basal Cover (cm²) of Thickspike Wheatgrass by Years

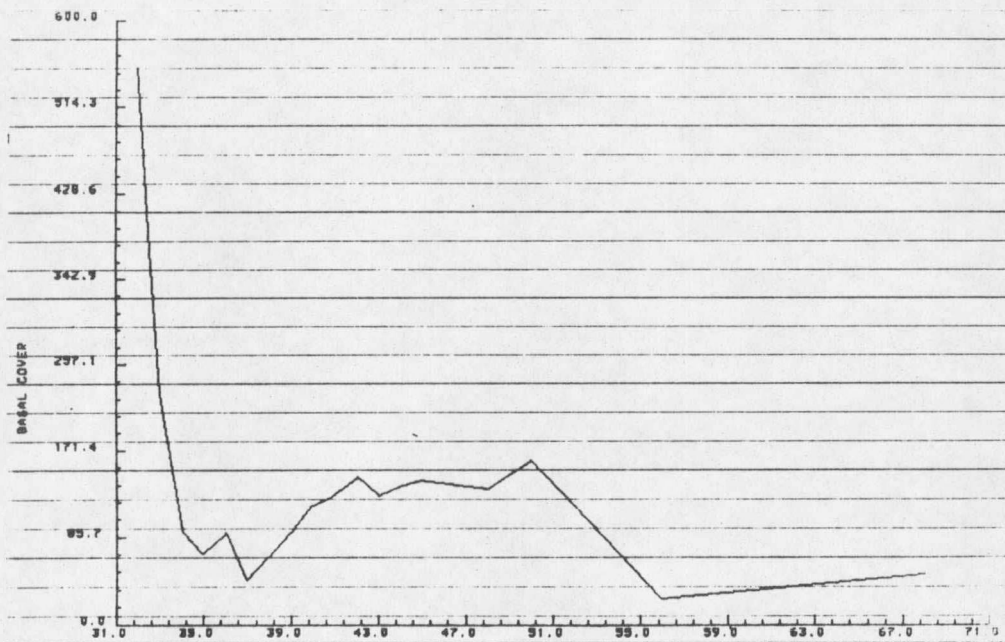


Figure A3. Basal Cover (cm²) of Western Wheatgrass by Years

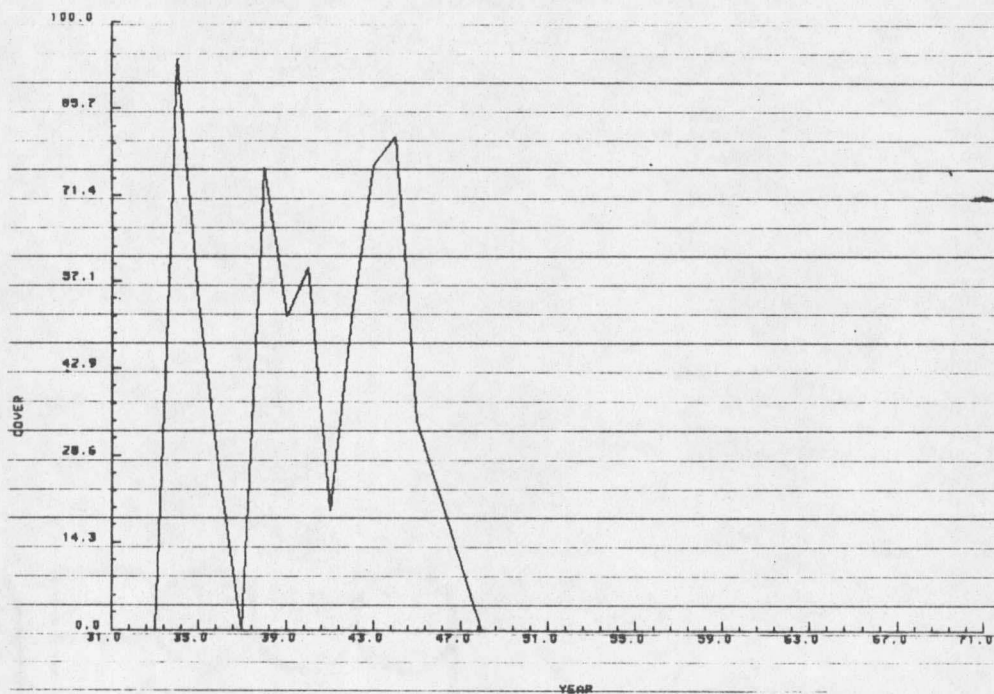


Figure A4. Basal Cover (cm²) of Bluebunch Wheatgrass by Years

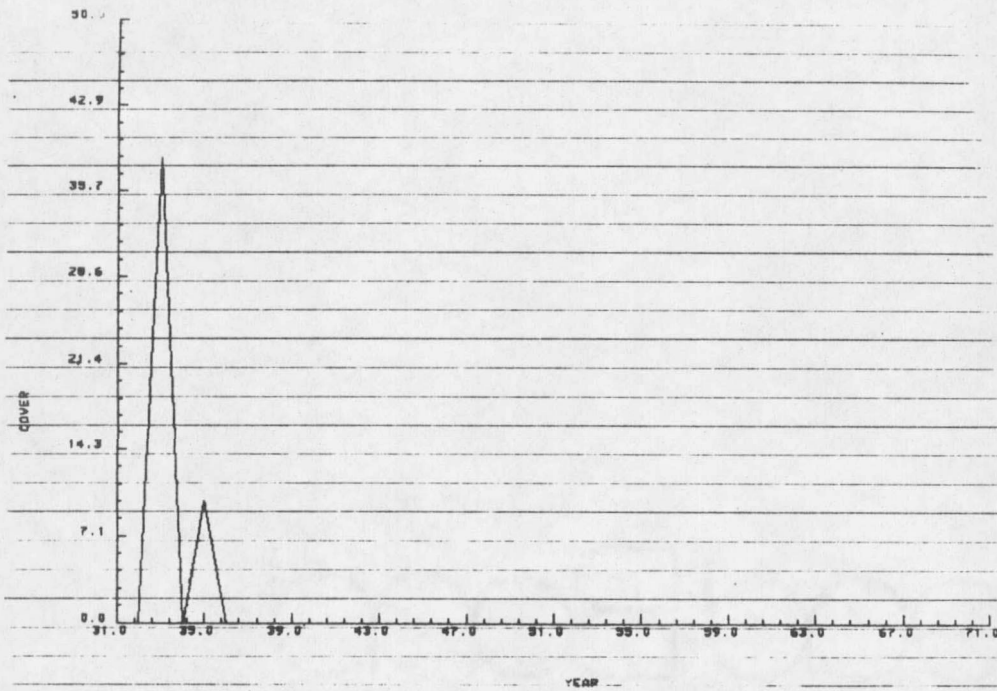


Figure A5. Basal Cover (cm²) of Slender Wheatgrass by Years

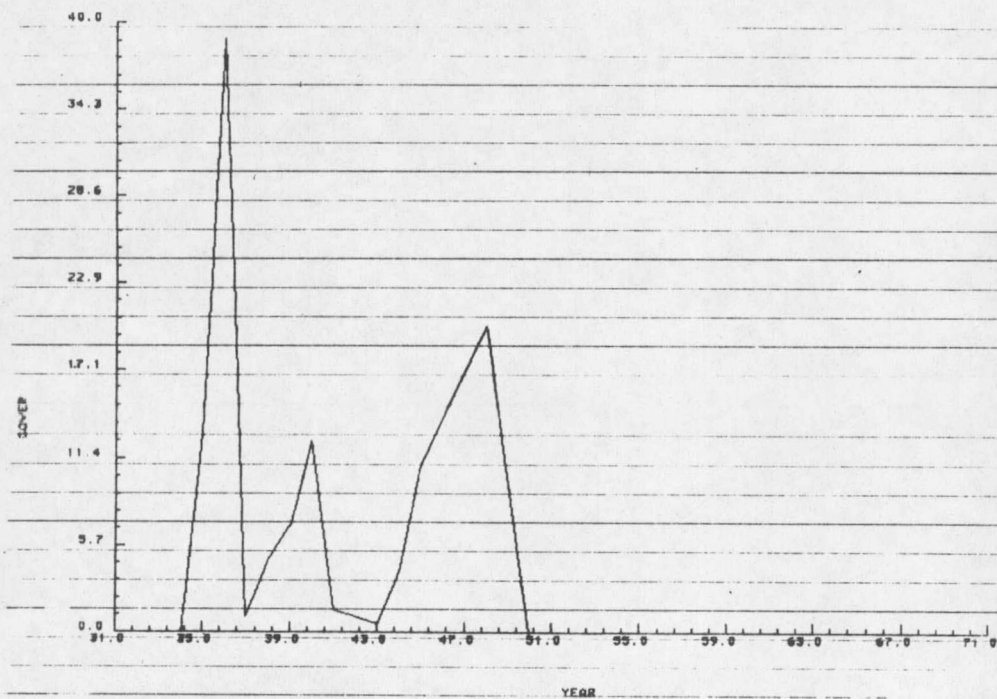


Figure A6. Basal Cover (cm²) of Field Pussytoes by Years

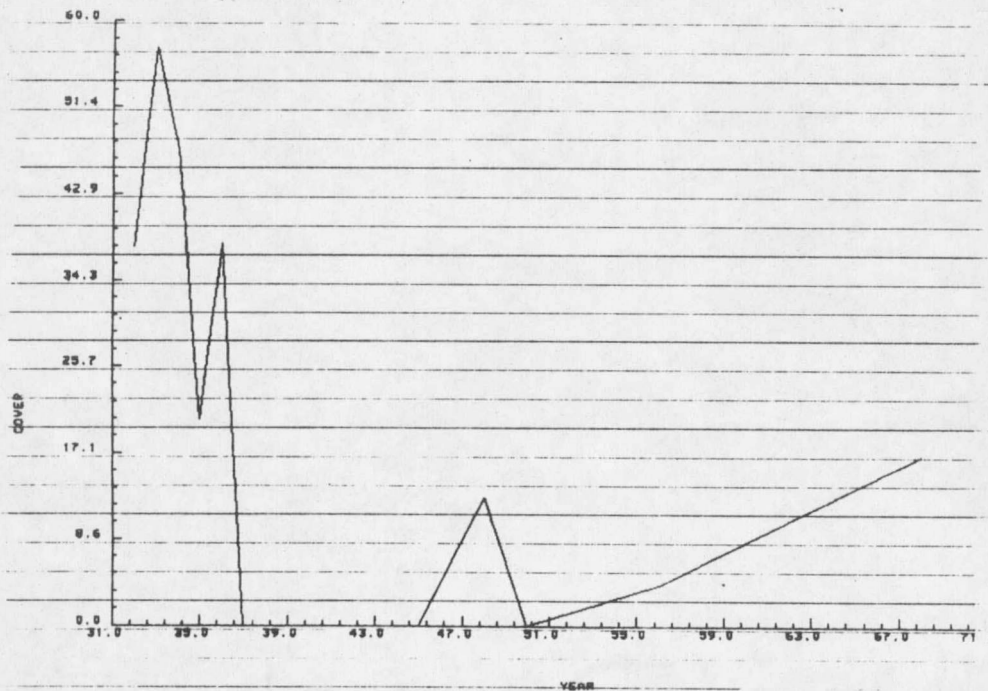


Figure A7. Basal Cover (cm²) of Red Threeawn by Years

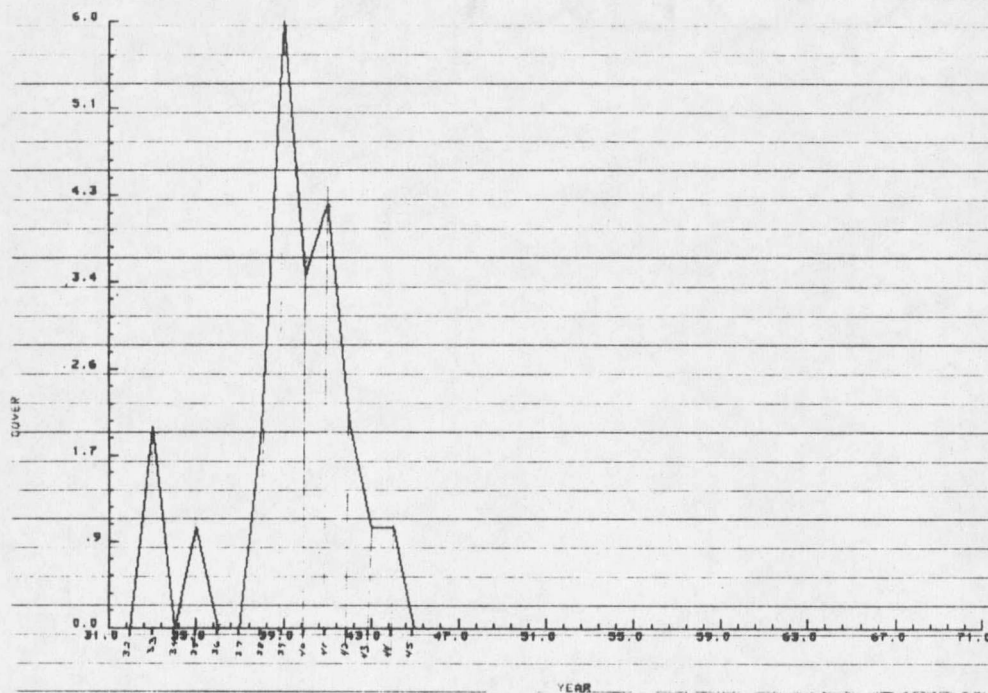


Figure A8. Basal Cover (cm²) of Hoary Tansyaster by Years

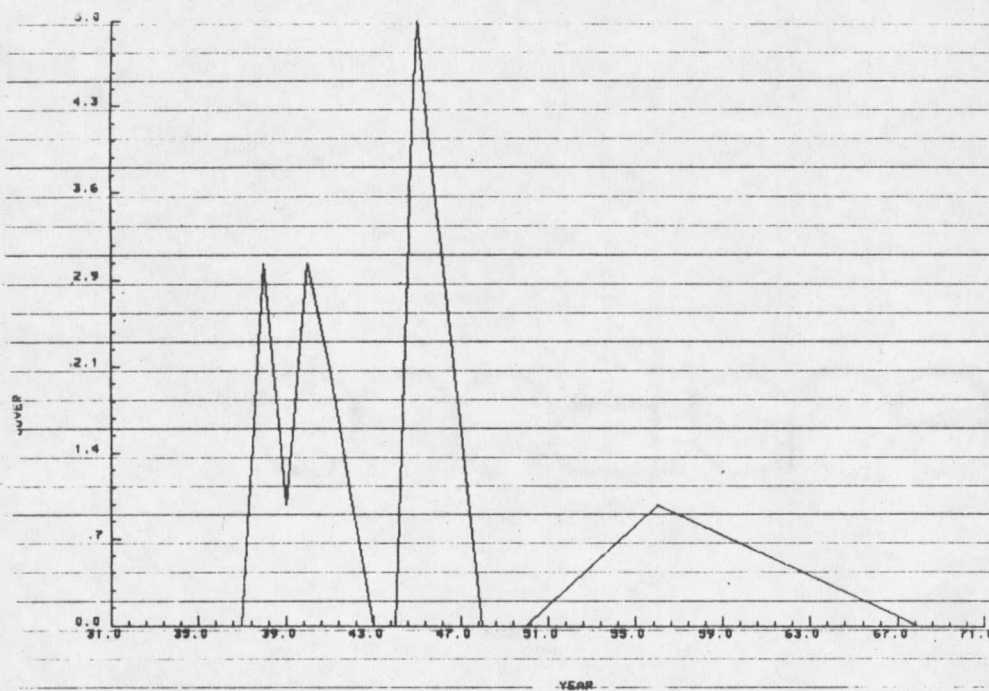


Figure A9. Basal Cover (cm²) of Tansyleaf Aster by Years

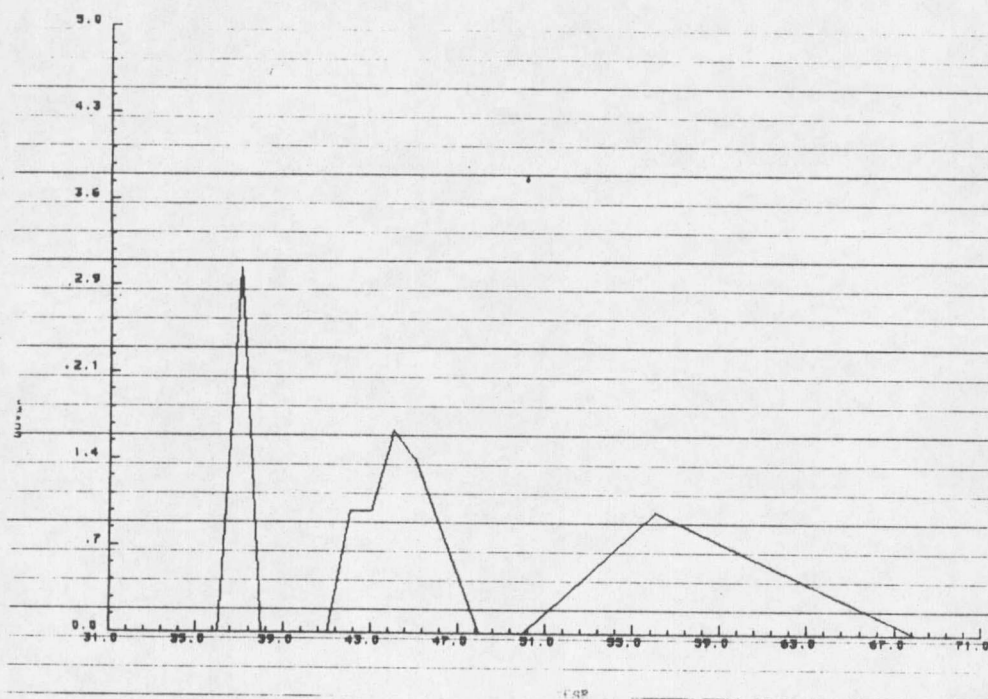


Figure A10. Basal Cover (cm²) of Threeleaved Milkvetch by Years

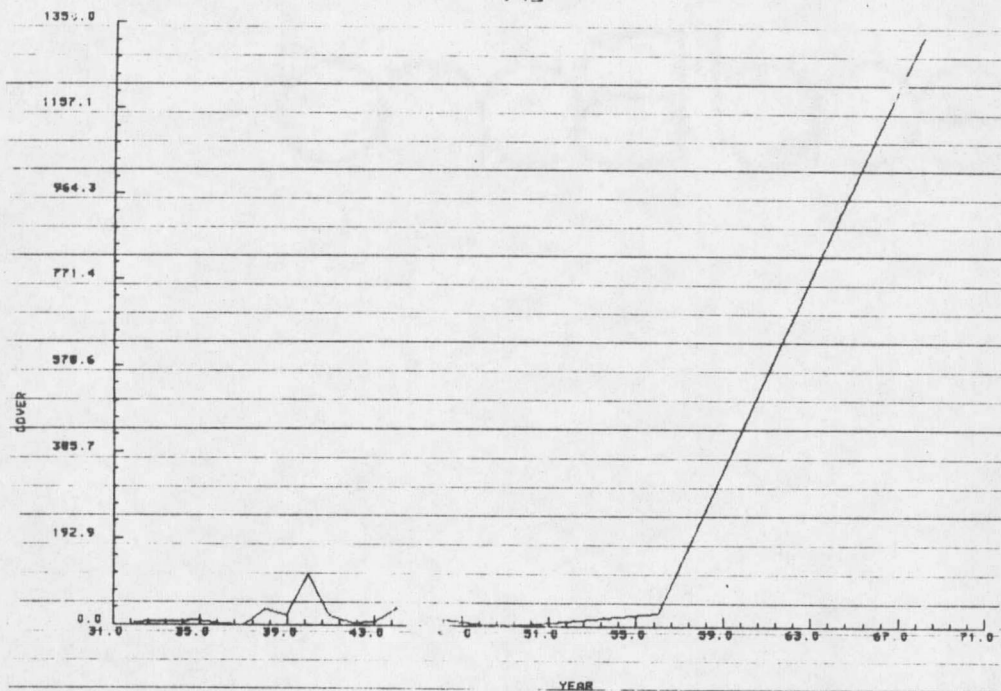


Figure A11. Basal Cover (cm²) of Silver Sagebrush by Years

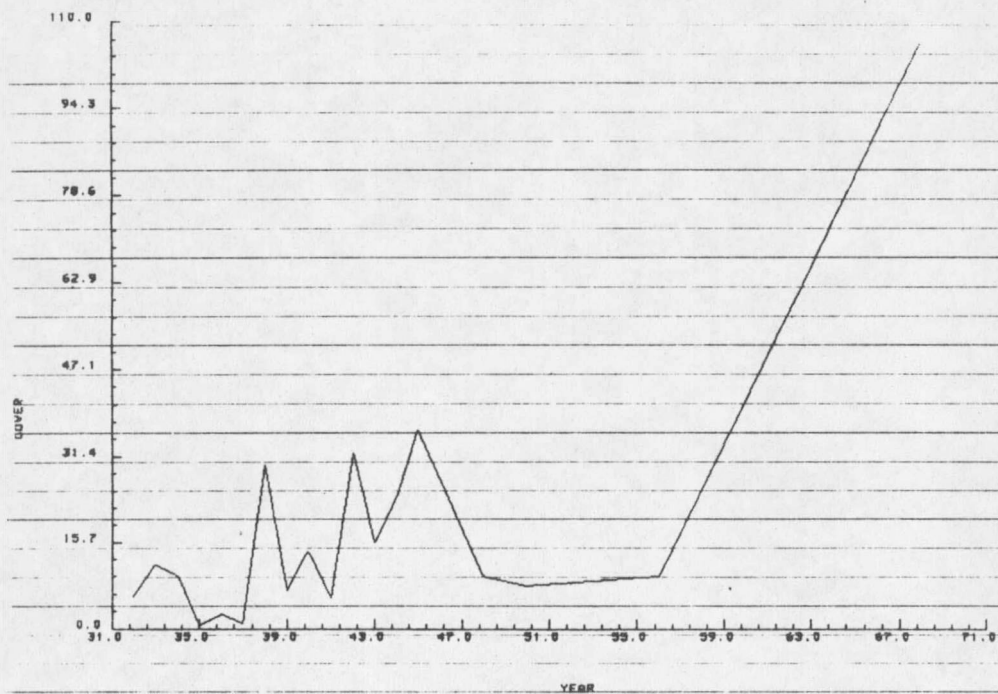


Figure A12. Basal Cover (cm²) of Fringed Sagewort by Years

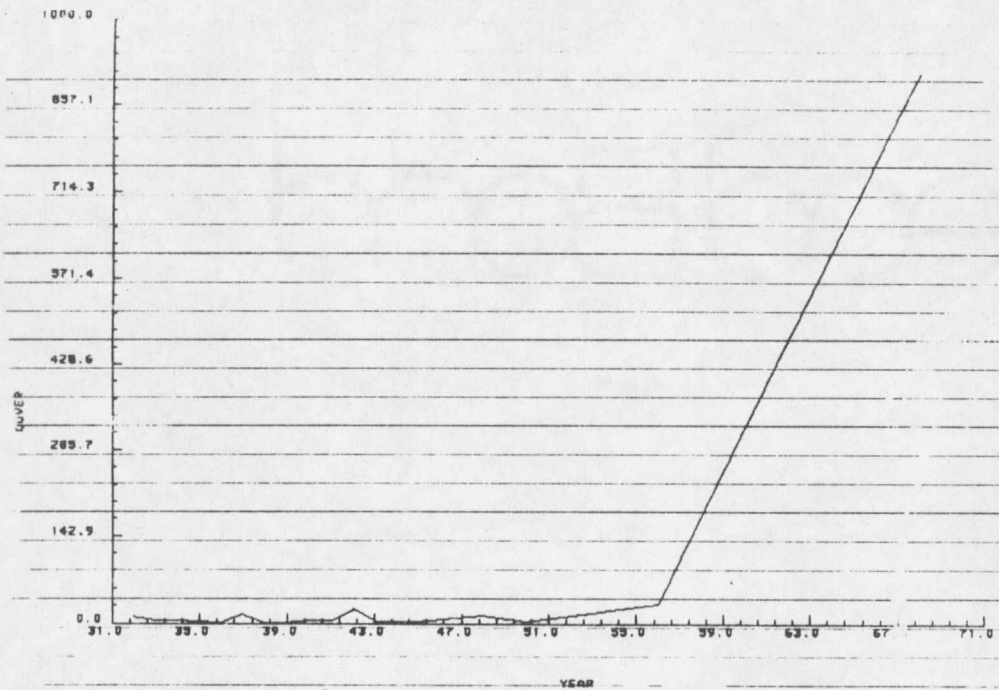


Figure A13. Basal Cover (cm²) of Big Sagebrush by Years

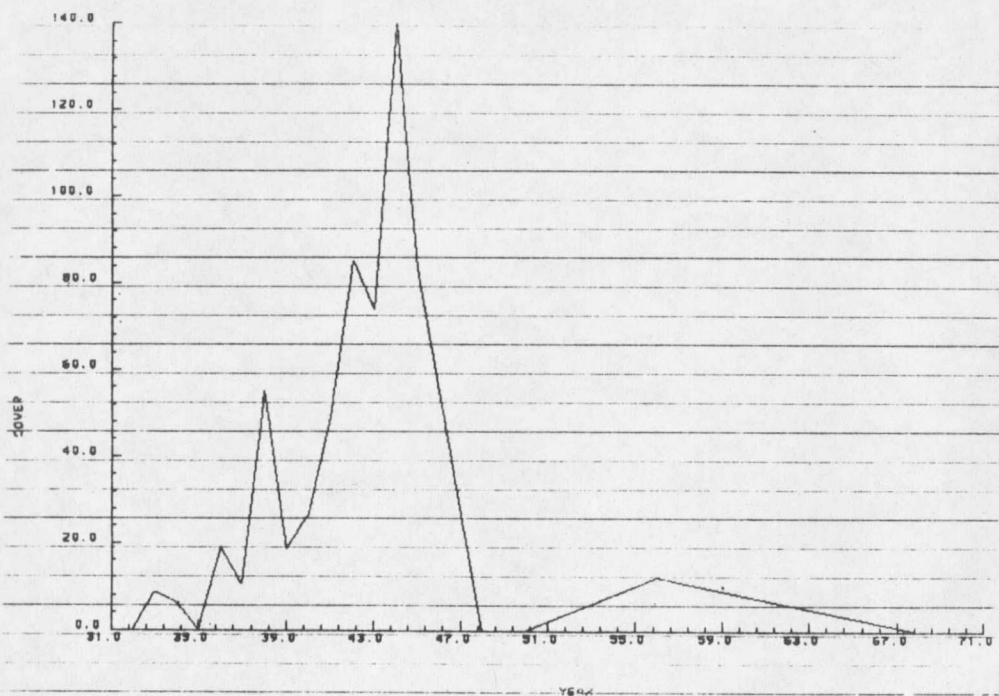


Figure A14. Basal Cover (cm²) of Shadscale by Years

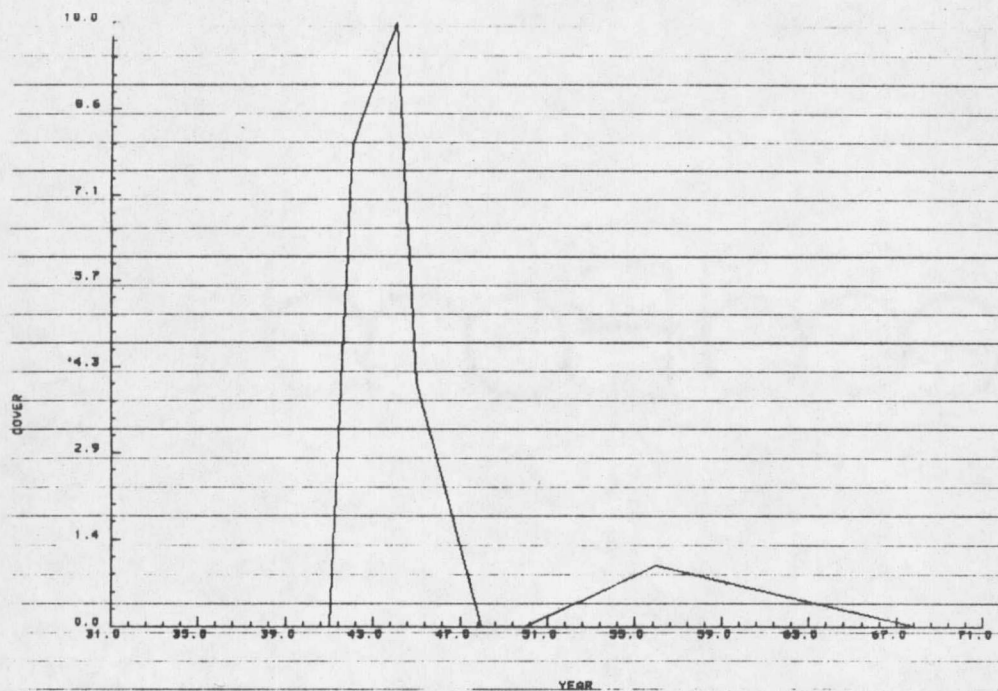


Figure A15. Basal Cover (cm²) of Nuttall Saltbush by Years

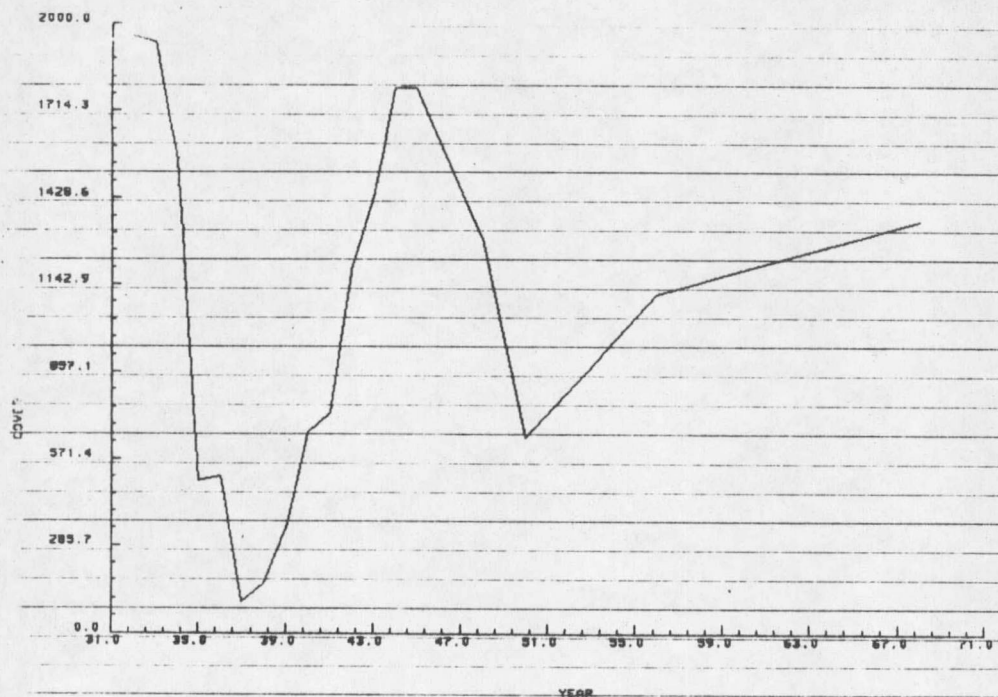


Figure A16. Basal Cover (cm²) of Blue Grama by Years

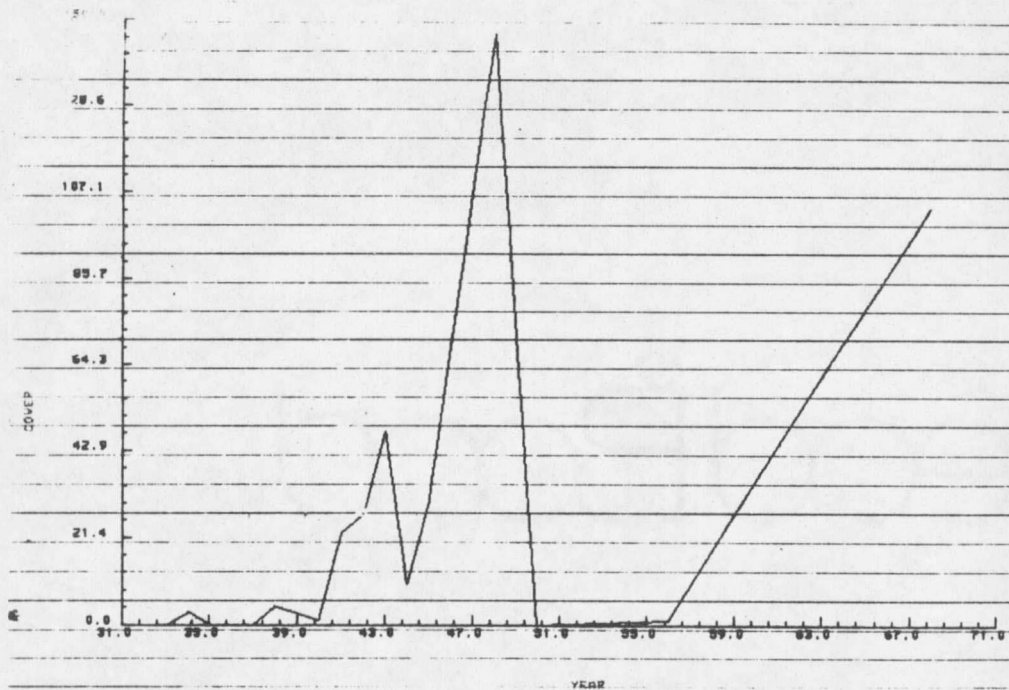


Figure A17. Basal Cover (cm²) of Cheatgrass by Years

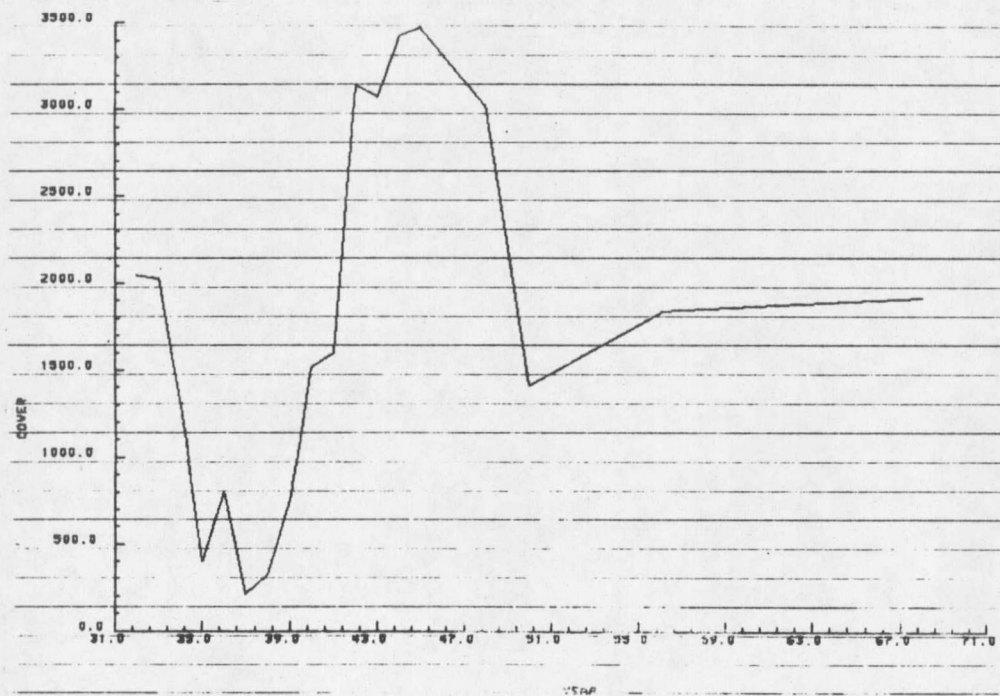


Figure A18. Basal Cover (cm²) of Buffalograss by Years

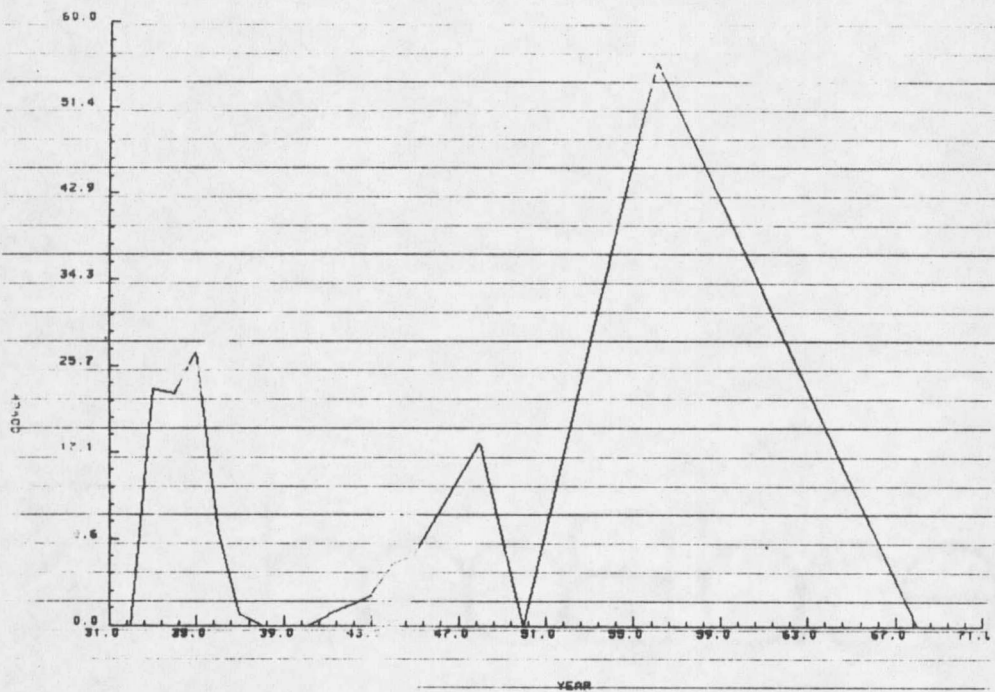


Figure A19. Basal Cover (cm²) of Prairie Sandreed by Years

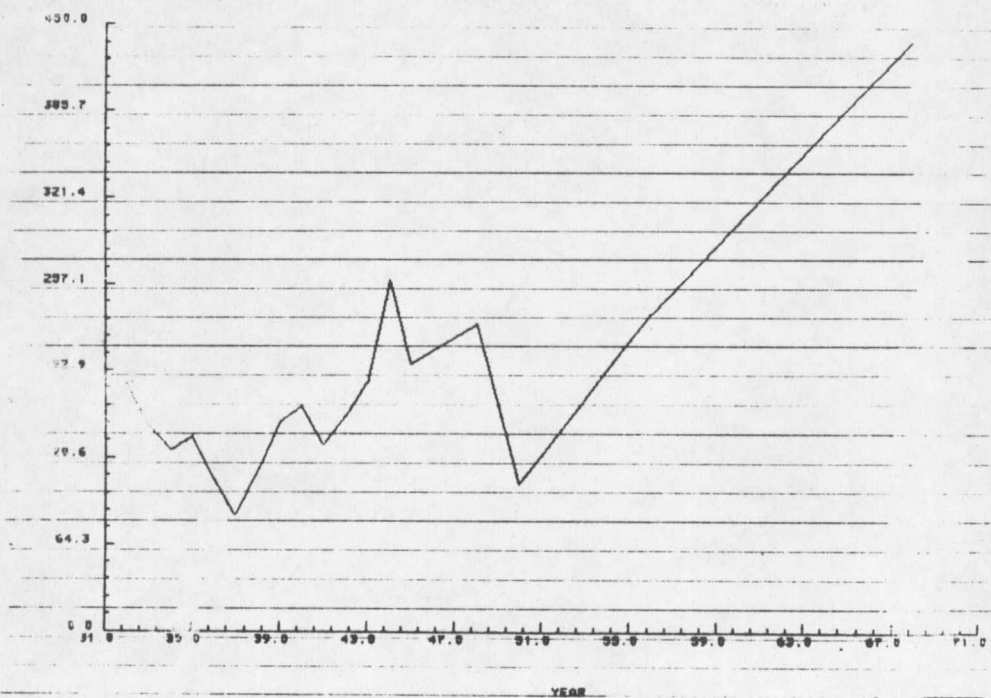


Figure A20. Basal Cover (cm²) of Threadleaf Sedge by Years

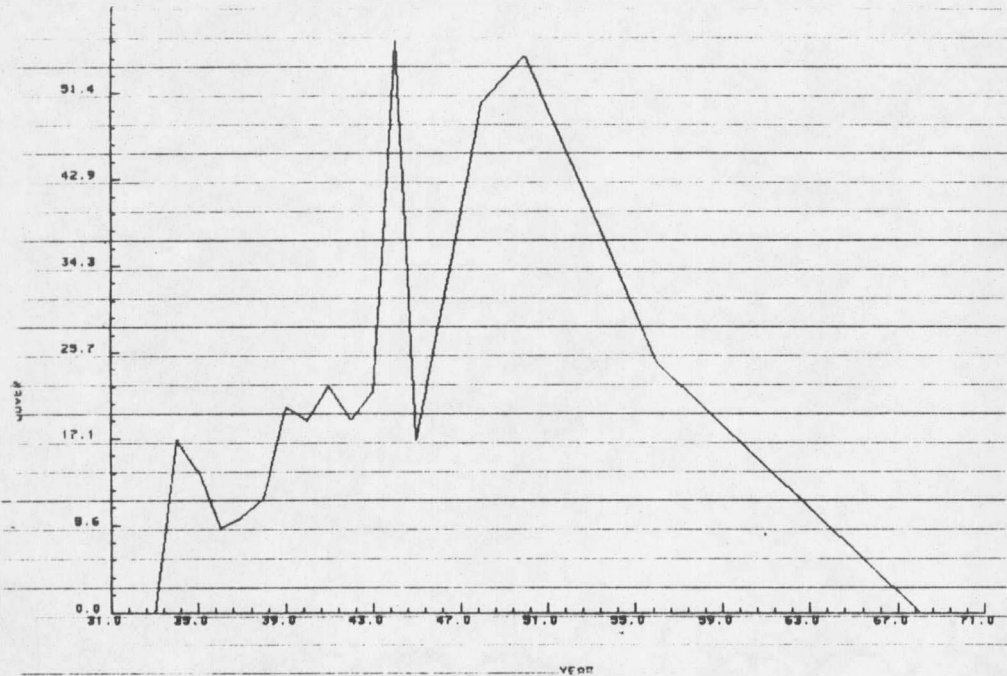


Figure A21. Basal Cover (cm²) of Needleleaf Sedge by Years

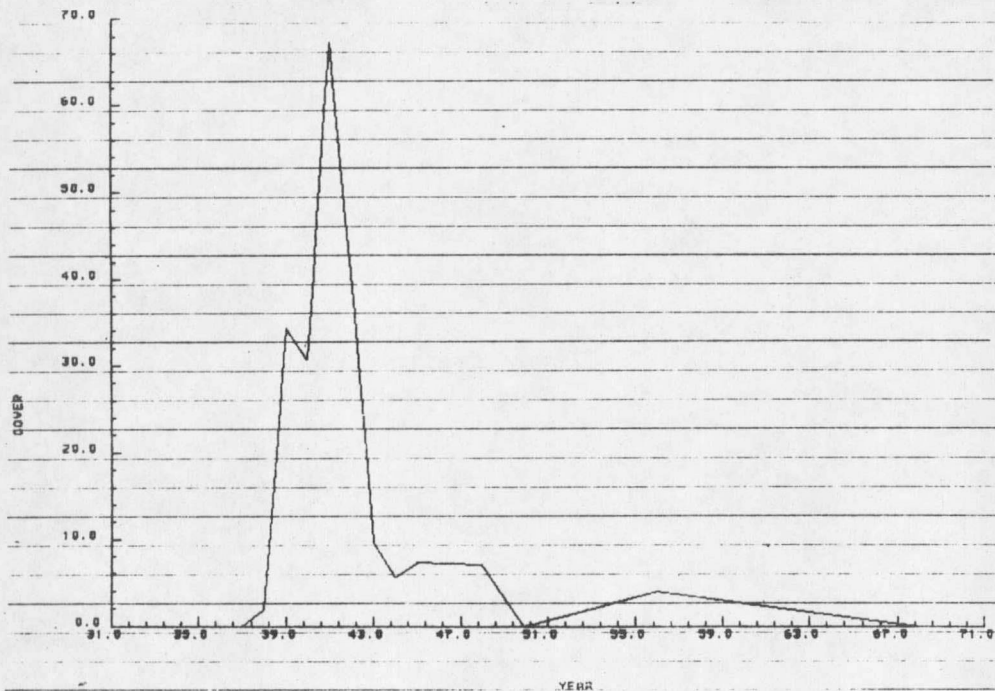


Figure A22. Basal Cover (cm²) of Winterfat by Years

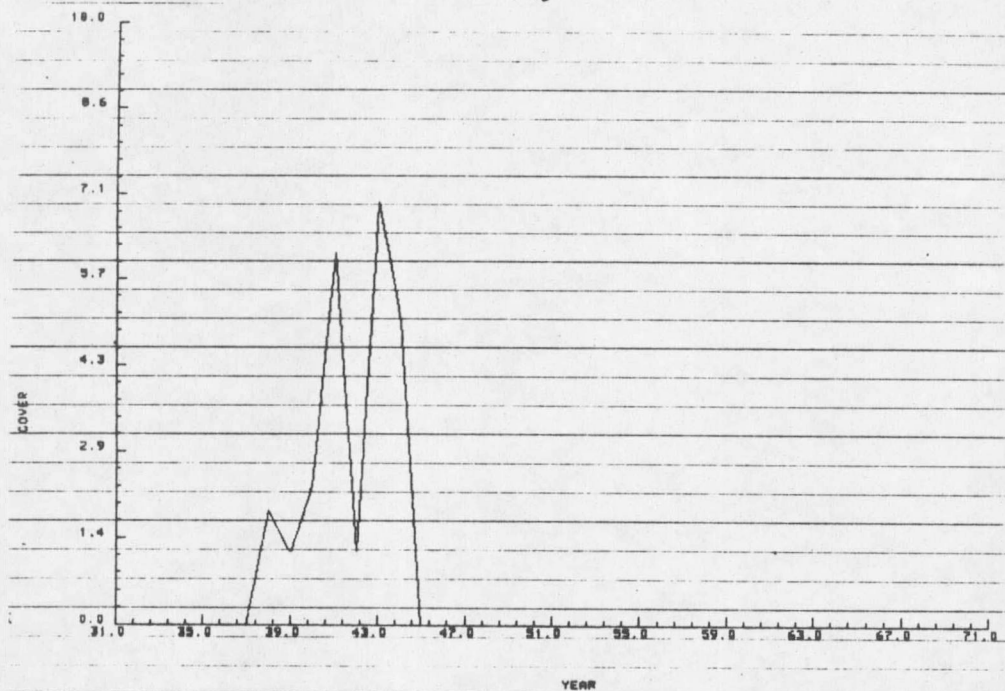


Figure A23. Basal Cover (cm²) of Western Tansymustard by Years

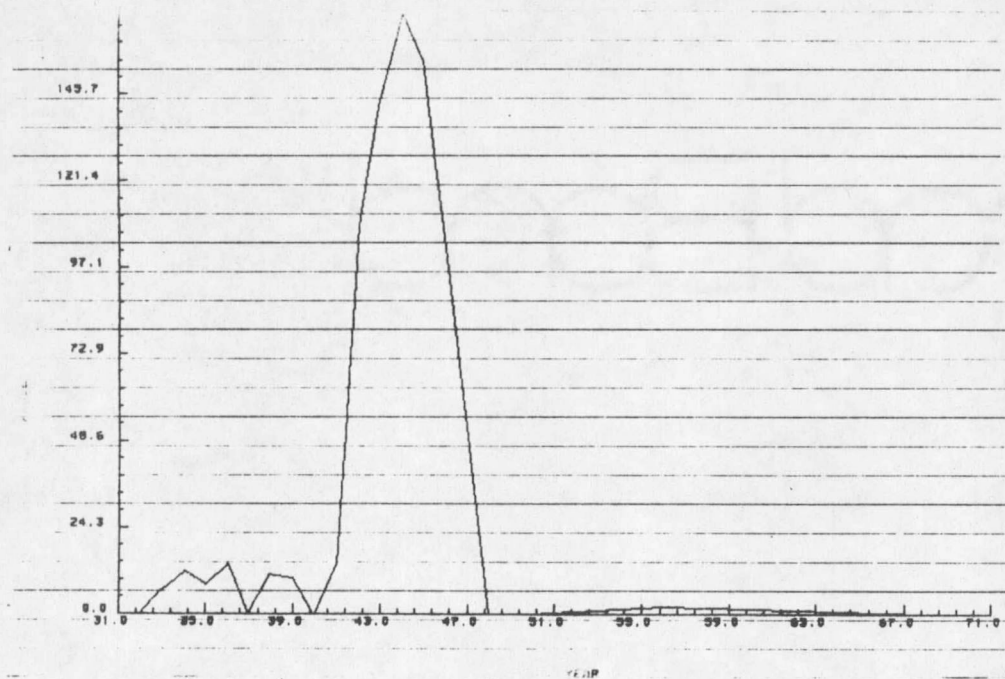


Figure A24. Basal Cover (cm²) of Inland Saltgrass by Years

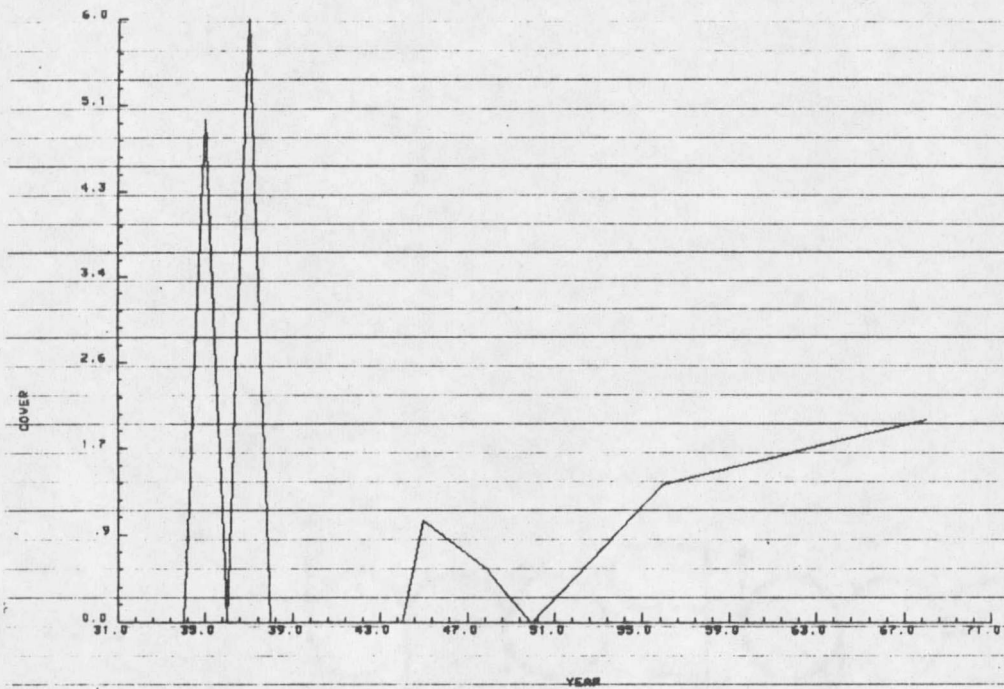


Figure A25. Basal Cover (cm²) of Snow-On-The-Mountain by Years

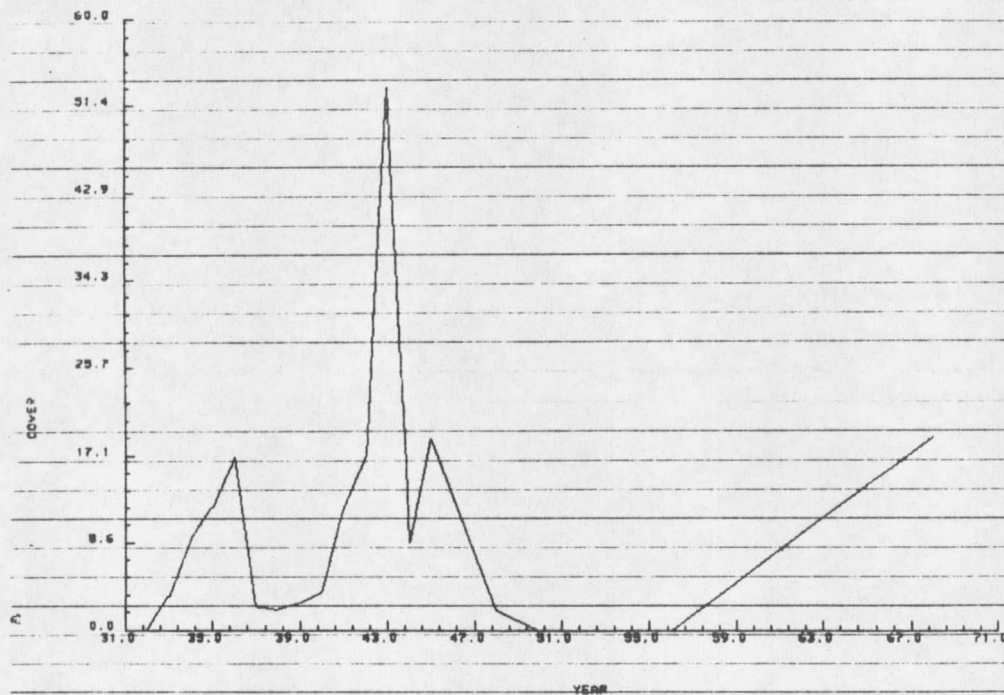


Figure A26. Basal Cover (cm²) of Little Barley by Years

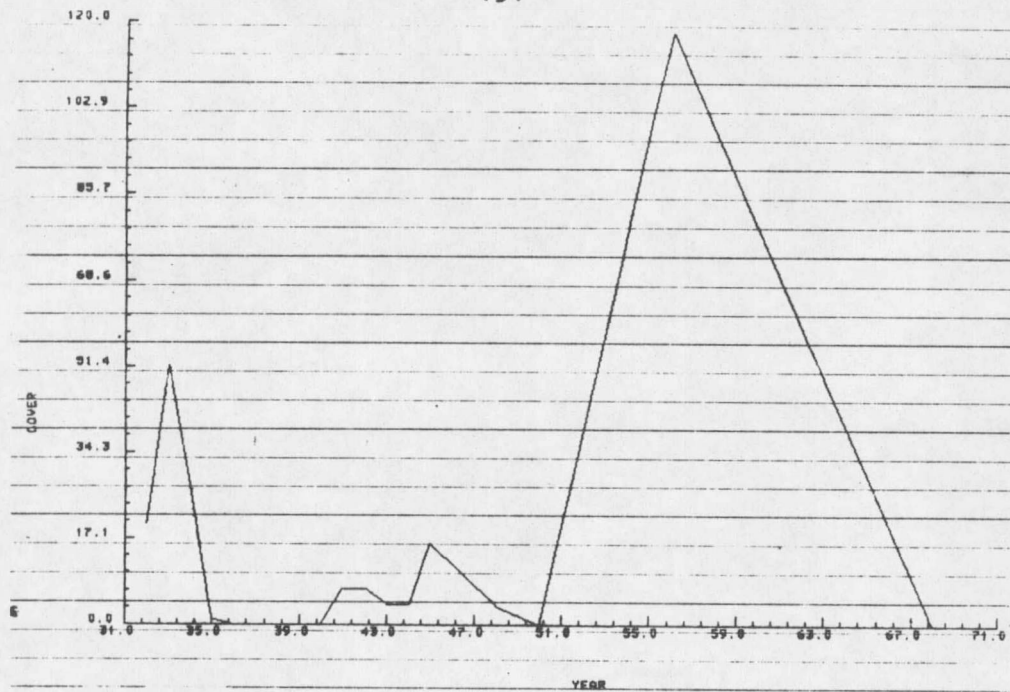


Figure A27. Basal Cover (cm²) of Prairie Junegrass by Years

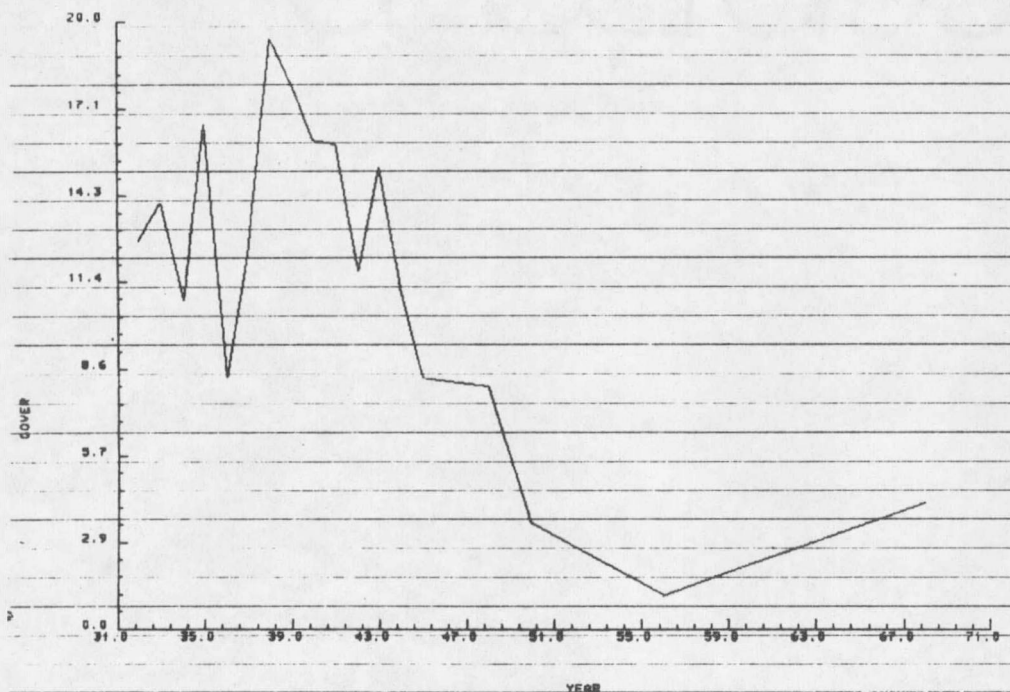


Figure A28. Basal Cover (cm²) of Pincushion Cactus by Years

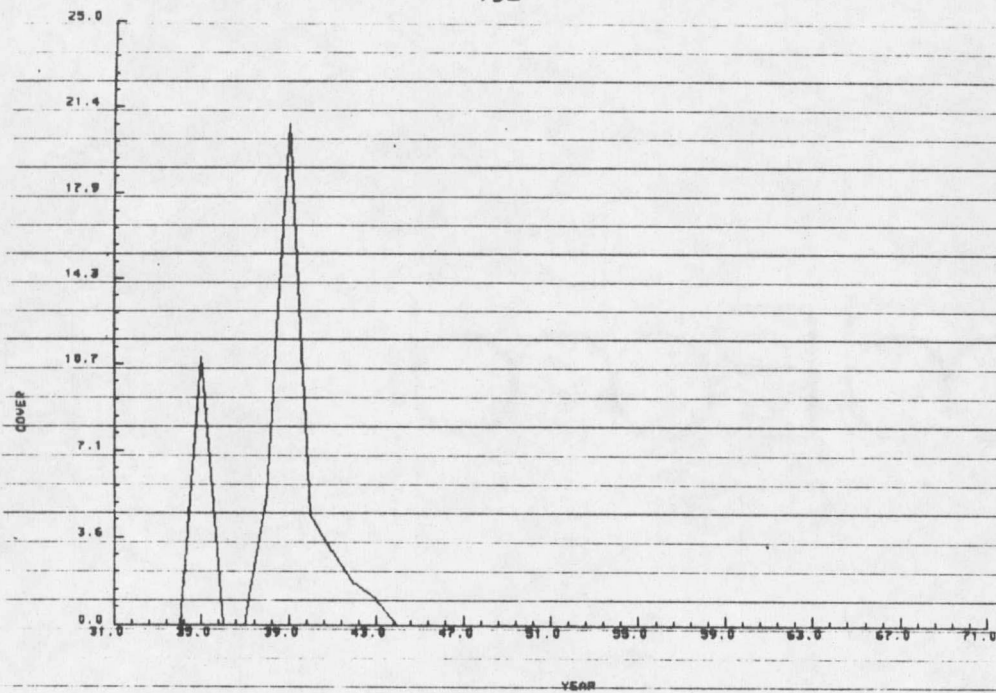


Figure A29. Basal Cover (cm²) of False Buffalograss by Years

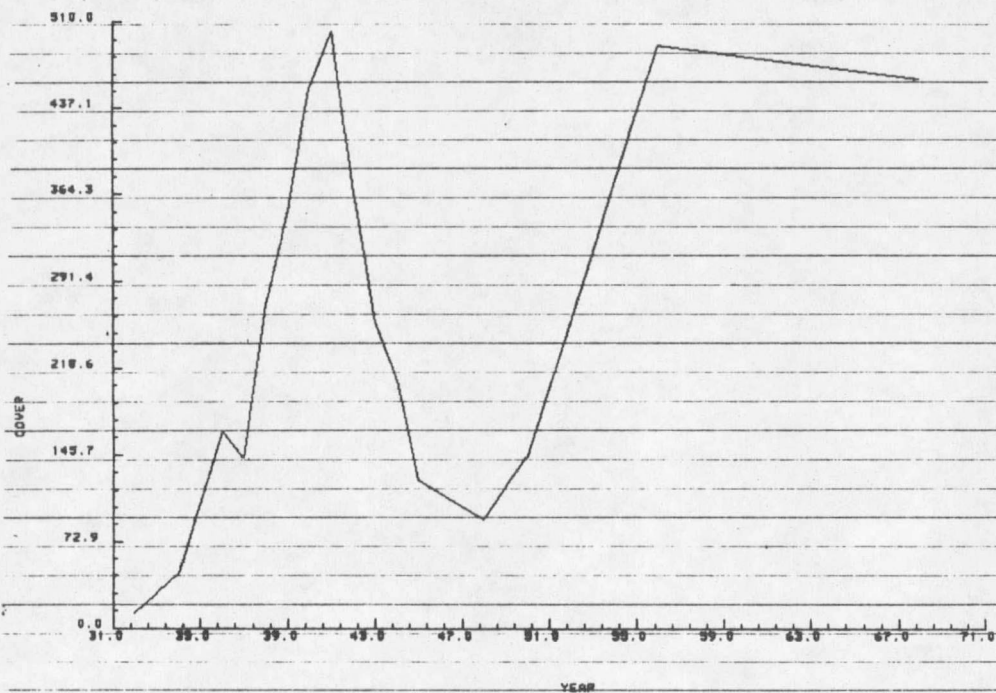


Figure A30. Basal Cover (cm²) of Plains Pricklypear by Years

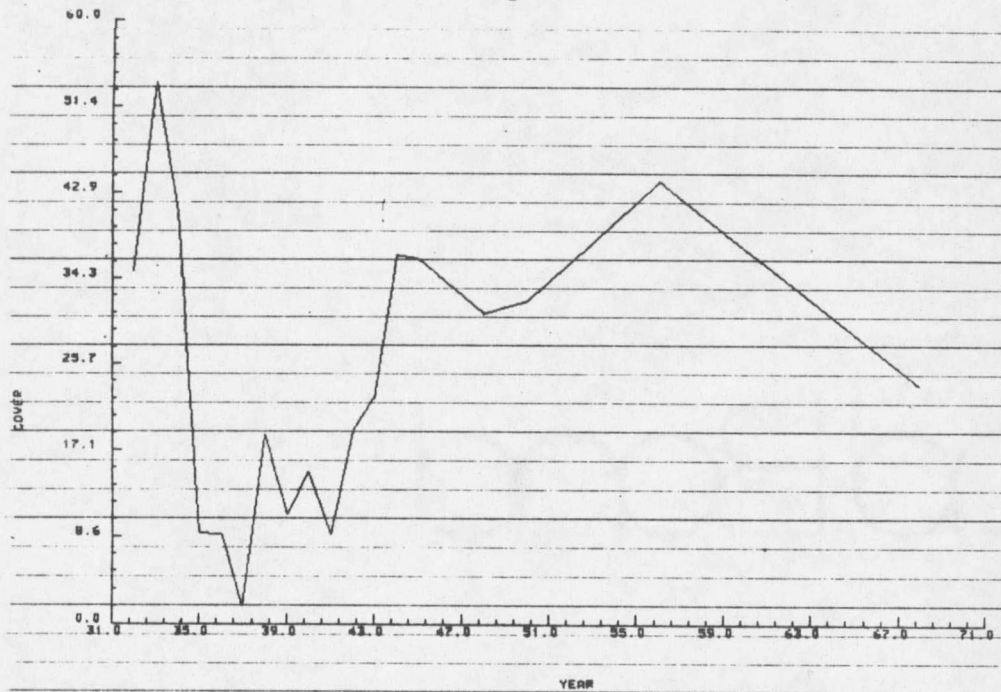


Figure A31. Basal Cover (cm²) of Hoods Phlox by Years

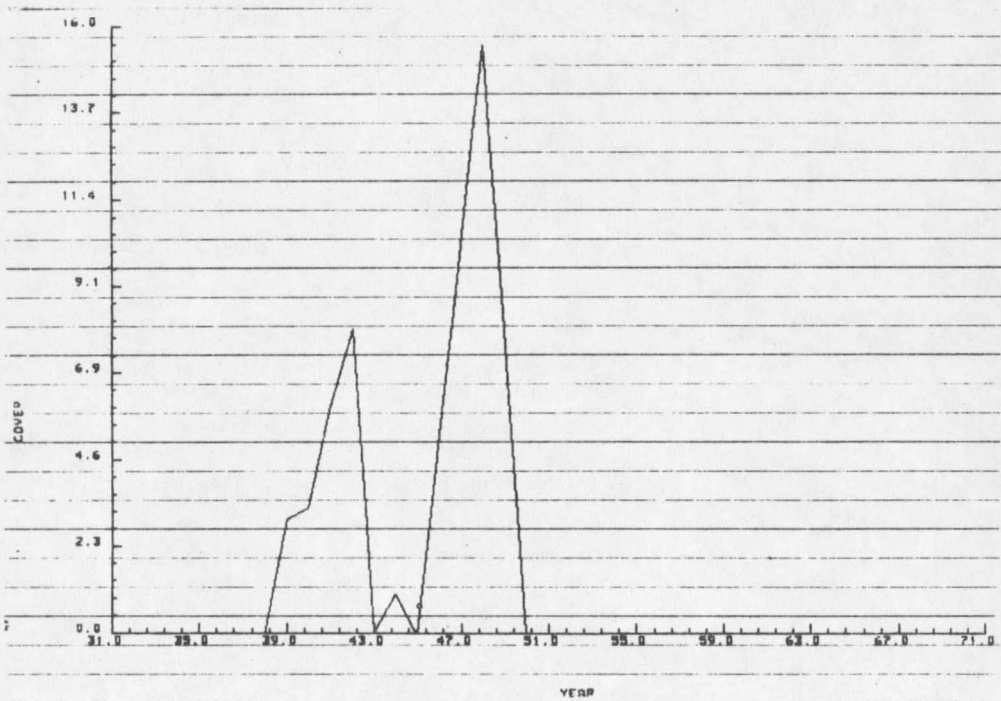


Figure A32. Basal Cover (cm²) of Big Bluegrass by Years

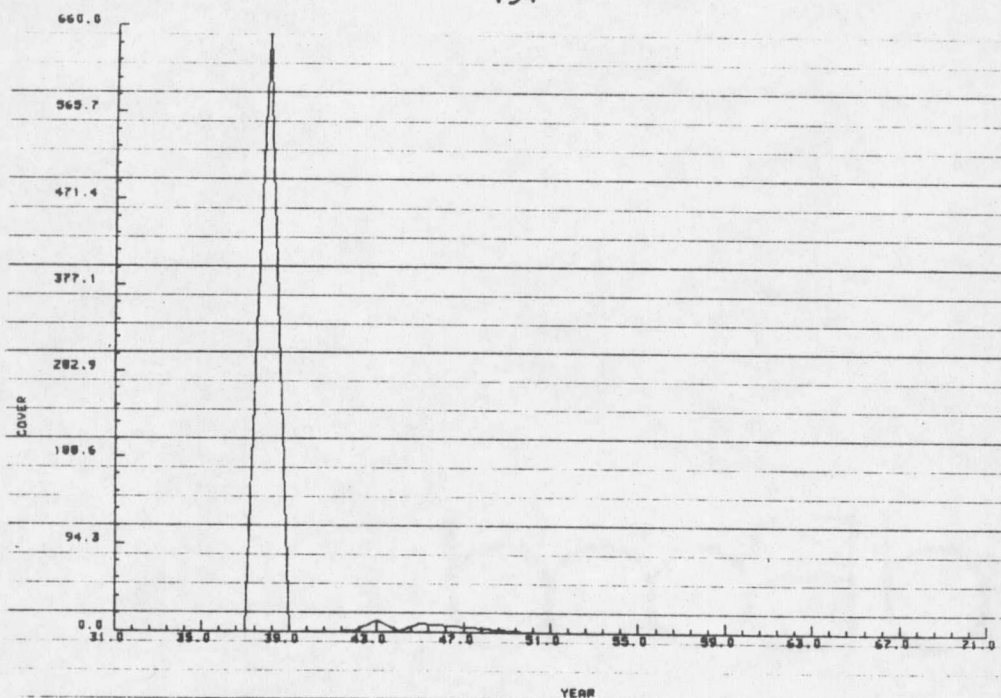


Figure A33. Basal Cover (cm²) of Kentucky Bluegrass by Years

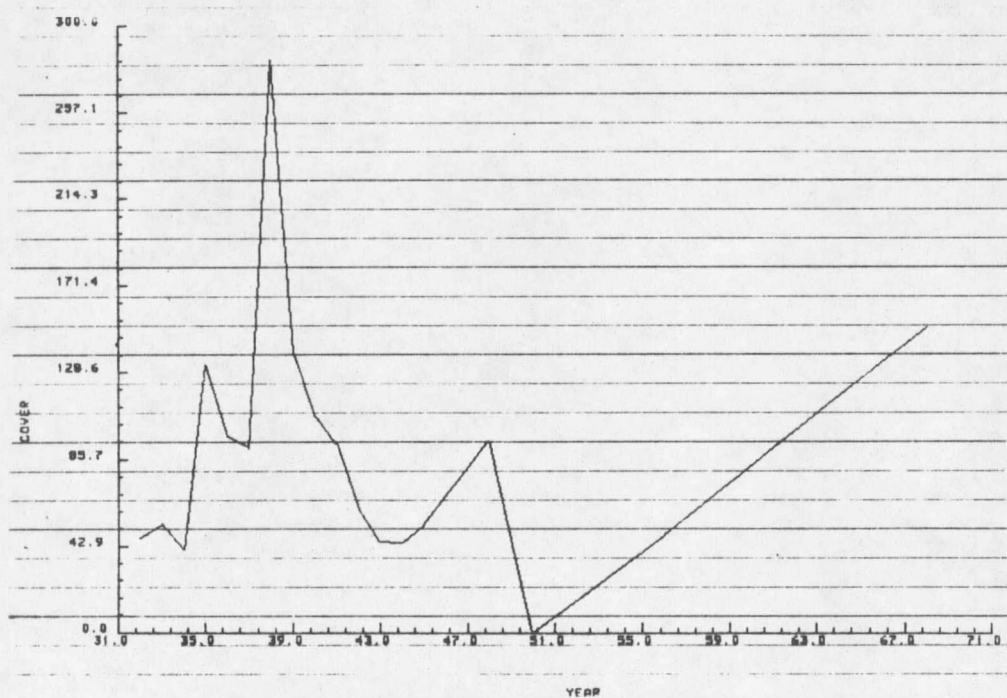


Figure A34. Basal Cover (cm²) of Sandberg Bluegrass by Years

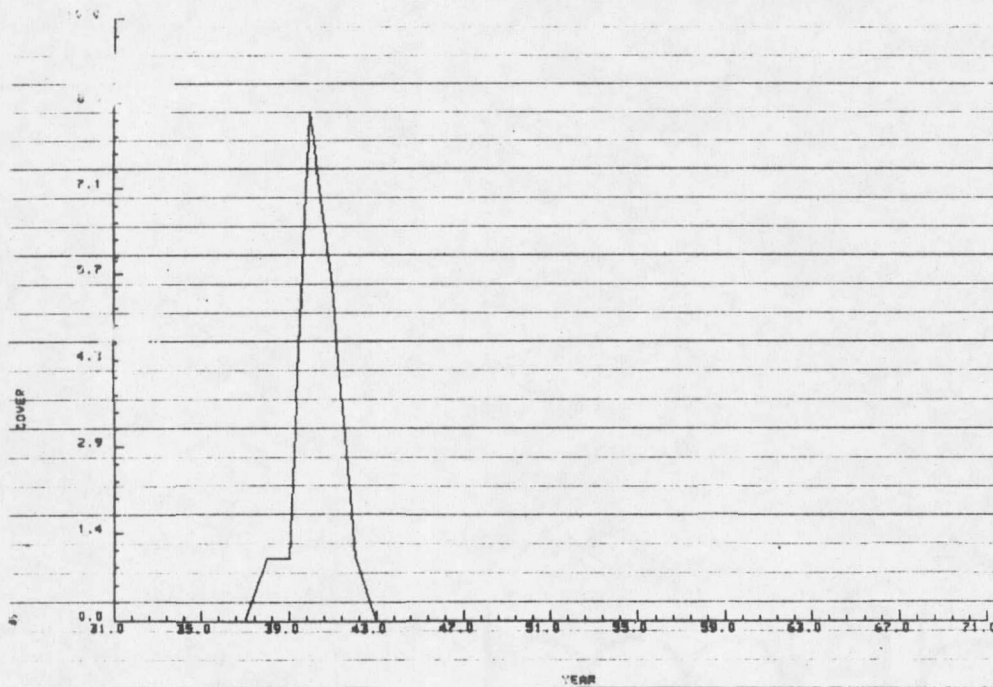


Figure A35. Basal Cover (cm²) of Russian Thistle (Salsola kali) by Years

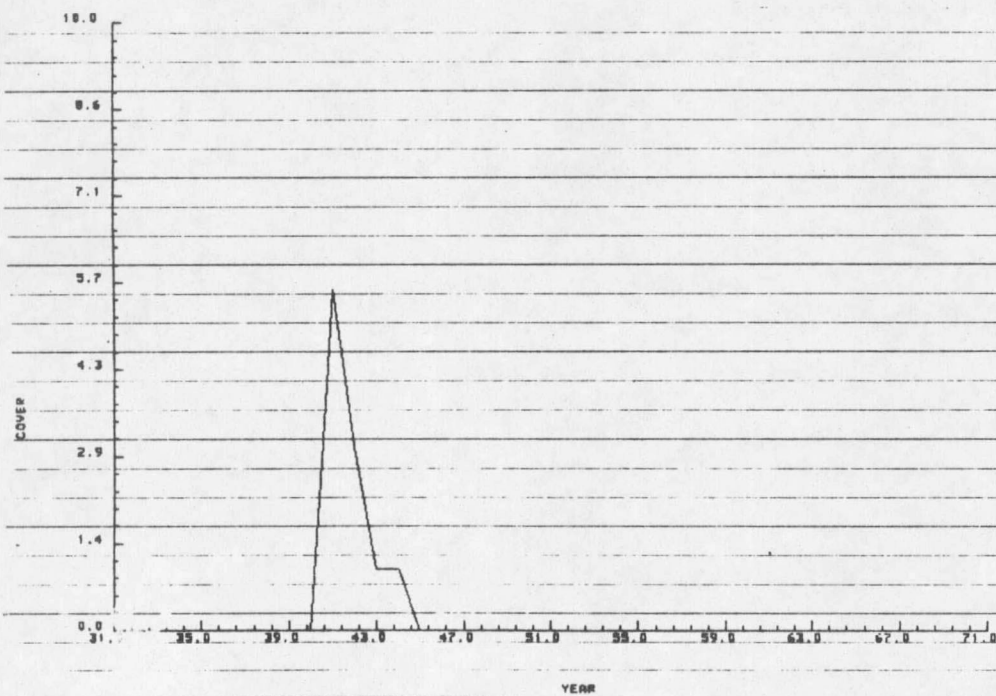


Figure A36. Basal Cover (cm²) of Russian Thistle (S. pestifer) by Years

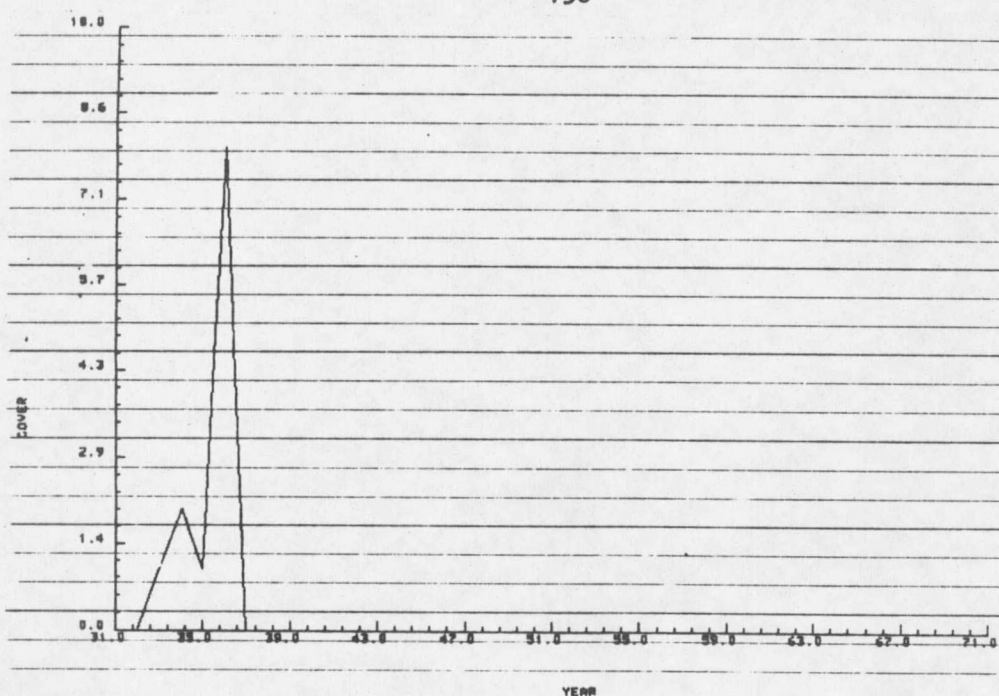


Figure A37. Basal Cover (cm²) of Greasewood by Years

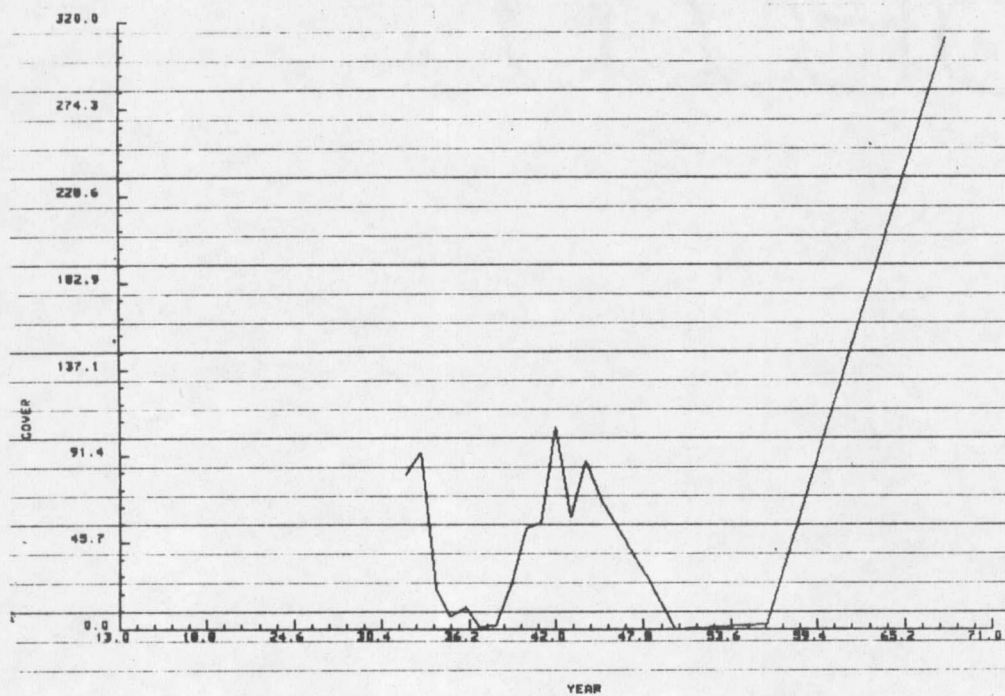


Figure A38. Basal Cover (cm²) of Tumblegrass by Years

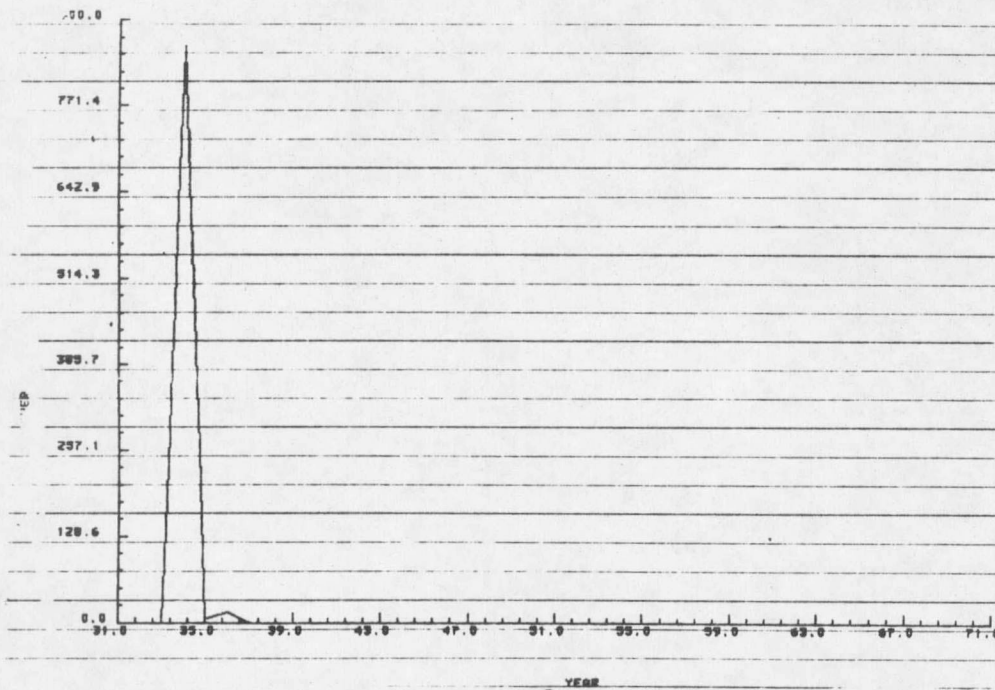


Figure A39. Basal Cover (cm²) of Little Bluestem by Years

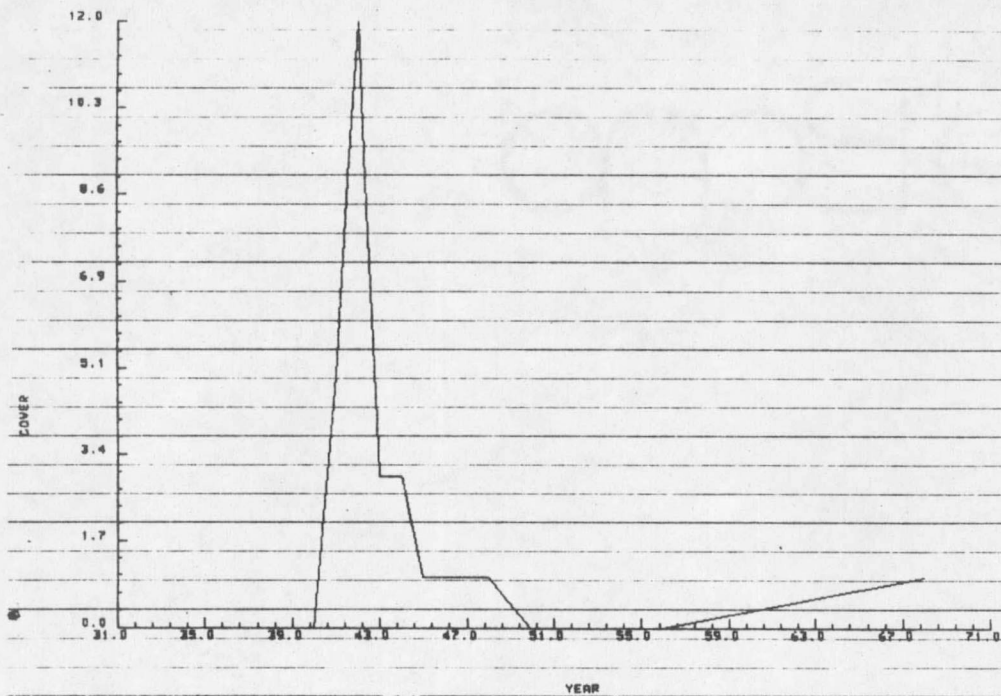


Figure A40. Basal Cover (cm²) of Bottlebrush Squirreltail by Years

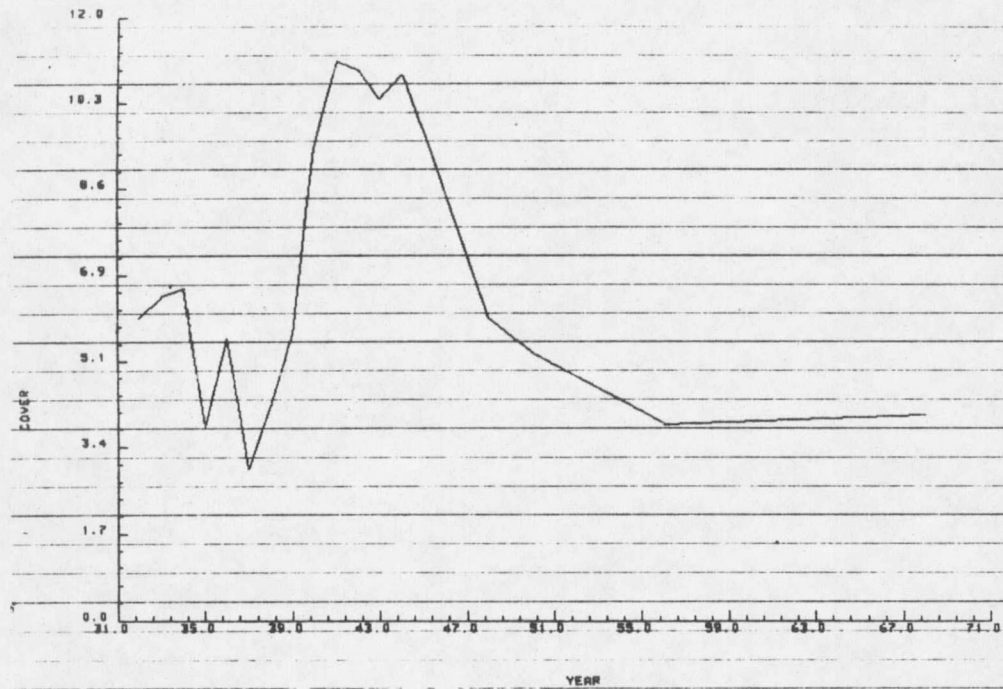


Figure A41. Basal Cover (cm²) of Scarlet Globemallow by Years

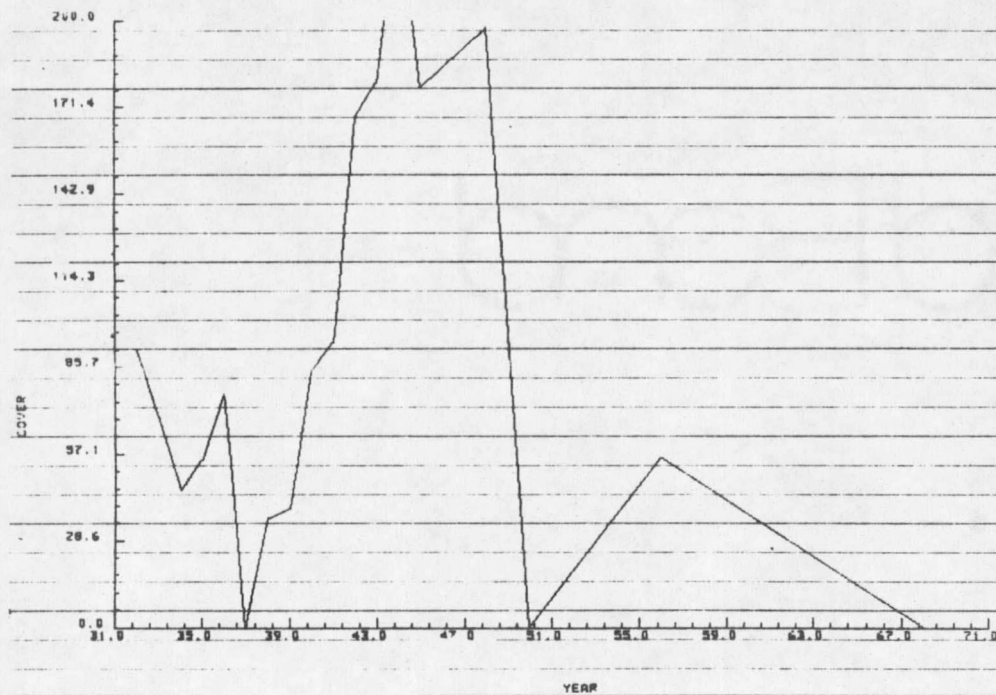


Figure A42. Basal Cover (cm²) of Sand Dropseed by Years

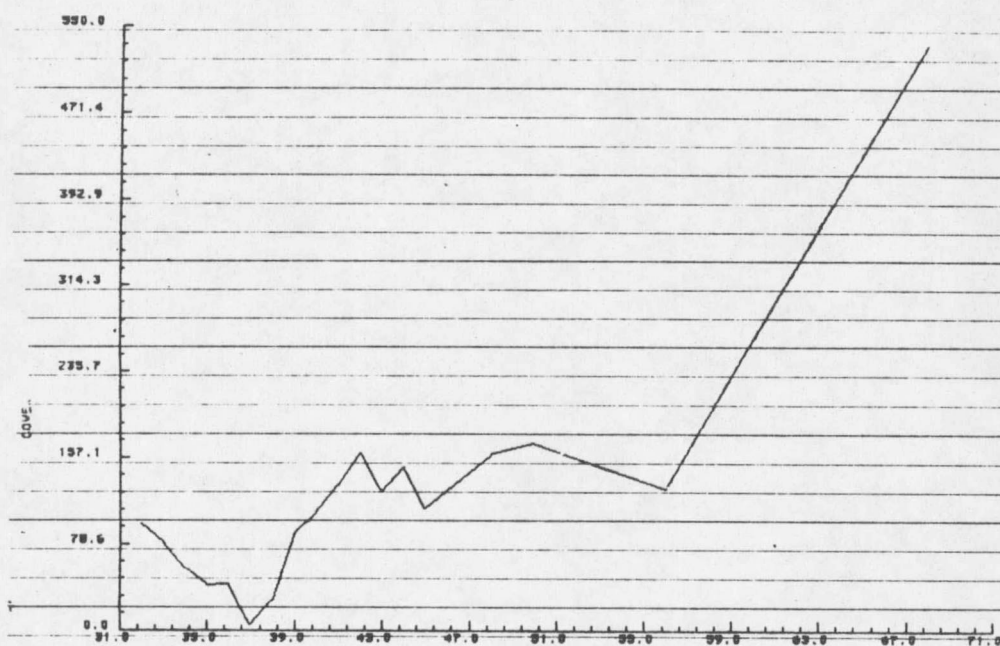


Figure A43. Basal Cover (cm²) of Needle-And-Thread by Years

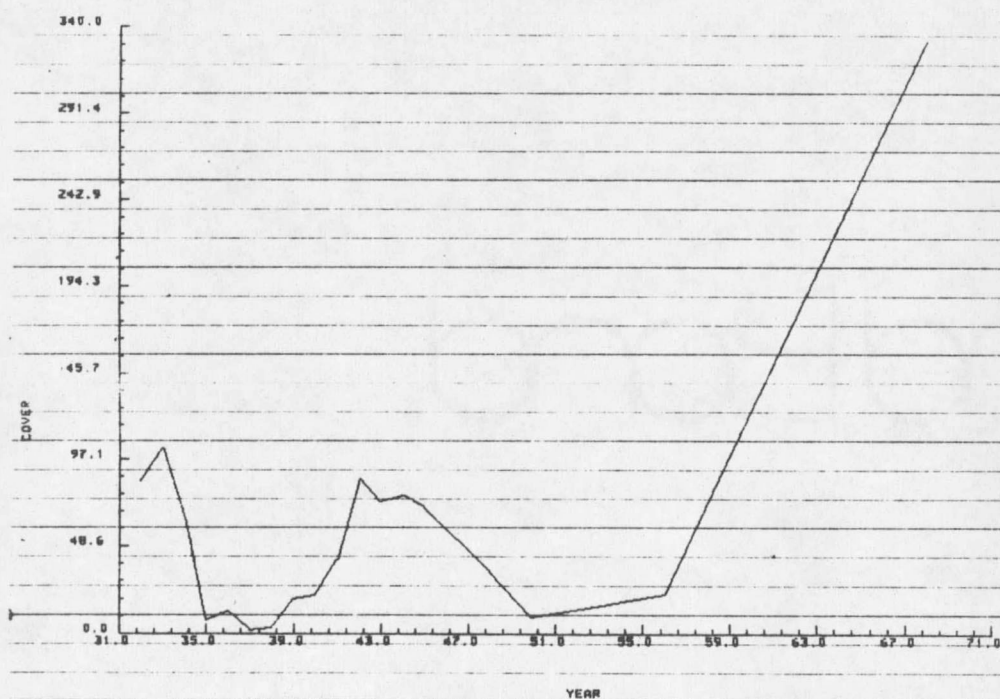


Figure A44. Basal Cover (cm²) of Green Needlegrass by Years

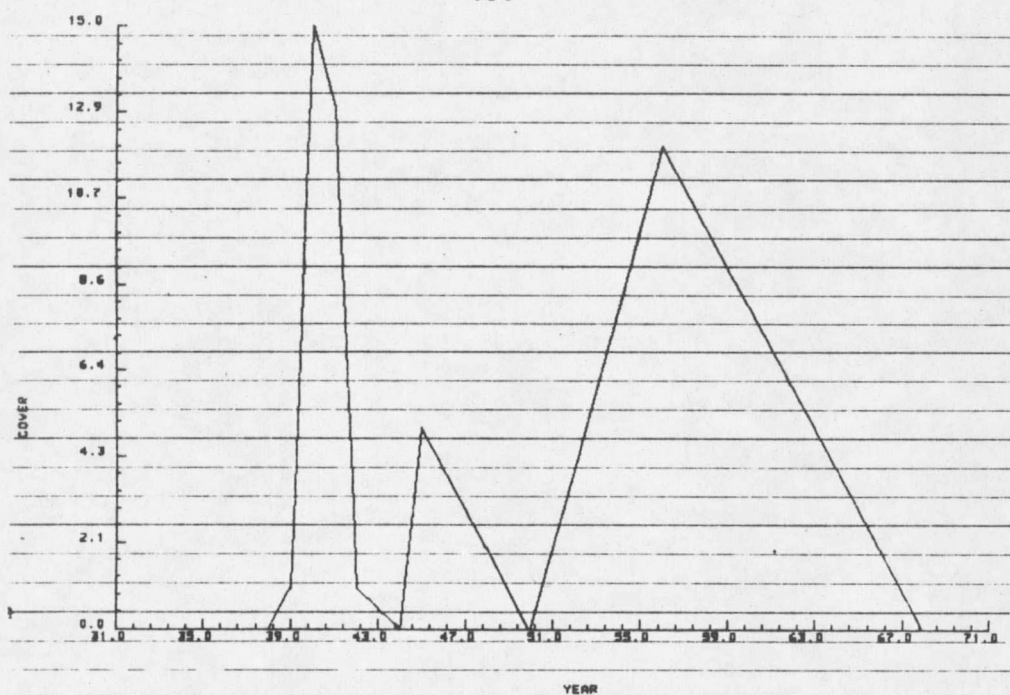


Figure A45. Basal Cover (cm²) of Field Pennycress by Years

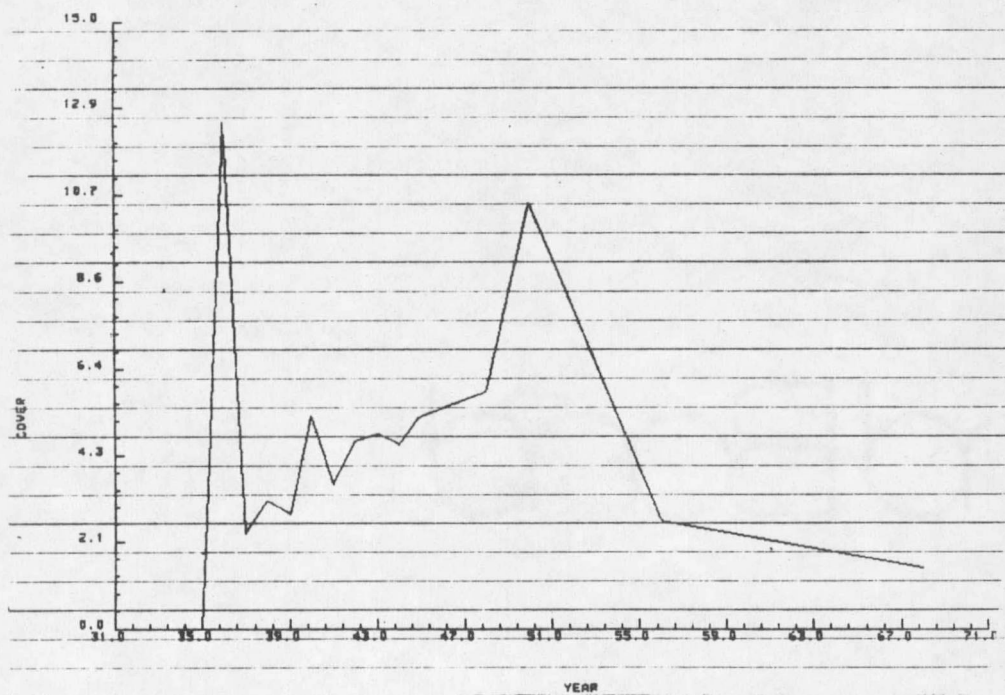


Figure A46. Basal Cover (cm²) of American Vetch by Years

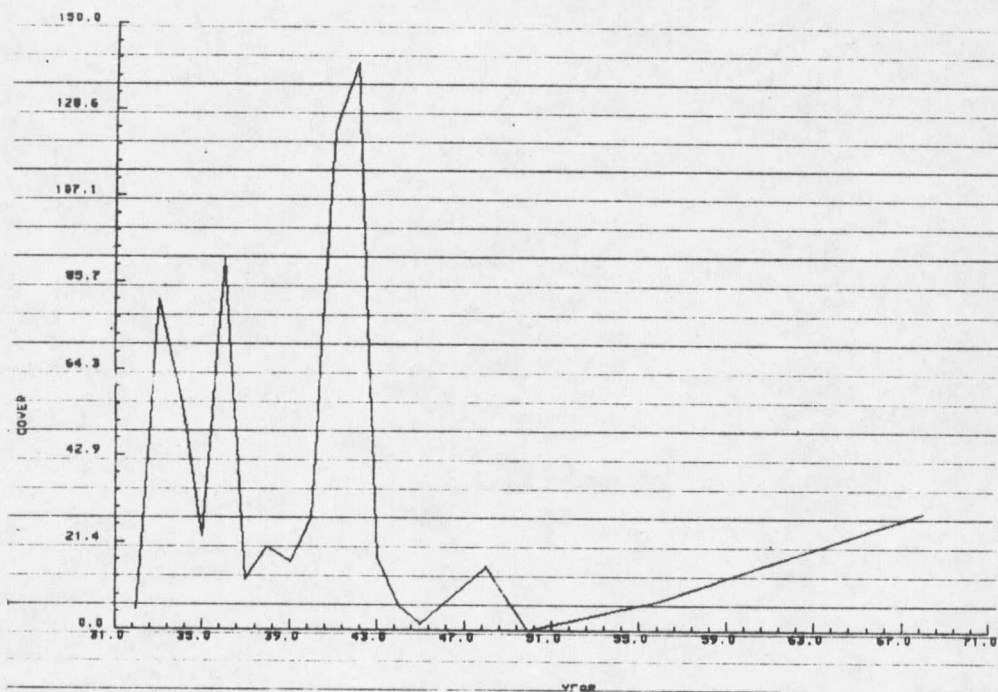


Figure A47. Basal Cover (cm²) of Six Weeks Grass by Years

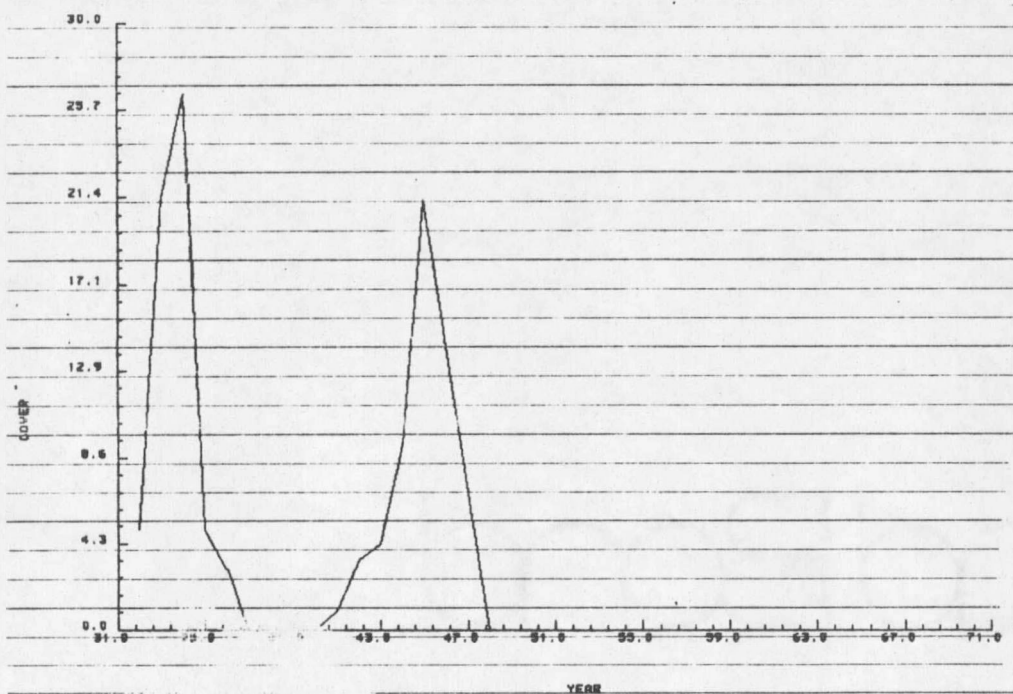


Figure A48. Basal Cover (cm²) of Broom Snakeweed by Years

APPENDIX B

Included are graphs of 21 species. For an explanation of these graphs, see page 42. These 21 species are the same as those indicated by an asterisk in Table 3.

The vertical axis represents basal cover (cm^2) of the species being considered and the horizontal axis represents annual precipitation (inches). Annual precipitation was determined on a calendar year basis.

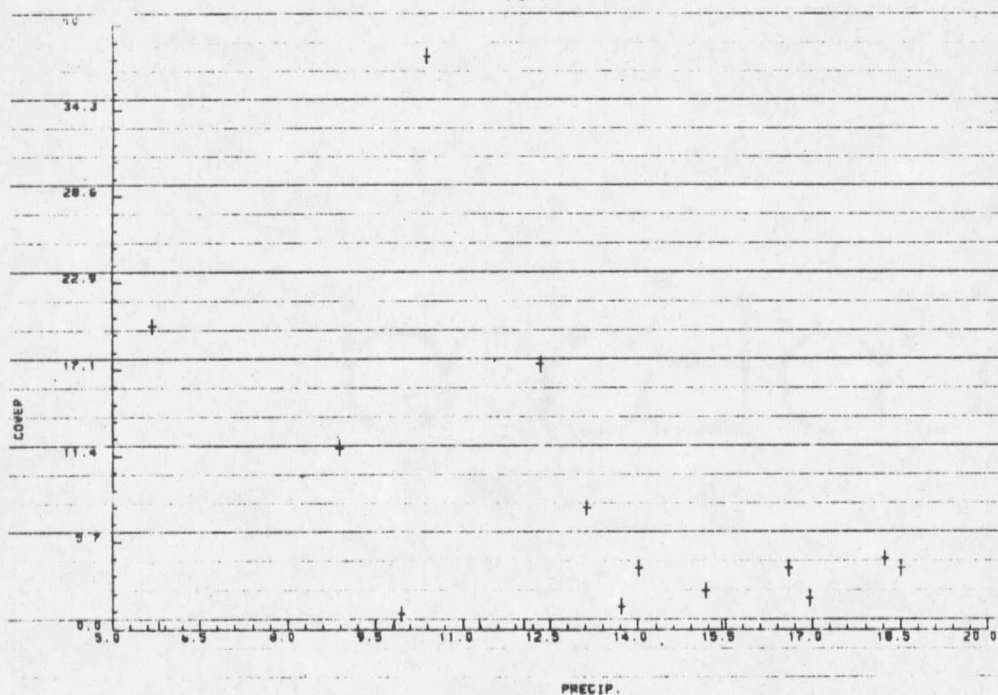


Figure B1. Basal Cover of Western Yarrow (cm²) vs. Ppt. (in.)

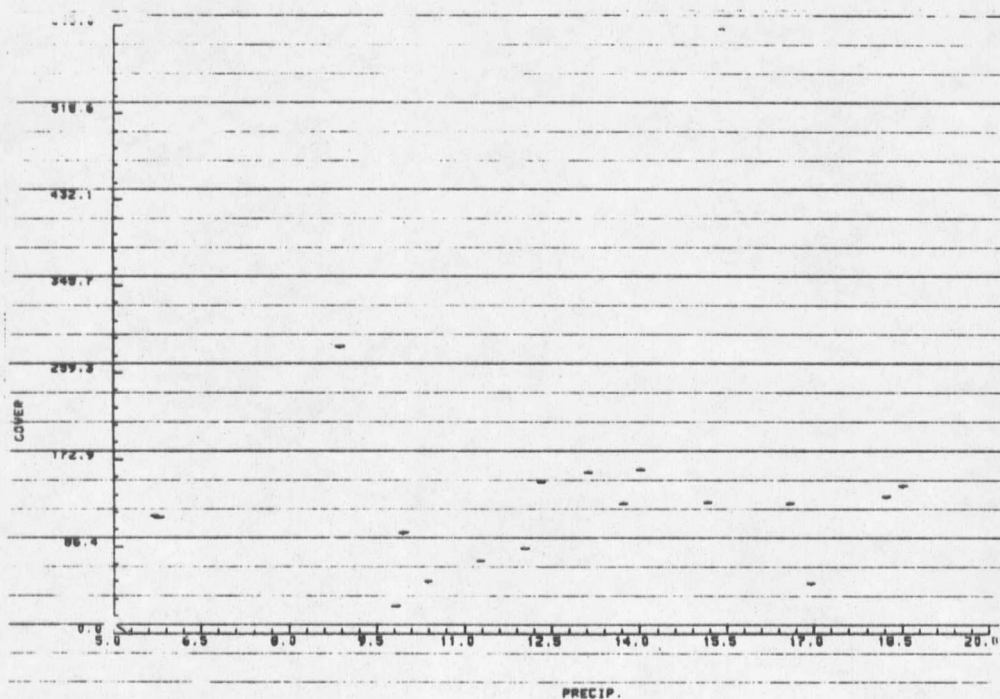


Figure B2. Basal Cover of Western Wheatgrass (cm²) vs. ppt. (in.)

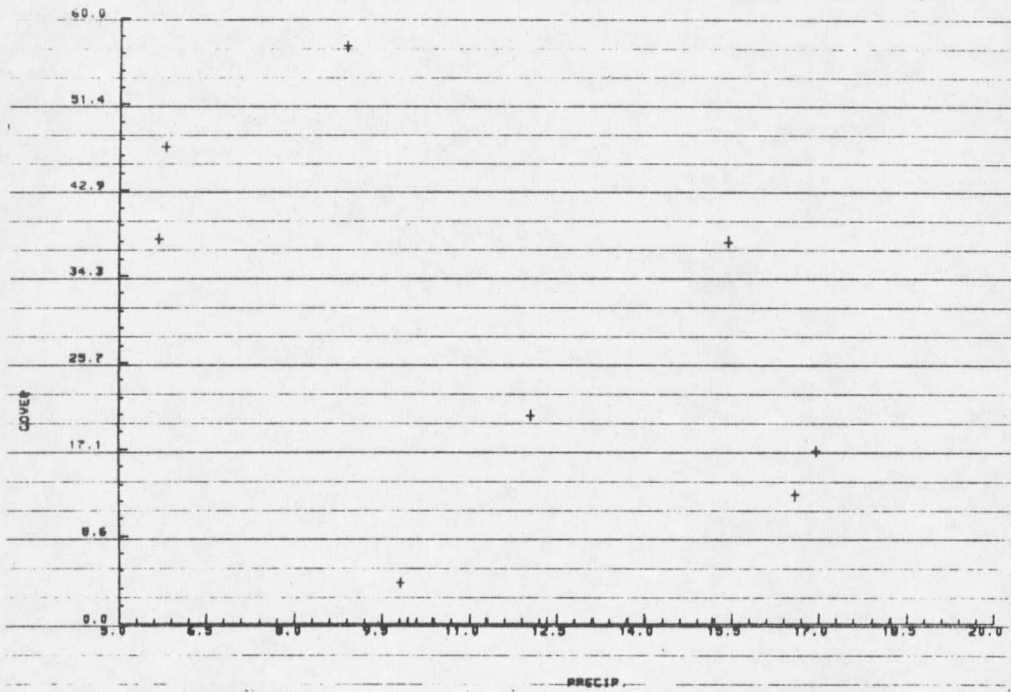


Figure B3. Basal Cover of Red Threeawn (cm²) vs. Ppt. (in.)

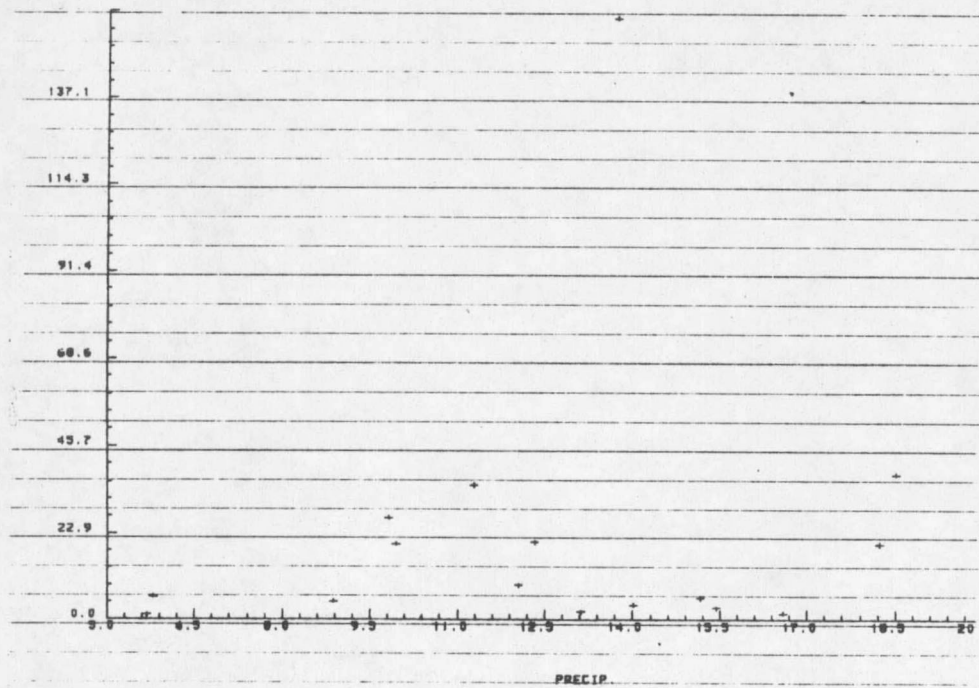


Figure B4. Basal Cover of Silver Sagebrush (cm²) vs. ppt. (in.)

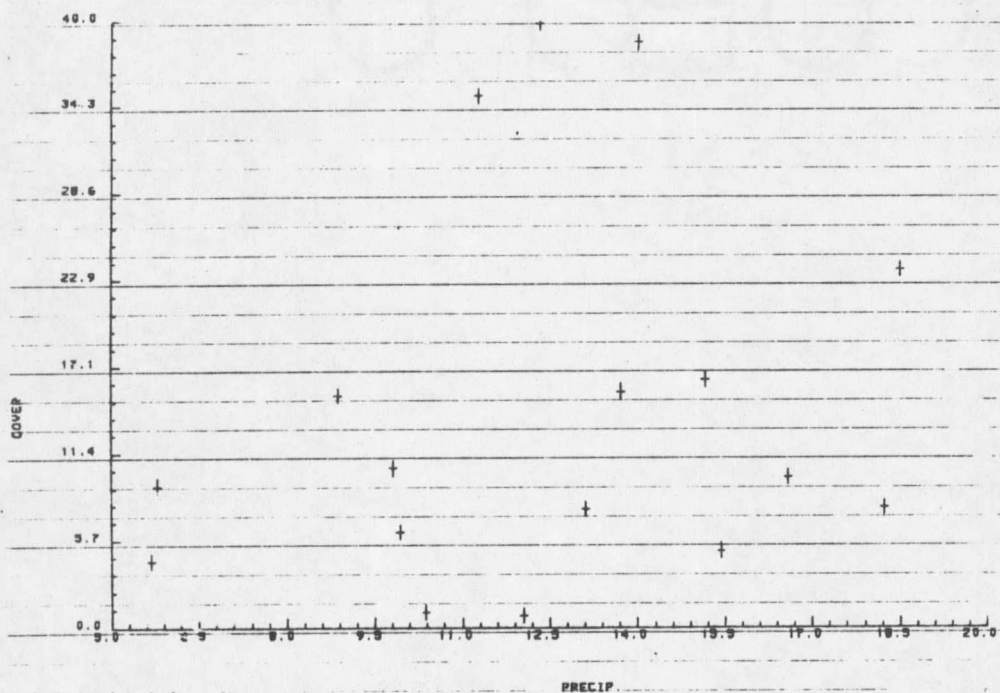


Figure B5. Basal Cover of Fringed Sagewort (cm²) vs. Ppt. (in.)

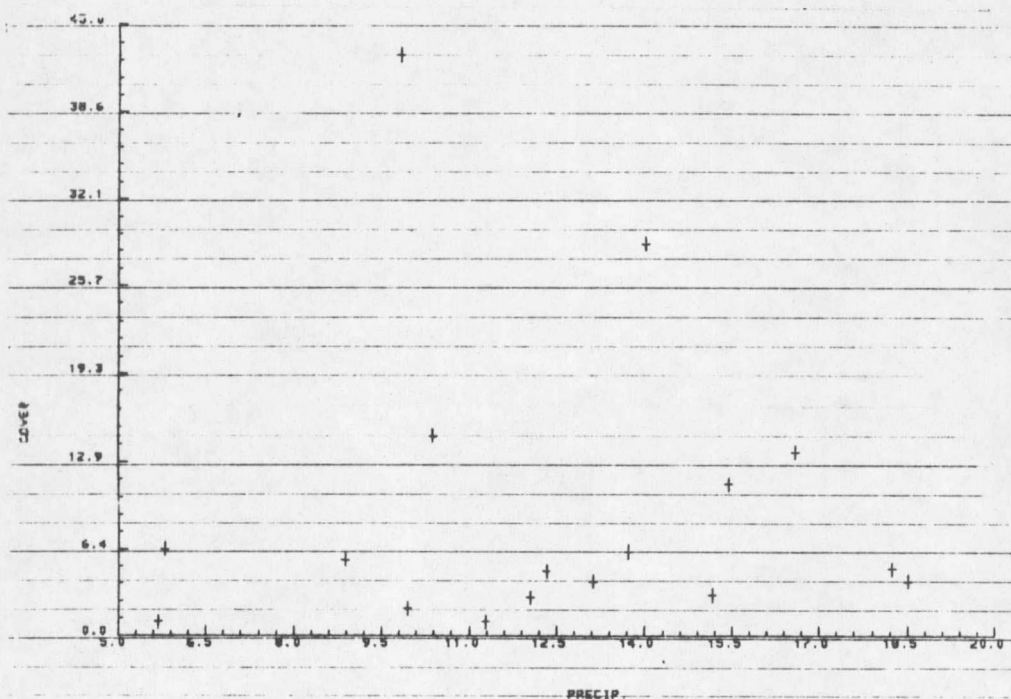


Figure B6. Basal Cover of Big Sagebrush (cm²) vs. ppt. (in.)

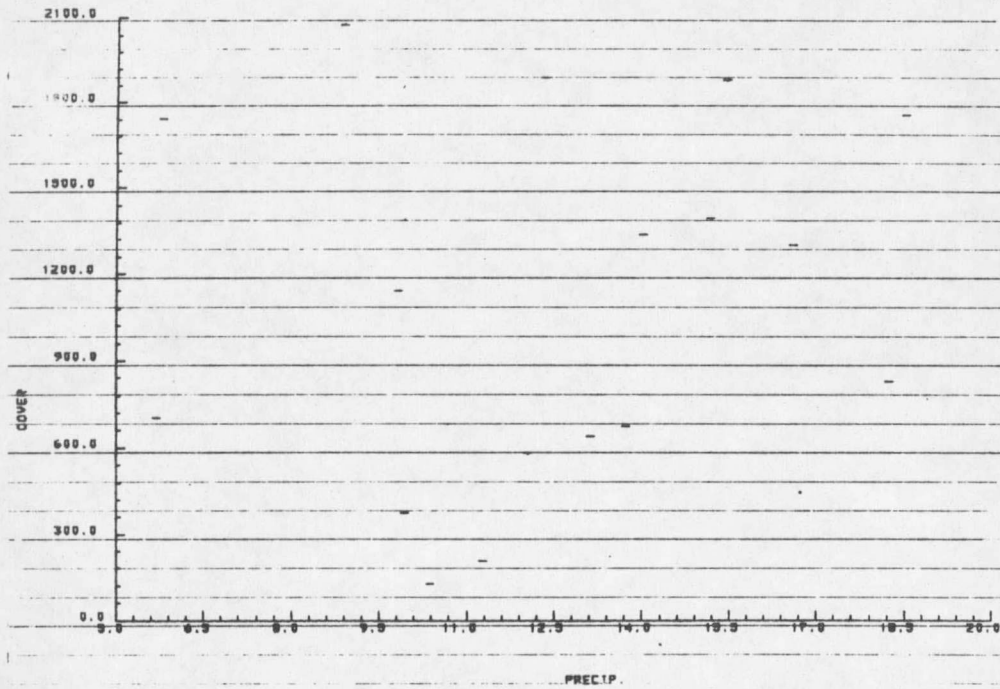


Figure B7. Basal Cover of Blue Grama (cm²) vs. Ppt. (in.)

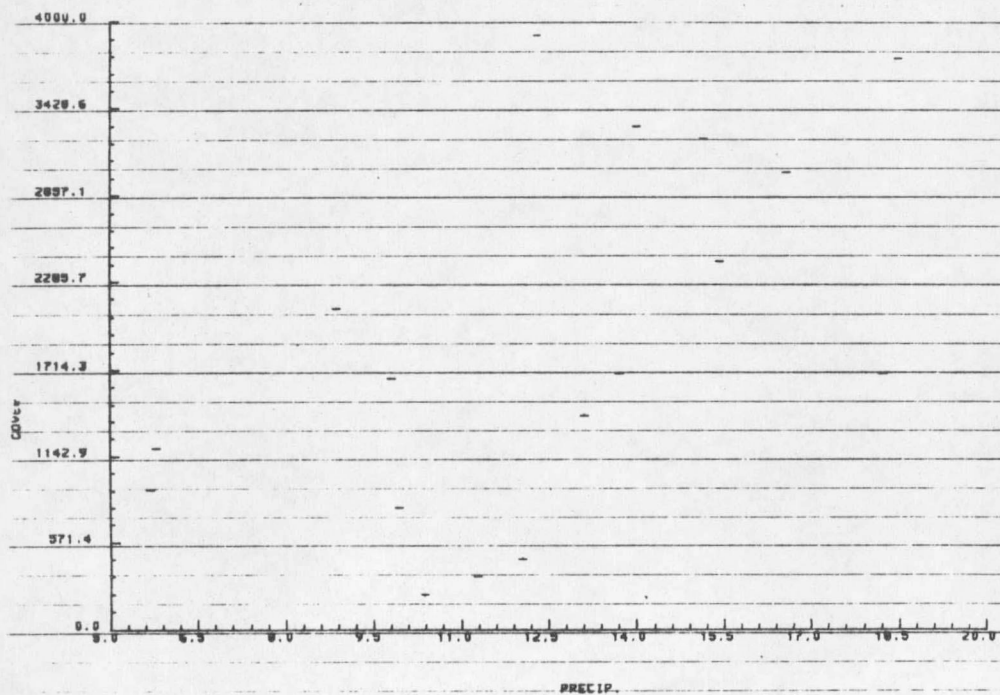


Figure B8. Basal Cover of Buffalograss (cm²) vs. ppt. (in.)

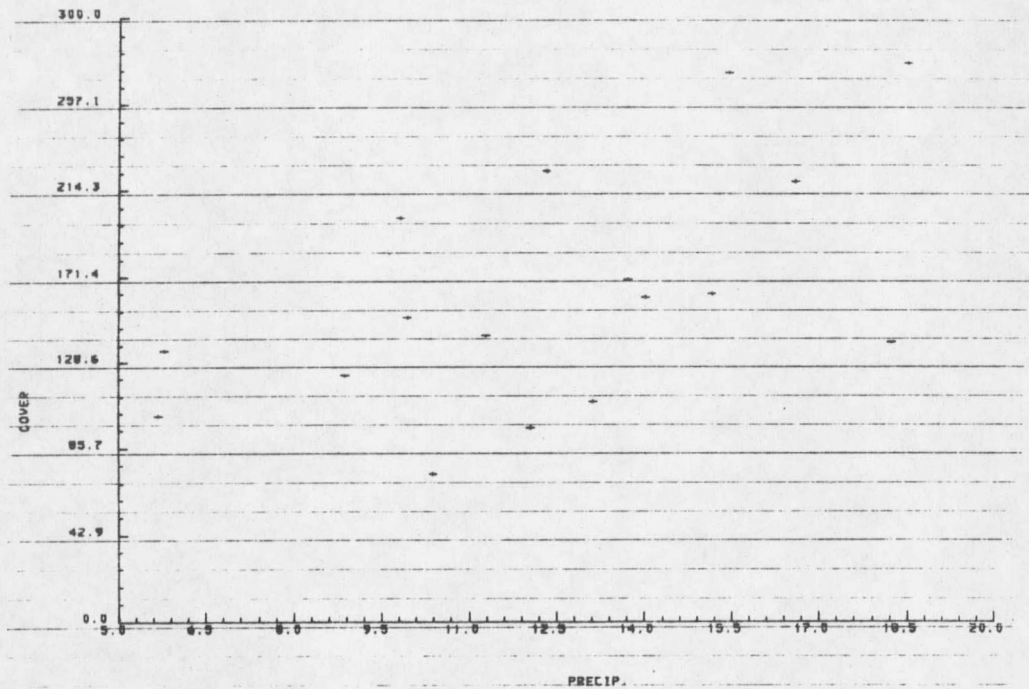


Figure B9. Basal Cover of Threadleaf Sedge (cm²) vs. Ppt. (in.)

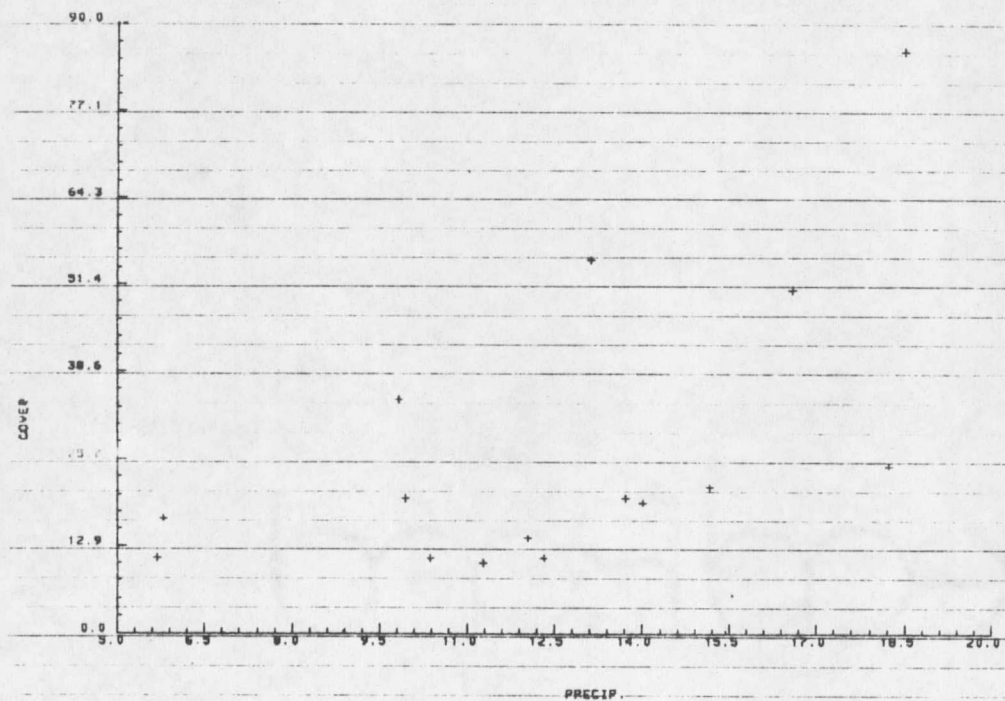


Figure B10. Basal Cover of Needleleaf Sedge (cm²) vs. ppt. (in.)

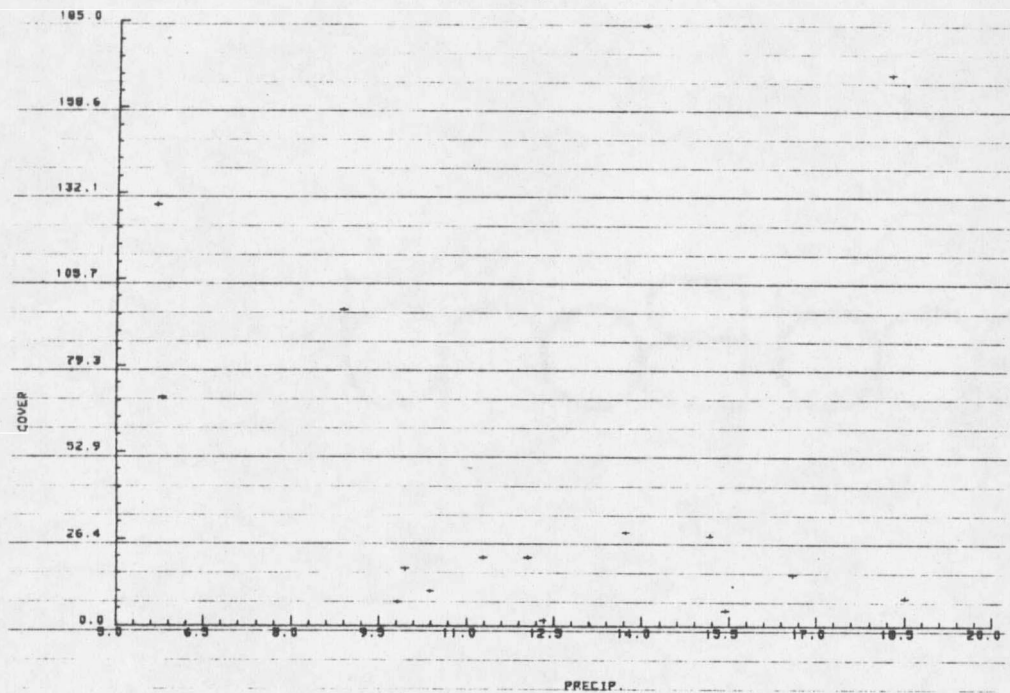


Figure B11. Basal Cover of Six Weeks Grass (cm^2) vs. Ppt. (in.)

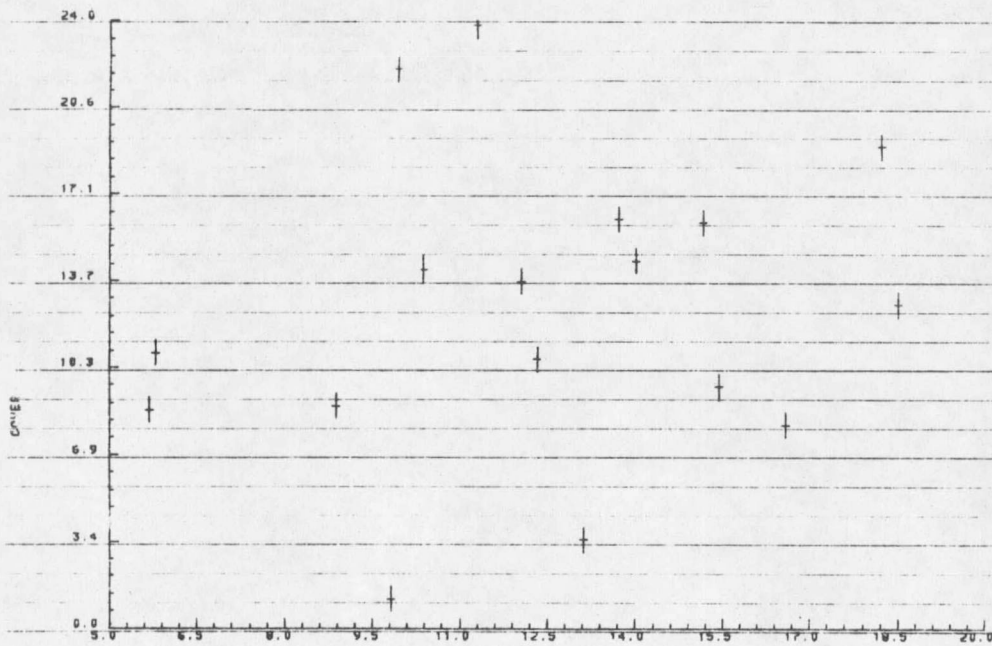


Figure B12. Basal Cover of Pincushion Cactus (cm^2) vs. ppt. (in.)

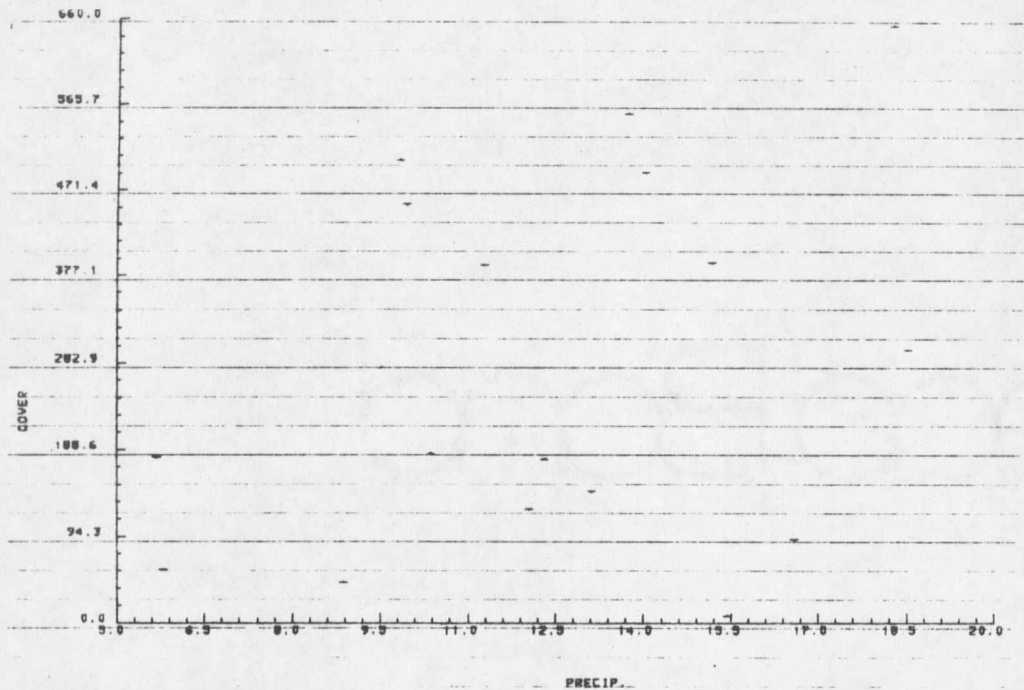


Figure B13. Basal Cover of Plains Pricklypear (cm²) vs. Ppt. (in.)

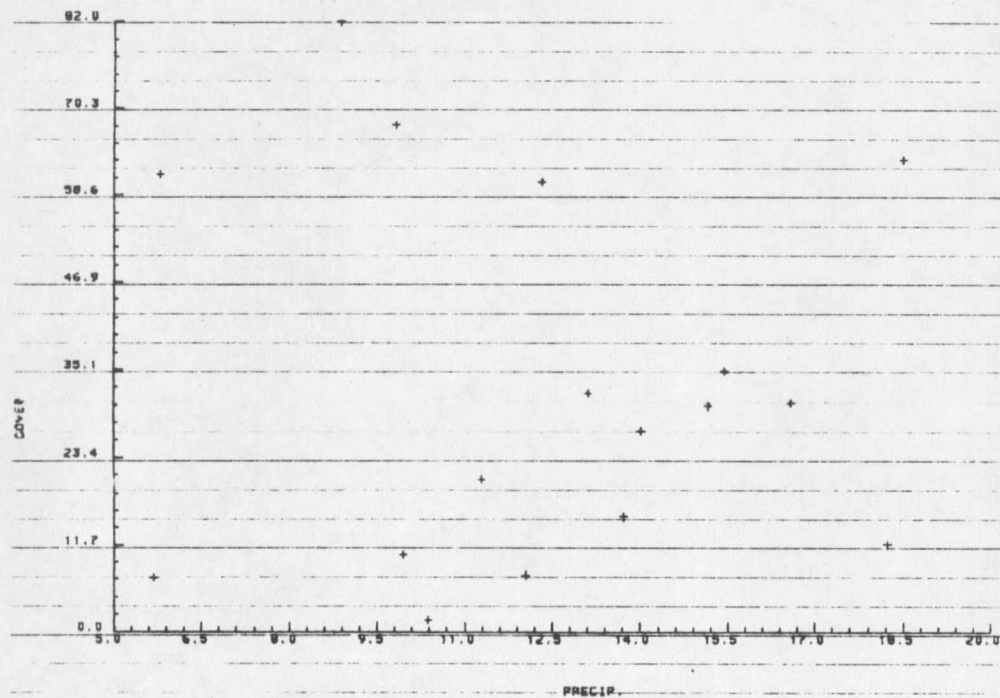


Figure B14. Basal Cover of Hoods Phlox (cm²) vs. ppt. (in.)

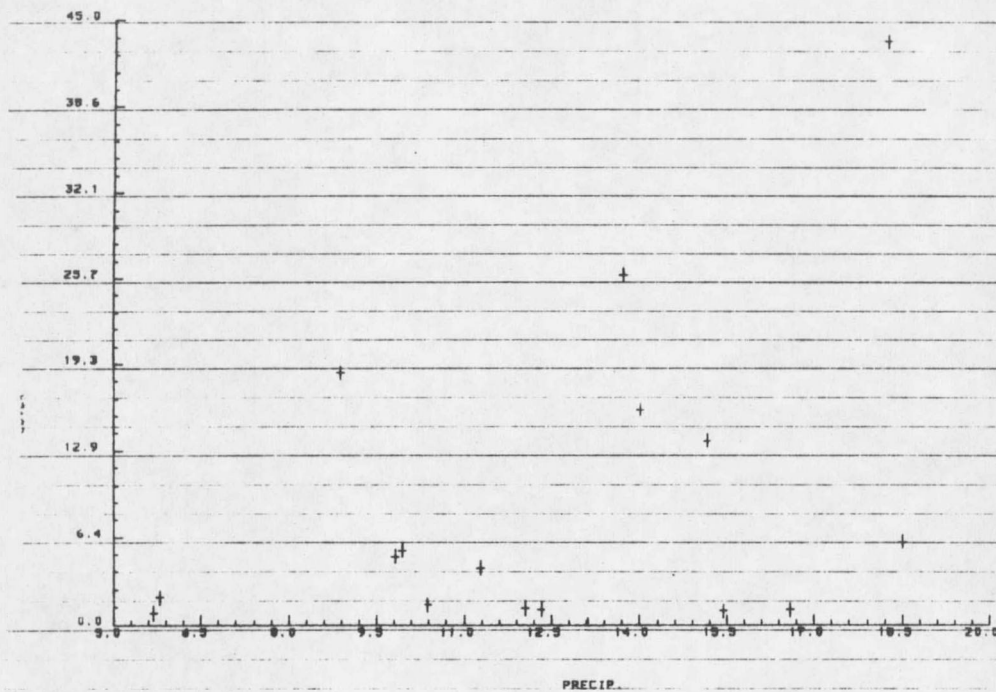


Figure B15. Basal Cover of Woolly Plantain (cm²) vs. Ppt. (in.)

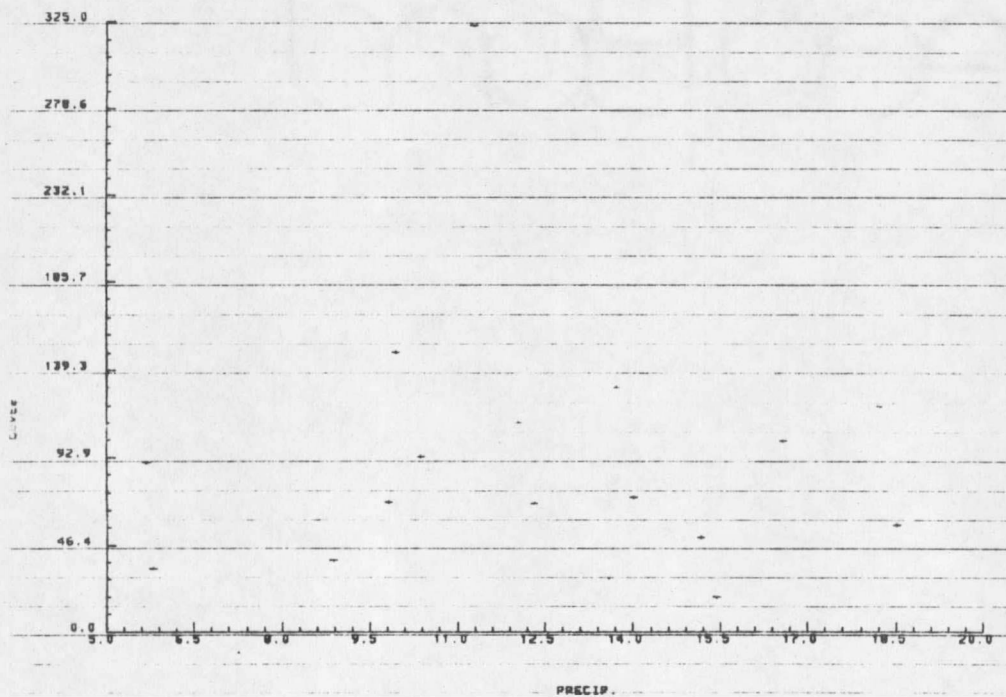


Figure B16. Basal Cover of Sandberg Bluegrass (cm²) vs. ppt. (in.)

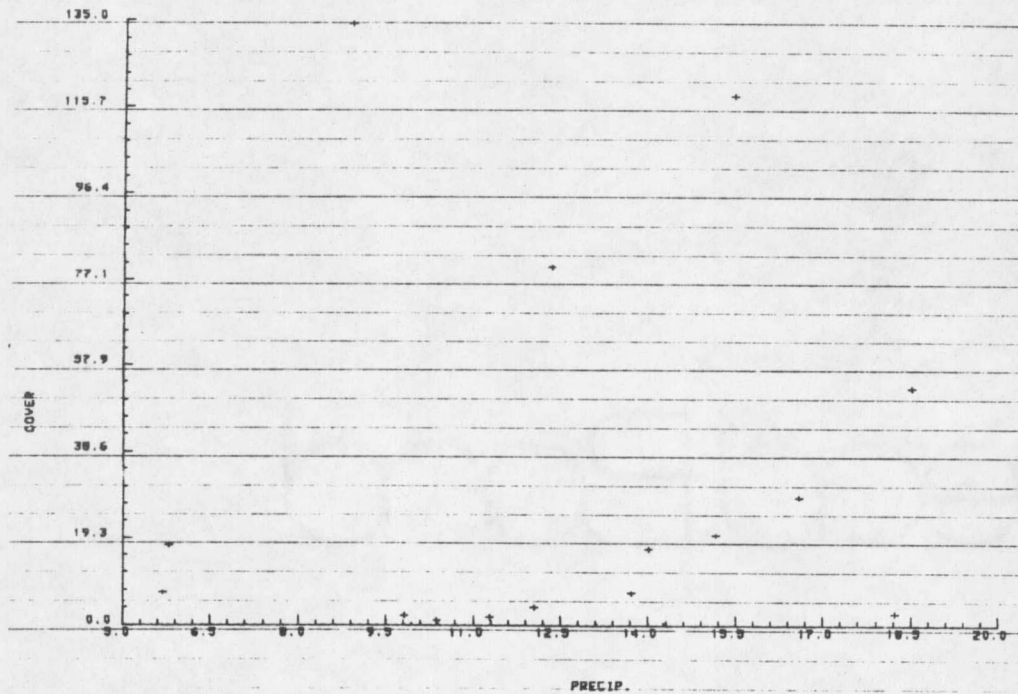


Figure B17. Basal Cover of Tumblegrass (cm²) vs. Ppt. (in.)

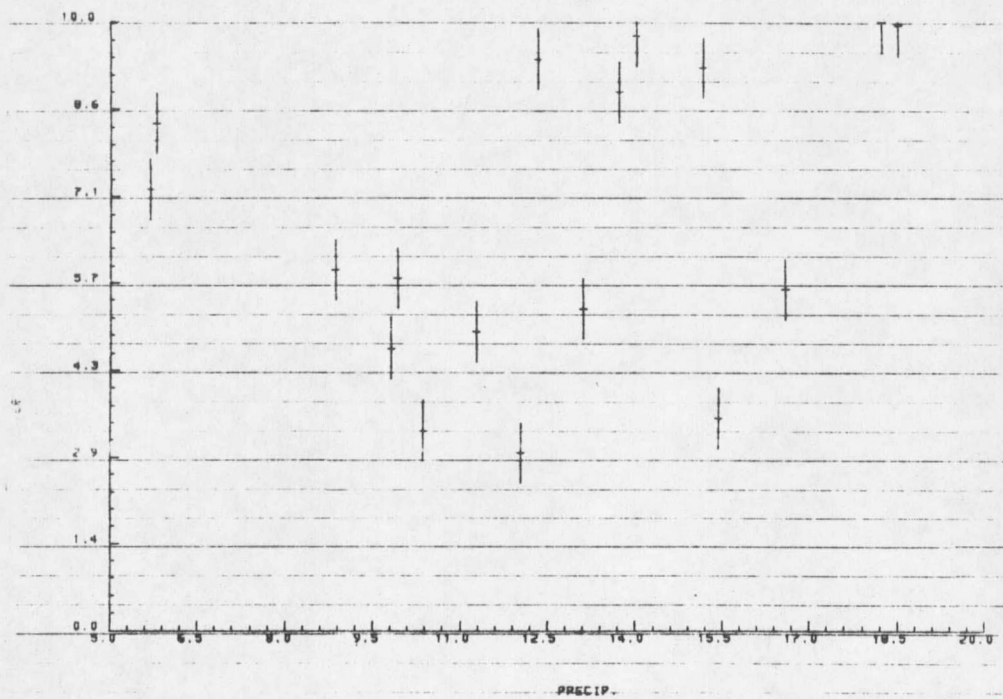


Figure B18. Basal Cover of Scarlet Globemallow (cm²) vs. ppt. (in.)

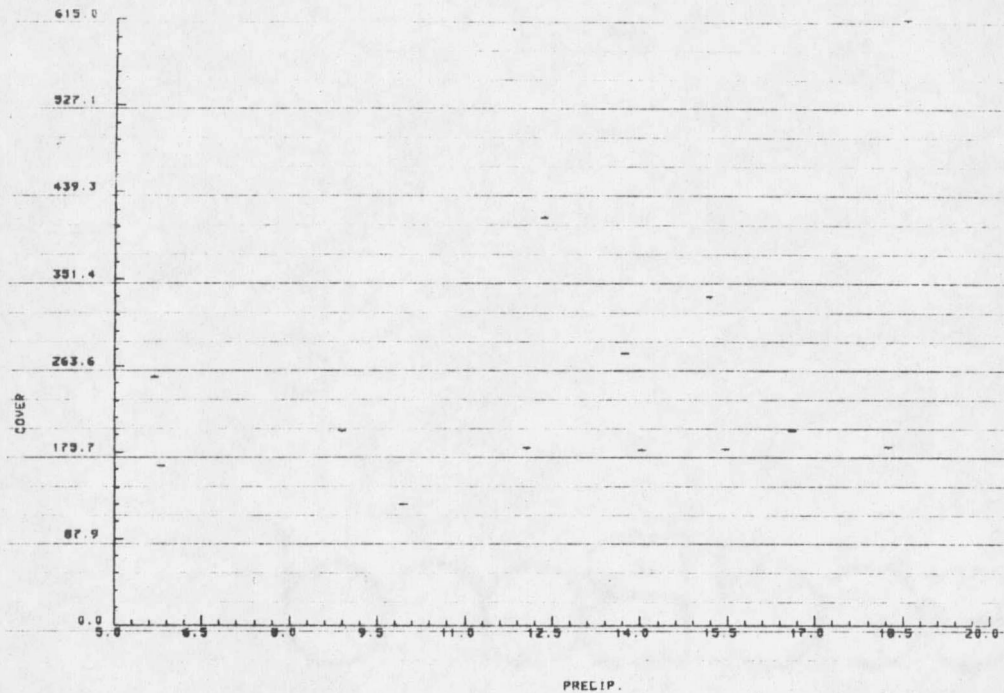


Figure B19. Basal Cover of Sand Dropseed (cm²) vs. Ppt. (in.)

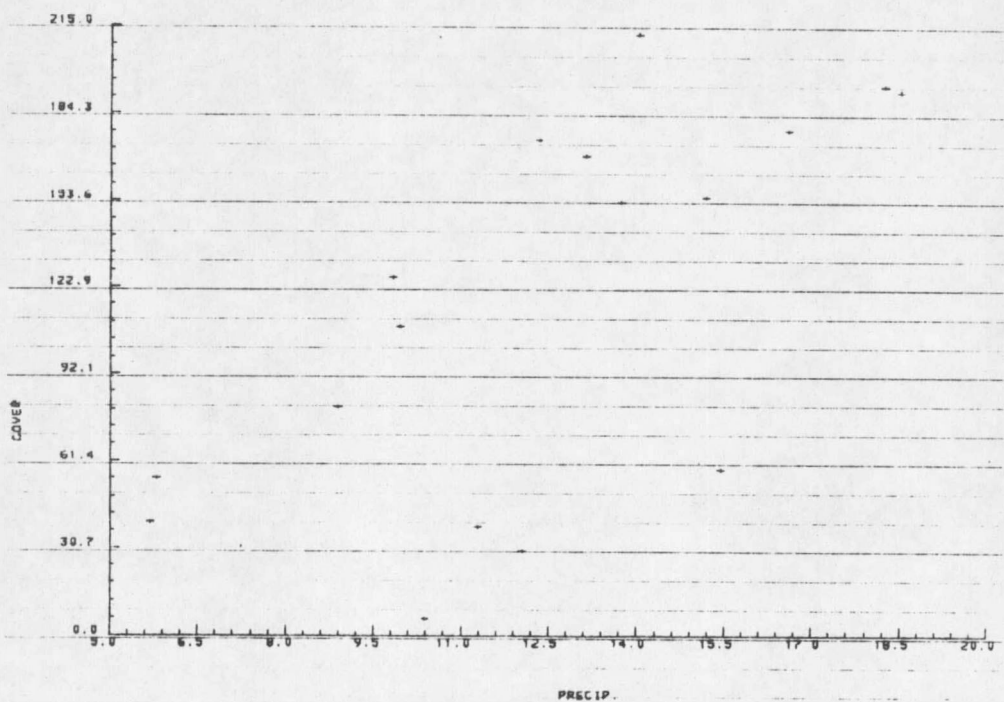


Figure B20. Basal Cover of Needle-And-Thread (cm²) vs. ppt. (in.)

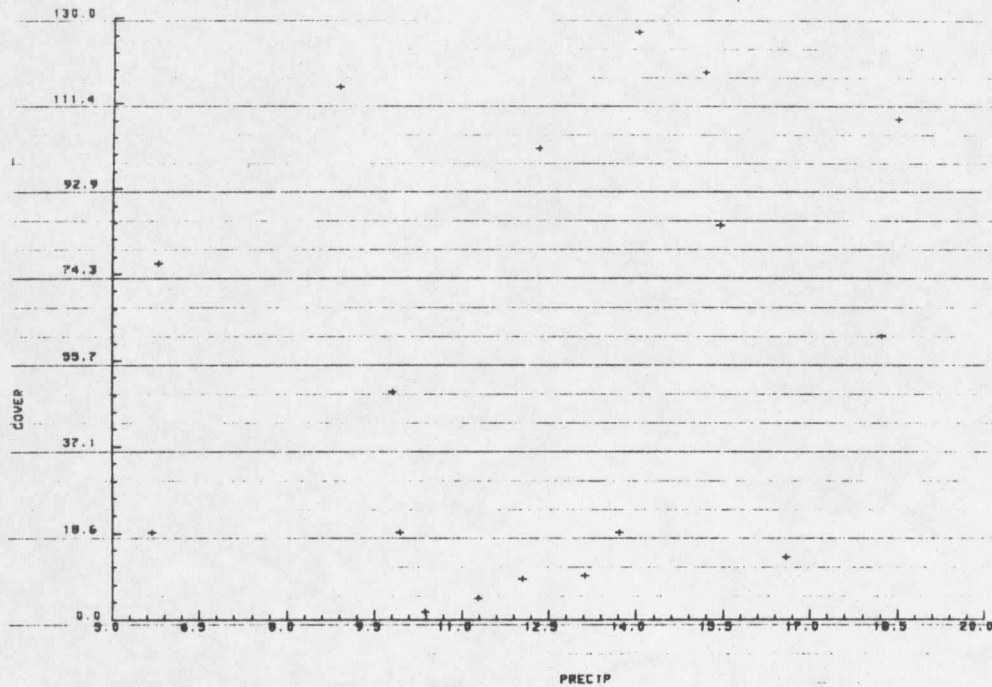


Figure B21. Basal Cover of Green Needlegrass (cm²) vs. Ppt. (in.)

APPENDIX C

These predictive equations were used to predict the r^2 values presented in Appendix D and to develop the response surfaces presented in the results and discussion (Figs. 3-40).

The format of these predictive equations is the same as that in Equation 1 (Table 2). The limits of the precipitation range for which these equations were developed and can therefore be considered accurate is described on page 70. The r^2 values for each equation are presented in Tables 11 through 15.

Table C1. Predictive Equations For Each Species, All Quadrats

western wheatgrass:

$$Y = 314.94552 - 124.279 X_1 + 11.8775 X_1^2 - 4.83999 X_2 + 3.55881 X_2^2 - .525034 X_1^2 X_2$$

red threeawn:

$$Y = 127.04529 - 28.5771 X_1 + 1.75123 X_1^2 + 1.81926 X_2 + .30904 X_2^2 - .0578837 X_1^2 X_2$$

fringed sagewort:

$$Y = -116.48492 + 5.15864 X_1 + .30566 X_1^2 + 18.6792 X_2 - .978152 X_2^2 + .0258527 X_1 X_2^2 - .112216 X_1^2 X_2 + .00449175 X_1^2 X_2^2$$

blue grama:

$$Y = 168.71558 - 250.312 X_1 + 32.4161 X_1^2 + 241.647 X_2 + 17.4964 X_2^2 - 45.7052 X_1 X_2$$

buffalograss:

$$Y = -596.02415 - 4.92507 X_1 + 4.75403 X_1^2 + 104.578 X_2 + .269783 X_1 X_2^2$$

Table C1. continued

tumblegrass:

$$Y = 135.59773 + 5.3621 X_1 + 7.08009 X_2 - 67.8864 X_2^2 - \\ .428921 X_1 X_2^2 + .194891 X_1^2 X_2$$

scarlet globemallow:

$$Y = 3.2561017 - .244123 X_1 + .612354 X_2 - .00347786 X_1 X_2^2 + \\ .000226045 X_1^2 X_2^2$$

needle-and-thread:

$$Y = -115.84551 + 9.36894 X_1 + 8.69832 X_2 + .0897017 X_1 X_2$$

green needlegrass:

$$Y = -388.33155 + 24.7982 X_1 + 1.05042 X_1^2 + 82.3713 X_2 - \\ 2.74464 X_2^2 - 7.92769 X_1 X_2 + .301237 X_1 X_2^2$$

Table C2. Predictive Equations For Each Species, No Grazing

western yarrow:

$$Y = 20.046803 - .661224 X_1 + .192152 X_1^2 - 4.382 X_2 + .384692 X_2^2 - .308826 X_1 X_2$$

blue grama:

$$Y = -10089.855 - 414774 X_1 + 137.308 X_1^2 + 1101.26 X_2 + 157.195 X_1 X_2 - 12.4052 X_1 X_2^2 - 25.0029 X_1^2 X_2 + 1.23554 X_1^2 X_2^2$$

buffalograss:

$$Y = -15490.895 - 291.462 X_1 + 160.399 X_1^2 + 2709.16 X_2 - 102.35 X_2^2 - 23.3204 X_1^2 X_2 + .903136 X_1^2 X_2^2$$

scarlet globemallow:

$$Y = -71.783237 + 9.29841 X_1 - .148333 X_1^2 + 7.75859 X_2 - .0900293 X_2^2 - .851612 X_1 X_2 - .00120556 X_1^2 X_2^2$$

green needlegrass:

$$Y = 730.63662 - 48.8834 X_1 + .506737 X_1^2 - 59.8564 X_2 + .27439 X_1 X_2^2$$

Table C3. Predictive Equations For Each Species, Light Grazing

western wheatgrass:

$$Y = 281.96973 - 84.4277 X_1 + 7.30098 X_1^2 - 1.79236 X_2 + 2.14408 X_2^2 - .302763 X_1^2 X_2$$

red threeawn:

$$Y = 9534.872 - 1497.58 X_1 + 57.702 X_1^2 - 1616.18 X_2 + 68.1226 X_2^2 + 249.923 X_1 X_2 - 10.3495 X_1 X_2^2 - 9.49594 X_1^2 X_2 + .387236 X_1^2 X_2^2$$

fringed sagewort:

$$Y = 6.5587718 + 1.58895 X_1 - 4.84677 X_2 + .349201 X_2^2 - .00660262 X_1^2 X_2$$

blue grama:

$$Y = 104550.85 - 17246.5 X_1 + 706.303 X_1^2 - 16595.5 X_2 + 663.123 X_2^2 + 2685.71 X_1 X_2 - 104.505 X_1 X_2^2 - 107.697 X_1^2 X_2 + 4.10807 X_1^2 X_2^2$$

buffalograss:

$$Y = 10500.415 - 1077.36 X_1 + 29.4025 X_1^2 - 1716.08 X_2 + 95.8159 X_2^2 + 112.903 X_1 X_2 - 5099788 X_1 X_2^2$$

Table C3. continued

tumblegrass:

$$Y = 49.302923 - 25.6069 X_1 + 2.22567 X_1^2 + 1.45874 X_2 + .635546 X_2^2 - .0984811 X_1^2 X_2$$

scarlet globemallow:

$$Y = 5.4501815 - .227872 X_1 - .113289 X_2 + .000191289 X_1^2 X_2^2$$

needle-and-thread:

$$Y = 23.302652 - 7.02391 X_1 - 2.08849 X_2 + 1.71237 X_1 X_2$$

Table C4. Predictive Equations For Each Species, Moderate Grazing

western wheatgrass:

$$Y = -1133743 + 61.6811 X_1 + 9.20687 X_1^2 + 126.245 X_2 + 6.14131 X_2^2 - 22.9712 X_1 X_2$$

red threeawn:

$$Y = 161.2628 - 4.41035 X_1 - 13.382 X_2 + 1.79356 X_2^2 - 2.96938 X_1 X_2 + .211868 X_1^2 X_2 - .0070872 X_1^2 X_2^2$$

fringed sagewort:

$$Y = 19.196825 - .487076 X_1 - 3.37432 X_2 + .230495 X_2^2$$

blue grama:

$$Y = 4125.9981 - 143.617 X_1 - 897.905 X_2 + 92.1704 X_2^2 - 5.58251 X_1 X_2^2 + 3.19802 X_1^2 X_2$$

buffalograss:

$$Y = -350.33276 + 108.94 X_1 - 40.9804 X_2 + 1.21977 X_1 X_2^2$$

needleleaf sedge:

$$Y = 2.1617686 - 4.45732 X_1 + 5.24831 X_2 - .0459848 X_1 X_2^2 + .0585517 X_1^2 X_2$$

Table C4. continued

scarlet globemallow:

$$Y = -20.80817 - 1.30123 X_1 + 5.49619 X_2 - .253495 X_2^2 - \\ .28289 X_1 X_2 + .0159205 X_1 X_2^2$$

Table C5. Predictive Equations For Each Species, Heavy Grazing

western wheatgrass:

$$Y = 235.62474 - 105.6 X_1 + 10.1142 X_1^2 + 1.04026 X_2 + 3.01918 X_2^2 - .445206 X_1^2 X_2$$

red threeawn:

$$Y = 2747.7708 - 428.534 X_1 + 16.3466 X_1^2 - 452.976 X_2 + 18.5732 X_2^2 + 69.3053 X_1 X_2 - 2.78545 X_1 X_2^2 - 2.59423 X_1^2 X_2 + .102359 X_1^2 X_2^2$$

buffalograss:

$$Y = -1569.4267 - 70.8638 X_1 + 24.9654 X_1^2 + 240.621 X_2 + 10.713 X_2^2 - 15.9065 X_1 X_2 - .672488 X_1^2 X_2$$

threadleaf sedge:

$$Y = 113.85799 + 7.55602 X_1 - .822696 X_1^2 - 35.0759 X_2 + 3.74578 X_2^2 + .506401 X_1 X_2 - .269074 X_1 X_2^2 + .167261 X_1^2 X_2$$

needleleaf sedge:

$$Y = 41.26365 - .745211 X_1 - .0918709 X_1^2 - 5.45874 X_2 + .0774817 X_2^2 + .24617 X_1 X_2$$

Table C5. continued

tumblegrass:

$$Y = -216.91736 + 9.10557 X_1 + 2.21234 X_1^2 + 20.1123 X_2 + 2.03869 X_2^2 - 5.17404 X_1 X_2$$

scarlet globemallow:

$$Y = -3.6343506 - .879599 X_1 + .0722715 X_1^2 + 1.51661 X_2 - .0769598 X_1 X_2$$

needle-and-thread:

$$Y = -58.564653 + 3.47362 X_1 + 4.17649 X_2 + .609354 X_1 X_2$$

green needlegrass:

$$Y = 16930.547 - 2686.29 X_1 + 104.01 X_1^2 - 2790.2 X_2 + 112.95 X_2^2 + 437.841 X_1 X_2 - 17.4778 X_1 X_2^2 - 16.7842 X_1^2 X_2 + .663431 X_1^2 X_2^2$$

APPENDIX D

Values presented were obtained using the predictive equations presented in Appendix C. These values were used to develop the response surfaces (Figs. 3-40).

Table D1. Predicted Cover Values of Western Yarrow for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4		4.2			
8	8		-3.1			
12	12		-1.9			
16	16		8.0			
20	20		26.4			
4	8		0.2			
8	12		0.2			
12	16		8.9			
16	20		26.1			
20	4		47.5			
4	12		8.5			
8	16		16.0			
12	20		32.0			
16	4		27.5			
20	8		23.8			
4	16		29.1			
8	20		44.0			
12	4		13.6			
16	8		8.6			
20	12		12.3			
4	20		62.1			
8	4		5.8			
12	8		-0.3			
16	12		2.1			
20	16		13.2			

Table D2. Predicted Cover Values of Western Wheatgrass for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	11.8		68.8	-504.0	-1.0
8	8	1.1		41.5	-118.2	11.8
12	12	81.1		83.8	23.7	103.1
16	16	50.3		79.3	-78.4	102.0
20	20	-293.0		-88.4	-424.4	-162.4
4	8	129.7		145.2	-71.2	119.6
8	12	132.1		128.3	143.0	143.6
12	16	157.9		142.3	113.8	189.1
16	20	5.8		70.6	-159.3	85.2
20	4	1777.7		1056.1	2548.2	1509.7
4	12	361.5		290.1	556.9	336.8
8	16	376.9		283.7	600.7	371.9
12	20	348.7		269.3	400.5	371.6
16	4	867.0		517.0	1343.2	732.0
20	8	1089.2		667.1	1510.3	946.8
4	16	707.1		503.7	1382.2	650.6
8	20	735.6		507.7	1254.9	696.9
12	4	269.1		172.8	432.9	221.0
16	8	480.8		302.5	672.9	425.4
20	12	514.6		346.6	668.9	480.4
4	20	1166.7		785.9	2403.9	1061.0
8	4	-16.0		23.4	-182.9	-23.3
12	8	118.1		94.0	130.0	113.7
16	12	208.6		156.6	199.0	215.4
20	16	53.8		94.8	24.0	110.7

Table D3. Predicted Cover Values of Fringed Sagewort for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	-36.3		-1.3	7.4	
8	8	3.6		-0.7	3.0	
12	12	7.3		5.6	6.0	
16	16	3.0		15.1	16.3	
20	20	43.9		25.0	34.0	
4	8	-7.7		-4.4	5.0	
8	12	8.5		6.0	7.9	
12	16	7.4		21.3	18.2	
16	20	29.6		38.8	35.9	
20	4	23.3		13.3	-0.4	
4	12	-4.9		3.7	9.9	
8	16	-3.0		23.9	20.2	
12	20	4.6		48.1	37.9	
16	4	12.1		11.0	1.6	
20	8	-26.4		-0.5	-2.8	
4	16	-28.1		22.9	22.1	
8	20	-31.0		53.0	39.8	
12	4	-1.6		7.8	3.5	
16	8	-5.7		1.2	-0.9	
20	12	-39.5		-3.2	2.1	
4	20	-77.2		53.3	41.8	
8	4	-17.7		3.7	5.5	
12	8	4.3		1.1	1.1	
16	12	-8.7		2.6	4.0	
20	16	-16.1		5.3	14.3	

Table D4. Predicted Cover Values of Red Threawn for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	49.3		1020.8	83.1	571.2
8	8	15.1		97.0	23.6	29.8
12	12	2.4		9.8	-0.3	-1.8
16	16	-11.3		-17.0	-14.6	-22.5
20	20	-48.1		718.1	-88.6	95.6
4	8	67.7		427.2	76.3	137.3
8	12	32.3		6.8	37.0	-2.7
12	16	10.8		34.0	13.8	1.0
16	20	-18.9		21.4	-40.8	-37.1
20	4	175.3		1253.9	105.1	356.7
4	12	95.9		-13.0	123.4	-6.6
8	16	59.3		239.7	93.5	55.0
12	20	29.2		47.4	53.1	-1.3
16	4	70.0		177.0	64.3	45.4
20	8	104.6		354.7	105.0	115.1
4	16	134.1		600.2	224.4	139.7
8	20	96.2		795.8	193.1	203.1
12	4	15.1		-70.8	47.0	-22.6
16	8	33.6		60.8	37.9	18.8
20	12	43.8		-34.4	72.7	-8.9
4	20	182.2		2266.9	379.1	576.0
8	4	7.9		510.4	53.3	152.6
12	8	3.8		-25.1	10.8	-9.7
16	12	6.2		-3.8	11.6	-3.9
20	16	-7.1		86.8	8.1	-15.4

Table D5. Predicted Cover Values of Blue Grama for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	201.4	-4869.8	21535.7	1282.0	
8	8	368.6	-484.1	1522.5	472.1	
12	12	670.5	84.3	884.8	780.7	
16	16	1107.1	1440.5	1236.1	1292.3	
20	20	1678.2	15777.0	9429.2	1091.5	
4	8	1276.5	-1143.1	6152.4	1247.5	
8	12	1272.3	614.4	712.4	1500.3	
12	16	1402.8	398.8	1452.3	1851.9	
16	20	1668.0	6608.8	2605.4	1387.0	
20	4	5719.0	16648.1	21761.2	2467.3	
4	12	2911.5	1628.0	715.6	3447.9	
8	16	2735.9	1066.5	2782.1	4048.9	
12	20	2695.0	1640.6	2039.5	3729.1	
16	4	2783.6	8529.9	5325.2	1557.0	
20	8	3869.0	4627.2	8299.5	3057.9	
4	16	5106.3	3443.7	5225.4	7883.3	
8	20	4759.4	872.2	7731.8	8118.0	
12	4	885.6	2237.6	-191.1	1056.0	
16	8	1664.9	2401.0	2596.1	1377.3	
20	12	2578.9	475.0	1756.8	3025.5	
4	20	7861.1	4303.8	19681.9	14553.6	
8	4	24.8	-2229.0	5212.4	964.3	
12	8	498.1	697.3	337.0	515.3	
16	12	1106.0	37.9	1233.0	1289.1	
20	16	1848.6	4191.6	2133.4	2370.0	

Table D6. Predicted Cover Values of Buffalograss for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	-104.1	-6152.6	2752.7	-59.0	-617.1
8	8	643.7	-675.3	321.6	271.4	710.0
12	12	1750.9	308.2	903.9	640.9	2153.6
16	16	3321.4	1713.1	2196.3	1049.3	3455.8
20	20	5458.6	14002.7	1895.6	1496.9	4358.5
4	8	366.1	-1027.8	1142.5	-164.3	562.1
8	12	1234.8	626.7	897.0	205.1	1848.5
12	16	2532.1	812.9	2129.3	613.6	3165.4
16	20	4361.8	7219.9	2536.2	1061.1	4254.8
20	4	1711.8	20505.7	2494.6	1684.1	5785.5
4	12	870.8	1284.2	1830.8	-230.6	2084.2
8	16	1895.0	503.0	3003.1	177.8	3329.8
12	20	3417.0	2203.4	4117.7	625.3	4520.0
16	4	1029.6	9925.9	1148.0	1248.3	3115.6
20	8	2389.3	6455.1	3503.6	1578.7	4914.5
4	16	1410.1	783.4	4817.7	-257.9	3949.0
8	20	2624.4	-1046.7	6639.9	189.6	5153.9
12	4	499.6	1956.2	742.1	812.5	1158.5
16	8	1655.3	3066.1	1502.1	1142.9	2886.2
20	12	3239.6	687.8	3740.1	1512.4	4386.4
4	20	1983.9	-2530.4	10103.0	-246.2	6145.7
8	4	121.7	-3403.3	1277.0	376.8	-85.7
12	8	1073.4	689.3	441.5	707.2	1484.6
16	12	2419.2	328.5	1851.6	1076.6	2999.6
20	16	4262.7	3203.6	3204.1	1485.1	4201.0

Table D7. Predicted Cover Values of Threadleaf Sedge for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4					52.1
8	8					60.9
12	12					101.1
16	16					133.6
20	20					119.1
4	8					58.7
8	12					107.1
12	16					139.3
16	20					116.1
20	4					77.0
4	12					150.8
8	16					204.3
12	20					194.1
16	4					78.2
20	8					165.9
4	16					328.3
8	20					352.4
12	4					74.5
16	8					114.5
20	12					202.6
4	20					591.3
8	4					65.8
12	8					79.5
16	12					133.0
20	16					187.0

Table D8. Predicted Cover Values of Needleleaf Sedge for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4				6.1	20.1
8	8				14.6	6.4
12	12				32.4	0.1
16	16				64.0	1.1
20	20				114.0	9.6
4	8				22.0	5.9
8	12				21.0	-1.4
12	16				25.0	-1.3
16	20				38.4	6.1
20	4				12.1	-11.4
4	12				31.9	-5.8
8	16				15.7	-6.7
12	20				-0.1	-0.3
16	4				-0.5	0.9
20	8				81.7	-9.8
4	16				36.0	-15.1
8	20				-1.5	-9.6
12	4				-5.7	10.3
16	8				44.5	-1.5
20	12				121.9	-5.8
4	20				34.2	-21.9
8	4				-3.5	16.7
12	8				22.1	3.9
16	12				66.0	-1.4
20	16				132.7	0.6

Table D9. Predicted Cover Values of Tumblegrass for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4		-882.4	-7.8		-114.8
8	8		-121.5	-11.0		-42.2
12	12		39.2	2.2		0.8
16	16		-128.2	-6.1		14.3
20	20		-1279.6	-73.3		-1.8
4	8		-551.9	22.3		-19.3
8	12		209.8	20.6		35.8
12	16		225.4	22.7		61.2
16	20		-705.9	-9.1		57.2
20	4		-3145.4	286.8		549.2
4	12		512.8	72.6		141.5
8	16		1038.7	72.5		179.0
12	20		515.1	63.5		187.0
16	4		-1086.6	125.1		277.0
20	8		-946.2	166.3		313.6
4	16		2311.6	143.3		367.5
8	20		2365.3	144.6		387.5
12	4		-23.2	22.1		75.6
16	8		-318.6	61.0		124.2
20	12		94.8	66.1		143.2
4	20		4844.6	234.3		658.8
8	4		44.9	-22.2		-55.0
12	8		-43.7	2.0		5.6
16	12		0.8	17.3		36.6
20	16		-22.3	-13.7		38.1

Table D10. Predicted Cover Values of Scarlet Globemallow for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	4.6	20.7	4.1	-1.2	-1.2
8	8	5.5	-1.0	3.5	7.5	1.1
12	12	6.6	-3.3	5.5	11.2	3.2
16	16	10.0	-12.4	13.1	16.3	5.3
20	20	18.6	-6.6	30.6	28.7	7.1
4	8	6.6	-6.9	3.8	7.2	3.7
8	12	7.0	0.7	4.1	10.4	4.7
12	16	8.3	-7.1	8.3	12.8	5.7
16	20	12.9	-12.0	20.0	20.6	6.4
20	4	1.1	22.8	1.7	5.6	7.5
4	12	8.4	4.6	3.6	9.5	8.5
8	16	8.2	1.6	5.1	9.3	8.3
12	20	9.7	-9.2	12.0	12.4	8.0
16	4	1.8	18.7	2.2	3.9	1.9
20	8	4.5	0.6	5.1	8.2	7.4
4	16	9.8	13.7	3.5	5.8	13.3
8	20	9.1	1.6	6.5	4.2	11.9
12	4	2.7	9.5	2.7	2.2	-1.4
16	8	4.4	2.7	4.2	7.9	3.0
20	12	8.6	-11.7	11.0	12.9	7.3
4	20	11.0	20.5	3.6	-3.9	18.2
8	4	3.6	-3.5	3.4	0.5	-2.5
12	8	4.8	2.2	3.6	7.7	0.9
16	12	7.2	-7.5	7.8	12.1	4.1
20	16	13.3	-14.2	19.6	19.7	7.2

Table D11. Predicted Cover Values of Needle-and-Thread for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	1360.6		14.5		-18.2
8	8	2873.4		60.0		41.6
12	12	4422.6		160.5		120.9
16	16	6008.0		315.8		219.7
20	20	7629.8		525.9		338.0
4	8	2166.4		33.3		8.2
8	12	3697.4		106.4		77.8
12	16	5264.7		234.3		166.9
16	20	6868.3		417.0		275.4
20	4	4116.0		11.4		76.3
4	12	2972.2		52.3		34.7
8	16	4521.4		152.8		114.0
12	20	6106.8		308.1		212.8
16	4	3427.1		12.1		52.7
20	8	4994.4		140.0		141.8
4	16	3778.0		71.4		61.1
8	20	5345.3		199.3		150.2
12	4	2738.3		12.8		29.1
16	8	4287.4		113.3		108.3
20	12	5872.9		268.6		207.2
4	20	4583.8		90.4		87.6
8	4	2049.5		13.5		5.4
12	8	3580.4		86.7		75.0
16	12	5147.7		214.6		164.1
20	16	6751.3		397.2		272.6

Table D12. Predicted Cover Values of Green Needlegrass for Given Precipitation Regimes

prev. yr. ppt.	current yr. ppt.	all quadrats	no grazing	light grazing	mod. grazing	heavy grazing
4	4	-94.4	329.3			3478.4
8	8	7.3	49.5			199.4
12	12	32.1	49.5			199.4
16	16	95.8	274.9			49.0
20	20	313.8	990.7			1305.2
4	8	34.3	142.5			823.8
8	12	56.1	-14.6			-2.6
12	16	78.2	125.1			88.0
16	20	216.1	666.8			159.5
20	4	275.3	-156.0			2278.3
4	12	113.7	-9.2			-114.0
8	16	94.1	-8.5			293.3
12	20	151.9	359.1			86.8
16	4	132.5	-59.0			299.1
20	8	127.7	-132.3			662.7
4	16	143.7	-125.9			664.8
8	20	121.4	67.7			1087.1
12	4	23.3	54.2			-160.5
16	8	54.0	-88.0			118.8
20	12	85.0	66.6			-38.1
4	20	124.4	-207.5			3161.3
8	4	-52.3	183.7			899.2
12	8	13.8	-27.4			-35.6
16	12	41.7	23.3			35.4
20	16	147.0	441.0			179.1

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