Range pitting and nitrogen fertilization on mixed prairie rangeland in northern Montana
by John Edgar Taylor

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Range Science
Montana State University

Abstract:
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Ground cover and production data were collected annually.

The climatic fluctuations over the three years reported were very wide. Two years were below normal in precipitation; one approached the record dry year. The third year approximated the long term average.

This variation caused some vegetation changes which probably confounded certain of the treatment effects.

Statistical analysis of the data showed that pitting and fertilization produced many parallel effects with regard to species composition and yields. Cool-season midgrasses responded favorably to both treatments , while blue grama and clubmoss decreased. The net result of these changes was an improvement in range productivity.

The study must be continued for several more years before enough information about residual effects is available to estimate the economics of fertilization on northern Montana plains ranges.

RANGE PITTING AND NITROGEN FERTILIZATION ON MIXED PRAIRIE RANGELAND IN NORTHERN MONTANA

by

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Range Science

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June, 1967

ACKNOWLEDGMENT

The author wishes to express his sincere appreciation to Drs. Gene F. Payne and Don E. Ryerson for countless instances of instruction, encouragement, and stimulation during the development of this thesis.

Many others have contributed in many ways. Chief among these are Mr. Harold A. R. Houlton and Mr. Claude Windecker of the North Montana Branch Station. The author's wife and children have provided both means and justification for the graduate program.

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ABSTRACT

A range renovation study was initiated at the North Montana Branch Station, Havre, in 1959. The purpose of this work was to evaluate the use of range pitting and nitrogen fertilization in the improvement of deteriorated mixed prairie rangelands in northern Montana.

Pitting was accomplished with an eccentric disk pitter. This treatment was applied in fall, 1959. Nitrogen fertilization was applied to pitted range and to adjacent non-pitted range starting in fall, 1959. Nitrogen rates were 0, 50, and 100 pounds per acre of actual nitrogen as ammonium nitrate (33.5-0-0). Applications were made annually during the falls of 1960 and 1961, giving all possible three-year combinations of nitrogen.

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Statistical analysis of the data showed that pitting and fertilization produced many parallel effects with regard to species composition and yields. Cool-season midgrasses responded favorably to both treatments, while blue grama and clubmoss decreased. The net result of these changes was an improvement in range productivity.

The study must be continued for several more years before enough information about residual effects is available to estimate the economics of fertilization on northern Montana plains ranges.

INTRODUCTION

The Northern Great Plains cover extensive areas of Montana, North and South Dakota, Wyoming, Alberta, and Saskatchewan. A portion of this region is occupied by wheat and other crops, but most of the rest is used in range livestock production (Weaver and Albertson, 1956).

With respect to climate, seasonal temperatures may range from over 100° to 40° Fahrenheit. Mean annual precipitation is around ten to fifteen inches, but some years fall well below the average. The low precipitation is effectively reduced by the nearly constant drying winds during the growing season (Webb, 1931; Weaver and Albertson, 1956).

White man introduced domestic livestock into the northern plains during the 1880's. By 1900, thousands of cattle had replaced bison as the predominant grazing animals. Early livestock operators had little understanding of the grazing resource, and serious overgrazing was widespread (Weaver and Albertson, 1956).

Today much of this area is dominated by low-growing plant species which have replaced more palatable and productive species. Livestock production is limited by low forage availability. The range operator is faced with high land prices and high operating costs. This means that increased forage production from plains ranges would be an extremely desirable management goal.

Two promising methods for bringing about such range improvement have been used in states adjacent to Montana. Research in Wyoming (Rauzi and Lang, 1956) showed several advantages of range pitting as a renovation treatment on plains ranges. Similarly, Rogler and Lorenz (1957) obtained promising results from range fertilization in North Dakota.

The research reported in this thesis combined these two treatments in an attempt to bring about a rapid and economic improvement of deteriorated ranges in northern Montana.

REVIEW OF LITERATURE

Range Pitting

Original research

Range pitting was originally studied as a moisture conservation practice during the drought of the 1930's. The first pitting on native range was done at the Archer substation of the Wyoming Agricultural Experiment station during the late 1930's. This pitting was done with an eccentric disk pitter which had been fabricated by A. K. Nelson for summer fallow treatments (Barnes and Nelson, 1945). Several mechanical treatments were studied simultaneously. Pitting was concluded to be most effective in increasing yields. Closely spaced mechanical treatments were the only ones to have any significant effect on forage production. Production of western wheatgrass (*Agropyron smithii*)[1/] increased markedly with pitting; this was a substantial improvement over the shortgrass cover existing on the site prior to pitting. A general increase in the yields of midgrasses appeared to reflect increased tillage, thinning, and moisture impoundment. Since this original work pitting has become more widely used in improving plains ranges (Barnes *et al*., 1958).

Equipment

The most commonly used pitting implement in the northern plains has been an eccentric disk plow (Barnes and Nelson, 1945; Barnes, 1949, 1950, 1952; Becker and Lang, 1953; Rauzi and Lang, 1956; Thomas and Young, 1956; Barnes *et al*., 1958; Lang, 1958, 1960; Canada Department of Agriculture, 1960; Rauzi *et al*., 1962; Houston, 1963; Dudley and Hudspeth, 1964). Two

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1/ Names of plants are based on Booth (1950) and Booth and Wright (1959).

styles of disk pitters have been used. Either the disks are re-drilled and mounted on eccentric centers, or a portion of the disk is cut away leaving the original mounting position on the shaft. Pits made by these two types of machines are similar.

Another pitter sometimes used on rangeland is the rotary disk type. This consists essentially of a heavy rolling frame mounted with spikes which punch holes in the ground at intervals rather than digging out pits as the eccentric disk machines do. This kind of equipment seems to be best suited to desert ranges with relatively sparse cover, where the renovation problem is one of increasing water infiltration into soils with shallow restrictive layers (Barnes *et al.*, 1958).

The type of pitter suited to a particular soil, vegetation, and climatic situation depends upon the nature of the soil to be treated, the management objective, and the projected use of additional treatments (Barnes *et al.*, 1958).

The pits

Pits made by eccentric or cutaway disk pitters are elongated and shallow. Pit dimensions range from six feet long, twelve inches wide and five or six inches deep (Dudley and Hudspeth, 1964) to pits that are one foot square and three inches deep (Canada Department of Agriculture, 1960). Pitting intensity has been less variable. Several pitting treatments have removed about one-third of the existing cover (Barnes, 1950, 1952; Lang, 1958; Rauzi *et al.*, 1962), and Dudley and Hudspeth (1964) report a cover removal of forty-five per cent. Several studies have indicated that closely spaced pitting produces greater responses than more widely spaced treatment

(Barnes and Nelson, 1945; Barnes *et al.*, 1958). Thomas and Young (1956) found that "solid" pitting was superior to "skip" pitting (leaving undisturbed range between subsequent passes of the pitter) in increasing forage yields.

Adaptability of pitting

Pitting has been used most extensively in three major range regions: (1) the northern plains, (2) the southern plains, and (3) the desert region of the southwest. Within these gross regions some sites appear more suited to pitting than others. Barnes and his coworkers at Wyoming have generally concluded that pitting is most suitable on ranges supporting a mixed vegetation of warm- and cool-season species (Barnes *et al.*, 1958). In a pitting trial involving more than fifty plots scattered all over the state of Wyoming Barnes (1950) found that vegetational composition was more important than soil type in determining the success of pitting treatment. Pure stands of western wheatgrass were little affected by pitting. On the other hand, mixed warm- and cool-season cover responded with a significant increase in the cool-season midgrasses. This was considered to be a big improvement. Dudley and Hudspeth (1964) found that pitting on an excellent condition range in Texas showed no production increases during a five year trial. This agrees with Canadian results from Swift Current, Saskatchewan (Canada Department of Agriculture, 1960), where good condition prairie range did not respond to pitting with increased forage production, although the treatment was considered effective in reducing runoff. Houston (1963), working with plains vegetation at Miles City, Montana, found that previous levels of grazing affected pitting response. Good condition ranges supporting substantial amounts of western wheatgrass showed the most forage increase with pitting. Weather and soils were more important in determining pitting response than any other variable in this work. Lang (1958) observed pitting on three sites in the Big Horn Mountains of Wyoming. The dominant vegetation was rough fescue (Festuca scabrella). Again, responses were affected by site differences. Thomas and Young (1956) also reported different pitting responses on different soils, but these were discussed in terms of pit longevity. Pits were gone the second year on clayey lakebed areas, while those on lighter upland soils were more stable. Soils may or may not play an important role in pitting effectiveness, depending upon the vegetational situation existing at the time and place being considered.

Responses to pitting

Forage production increases have been the principal criteria used to evaluate pitting success (Barnes, 1949; Barnes et al., 1958; Houston 1963; Lang, 1958, 1960; Rauzi and Lang, 1956; Thomas and Young, 1956). The amounts of such increases have varied with a number of site, climatic, and treatment differences. However, increased total production may be misleading unless it is known which vegetational components contribute to the increase. Various pitting studies have recorded such changes, and some generalized species composition transitions have been reported.

Most workers in the Northern Great Plains have noted an increase in cool-season grasses, especially western wheatgrass (Barnes, 1949, 1950, 1952; Barnes and Nelson, 1945; Barnes et al., 1958; Houston, 1963; Canada Department of Agriculture, 1960; Lang, 1958; Rauzi et al., 1962). Other species increasing with pitting are fringed sagewort (Artemisia frigida) in Wyoming (Lang, 1958), prairie sandreed (Calamovilfa longifolia) in Canada (Canada Department of Agriculture, 1960), and sand muhly (Muhlengergia arenicola), purple three-awn (Artistida purpurea), and sideoats grama (Bouteloua curtipendula) in Texas (Thomas and Young, 1956). Buffalo grass (Buchloe dactyloides) increased with pitting in one Wyoming study (Rauzi et al., 1962), and in Texas (Thomas and Young, 1956), but showed no change in a Wyoming study reported by Barnes (1950). Blue grama (Bouteloua gracilis) commonly decreases with pitting in the northern plains (Barnes, 1950; Rauzi et al., 1956; Canada Department of Agriculture, 1960). Other species seem relatively unaffected by pitting. These include tobosa grass (Hilaria mutica) in Texas (Thomas and Young, 1956) and total forbs in Wyoming (Lang, 1958).

Evaluation of pitting in terms of animal responses has been limited. The Archer, Wyoming pitting was grazed by sheep in the only detailed study of this kind. It was found that pitting produced eight year average increases in lamb gains per acre and per head of 34 and 29 per cent, respectively (Barnes, 1949, 1950). It would appear that much more research is needed in this area.

Houston (1963) at Miles City, Montana reported an increase in soil nitrogen under both pitting and seeding treatments. A related response, increased forage protein, was found on the seeding. This was thought to be due to the release of soil nitrogen in the process of soil disturbance.

Reasons for pitting and for pitting responses

Several reasons for range pitting have been advanced. The most obvious of these, and the one most commonly mentioned, is the impoundment of runoff moisture. Over-the-surface flow is retained in the pits long enough for rather complete infiltration of the impounded water (Barnes, 1950, 1952; Barnes and Nelson, 1945; Barnes *et al.*, 1958; Anderson and Swanson, 1949; Thomas and Young, 1956; Canada Department of Agriculture, 1960). The water storage capacity of pitted range has been estimated to be 0.3 to 0.4 inches of precipitation in Texas (Thomas and Young, 1956) and 0.28 acre-inches of moisture in Wyoming (Barnes, 1950). Lang (1958) and Rauzi *et al.* (1962) have demonstrated greater infiltration rates on pitted than on non-pitted range in Wyoming. It would appear that reduction in runoff should produce a concomitant reduction of soil loss, although the effectiveness of pitting in soil conservation has not been examined.

Several workers have pointed out various relationships among pitting and production increases, litter increases, improved mulching effects, more efficient snow catch, and generally more favorable soil moisture relationships (Barnes, 1950, 1952; Barnes *et al.*, 1958; Thomas and Young, 1956). Houston (1963) reported that plants on pitted range exhibited about one-half as much moisture stress as unpitted range. The effect on plants was most marked during dry years. Dudley and Hudspeth (1964) found that five years of observation showed no forage production increase because increased moisture obtained by pitting was utilized primarily by weeds. These authors speculated that drier years might produce more favorable results. This work was done on Texas range in excellent condition, so that increased production through pitting might have been an unrealistic goal.

The role of pitting as a competition removal treatment *per se* has been less emphasized than the runoff retention effect, and yet this might be a more important factor in many situations. Rauzi et al. (1962) attributed the success of pitting to competition removal as well as to increased moisture holding, root pruning of western wheatgrass, and tillage effects. Other references to competition in pitting are related to seeding attempts. Tillage has been considered important by Barnes and Nelson (1945) and Barnes (1950, 1952). The benefits of closely spaced mechanical treatments are summarized by Barnes (1952) as:

1. Thinning of cover, creating basins for the retention of runoff water.

2. Reduction of competition for water, space, and nutrients, allowing increased production and litter accumulation.

3. Holding soil during torrential rains.

Reseeding pitted range

Although pitting has been shown often to promote favorable changes in species composition such changes do not always occur, or may be too slow or too slight to justify the treatment expense. Since pitting combines competition removal and tillage, and often shows improved soil moisture relationships, it has been postulated that this treatment might be combined with artificial seeding to produce greater forage production responses in fewer years with little increase in cost. The success of this combination appears to depend upon several variables, and these variables in turn are related to gross geographic areas. The main difference among areas appears related to the degree of ground cover and the related factor of post-treatment competition contributed by the undisturbed portion of the plant cover (Barnes, 1950). Several unsuccessful seeding attempts on pitted range have been reported from Wyoming (Barnes, 1949, 1950, 1952; Lang, 1958, 1960) representing a variety of sites, species, and years. Farther south, successful seedings have been reported from Arizona (Anderson and Swanson, 1949) and Texas (Thomas and Young, 1956; Dudley and Hudspeth, 1964). Barnes et al. (1958) view pitting as a reseeding preparation treatment as follows:

> "Seeding with the pitting operation has generally been unsuccessful in the northern Plains. In some parts of the southern Plains and under Southwest conditions, seeding and reestablishment of perennial grass cover has been successful and are the major objectives of the mechanical treatment."

Longevity of pitting

The water retention function of pitting obviously depends upon the continued physical presence of the pits. Estimates of pit longevity vary, depending primarily upon soil texture and grazing animal pressures. Dudley and Hudspeth (1964) reported that ungrazed pits at their north Texas location were still effective in impounding water after five years. Thomas and Young (1956) found that pits on a clayey lake bed were about gone the second year, but adjacent upland pits were longer lasting. They also noted that even light grazing caused measurable pit damage. Wyoming researchers have suggested that range pitting should be re-done every ten years, based upon observations of pitted range grazed by sheep (Rauzi et al., 1962). Studies of pit longevity are extremely limited, and generalizations drawn from existing data probably are invalid.

The longevity of pitting effects, such as changes in speciation and increased forage production, is even less clear. Much pitting research has been reported in terms of total production, and a great deal more investigation into compositional changes and grazing responses is needed. The

Archer, Wyoming pitting established in 1942 was still exceeding the control in 1949 with respect to sheep days per acre, lamb gains per acre, and vegetation left at the end of the grazing season (Barnes, 1949). Western wheatgrass continued to show a marked increase after eight years (Barnes, 1950). However, by the end of the thirteenth year, vegetational composition had reverted to essentially the pre-treatment situation, and animal gains no longer exceeded the check levels (Rauzi and Lang, 1956).

Economics of range pitting

Expressions of the economics of pitting have been limited to comparisons with other treatments and have been based for the most part upon empirical observations. Barnes and Nelson (1945) and Barnes (1950) reported that pitting was the most economical and simplest of several mechanical treatments in Wyoming studies. Houston (1963) suggested that pitting may have been the most economical of several practices on plains ranges near Miles City, Montana. Other treatments included seeding and fertilization. Although pitting did not produce the greatest responses it appeared to show the most favorable cost and return balance. Barnes *et al.* (1958) state that "in the northern Plains pitting is the most common mechanical treatment used to improve range production". If this is the case, perhaps this constitutes *prima facie* evidence that the treatment is economical under some circumstances. Additional work needs to be done following post-treatment responses to grazing. Any economic analyses must be based on treatment longevity, and this has received little attention.

Summary of pitting in the Northern Great Plains

Pitting appears to be best adapted to plains ranges, especially those supporting mixtures of warm- and cool-season grasses. This practice seems most practicable on ranges whose composition of cool-season midgrasses is less than their potentials, and where moisture runoff is likely to occur. Pitting is apparently inadequate in producing a suitable environment for artificial revegetation, and ranges demanding reseeding should probably be treated in some other manner, at least in the Northern Great Plains.

Range Fertilization

Original research

Early studies of fertilization on the Northern Great Plains were limited to observations of the effects of manure and other treatments on native vegetation. Starting in 1925 the North Montana Branch Station at Havre conducted limited observations on a native prairie site which received barnyard manure in various year sequences, coupled with disking, harrowing, and reseeding with crested wheatgrass and sweet clover (Heady, 1952).

No stands of seeded species were obtained, but by 1927 an increase in native grass and a decrease in dense clubmoss (Selaginella densa) were noted. Manuring improved yields more than did the mechanical treatments, and manuring also improved the grass stand. Severe cultural renovation destroyed much of the clubmoss and damaged blue grama. Western wheatgrass increased markedly with renovation, especially if early rains occurred. By 1947, the vegetation on this area had largely reverted to mixed prairie species, particularly needle-and-thread (Stipa comata). Height measurements showed that residual effects were still apparent from four manure applications, but three-year effects were no longer measurable.

Dolan (1966) examined this area forty years after the first treatments had been applied. The heavier rates of manure and of mechanical disturbance still showed significantly lower levels of clubmoss cover, with corresponding yield advantages to needle-and-thread and western wheatgrass. The species composition changes brought about by treatments were still observable.

Clarke et al. (1947) discussed another early manure study at Manyberries, Alberta. Starting in 1928 and again in 1932 manure applications were made every second, third, and fourth years to native vegetation on a sandy loam (dominated by blue grama and needle-and-thread) and silt loam sites (dominated by western wheatgrass). Manure applications totaled twelve tons per year of treatment, and the effects of these treatments were evaluated in terms of yields. The plots which were treated only in 1928 still doubled the check plots after eleven years. The western wheatgrass community demonstrated less response than the upland vegetation, although there were significant increases in yield on all treated plots.

Neither of these early studies developed into very intensive work, and although some promising results were obtained, they were followed by a period of fifteen to twenty years before more intensive work was initiated by several researchers during the late 1940's and early 1950's. This later work was undertaken on a variety of locations under different conditions, but many of the results and conclusions are similar. The following discussion will attempt to summariz e the pertinent points brought out in this research.

Materials used

Nitrogen has been the most commonly used element in range fertilization on the Northern Great Plains, although it is frequently combined with phosphorus and occasionally with potassium. Most of the work with range fertilization has used commercial materials although some limited investigations using barnyard manure continue in Canada.

Nitrogen sources

Most commercial nitrogen has been applied as ammonium nitrate, although Thomas and Osenbrug (1959) used ammonium sulfate and Kilcher (1958) compared ammonium phosphate, ammonium sulfate, and ammonium nitrate. Haas (1958) applied seven different commercial fertilizers as well as barnyard manure to grass seedings in North Dakota. The general conclusion of these workers has been that the amount of nitrogen rather than its source is the important factor in vegetational responses.

Fertilizer placement

Most range fertilization studies have been limited to broadcast applications on the soil surface (Canada Department of Agriculture, 1958; Heady, 1952; Launchbaugh, 1962; Lodge, 1959; Lorenz and Rogler, 1962; McGinnies, 1962; Rogler and Lorenz, 1957; Smika et al., 1961; Van Dyne, 1961). Smith and Lang (1961) used aerial application of fertilizers in a Wyoming study. Thomas and Osenbrug (1959) broadcast nitrogen but drilled phosphorus. The only Northern Great Plains study comparing broadcast and drilled applications is reported by Smika et al. (1963), and their conclusion was that these methods of fertilizer placement did not produce different responses once the mechanical effects of drilling were removed.

Season of treatment

Most of the studies reported in the literature have used fall applications of fertilizers. Fall is probably the most generally desirable season because it precedes the expected moist season. The area under discussion seldom receives sufficient precipitation to produce significant nitrogen loss through leaching. No studies have been reported comparing seasons of fertilizer application on rangeland in the northern plains.

Results of range fertilization

Even though range fertilization studies have been conducted over a wide geographic area within the northern plains some general conclusions have emerged. One of the most striking of these is that nitrogen increases yields in every instance. This conclusion has been reached by workers in North Dakota (Rogler and Lorenz, 1957; Smika et al., 1963), South Dakota (Cosper and Thomas, 1961), Wyoming (Becker et al., 1957), Montana (Van Dyne, 1961), Alberta (Canada Department of Agriculture, 1958), and Saskatchewan (Lodge, 1959). Manure has given similar yield increases (Canada Department of Agriculture, 1958; Clarke et al., 1947; Heady, 1952; Lodge, 1959; Dolan, 1966). A study at the Manyberries, Alberta Experimental Farm compared commercial fertilizer with manure and straw on native prairie range (Canada Department of Agriculture, 1958). It was found that after eight years treatment differences had disappeared, suggesting that the mulching effect of the straw was effective in producing yield and species changes. Lodge (1959) studied the effects of commercial fertilizers and manure at Swift Current, Saskatchewan. He concluded that both kinds of nitrogen produced yield increases, and suggested that commercial fertilizers be more thoroughly studied. Other fertilizer/manure studies have been reported from Colorado plains ranges (Klipple and Retzer, 1959), and from Northern Great Plains grass seedings (Haas, 1958). These authors generally agree with those mentioned above, although some differences exist in details of responses.

Another very important result of nitrogen fertilization is changing species composition. This has not been followed in every study, but may be the most significant factor in range fertilization (Rogler and Lorenz, 1957). Nitrogen, and in many cases manure, appears to increase the abundance and vigor of cool-season midgrasses, especially western wheatgrass. This effect is accompanied by a concurrent reduction of such species as blue grama, dense clubmoss, and various legumes (Becker _et al._, 1957; Heady, 1952; Rogler and Lorenz, 1957; Van Dyne, 1961). Similar differential species responses have been reported in grass seedings (Birch and Lang, 1961; Haas, 1958; Kilcher, 1958; Stitt _et al._, 1955; Thomas and Osenbrug, 1959).

It is interesting to compare the conclusions of workers from the Central Great Plains. In Colorado Klipple and Retzer (1959) found erratic responses of the relatively scarce midgrasses to nitrogen, while manure favored shortgrasses. In Kansas Launchbaugh (1962) found that cool-season species, where present, were most benefited by nitrogen, although some sites supported very small proportions of these species. These conclusions tend to support the remarks of Rogler and Lorenz (1957) that range fertilization may have the greatest chance of successful application in the Northern Great Plains because of the characteristic mixture of warm- and cool-season grasses present in that region.

In addition to yield and species changes, several authors have described chemical changes in nitrogen-fertilized plants. Increased forage protein levels have been obtained by the application of nitrogen to rangeland (Clarke and Tisdale, 1945; Lodge, 1959; Rogler and Lorenz, 1957) and to seeding of dryland grasses (Stitt et al., 1955; Thomas and Osenbrug, 1959).

Another nitrogen response is an earlier spring greenup and a longer green feed season (Kilcher, 1958; Rogler and Lorenz, 1957). Kipple and Retzer (1959) found that manured grasses stayed green about one week longer than those on commercial nitrogen plots and two weeks longer than the control treatment. The following spring similar differences in greenup rate were observed, and cattle showed a marked preference for green (fertilized) plots.

This phenomenon of improved palatability was studied by Smith and Lang (1958) in the Big Horn Mountains of Wyoming. Nitrogen as urea and as ammonium nitrate was aerially broadcast on range which was only lightly used by cattle. Following treatment, utilization was markedly increased on both fertilized and adjacent non-fertilized range. This might offer a means of improving livestock distribution on Northern Great Plains ranges, especially on those saline and alkaline sites where salt placement is not an effective means of controlling distribution.

Soil responses

Soil responses to range fertilization have been studied less than vegetational responses. Haas (1958) noted considerable variation among fertilized seeded species with respect to soil nitrogen. Carbon/nitrogen ratios increased slightly under both grass and alfalfa. Smika et al. (1961) found that soil moisture at rooting depths under nitrogen-treated plots decreased, reflecting the increased vigor of the fertilized plants. These plants also withdrew moisture to greater depths than did those on untreated plots. Soil fertility was found to vary with treatments and depths. After several years of nitrogen application at 30 pounds per year, pH of the surface six inches changed from 6.5 to 6.1. Plots receiving 90 pounds of nitrogen annually showed a somewhat greater increase in acidity, which appeared to make soil phosphorus more available. Thomas (1961) found that nitrogen fertilization caused a depletion of soil phosphorus, and suggested that phosphorus be supplied with nitrogen on phosphorus-deficient sites.

Other uses of fertilization on the Northern Plains

In addition to the range studies discussed above various aspects of fertilization have been studied on dryland pasture plantings (Birch and Lang, 1961; Kilcher, 1958; Thomas, 1961; Thomas and Osenbrug, 1959; Haas, 1958; Lorenz and Rogler, 1962; Smika *et al.*, 1963; Stitt *et al.*, 1955). The conclusions of these various authors are in general agreement. Fertilization may produce increased yields, improved nutrient contents, and longer green forage periods, although the economics of such changes needs further research.

The use of fertilizers in the renovation of old stands of crested wheatgrass also has been studied in the northern plains. Lorenz and Rogler (1962) found that the application of 30 and 60 pounds per acre of nitrogen to undisturbed sods of crested wheatgrass was more effective in restoring grass vigor and productivity than were several mechanical treatments or reseeding. These authors concluded that fertilization and weed control should be effective in renovating old stands of crested wheatgrass having fair-to-good stands of low vigor plants if sufficient soil moisture is available to support spring growth. In a similar study at Miles City, Montana, Houston (1957) found nitrogen to be effective for a brief period, but by the third growing season the fertilizer effects had largely disappeared. Houston pointed out that the period of this study was marked by drier-than-normal years, and speculated that different results might be obtained in more favorable years. Stitt _et al_. (1955) reported some promising effects from fertilizing dryland grass seedings at Mocassin, Montana.

Detrimental effects of range fertilization

Although most authors have reported favorable results from range fertilization, some detrimental effects have been noted. Nitrogen has been reported to decrease grass seed yields during dry years (Birch and Lang, 1961, McGinnies, 1962), and to cause lowered survival of plants during drought periods (Klipple and Retzer, 1959). This latter effect may be related to the increased vigor and consequently more rapid soil moisture depletion on fertilized plots (Rogler and Lorenz, 1957; Smika _et al_., 1961). Thomas and Osenbrug (1959) found that fertilized grass seedings demonstrated drought stress symptoms earlier than did untreated seedings during dry periods. Increased soil fertility may also promote weed problems on ranges with insufficient cover to rapidly utilize added increments of fertilizers (Cosper and Thomas, 1961).

Commercial fertilizers other than nitrogen

As indicated previously, phosphorus has been studied in conjunction with nitrogen on many different areas, but has been found to be much less effective in producing yield or composition changes. Phosphorus responses were not observed in range studies in North Dakota (Rogler and Lorenz, 1957; Smika et al., 1963) or in tame pasture studies in North Dakota (Smika et al., 1963; Lorenz and Rogler, 1962) or Colorado (McGinnes, 1962).

On the other hand, phosphorus alone has been found to increase yields on some sites in Kansas (Launchbaugh, 1962) and South Dakota (Thomas and Osenbrug, 1959), forage phosphorus levels in South Dakota (Cosper and Thomas, 1961), and forage protein levels in Colorado (Klipple and Retzer, 1959). When applied with nitrogen, phosphorus has increased yields on rangeland (Cosper and Thomas, 1961; Launchbaugh, 1962) and on seeded dryland pastures (Smika et al., 1963; Stitt, 1955). Phosphorus also has been found to produce species composition changes favoring legumes (Stitt et al., 1955; Van Dyne, 1961).

Cosper and Thomas (1961) found that phosphorus was more effective in moist years and when supplementary water was supplied by a water spreader. Thomas (1961) found that phosphorus increased forage yields only during high moisture years or when phosphorus was applied at rates greater than the absorptive capacity of the soil.

Potassium has had little study on the plains. Haas (1958) reported an influence on rooting depths, while Klipple and Retzer (1959) and Launchbaugh (1962) found no significant potassium responses.

Residual effects

Fully as important as the kinds and degrees of fertilizer responses is the longevity of these responses, and yet these are very poorly understood. The duration of responses in any particular instance depends upon the kind and magnitude of the original response as well as the various complex factors which impinge upon the plants under study. These include such diverse and complicated variables as plant species, years, sites, treatments, soil chemistry, grazing, and many others. No single author has considered more than one or two of these factors in residual effects and some factors have not been considered at all.

It also must be remembered that there is a difference between the actual biological response of range to fertilization and man's interpretation of that response. The former is inclined to be rather more complicated than the latter; the simplification of criteria of measuring response must compromise the completeness of the measurement. This has been extremely apparent in reviewing the literature on range fertilization on the Northern Great Plains. Both initial and residual rexponses have been masked by inadequate or incomplete observation.

The most commonly used criterion of residual effects, as in initial effects, is increased production (Cosper and Thomas, 1961; Houston, 1957; Launchbaugh, 1962; McGinnies, 1962; Stitt <u>et al</u>., 1955; Thomas, 1961; Thomas and Osenbrug, 1959). Lodge (1959) reported residual effects with regard to both yield and species composition changes. Klipple and Retzer (1959) found protein differences three years after manure and phosphorus treatments, while Smith and Lang (1958) noted a one-year carry over in palatability with nitrogen fertilization on high elevation ranges. Heady (1947) found that range plots which had been fertilized four times at the rate of ten tons manure per acre during the period 1925-35 still showed plant height differences in 1947. On the same area Dolan (1966) observed residual species composition differences, as well as litter, production, and ground cover levels related to treatment intensities thirty years after the last treatments had been applied.

The actual number of years' duration of fertilizer treatments responses is probably meaningless in a broad context since so many criteria of analysis have been used. In particular, it seems odd that no more workers have indicated residual species composition changes, especially those who have noticed such changes in their initial evaluations.

Explanations of residual responses, or lack of them, vary considerably. Several authors have noted the effects of climate or local moisture availability (Cosper and Thomas, 1961; Houston, 1957; Launchbaugh, 1962). Increased carry-over with heavier application rates was reported by Heady (1957), McGinnies (1962), Stitt et al. (1955), and Thomas (1961). On the other hand, Thomas and Osenbrug (1959) found residual yields for three cropping seasons at all levels of nitrogen. Differences among fertilizer materials have been found by Cosper and Thomas (1961), Klipple and Retzer (1959), and Lodge (1959).

In summary it might be said that range fertilization may produce effects which are present for one or more years after application. These effects may take several forms, and the longevity of any effects is partially controlled by the climate and site variation existing on the range. There is no standard criterion for evaluating residual effects of fertilizers, so no valid generalizations can be drawn from the extant literature. It is important to the eventual understanding of the economics of range fertilization that more adequate response criteria be used, especially with regard to species composition changes.

Factors influencing range fertilization responses

Species: The differential responses exhibited by different species has been discussed. It follows that the species composition of a range will determine the overall response of that range to fertilization. It is significant that researchers working with predominantly warm-season species have found few differential species responses (Launchbaugh, 1962; Klipple and Retzer, 1959). The advantage ascribed to cool-season midgrasses is an important one, and according to Rogler and Lorenz (1957) explains the species composition changes reported from Northern Great Plains research.

Rate of fertilizer application: Cosper and Thomas (1961) found that total production was a linear function of nitrogen and phosphorus rates. Other workers have found less tidy relationships, but in general the greater the amount of fertilizer applied the greater the production degree of response, assuming moisture to be adequate to support the increased growth (Kilcher, 1958; Rogler and Lorenz, 1957; Thomas, 1961).

Climate: One of the most important factors contributing to the northern plains environment is the highly variable climate. Fertilization responses have been shown to be dependent upon precipitation (Cosper and Thomas, 1961; Kilcher, 1958; Haas, Thomas and Osenbrug, 1959), although Stitt et al. (1955) found that available soil moisture was less important than fertility in determining grass yields.

Soils and sites: Work at the Manyberries, Alberta Experimental Farm has pointed out an interesting relationship between sites and fertilizer responses (Clarke and Tisdale, 1945; Clarke *et al.*, 1947). Fertilizers were applied to two sites; a silt-loam soil supporting a stand of western wheatgrass, and a fine sandy loam soil with a blue grama/needle-and-thread cover. The silt loam (western wheatgrass) site responded more with regard to protein increases, but the fine sandy loam site (blue grama/needle-and-thread) showed the greater production increase. This illustrates the difficulty of separating site effects from species responses, since different sites are likely to support different species.

Launchbaugh (1962) found that on low-fertility sites nitrogen and phosphorus gave complementary effects with regard to yield increases. On a site occupied by a 90 per cent cover of sideoats grama (*Bouteloua curtipendula*) no responses were noted.

McGinnies (1962), working at a higher elevation in Colorado, concluded that range fertilization at that location might produce reasonable results on better sites and during better years, but felt that no worthwhile responses could be expected from poor sites or badly depleted rangelands. This agrees with the statement of Thomas (1961) that one of the important factors influencing fertilizer reponse is the relative soil fertility.

Economics of range fertilization

The economics of range fertilization is dependent upon (a) the kind and degree of responses per unit of treatment, (b) the length of time such responses last, and (c) the cost of producing these responses. No complete economic analysis has been made of this practice, partly because not all of the variables are known. In particular the length of time species composition changes can be maintained under proper post-treatment management is still to be determined. In addition, many experimental studies have been designed without concern for economic questions. This is an area which needs further study, but such study must necessarily await long-term results of range fertilization on a variety of locations and under varying systems of grazing management.

A few statements have been made regarding the economics of range and dryland pasture fertilization. In renovating old stands of crested wheatgrass, Lorenz and Rogler (1962) concluded that nitrogen and weed control should be effective treatments. On the other hand, Houston (1957) did not obtain sufficient responses to pay for fertilization, but postulated that during more favorable years the economics may be improved. When applied to several species of seeded grasses, fertilization has been found to be uneconomical (Launchbaugh, 1962), "borderline" (Kilcher, 1958) and economical under adequate moisture conditions (Thomas, 1961). It has also been pointed out that increased forage protein may make fertilization an economic treatment where yield increases would not (Thomas, 1961).

Fertilization on rangeland has yielded similar conclusions. Klipple and Retzer (1959) found range fertilization to be uneconomic in dry areas such as their northeastern Colorado location. Lodge (1959) indicated some question about the economics of fertilization, and suggested that further research pay particular attention to species composition changes. The most complete statement regarding the economics of range fertilization was made by Rogler and Lorenz (1957). They found fertilization to be "borderline", but suggested that other benefits (than yield increases) may make the practice economic in some areas. These included (a) rapid recovery of range condition, (b) differential species response, and (c) higher protein levels. It was pointed out that in the Mandan research two annual applications of 90 pounds of nitrogen per acre did more to improve range condition and production than six years deferment.

THE STUDY AREA

This study was conducted at the North Montana Branch Station, Havre, Montana. The experimental site was located on Section 16, T31N, R15E, Montana Principal Meridian. This is a State school section which has been leased by the North Montana Branch Station since 1923. It is used as spring and fall cattle pasture in connection with the Station lease in the Bear Paw Mountains. The section had a long history of over use prior to 1923. During the five years ending in 1963 and including the reported research period less than 150 animal unit months of forage were removed annually by Station cattle[1/].

An exclosure was established on this section during April, 1959. The original fenced area was a 550' X 600' rectangle, oriented roughly WNW by ESE.

Vegetation

The study supports typical mixed prairie vegetation. The six-to-eight inch overstory is dominated by dispersed bunches of needle-and-thread (Stipa comata) and lesser amounts of western wheatgrass and green needlegrass (Stipa viridula). The understory is composed of a dense mat of blue grama (Bouteloua gracilis), pussytoes (Antennaria spp.) and dense clubmoss (Selaginella densa). Other species present include prairie junegrass (Koeleria cristata), Sandberg bluegrass (Poa secunda), plains reedgrass (Calamagrostis montanensis), needleleaf sedge (Carex eleocharis), American vetch (Vicia americana), Hood's phlox (Phlox hoodii), scarlet globemallow (Sphaeralcea coccinea) and fringed sagewort (Artemisia frigida).

1/ Windecker, Claude. 1963. Personal correspondence (April 2, 1963).

Soils and Topography

The major soil of the experimental area is classified as a Scobey loam. This material is derived from medium textured glacial till, and is quite smooth-textured due to rather high percentages of silt. This soil is characterized by thin grayish brown loam surfaces and strong prismatic-blocky clay loam subsoils, with prominent horizons of lime accumulation at 12 to 14 inch depths (Soil Conservation Service, 1959). The study area is located on a typical glaciated upland site. Well developed drainage courses occur to the north and south. The general aspect is one of gently rolling uplands alternating with coulees, draining generally toward the north.

Climate

The area is a typical Northern Great Plains environment. Moisture amounts and distribution are unpredictable between and within years, although spring and summer precipitation is the expected pattern. Frequent droughts occur, with more years below than above long term percipitation averages. The summers are marked by high temperatures, low humidities, and nearly continuous winds, creating a very dry climate. Winter temperatures may drop to 20 or more degrees below 0^{o} F., with considerable snowfall. Occasional chinook winds may cause rapid warming and snow melt at any time during the winter. When these warming winds persist for several days plants may initiate growth and then be frozen with returning freezing temperatures. These various factors have created a severe habitat for plants, allowing the survival of only very hardy and well adapted species.

Precipitation data for the three data years of this study are presented in Table I and Figure 1. Although some yearly differences were present, precipitation alone does not fully explain the yearly variations in plant development. Precipitation was below average in 1960 and 1961 approached the record drought year. The following year, 1962, was near the long term average. An important difference between 1961 and 1962 is seen in seasonal moisture distribution. Both years started at about the same level, but the rainy season extended through the summer in 1962, while the 0.33 inch of rain on July 7, 1961 was the last precipitation through September of that year. Not shown in Figure 1 is the pre-season precipitation, which was much more plentiful in 1962.

Table I. Cumulative precipitation at study exclosure, North Montana Branch Station (1960-62).

YEAR	MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER	
1960					*3[1/]	0.18[2/]	10	0.89	4	2.14	1	2.38	16	3.93
					7	0.22	13	0.94			3	2.39		
					10	0.25	14	0.96			5	2.42		
					11	0.28	20	1.91			13	2.52		
					15	0.31	21	1.94			22	3.69		
					16	0.34					24	3.73		
					17	0.44					25	3.75		
					18	0.45					27	3.79		
					25	0.69								
					26	0.70								
					27	0.74								
1961	*29	0.02	3	0.07	3	1.23	20	3.50	6	3.54				
	30	0.04	9	0.10	5	1.24			7	3.87	(last recorded precipitation through September, 1961)			
			10	0.33	6	1.29								
			13	0.53	10	1.35								
			18	0.61	15	1.38								
			23	0.92	16	1.67								
			30	1.09	29	1.68								
					31	3.31								
1962			*5	0.05	6	0.50	1	2.82	7	4.01	5	5.95	5	6.40
			10	0.17	10	0.55	3	2.89	13	4.22	10	6.06	8	6.82
			11	0.26	13	0.98	4	3.01	14	4.93	29	6.17		
			28	0.36	14	1.03	11	3.19	16	5.22				
			29	0.37	19	1.28	12	3.36	17	5.39				
					20	2.74	14	3.71	18	5.54				
					31	2.75	15	3.72	30	5.73				
							16	3.76						
							17	3.88						
							26	3.88[3/]						

1/ Date of recorded precipitation 2/ Inches of precipitation 3/ Trace recorded
*Indicates first data of the season

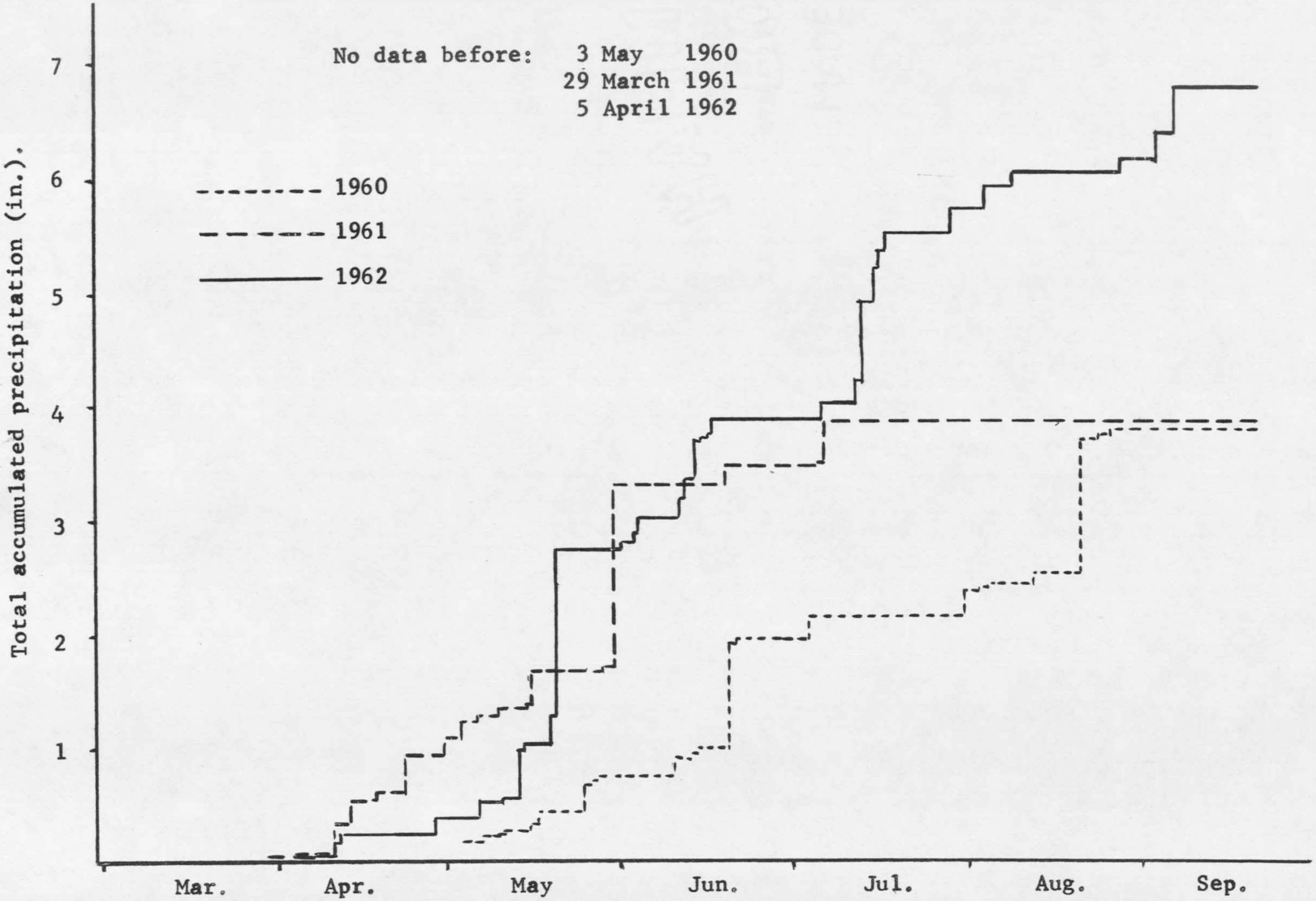


Figure 1. Cumulative precipitation, 1960-62. North Montana Branch Station, Havre.

PROCEDURES

Selection of Treatments

Initial studies were begun in April 1959 to obtain some directional information for subsequent research. These original studies were concerned with (a) competition removal by hand pitting, including varying depths and percentage cover of pits and by removal and non-removal of sods, (b) competition removal by placement of roofing slates in varying densities and patterns, (c) the application of nitrogen and phosphorus fertilizers to natural vegetation, and (d) machine pitting with and without sods left in place. Observations were made of vegetation responses (production, species composition changes, chemical analysis) and soil responses (moisture, organic matter, nitrifiable nitrogen) (Houlton, 1959).

The removal of competition by hand pitting, pitting, and slates all increased production of vegetation. Depth of pitting appeared less important than per cent removal of competition. The most productive mechanical treatment was obtained by pitting one-fourth of the soil surface and leaving the displaced sods overturned next to the pits. Nitrogen fertilization appeared to increase range productivity, but phosphorus yielded no measurable response although the soils of the area are low in phosphorus.

Based on pilot study indications a pitting and fertilization study was established within the exclosure in the fall of 1959. The study was laid out as a nested nested design in three replicates. The pitting was done with a cutaway disk pitter (Figures 2 and 3). Pits were about 30 inches long, eight inches wide, and four inches deep. The removed sods were hand-placed parallel and adjacent to the pits (Figures 4 and 5). Approximately

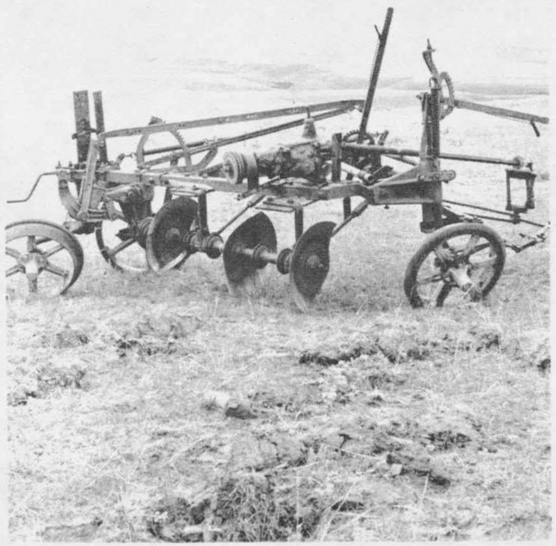


Figure 2. Pitting machine used in this study. Modified one-way disk plow.

Figure 3. Freshly pitted rangeland, North Montana Branch Station.

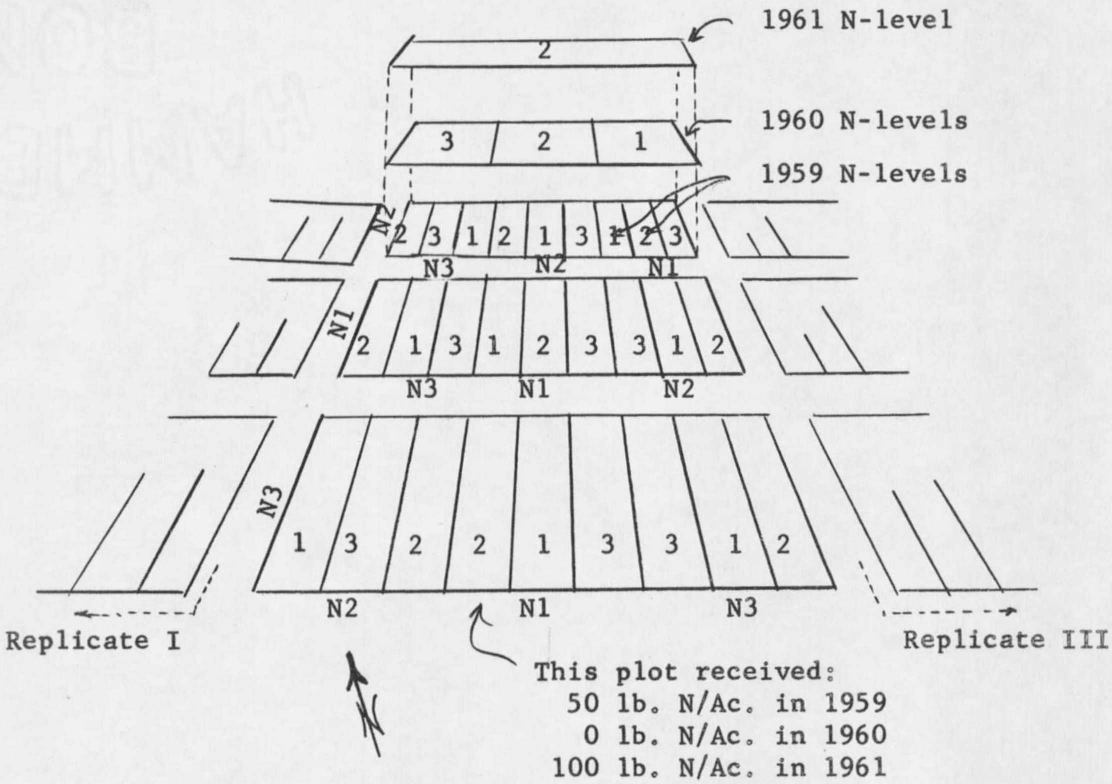
Figure 4. Freshly made pit. Overturned sod oriented by hand.

Figure 5. Detail of two-year old pitting treatment. Note stimulated grass growth along sod edges.

45 per cent of the ground surface was turned over or covered. Due to limitations of equipment and to minimize plot edge effects the pitting and non-pitting treatments were applied to large blocks, comprising, in essence, two separate studies. Within each major treatment (i.e. pitted or non-pitted range) three replicates of twenty-seven treatment plots each were established. Plots were 30 X 10.5 feet. Each replicate is arranged in three major blocks, corresponding to the fall 1961 fertilizer treatments. Within each major block are three minor blocks, representing fall 1960 fertilizer treatments. Each minor block in turn contains three treatment plots which were the fertilizer plots in fall, 1959. Ammonium nitrate (33.5-0-0) was hand broadcast at the rates of 0, 50 and 100 pounds per acre of actual nitrogen. Nitrogen rates were randomly distributed over plots in late fall, 1959, 1960, 1961, giving all possible three-year combinations by the time of the 1962 data collection (Figure 6).

Data Collection

Line intercept data were collected in 1960, 1961, and 1962 at the termination of annual foliage development. Two five-foot lines were read in each treatment plot each year, using the technique of Fisser and Van Dyne (1959) and Van Dyne (1959). This procedure uses a mechanical device consisting essentially of an aluminum bar graduated in hundredths of feet. A sliding sleeve moves along this bar and supports a horizontal frame bearing a vertical pin. The point of this pin is moved along the ground surface, and as successive species of plant, mineral, or fecal material are encountered their corresponding intercept positions are read on the graduated bar. The device is constructed with three legs at each end,



Nitrogen rates: 1 = 0 lbs.
2 = 50 lbs.
3 = 100 lbs. N/Ac.

Figure 6. Diagrammatic representation of treatment applications.

which contain holes fitting over permanent steel pin field markers, allowing accurate line replacement at successive readings (Figures 7 and 8).

Group codes, intercept name codes[1/], and beginning intercept positions were recorded from the beginning (000) position to the end (500) position of each transect. Each intercept was read to the nearest 0.01 foot. Data were collected with the use of a Dejur-Grundig Stenorette portable tape recorder. Completed tapes were sent to the Computing Center at Montana State University, where IBM cards were punched directly from the tapes. After verification these cards were summarized by the IBM 1620 Computer and listed on the IBM 407 accounting machine. In the event of incorrect line order or incorrect group or species codes the field worker was notified and the line was re-read.

Once line data were corrected the data summary cards were analyzed on the computer and complete analyses of variance and treatment means were computed using a program specially written for this study[2/]. Means were compared among treatments with Duncan's Multiple Range Test.

Production data were collected during summers of 1961 and 1962. Species or groups of species were clipped on two five-square-foot circular plots per treatment plot. Plot positions were randomized annually and samples were oven dried to a constant weight and weighed to the nearest tenth gram. Production data were summarized, converted to a pounds-per-acre basis, and statistically analyzed on the IBM 1620 computer.

1/ Codes are presented in Appendix I.
2/ Program was written by Dr. Glen Ingram, MSU Computing Center Director.

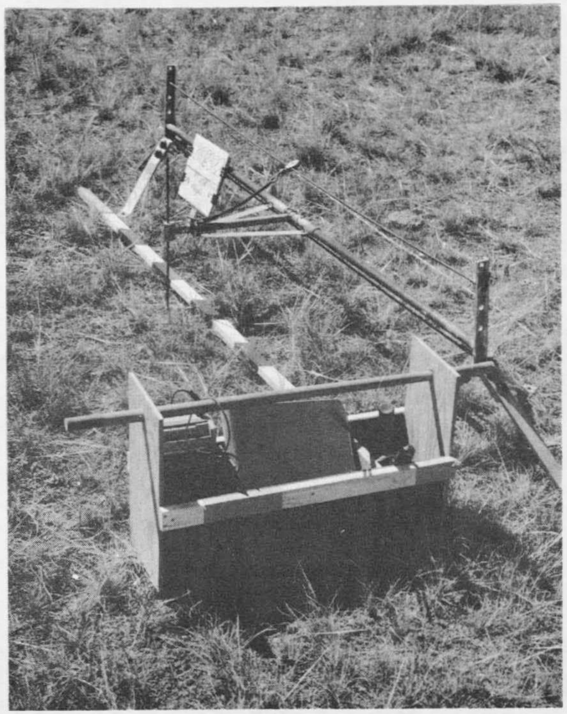


Figure 7. Transect device in position for reading.

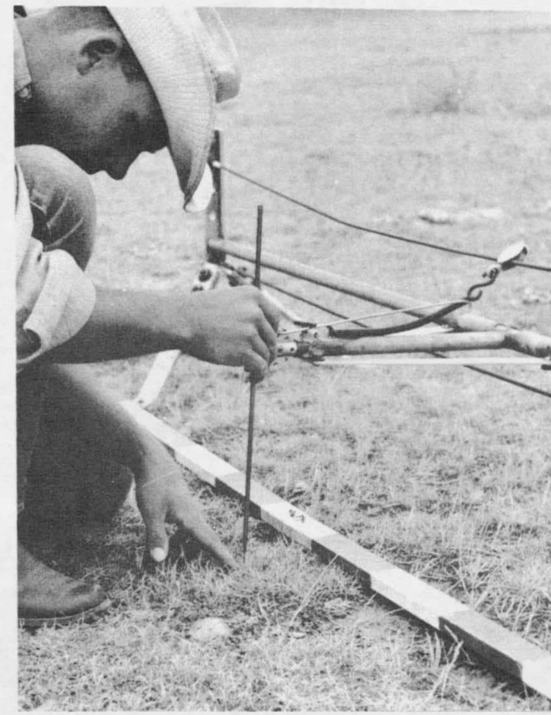


Figure 8. Transect device in use. Moving point read at ground intercepts of plants or other cover.

RESULTS

Yearly Variation

Because of the great variation in growing conditions among the three years of this study, some treatment effects may be masked. Part of this variability may be identified by examining the annual species compositions on non-pitted and non-fertilized range.

Some species responses to years are shown in Figures 9 and 10. The general decline in ground cover shown by grasses continued into 1962, even though favorable moisture conditions recurred that year. This is evidence of the loss in ground cover caused by the two dry years of 1960 and 1961. Needle-and-thread in particular was observed to suffer high mortality rates and in spring 1962 dead bunches became apparent when the living portion of the cover began to green up. Most of the litter cover in 1962 came from these dead bunches of needle-and-thread.

Species composition changes over the three years is shown for pitted and non-pitted range in Table II. It may be seen that many of the same kinds of changes occur in both treatments, but that the differences between pitted and non-pitted range rests largely with the amount of bare ground and the amount of dense clubmoss. Even though ground cover of grasses was decreased by the pitting treatment the productivity of the remaining grass was greatly increased. Many of the species composition changes seen in the fertilization studies were noted in pitting alone.

Treatment Responses

<u>Non-pitted range</u>

<u>Ground cover</u>: Basal area is an important descriptive characteristic of vegetation. It is affected less by yearly climatic variation than are

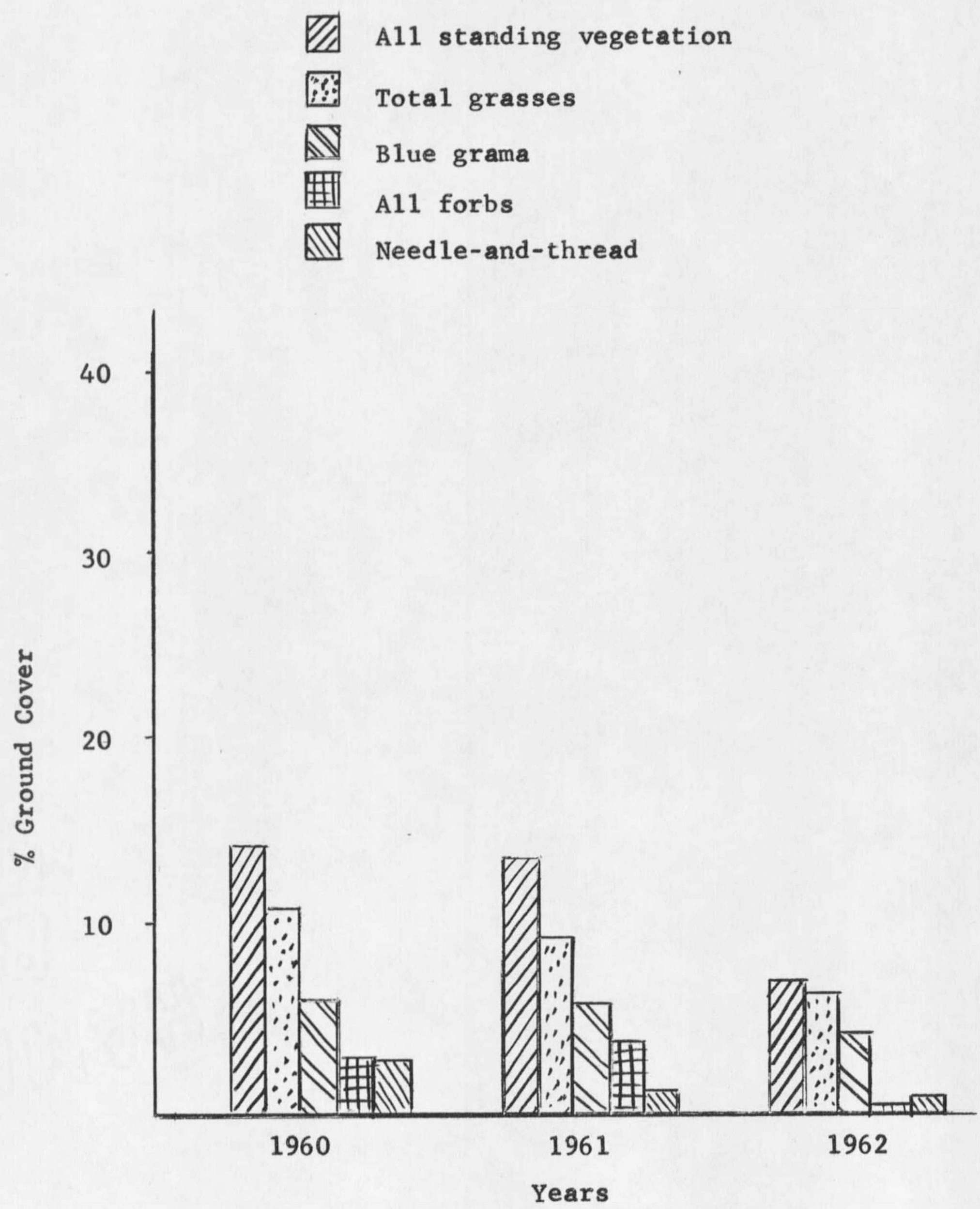


Figure 9. Responses of total standing vegetation, all grasses, all forbs, blue grama and needle-and-thread 1960-1962 on untreated range.

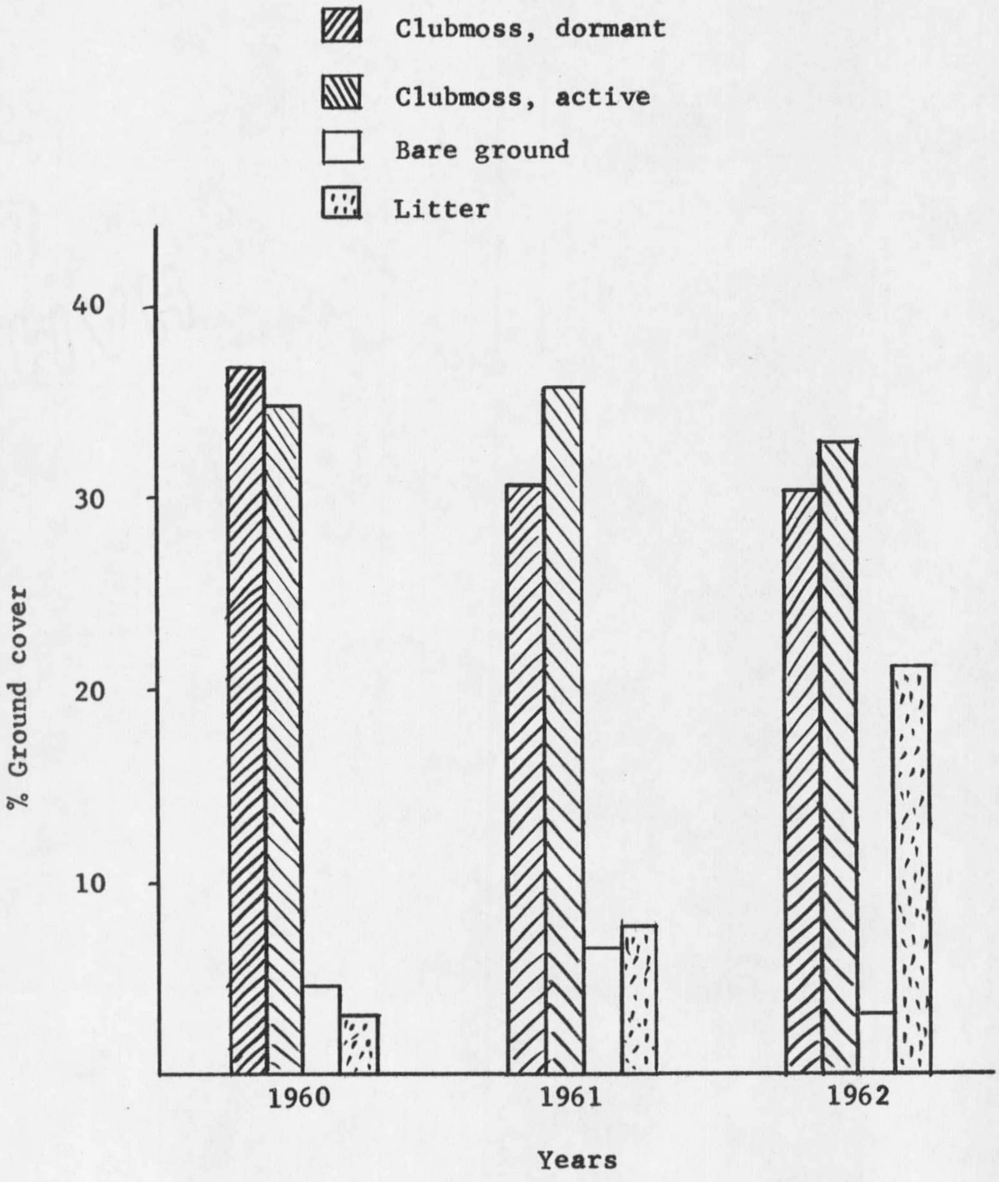


Figure 10. Bare ground, litter and clubmoss changes 1960-1962 on untreated range.

Table II. Species composition on unfertilized pitted and non-pitted range, 1960-62.

Species and Groups of Species	Pitted Range 1960	Pitted Range 1961	Pitted Range 1962	Non-pitted Range 1960	Non-pitted Range 1961	Non-pitted Range 1962
	PERCENT GROUND COVER (BASAL)					
Total grasses and sedges 1/	4.8	4.1	3.0	11.4	9.4	6.2
Stipa comata	0.5	0.9	1.2	2.9	1.3	0.8
Bouteloua gracilis	2.8	2.0	0.5	6.2	5.8	4.1
Total forbs 2/	1.9	1.7	1.0	3.1	4.3	0.4
Total half-shrubs and shrubs 3/	1.3	0.0	0.0	0.0	0.0	0.0
Total standing vegetation 4/	8.1	5.8	4.0	14.5	13.7	6.7
Lichens	0.0	0.2	0.5	0.3	0.7	0.3
Litter	3.9	2.8	19.9	2.9	7.3	21.8
Selaginella densa, active	18.2	12.5	9.2	35.4	36.5	33.3
Selaginella densa, dormant	11.2	19.1	12.6	37.4	31.0	31.0
TOTAL VEGETATIONAL MATERIAL	41.4	40.4	46.2	90.4	89.2	93.1
Bare ground	57.8	58.8	53.8	4.5	6.9	3.1

1/ Including Agropyron smithii, Bouteloua gracilis, Poa secunda, Koeleria cristata, Calamagrostis montanensis, Stipa comata, Stipa viridula, Carex eleocharis.

2/ Including Antennaria spp., Chrysopsis villosa, Erigeron pumilus, Haplopappus spinulosus, Pentstemon albidus, Phlox hoodii, Sphaeralcea coccinea, Vicia americana.

3/ Primarily Artemisia frigida.

4/ Grasses, forbs, and shrubs; excluding litter, lichens, clubmoss.

aerial cover or weight. In this study changes in ground cover were observed in species composition as well as in total amounts of vegetation in relation to treatments.

Analyses of variance for ground cover by species and groups of species are summarized in Table III. No clear trend in significant factors is evident due to the great number of variables included. Some of the higher confidence levels on relatively uncommon species should be viewed with suspicion because of the small number of observations and the great variation among plots. The presence of significant differences with lines and various line interactions suggests inadequate sampling to remove substrate variability. In some instances visual differences which were observed in the field were not separated in the statistical analysis---another indication of inadequate sampling.

Treatment years affected several important species, including blue grama, needle-and-thread, and total grasses. Part of these differences were felt to be due to the high mortality of needle-and-thread following the drought year of 1961. Also, nitrogen fertilization would be expected to act differently under such substantial yearly differences in available moisture.

Mean ground cover responses to specific nitrogen rates are shown in Table IV. Although total grass cover did not vary the per cent composition of grasses was affected by fertilization. Needle-and-thread tended to increase with nitrogen application. Blue grama decreased under the same conditions. A similar trend was seen with clubmoss. Nitrogen increased the amount of dormant clubmoss at the expense of active clubmoss. The

Table III. Analysis of variance summary: mean squares for ground cover on non-pitted range.

Sources of Error1/	df	STCO	BOGR	10 MISC	1012	1315	10's	1017	Litter	SEDE	SEDED	Bare	1019
							Variables2/						
R	2	.0192	.0416#	.0075	.0224	Too few values for meaningful analysis.	.0230#	.0190	2.4756*	1.3585	2.3286#	.0491	.1192
A	2	.0097	.0315#	.0024	.0345		.0282#	.0400#	1.4634@	1.2528	5.4091@	.0132	.0520
Error A	4	.0119	.0104	.0093	.0116		.0082	.0125	.3152	.8050	.9547	.1030	.1084
B	2	.0037	.0212#	.0002	.0110		.0083	.0290	.3059	1.5524**	1.0875*	.0314	.0042
AB	4	.0041	.0146	.0030	.0124		.0084	.0069	.1475	.2390#	.4845#	.0389	.0574
Error B	12	.0078	.0114	.0031	.0126		.0132	.0193	.1529	.1261	.2586	.0535	.0963
C	2	.0219*	.0092	.0006	.0282#		.0313#	.0130	.4845*	2.0230**	.4385	.0006	.0154
AC	4	.0036	.0041	.0010	.0036		.0020	.0030	.0144	.1624	.1968	.0043	.0551
BC	4	.0027	.0051	.0008	.0059		.0070	.0038	.0439	.3867#	.2352	.0192	.0398
ABC	8	.0112@	.0030	.0012	.0091		.0091	.0151	.0645	.2949	.5822	.0444	.1221#
Error C	36	.0052	.0070	.0021	.0133		.0131	.0133	.1313	.2406	.4473	.0402	.0889
D	1	.0004	.0133@	.0008	.0189#		.0133	.0141	.0019	.2207	.6498@	.0087	.0658
AD	2	.0257*	.0018	.0029	.0357@		.0421*	.0318#	.0226	.4265@	.3833#	.0016	.0306
BD	2	.0005	.0018	.0028	.0066#		.0068	.0133	.2437#	.4032#	.2817	.0287	.0876
CD	2	.0007	.0071#	.0001	.0029		.0036	.0085	.1645	.2807#	.4932#	.0234	.0061
ABD	4	.0028	.0091	.0017	.0190#		.0156	.0213	.2582#	.6445**	1.1528**	.0436#	.1454#
ACD	4	.0080#	.0027	.0009	.0118		.0094	.0214	.1116	.2013	.0850	.0060	.0563
BCD	4	.0142*	.0069#	.0026	.0170		.0199#	.0198	.0018	.1421	.3704#	.0570@	.1770@
ABCD	8	.0076#	.0048	.0045@	.0095		.0095	.0079	.3112@	.2382#	.3621#	.0077	.0590
Error D	54	.0052	.0044	.0024	.0132		.0128	.0160	.1250	.1696	.2253	.0250	.0832
Total	161	.0066	.0071	.0025	.0132		.0128	.0151	.1876	.3027	.4617	.0326	.0842

1/ R = replicates
A = 1961 nitrogen levels
B = 1960 nitrogen levels
C = 1959 nitrogen levels
D = lines

2/ STCO = needle-and-thread
BOGR = blue grama
10 MISC = all other perennial grasses
1012 = all grasses and sedges
1315 = all forbs
10's = all grasses
1017 = all standing vegetation
SEDE = active clubmoss
SEDED = dormant clubmoss
Bare = bare ground
1019 = all plant material

Significance: ** P = .01
* P = .05
@ P = .10
# P = .25

Table IV. Percent ground cover as affected by fertilization of non-pitted rangeland.

Treatments (nitrogen levels)	Total N (lbs/A)	STCO	BOGR	1012	1017	Litter	SEDE	SEDED	1019	Bare
		VARIABLES[1/]								
3 3 3	300	2.2abc	2.6ab	5.2ab	5.4a	14.0 cdef	22.6 def	51.6abc	94.2a	4.4a
3 3 2	250	0.8 bc	1.8ab	3.4 bc	1.6a	13.0 cdef	19.4 f	56.4ab	92.6a	4.6a
3 2 3	250	1.8abc	0.8 b	3.2 bc	1.2a	13.6 cdef	24.8 cdef	52.0abc	94.8a	1.6a
2 3 3	250	2.2abc	0.8 b	3.4 bc	1.6a	16.4 bcde	21.0 ef	56.4ab	98.0a	1.8a
3 3 1	200	1.4abc	1.8ab	5.2ab	5.4a	17.0 bcde	20.2abcdef	44.0abc	96.8a	1.8a
3 1 3	200	1.8abc	2.4ab	4.6abc	5.4a	16.4 bcde	21.2 ef	52.8ab	96.4a	1.6a
1 3 3	200	2.6abc	1.0 b	4.6abc	4.6a	22.2ab	26.8 bcdef	39.4abc	93.6a	5.0a
3 2 2	200	1.6abc	1.2 b	3.4 bc	4.4a	11.0 ef	28.2abcdef	51.0abc	95.0a	2.4a
2 3 2	200	3.4a	0.4 b	4.0abc	4.1a	15.8 bcde	25.2 cdef	48.0abc	93.8a	4.2a
2 2 3	200	2.6abc	1.0 b	4.8abc	5.0a	16.0 bcde	25.4 cdef	49.6abc	96.6a	2.4a
3 2 1	150	2.6abc	0.8 b	4.0abc	4.0a	10.8 ef	35.2abcde	43.0abc	94.0a	3.2a
2 3 1	150	1.2 bc	1.6 b	3.4 bc	1.4a	11.8 ef	33.6abcdef	48.0abc	97.2a	2.0a
3 1 2	150	1.8abc	1.2 b	3.6abc	5.6a	11.8 ef	34.0abcdef	41.4abc	93.6a	2.0a
1 3 2	150	1.2 bc	1.6 b	4.4abc	5.0a	17.8abcde	31.6abcdef	41.2abc	96.0a	2.8a
1 2 3	150	2.8ab	1.4 b	5.2ab	6.2a	17.4abcde	30.0abcdef	40.0abc	94.0a	4.4a
2 1 3	150	3.4a	1.2 b	5.2ab	5.4a	17.2abcde	29.4abcdef	39.8abc	92.0a	4.4a
2 2 2	150	2.2abc	0.8 b	3.6abc	1.6a	12.4 def	39.2abc	36.6 bc	92.0a	3.2a
3 1 1	100	1.0 bc	2.6ab	4.2abc	5.0a	8.4 f	23.8 def	60.0a	97.4a	2.2a
1 3 1	100	2.8ab	1.0 b	4.6abc	4.6a	19.2abcd	25.8 cdef	40.0abc	90.4a	5.0a
1 1 3	100	2.2abc	2.2ab	5.6ab	5.8a	24.0a	29.8abcdef	35.4 bc	95.2a	0.4a
2 2 1	100	1.6abc	1.4 b	3.6abc	1.8a	11.8 ef	33.8abcdef	48.6abc	98.6a	1.4a
2 1 2	100	1.4abc	0.4 b	2.2 c	1.2a	12.0 ef	42.8a	39.6abc	97.8a	2.0a
1 2 2	100	2.2abc	1.8ab	4.4abc	4.4a	16.0 bcde	34.4abcdef	39.2abc	94.2a	2.2a
2 1 1	50	2.0abc	1.2 b	3.8abc	4.4a	12.2 def	37.2abcd	37.8 bc	91.6a	5.6a
1 2 1	50	1.0 bc	1.8ab	3.4 bc	1.8a	13.2 cdef	41.6ab	36.0 bc	95.6a	2.6a
1 1 2	50	1.2 bc	2.4ab	5.0ab	5.0a	20.0abc	33.0abcdef	36.2 bc	94.6a	3.8a
1 1 1	0	0.6 c	4.0a	6.2a	6.6a	21.8ab	33.2abcdef	31.0 c	93.0a	3.0a

Means with one or more letters in common are not significantly different (P=.05) according to Duncan's Multiple Range Test.

1/ For identification of variables see Table III, page 44.

net result of these species composition changes was a more productive speciation.

Production: The analyses of variance for non-pitted production data are summarized in Table V. Treatment years again influenced species responses. In general, grasses were the vegetational components most affected. Needle-and-thread and blue grama contributed most of the variation related to treatments.

Species responses are better seen in the mean production values shown in Table VI. Significant increases in production of needle-and-thread and of blue grama were generally related to increased fertilization rates. A similar trend is seen in annual and biennial forbs and total standing vegetation. Western wheatgrass and perennial forbs and shrubs showed no clear effects.

Pitted range

Ground cover: Pitted range ground cover was less affected by all experimental variables than was cover on non-pitted range (Table VII). In particular, treatment year differences are less consistent. This may reflect a more favorable overall moisture situation on pitted range. In such a case any advantage of fertilization would tend to be diminished by more available moisture for plant growth.

Individual treatment means for pitted range are given in Table VIII. The species responses previously noted on non-pitted range are less apparent here. Needle-and-thread shows a tendency to increase with fertilization; dormant clubmoss decreases. No other species or groups exhibit clear trends.

Table V. Analysis of variance summary: mean squares for production influenced by fertilization of non-pitted range.

Sources of variation[2/]	df	Variables[2/] AGSM	STCO	BOGR	10 MISC	1314	1517	1017
R	2	7,972	636,430#	29,002*	63,757	6,209	4,413	57,247
A	2	4,926	303,630	34,848**	3,547	29,308	11,442#	794,401*
Error A	4	4,297	217,915	1,706	70,917	18,723	3,380	90,094
B	2	1,196	539,863*	7,783#	32,845#	21,700	3,229	321,846*
AB	4	2,049	234,233@	12,844*	13,498	23,960	1,100	32,251
Error B	12	2,889	83,753	2,995	20,271	27,923	3,129	63,779
C	2	1,765	49,133#	497	24,778#	1,179	10,320*	136,830*
AC	4	702	83,484@	1,304	2,692	2,635	2,717	108,892*
BC	4	2,930#	132,930**	75	4,635	2,073	7,001@	110,362*
ABC	8	2,227	66,754@	1,907	6,200	3,938#	1,790	64,173#
Error C	36	1,972	32,178	3,497	10,952	2,124	2,916	41,096
D	1	190	47,579#	1,156	30,461*	974	2,418	271,463**
AD	2	693	6,662	2,663#	5,037	3,268	3,322	15,871
BD	2	2,251#	37,790#	2,725#	15,462@	13,200	1,105	101,126*
CD	2	561	4,698	118	1,214	14,830#	193	20,696
ABD	4	1,954	24,903	190	2,620	5,129	3,768#	31,810
ACD	4	2,343#	29,188	673	2,030	8,152	3,906#	23,191
BCD	4	80	55,482*	706	2,766	13,050#	780	35,406
ABCD	8	1,220	26,452#	573	3,285	12,924#	2,611	40,864
Error D	54	1,422	18,304	1,433	5,946	9,294	2,532	31,643
Total	161	1,903	63,441	3,015	10,900	9,463	2,953	60,182

1/ R = replicates
A = 1961 nitrogen levels
B = 1960 nitrogen levels
C = 1959 nitrogen levels
D = observations

2/ AGSM = western wheatgrass
STCO = needle-and-thread
BOGR = blue grama
10 MISC = all grasses and sedges
1314 = all annual and biennial forbs
1517 = all perennial forbs, half-shrubs and shrubs
1017 = all standing vegetation

3/ Significance:
** P = .01
* P = .05
@ P = .10
# P = .25

Table VI. Production as affected by fertilization of non-pitted range (pounds per acre).

Treatments (nitrogen levels)	Total N (lbs/A)	AGSM	STCO	BOGR	10 MISC	1314	1517	1017
		Variables1/						
3 3 3	300	42.08a	416.32 bcde	105.72abc	190.08a	131.10ab	45.72 cdefg	931.04ab
3 3 2	250	5.53a	345.66 cde	127.20ab	61.40 bc	105.21abc	78.49abcdef	723.52abcde
3 2 3	250	35.87a	798.52a	15.77 f	42.91 bc	13.28 d	85.47abcde	991.84a
2 3 3	250	40.32a	490.43abcd	32.44 ef	143.20ab	14.62 d	26.20 efg	747.23abcde
3 3 1	200	28.89a	378.36 cde	131.45a	120.09abc	147.10a	64.19abcdefg	870.11abc
3 1 3	200	4.83a	447.48abcde	101.92abcd	107.00abc	87.55abc	49.21 cdefg	798.01abc
1 3 3	200	3.84a	307.87 cde	42.04 def	130.46abc	55.64 bcd	25.08 fg	564.96 cdef
3 2 2	200	15.20a	652.09abc	44.12 def	21.56 c	13.40 d	90.91abc	837.31abc
2 3 2	200	14.24a	619.29abc	35.96 ef	47.61 bc	12.16 d	87.58abcd	816.86abc
2 2 3	200	47.55a	462.68abcde	35.29 ef	113.88abc	8.28 d	67.93abcdefg	735.64abcde
3 2 1	150	7.29a	750.27ab	49.02 cdef	40.38 bc	9.50 d	49.72 cdefg	906.20abc
2 3 1	150	47.55a	491.29abcd	29.82 ef	52.96 bc	5.05 d	61.72abcdefg	688.41abcde
3 1 2	150	5.44a	364.44 cde	82.49abcde	73.34 bc	13.92 d	111.45ab	651.10abcde
1 3 2	150	10.08a	607.61abc	23.23 ef	134.43ab	4.89 d	29.95 defg	810.20abc
1 2 3	150	4.60a	443.04abcde	48.92 cdef	67.55 bc	10.43 d	28.09 defg	602.65 bcdef
2 1 3	150	55.07a	642.24abc	15.13 f	62.20 bc	13.72 d	44.73 cdefg	833.12abc
2 2 2	150	36.41a	533.31abcd	40.28 ef	101.12abc	9.08 d	54.20 bcdefg	774.43abcd
3 1 1	100	22.59a	588.67abc	70.88 bcdef	86.17abc	14.84 d	59.68 bcdefg	842.84abc
1 3 1	100	52.96a	411.04 bcde	31.13 ef	133.63ab	18.97 d	44.22 cdefg	691.96abcde
1 1 3	100	59.87a	392.06 bcde	35.90 ef	148.09ab	7.61 d	70.33abcdefg	713.88abcde
2 2 1	100	22.01a	465.18abcde	42.52 def	62.43 bc	29.82 cd	65.47abcdefg	687.45abcde
2 1 2	100	41.50a	316.32 cde	37.72 ef	83.39abc	59.48 bcd	120.06a	658.75abcde
1 2 2	100	6.72a	475.48abcde	43.96 def	68.89 bc	48.38 bcd	17.82 g	661.28abcde
2 1 1	50	31.58a	189.24 de	69.76 bcdef	76.19 bc	22.20 cd	35.32 cdefg	424.32 def
1 2 1	50	22.52a	461.02abcde	26.88 ef	51.90 bc	3.55 d	55.13 bcdefg	620.86 bcdef
1 1 2	50	56.00a	179.20 de	44.70 def	55.45 bc	0.03 d	78.81abcdef	414.20 ef
1 1 1	0	5.85a	124.25 e	29.72 ef	78.91 bc	21.56 cd	31.32 cdefg	291.64 f

Means with one or more letters in common are not significantly different at the .05 percent level of confidence according to Duncan's Multiple Range Test.

1/ For identification of variables see Table III, page 44 and Table V, page 47.

Table VII. Analysis of variance summary: mean squares for ground cover on pitted range.

Sources of Error1/	df	Variables2/											
		STCO	BOGR	10 MISC	1012	1315	10's	1017	Litter	SEDE	SEDED	Bare	1019
R	2	.0521	.0234#	.0049	.0672	.0377**	.0709#	.0142	.1381	.1200	.6755	.7340	.4025
A	2	.0256	.0053	.0014	.0210	.0002	.0179	.0287#	.1272	.6376	.0102	1.3887	1.2779
Error A	4	.0512	.0061	.0042	.0192	.0019	.0215	.0101	.1123	.4570	1.2189	3.5715	3.7986
B	2	.0993@	.0021	.0006	.0926@	.0019	.0930@	.0746#	.3092	.2821@	.0351	.0417	.0041
AB	4	.0207	.0025	.0029#	.0170	.0025	.0186	.0251	.0578	.0828	.1324	.1695	.1421
Error B	12	.0289	.0019	.0017	.0302	.0048	.0302	.0362	.2055	.0757	.2582	.7937	.6873
C	2	.0141#	.0013	.0002	.0119	.0005	.0110	.0149	.8512*	.2150*	.0110	.0898	.2597
AC	4	.0113	.0051	.0015	.0241#	.0018	.0242#	.0384@	.1372	.0057	.2781	.0996	.1922
BC	4	.0238*	.0031	.0071*	.0194	.0044	.0213#	.0324#	.2123	.0581	.6649*	.8973@	1.4281*
ABC	8	.0113	.0017	.0010	.0133	.0063#	.0112	.0269#	.1294	.0341	.5527*	.8868@	.7944
Error C	36	.0090	.0057	.0025	.0139	.0042	.0138	.0159	.1801	.0551	.2169	.4024	.3776
D	1	.0025	.0007	.0003	.0010	.0024	.0009	.0021	.0069	.2230*	.0559	.0620	.0739
AD	2	.0002	.0015	.0001	.0050	.0015	.0026	.0034	.1395	.1410@	.8422*	1.3823#	1.5437@
BD	2	.0156	.0040	.0008	.0269	.0030	.0284#	.0333#	.1254	.0616	.3466#	.6583	.9718
CD	2	.0163	.0047#	.0028	.0213	.0038	.0206	.0160	.0623	.1241#	.1253	.0375	.0406#
ABD	4	.0152	.0043	.0020	.0373#	.0064	.0377#	.0421#	.1740	.0164	.1641	.4001	.3658
ACD	4	.0057	.0009	.0028	.0164	.0067	.0166	.0167	.0809	.0685	.2725	.4806	.4991
BCD	4	.0244#	.0021	.0015	.0339#	.0062	.0330#	.0370	.0951	.0122	.3613#	.1382	.2230
ABCD	8	.0065	.0022	.0011	.0038	.0037	.0036	.0016	.0491	.0507	.2774	.5181	.3918
Error D	54	.0157	.0032	.0026	.0188	.0051	.0194	.0219	.1331	.0545	.2396	.6019	.5523
Total	161	.0169	.0038	.0023	.0197	.0049	.0199	.0224	.1526	.0789	.2919	.6181	.6013

1/ R = replicates
A = 1961 nitrogen levels
B = 1960 nitrogen levels
C = 1959 nitrogen levels
D = lines

2/ For identification of variables see Table III, page 44.

Significance: ** P = .01
* P = .05
@ P = .10
# P = .25