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EFFECTS OF RANGELAND FERTILIZATION ON FORAGE CROP YIELD AND QUALITY

by

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TABLE OF CONTENTS

	page
INTRODUCTION	1
HERBAGE YIELD RESPONSE	3
VEGETATIONAL FACTORS	3
Season of Growth	3
Life Span	5
Range Renovation	6
Total Biomass Yield	12
Undesirable Species	20
FERTILIZER TREATMENT EFFECTS	24
Rate of Fertilizer Application	24
Length of effect	26
SOIL FACTORS	28
Soil Chemistry Effects	28
Nitrate-nitrogen	31
GRAZING EFFECTS	32
CHEMICAL COMPOSITION	33
CRUDE PROTEIN	33
ASH	36
ETHER EXTRACT	40
CRUDE FIBER	41
NITROGEN-FREE EXTRACT	41
TOTAL NONSTRUCTURAL CARBOHYDRATES	42
DIGESTIBILITY	43
PALATABILITY, UTILIZATION, AND PREFERENCE	44
CONCLUSIONS	46
LITERATURE CITED	49

Abstract

Fertilization of native rangeland often results in significant increases in herbage production. Responses of vegetation depend in part upon the climate, season of growth, life span, initial botanical composition of the stand, range condition, soils, rate and type of fertilizer used, and grazing management of the fertilized stand. Undesirable changes in botanical composition may result from rangeland fertilization, leading to weed infestation, loss of valuable forage species, and retrogression in range condition. Fertilization may lead to local overuse of the range. At heavy rates of nitrogen, nitrate-nitrogen toxicity may be a problem. These problems could necessitate chemical weed control in conjunction with fertilization, further adding to the cost and potential environmental effects. However, the tendency for fertilization to produce changes in botanical composition may also be used as a tool in range renovation.

In many cases, protein content of grasses may be increased by nitrogen addition. Fertilization is also a possible substitute for supplementation of deficient minerals to range livestock. Fertilization may increase forage utilization, and may be useful as a tool in securing proper distribution of grazing animals, particularly on mountain ranges.

INTRODUCTION

Soil fertility may be a major factor limiting the herbage production of semiarid rangelands. According to Wight and Black (1972), Northern Great Plains ecosystems cycle nitrogen at the rate of 66 kg/ha (kilograms per hectare) or less per year, while 113 to 185 kg/ha per year is needed for maximum yield. They believe that these ecosystems are functioning at an energy level about 1/3 to 1/2 of that obtainable when nitrogen and phosphorus availability is adequate.

In natural (unfertilized) ecosystems, nonsymbiotic fixation may be the major source of nitrogen (Miles, 1958). Vigorous plants constantly replace roots; these roots, together with plant litter, provide a source of energy to the nitrogen-fixing bacteria. Fertilizer nitrogen could enhance root production, increasing the rate of root replacement and litter accumulation, thus increasing the rate of nitrogen fixation. In North Dakota, 34 kg/ha of nitrogen significantly increased root weight within a 1.2 meter profile, while 101 kg/ha did not further increase root growth even though top growth was significantly increased (Lorenz and Rogler, 1967). In this case, the root to top growth ratio was much lower for the 101 kg/ha than 34 kg/ha treatment.

Power (1972) has suggested that large amounts of fertilizer nitrogen are immobilized in grass roots, soil organic matter, fixed ammonium, or are volatilized. Addition of high amounts of nitrogen saturates the ability of the soil-plant system to immobilize nitrogen; once these "nitrogen sink" requirements are satisfied, the soil can be maintained in a nitrogen-saturated condition, and nitrogen can be eliminated as a growth-limiting factor. He reported that this immobilization and loss increased to about 350 kg/ha after three to four years of fertilization, and remained constant thereafter.

Apparently, additional research will be necessary to increase our understanding of nitrogen cycling, effects of fertilizer nitrogen on plant roots, and the relationship between top growth and root growth under natural and fertilized conditions.

Fertilization to enhance, maintain, or restore the productivity of cropland and tame pasture has long been accepted practice. In recent years, increasing demand for red meat from rangelends, a dwindling supply of rangeland due to population expansion, and unfavorable economic conditions in the range livestock industry have required maximum production from existing rangelands. As management has

increased, fertilization has been proposed as a method of increasing livestock production from rangeland by enhancing forage yield and quality. Forage yield may be effectively increased by actual increases in herbage production, or by increasing the use of unpalatable forage by grazing livestock. Forage quality may be affected by fertilization through changes in chemical composition of the stand, or through changes in chemical composition of individual plants. Changes in botanical composition of the stand will affect forage quality due to the different nutrient contents of various species and types of plants on the site. This paper reviews literature concerning effects of rangeland fertilization on forage crop yield and quality.

HERBAGE YIELD RESPONSE

Vegetational Factors

Season of Growth. Generally, cool-season grass species show greater response to application of nitrogen fertilizer than do warm-season species (Williams, 1953). Fertilized vegetation is often darker in color, more robust, with increased basal area per plant, increased size of plant parts, longer green-growth period, and higher yields. Rauzi, Lang, and Painter (1968) reported that yields of warm-season

grass species were not significantly affected by fertilization with 37 or 74 kg/ha of ammonium nitrate. Yields of cool-season species varied among treatments, and were mostly a function of the passage of time rather than fertilization. They concluded that nitrogen fertilization was not an economical practice during the years of the study at two locations in northeastern Wyoming because moisture was the greatest limiting factor.

Western wheatgrass (Agropyron smithii) in particular seems to respond favorably to nitrogen fertilization. In a W yoming study (Cooper et al, 1967), a single application of ammonium nitrate to a deteriorated range changed the botanical composition from predominately forbs/shortgrasses to western wheatgrass/shortgrasses. Nitrogen significantly increased mid-grasses, but decreased short-grasses and other species. Nitrogen (179 kg/ha) in combination with P_2O_5 increased the population of intermediate grasses from 11.6 percent to 48.3 percent, by weight of the total plant population, decreased shortgrasses from 62.3 percent to 34.5 percent, and decreased other plant species from 25.9 percent to 16.7 percent of the total plant population. Forage yield was increased, but the increase was due to the changes in

botanical composition as well as nitrogen stimulation. Phosphorus had no effect on botanical composition in this study.

In North Dakota, Goetz (1969) found that western wheatgrass increased as nitrogen increased on four different range sites. Blue grama (Bouteloua gracilis) decreased with increased nitrogen on sites where it was the dominant cover. Other grasses and sedges increased or decreased in cover or density only at certain rates of fertilization. This indicates that the optimum rate of application varies with different species, and emphasizes the difficulty of predicting responses to fertilizer applied to a vegetational complex. Goetz (1970) indicated that the single most important factor in determining degree of response to added nitrogen by any one species is the Range Site.

Life Span

Differences in fertilizer response between annual and perennial grasses were reported by Martin, Pierce, and Osterli (1964) and Kay and Evans (1965), both in California. On winter range consisting mostly of Hardinggrass (Phalaris tuberosa var. stenoptera) and annual grasses (mostly soft chess (Bromus mollis) fertilized with ammonium sulfate, yields were almost doubled in some instances (Martin et al, 1964). At low levels of nitrogen, the yield increases were

almost entirely due to increases in annuals. At high nitrogen levels, added production was mostly due to increased Hardinggrass. Nitrogen recovery showed that the annual grasses took up more nitrogen at low rates, while Hardinggrass took up more at high rates. Total recovery of fertilizer nitrogen was 30 percent at low levels, but only 13-19 percent at high levels. In contrast, Kay and Evans (1965) found that high levels of nitrogen under drought conditions favored cheatgrass (Bromus tectorum) at the expense of intermediate wheatgrass (Agropyron intermedium). High nitrogen levels stimulated cheatgrass production, causing a rapid depletion of soil moisture, which led to a marked reduction in wheatgrass. This effect intensified under grazing pressure.

Range Renovation

Differential responses to fertilization which are exhibited by plant species and types may make it possible to accelerate successional changes and promote renovation of depleted rangeland. Rogler and Lorenz (1957) achieved more success in improving range condition and production by two years of fertilization and rest than by six years of complete rest from grazing. Remnant western wheatgrass plants made rapid recovery at the expense of blue grama, and

accounted for most of the increased yield. Western wheatgrass responded because of its cool-season growth habit, and the increase of readily available nitrogen in the early spring before soil temperature had warmed sufficiently to permit a rapid rate of natural nitrification.

Since nitrogen fertilization sometimes stimulates forbs to the detriment of perennial grasses, fertilization in combination with herbicide treatments has been attempted (Nichols and McMurphy, 1969; Currie, 1976; Nichols, 1969; Smith and Lang, 1962). On deteriorated western wheatgrass/green needle grass (Stipa viridula) range in South Dakota, the combination of 2,4-D and nitrogen fertilization was more effective than either treatment alone (Nichols, 1969). Initially, weeds comprised 79 percent of the total vegetation, and 80 percent of these were annuals. Spraying with 2,4-D at 2 kg/ha and nitrogen fertilizer at 135 kg/ha increased the frequency of perennial grasses by 10 percent three grazing seasons after treatment. However, rapid range recovery was also achieved by rest alone; the use of 2,4-D and fertilizer was not economically justifiable. In this case, range improvement by secondary succession proceeded extremely rapidly, with remnant western wheatgrass plants recolonizing bare areas rapidly. The rate of recovery was accelerated by spraying and fertilization. Where the major

portion of the weedy growth is annuals, the author believed that this abundance would decline as grasses regained vigor. With perennial weed growth and low soil nitrogen, spraying and fertilization might be justified.

In Colorado, applications of 2,4-D or fertilization increased forage yields and changed vegetational composition under a variety of grazing treatments (Currie, 1976). The herbicide reduced weed competition and allowed rapid grass recovery. Spraying alone was effective, but the grasses required more time to take advantage of the removal of forb competition when not fertilized. Fertilization alone also increased ground cover and herbage yield, but increased non-forage producing species as well. In contrast to the success with spraying and fertilization, the season and system of grazing, including complete rest, did not influence yields, basal areas, or plant densities during the five year study period.

In a bluebunch wheatgrass (Agropyron spicatum) Sandberg bluegrass (Poa sandbergii) type, cheatgrass yields increased with increasing rates of ammonium sulfate during the growing season immediately following either fall or spring application (Wilson, Harris, and Gates, 1966). Nitrogen (90 kg/ha) in four consecutive growing seasons produced retrogression in range condition. Yields of bluebunch

wheatgrass fell 50 percent; cheatgrass yields increased 400 to 600 percent. This retrogression occurred regardless of the initial density of the wheatgrass. Neither ammonium nitrate nor calcium sulfate greatly increased cheatgrass yield alone. In a combination equivalent to 90 kg/ha of ammonium sulfate, they increased cheatgrass yield 600 percent.

Beneficial reductions in clubmoss (Selaginella densa) may result from fertilization (Dolan and Taylor, 1972; Heady, 1952; Ryerson et al, 1970; Smoliak, 1965; Wight, 1976). Smoliak (1965) found that the basal area of clubmoss was substantially reduced by treatment with manure, straw, or straw and commercial fertilizer, although some of the result from manure treatment was caused by a mulch effect. Heady (1952) found that within two years of manure treatment, grasses increased while clubmoss decreased. Manuring improved yields more than disking and spring-tooth harrowing. In northern Montana, reduced ground cover of clubmoss was clearly evident 30 to 40 years after mechanical and manuring treatment (Dolan and Taylor, 1972). Manure application reduced clubmoss, although there was little difference among treatment intensities. As the ground cover of clubmoss decreased, the yield and ground cover of other vegetation on the site increased significantly.

Tall larkspur (Delphinium barbeyi) is a poisonous plant which can inhibit use of large expanses of mountain ranges. In Utah, Binns, James, and Johnson (1971) reported success in controlling larkspur with herbicides plus nitrogen fertilizers. The herbicide apparently weakened the larkspur, while the fertilizer stimulated grass production, thus providing competition to the larkspur and furthering the control effectiveness. However, another study in Utah (Cronin, Bowns, and Johnson, 1977) indicated that nitrogen fertilizer added to herbicides did not enhance larkspur control, nor did it stimulate increased forage production. The authors speculated that aspen trees on the site may have utilized the nitrogen before the herbaceous plants initiated growth in the spring; dentrification could have been a factor since conditions were optimal, or leaching could have effectively removed the nitrogen.

Since range renovation work may include reseeding, the possible effects of fertilization on seedling emergence and growth should be of interest to rangeland managers. A study of grass establishment (Welch, 1962) showed that the ease of establishment of grasses was directly related to the inherent seedling vigor of the particular grass species.

Fertilization did not increase seedling emergence of any of the grass species tested in any year tested. Fertilization at the time of seeding increased the final plant stand in only one species in one year. The initial growth response of the various grasses to fertilization was also directly related to inherent seedling vigor. Species with medium or high seedling vigor responded to fertilization in all four years of the study, while species with low seedling vigor did not. Apparently, the growth and development rate of species of low seedling vigor is so low that fertilization is of little benefit.

Nitrogen fertilization generally stimulates grass production and depresses the legume component of a stand, while phosphorous fertilization stimulates growth of legumes (Vallentine, 1971; Russel et al, 1965; Jones and Winans, 1967). Thus, changes in dry matter yield and chemical composition of the forage of fertilized stands are due to variations in initial botanical composition and resultant changes in botanical composition, as well as chemical components of individual plants (Russell et al, 1965). In this study, radioactively tagged (P_{32}) phosphorus showed that legumes used greater amounts of applied phosphorus than did grasses. Nitrogen application appeared to result in

increased utilization of applied phosphorus by grasses.

Jones and Winans (1967) reported that subterranean clover (Trifolium subterraneum) was competitive with grass when the stand was grazed or mowed, if not fertilized. Clover establishment had the advantage of providing higher protein content in the forage when the need was greatest, during the dry season, compared to nitrogen fertilized grass, in which protein levels were depressed during this period.

In Georgia, addition of white clover (Trifolium repens) to perennial grass mixtures resulted in significantly greater yields than nitrogen fertilization alone (Dobson and Beaty, 1977). Grass production averaged 1029 kg/ha without clover or nitrogen. Clover increased production to 3284 kg/ha, an increase of 219 percent. Application of 37 kg/ha of nitrogen increased yield to 2046 kg/ha; addition of clover increased the total yield to 3946 kg/ha, an additional 93 percent increase. Only at 336 kg/ha nitrogen were the grass/nitrogen yields equal to the grass/clover yields with nitrogen.

Total Biomass Yield

In many areas, rangeland fertilization has increased herbage yields dramatically; however, yield response seems closely related to the type and amount of fertilizer used,

the site, and the initial and eventual botanical composition of the stand, as well as climatic factors.

Yield increases have been reported in Alberta (Johnston et al, 1968b; Johnston et al, 1967), British Columbia (Mason and Miltmore, 1972), Washington (Patterson and Youngman, 1960), North Dakota (Goetz, 1969), South Dakota (Cosper and Thomas, 1961; Westin, Buntley, and Brage, 1955), Montana (Wight and Black, 1972), Wyoming (Houston and Hyder, 1975), Oregon (Baldwin, Hawkinson, and Anderson, 1974; Bowns, 1972), Colorado (Klipple and Retzer, 1959), Nebraska (Burzlaff, Fick, and Rittenhouse, 1968), Oklahoma (Huffine and Elder, 1960), Arizona (Holt and Wilson, 1961), California, (Conrad, Wolfolk, and Duncan, 1966; Wolfolk and Duncan, 1962; Kay, 1966), and Texas (Pettit and Deering, 1974; Drawe and Box, 1969; Reardon and Huss, 1965).

In Alberta, fertilization benefited both native and seeded range (Johnston et al, 1068b). Medium to high rates of nitrogen or nitrogen plus phosphorus produced changes in botanical composition which will be discussed later. Total yields increased up to eight times by fertilizer treatments, although little improvement of basal area ground cover was produced by low levels of nitrogen, phosphorus, or nitrogen plus phosphorus (Johnston et al, 1967).

In British Columbia, ammonium nitrate at rates up to 504 kg/ha approximately doubled yields of beardless wheatgrass (Agropyron inerme) for the first four years, compared to the control (Mason and Miltmore, 1972). However, the general yield levels declined in later years of the ten-year experiment. The ten-year accumulated yield of beardless wheatgrass increased from 3363 kg/ha at 0 nitrogen to 8688 kg/ha at 504 k g/ha.

In Washington, nitrogen fertilization increased yields on bunchgrass ranges by 61 to 103 percent; however, increased nitrogen increased yields of cheatgrass at the expense of native grasses (Patterson and Youngman, 1960).

Composition and yield of native grassland at four different range sites were studied in North Dakota (Goetz, 1969). Thirty-seven kg/ha of nitrogen did not significantly affect yields, while 75 and 112 kg/ha produced yield increases of 35 to 110 percent. The probability of increased production on a given range site by fertilization was closely associated with the inherent productive potential of the site, with more productive sites producing the greatest response to fertilization.

In western South Dakota, nitrogen fertilizer at rates of 0, 45, 89, and 179 kg/ha with and without 89 kg/ha

of P_2O_5 increased yields by 16 to 109 percent (Cosper and Thomas, 1961).

Also in South Dakota, Westin et al (1955) reported yields doubled by application of nitrogen fertilizer, while phosphorus effects on seed and forage yield were small and inconsistent.

In Montana, yields were tripled by addition of 1009 kg/ha of nitrogen together with 224 kg/ha of phosphorus (Wight and Black, 1972). This represented a great increase in precipitation-use efficiency. During the study, 30.5cm of precipitation was received. Yield of unfertilized plots was 1484 kg/ha, or 48.6 kg/ha/cm of precipitation, while fertilized plots yielded 4513 kg/ha, or 148 kg/ha/cm of precipitation.

In southeast Wyoming, Houston and Hyder (1975) reported average yield increases of 53, 57, and 86 percent on mixed-grass plains fertilized with 224, 448, and 672 kg/ha, respectively, of ammonium nitrate; however, they also noted significant changes in botanical composition. These changes w ill be discussed elsewhere.

In northeastern Oregon, Baldwin et al (1974) reported yield increased as much as four times by application of up to 4932 kg/ha of 27-12-0 fertilizer with four percent sulfur. These high levels of fertilization may cause problems of

nitrate-nitrogen toxicity, which will be discussed later. This level of fertilization also caused severe overuse, resulting in barren ground and invasion by annual weeds. Mustards (Brassica spp.), cheatgrass, and fanweed (Thlaspi arvense) invaded the site; Kentucky bluegrass (Poa pratensis) increased markedly in the composition, and Idaho fescue (Festuca idahoensis) decreased in plant numbers, although individual plants were more vigorous.

Fertilization of mountain meadows in eastern Oregon led to increases of up to 2240 kg/ha in hay production (Cooper and Sawyer, 1955). Meadows were fertilized with 0, 22, 45, and 67 kg/ha of nitrogen, and 0, 45, 90, and 134 kg/ha treble superphosphate. All treatments increased production, although no additional benefits were noted for P_2O_5 above 45 kg/ha. Phosphorus fertilization stimulated the growth of white-tip clover to 76 cm in height compared to 13 cm height on the control, accounting for most of the yield increase.

On high elevation ranges in Utah, low level nitrogen and phosphorus fertilization increased production by 32 to 65 percent (Bowns, 1972). Nitrogen at 34 and 67 kg/ha, phosphorus at 34 and 67 kg/ha, as well as 34 kg nitrogen with 34 kg phosphorus and 67 kg nitrogen with 67 kg of

of phosphorus per hectare were applied once. Over three years, all treatments increased production.

Also in Utah, Bayoumi and Smith (1976) reported increases of 21 to 174 percent in production of beardless wheatgrass, prairie Junegrass (Koeleria cristata), and Pacific aster (Aster chilensis), and twig lengths of bitterbrush (Purshia tridentata) and big sagebrush (Artemisia tridentata). Ammonium nitrate was applied in the spring at rates of 34, 67, 101, and 168 kg/ha.

In Colorado, manuring increased herbage yields by 15 to 50 percent, while plots treated with commercial fertilizer seldom yielded more than untreated native range (Klipple and Retzer, 1959).

In western Nebraska, ammonium nitrate at 17 kg/ha failed to produce significant yield increases on native range, while 34 and 67 kg/ha produced yields about 50 percent greater than the control (Burzlaff et al, 1968).

In Oklahoma, Huffine and Elder (1960) reported yield increases of 15 to 159 percent after fertilization with 37 kg/ha actual nitrogen and 336 kg/ha of superphosphate; however, most of the yield increase was due to increases in weed production, while grass and legume yields increased only slightly.

On desert grassland in Arizona, ammonium phosphate and ammonium nitrate were applied at rates of 28, 56, and 112 kg/ha actual nitrogen (Holt and Wilson, 1961). Forage production increased 85, 119, and 158 percent, respectively, by ammonium phosphate, and 66, 114, and 117 percent by ammonium nitrate. However, the summer of this study the area received 12.5 cm more precipitation than normal. The authors believed that responses might not have been so dramatic had moisture been more limiting as in normal years.

In the California annual grasslands, fertilization with sulfur and nitrogen plus sulfur resulted in increases of 22 to 260 percent in herbage production (Conrad et al, 1966; W olfolk and Duncan, 1962) and lengthening of the green-feed season (Conrad et al, 1966). However, Kay (1966) reported that yield increases occurred only in wet years and thus only rarely could be used. In poor years when increased production would have been useful, yields were not increased by fertilization.

On bluestem ranges in Texas, Reardon and Huss (1965) reported that little bluestem (Andropogon scoparium) yield responded to nitrogen fertilization only with adequate moisture, while 89 kg/ha phosphorus increased little bluestem production by 50 percent, even under drought conditions.

Ammonium nitrate, ammonium sulfate, and ammonium phosphate-sulfate at 30 and 60 kg/ha actual nitrogen were applied tp west Texas High Plains bluestem range in good condition (Pettit and Deering, 1974). Treatments produced increases of 24 to 54 percent in herbage production. Sixty kg/ha of ammonium sulfate and ammonium phosphate-sulfate produced the highest yields, while the other treatments did not differ significantly. Fertilization seemed detrimental to shrubs, and to forbs on sandy sites. The initial range condition was of prime importance in the fertilizer response in this study. Fertilization of sandyland ranges in poor or fair condition led to vigorous growth of undesirable plants such as sandbur (Cenchrus spp.), false buffalograss (Munroa squarrosa), and several annual lovegrasses (Eragrostis spp.). I ncreased growth of these undesirable plants placed the desirable perennial forage plants under additional soil moisture stress.

On Coastal Prairie range in Texas, up to 1009 kg/ha nitrogen with and without 112 kg P_2O_5 increased total production by up to 85 percent three months, 15 months and 27 months after the treatment (Drawe and Box, 1969). However, there was a steady decrease in grass production on plots with high rates of nitrogen. Forb production increased as the nitrogen was

increased. At the lowest rates there were no significant changes in the composition of the stand, but rates over 673 kg/ha of nitrogen produced significant decreases in grasses and significant increases in forbs.

Undesirable Species

Weed growth is a major concern in range fertilization. Early spring growth of weeds gives them a competitive advantage for available soil moisture and nutrients; thus, early spring fertilization or carryover from previous years benefits them over more desirable species (Wight, 1976). In a Central Great Plains study (Klipple and Retzer, 1959), abundant weed growth occurred on all plots after a drought year, but weeds were much heavier on manured plots than on untreated native range. Many of the perennial grasses died, and manured plots had the greatest mortality. A year later, plots fertilized w ith nitrogen showed severe shortgrass mortality, but check plots and potassium plots had little if any new mortality, and vegetation of phosphorus plots appeared to have made some recovery. Manured plots produced more annual forbs, especially Russian thistle (Salsola kali) than untreated plots, but grass density was not greater. Density and growth of annual forbs was greater on nitrogen fertilized plots than on the phosphorus, potassium, or check plots.

Fertilization with potassium increased weed production by 50 percent in a study in Texas (Reardon and Huss, 1965). This resulted in a decrease in production of little bluestem. With chemical weed control, potassium had no effect. Nitrogen fertilization showed some beneficial effects, but only when soil moisture was adequate. Phosphorus fertilization increased little bluestem production by 50 percent, and when weed control was added production increased 22 percent.

In north-central Oklahoma, forbs were reduced by burning, fertilization,or a combination of the two treatments (Gay and Dwyer, 1965). Nitrogen fertilization by itself was of very little value. Application of 112 kg/ha of nitrogen produced only 122 kg/ha additional growth, and 56 kg/ha actually produced 25.6 percent less than the control. Burning alone gave no significant improvement over the control, but with the addition of nitrogen, production increased markedly. The reduction of forbs in this case may have resulted from increased grass competition.

Another study in Oklahoma (Huffine and Elder, 1960) showed that fertilized pastures produced from two to five times as many weeds by weight as the control. On former cropland which had been abandoned 20 years earlier, the non-

fertilized pastures were 16 percent weeds, while fertilized areas had 50 percent weeds. On another site which had never been plowed but which had had some brush control and some timber cut off, unfertilized plots were 22 percent weeds, w hile fertilized areas were 42 percent weeds. Total herbage from fertilized areas was greater than from unfertilized areas, but grass yield was actually greater on areas which had not been fertilized.

In the Big Horn Mountains of Wyoming, forbs were not significantly affected by nitrogen fertilization; however, spraying with 2,4-D and fertilizing gave significantly higher grass yields than fertilization alone (Smith and Lang, 1962). Heavy rates of nitrogen fertilization were thought to decrease yields of forbs; however, the expense of fertilization for grass production and the e xpense of 2,4-D to control weeds were not thought to be justified by actual production increases.

In Washington, fertilization with more than 45 kg/ha of nitrogen increased cheatgrass from 13 percent to 66 percent of the yield (Patterson and Youngman, 1960). Increased nitrogen aided cheatgrass at the expense of native grasses, especially bluebunch wheatgrass and Idaho fescue. Sandberg bluegrass was not affected.

The composition of native range in Alberta was changed substantially by application of nitrogen or nitrogen plus phosphorus at medium to high rates (Johnston et al, 1968 Rough fescue (Festuca scabrella) responded to medium and high rates, but most other species in the native range died from high rates of fertilizer. Weeds gradually invaded the bared areas where native plants had been killed.

Johnson et al (1967) also reported major changes in botanical composition of mixed prairie range in fair condition in southeastern Alberta. Fertilization caused blue grama and clubmoss mortality, and declines in needle and thread (Stipa comata) and prairie Junegrass. The stand was then invaded by a variety of undesirable plants. Fringed sagewort (Artemisia frigida) increased up to 14 times the composition on the control, and increased individual plant size as well.

Range condition was important in determining response to fertilization in a South Dakota study (Cosper and Thomas, 1961). On sites in poor condition, non-grasses responded markedly to nitrogen and phosphorus, presenting serious weed control problems. Grasses responded principally to nitrogen, with western wheatgrass accounting for most of the increased yield.

Fertilizer Treatment Effects

Rate of fertilizer application. Effects of various rates of fertilization are evident in yield responses and changes in botanical composition which have already been discussed. Additionally, in a study of the effects of massive nitrogen levels in the mixed-grass plains of Wyoming, a single application of ammonium nitrate was made at rates of 224, 448, and 672 kg/ha (Houston and Hyder, 1975). A single, heavy application was used to test the practicality of this method in contrast to more frequent, lighter applications. Effects upon soil nitrogen will be discussed later. Major undesirable responses of the vegetation were as follow:

1) Needle and thread (Stipa comata)--Nitrogen treatments, averaged over treatment intensities, reduced apparent plant density (measured by frequency) by 73 percent compared to the control.

2) Sandberg bluegrass (Poa sandbergii)--Nitrogen treatments decreased apparent plant density by 88 percent.

3) Prairie Junegrass (Koeleria cristata)--After four years, the average frequency on the control was 40 percent, while on treated plots frequency ranged from 1 to 2 percent.

4) Geyer larkspur (Delphinium geyeri)--Increased on all plots. This is significant because geyer larkspur is a poisonous plant.

5) Prairie pepperweed (Lepidium densiflorum)--Increased 16 times one year after treatment, three times over the control the second year, and five times over the control the third year. This was thought to be especially significant as this species accumulates nitrate nitrogen, and could lead to toxicity problems.

6) Slimleaf goosefoot (Chenopodium leptophyllum)--Increased nine times the year of treatment, 14 times the following year, and five times the next year. It also accumulates nitrate nitrogen, and poses a danger of toxicity.

7) Cheatgrass (Bromus tectorum)--Increased from less than one percent in frequency to between six and 17 percent on the fertilized plots three years after treatment.

8) Blue grama (Bouteloua gracillis)--Decreased in the fourth year from 100 percent frequency to only 40 to 80 percent frequency, depending upon the treatment.

Favorable plant responses were:

1) Fringed sage (Artemisia frigida)--Initially increased, but finally decreased 85 percent in plant density after two years.

2) Western wheatgrass (Agropyron smithii)--The first year, western whewtgrass frequency significantly increased over the control, and yield increased as well. In the second

and third years, there were no significant differences among treatments. In the fourth year, the response depended upon the treatment, with highest and lowest levels of nitrogen fertilization showing significant indreases in western wheatgrass frequency.

Since decreases in desirable forage plants were only partially offset by increases in western wheatgrass, and because of potentially very serious poisonous plant and nitrate-nitrogen toxicity, the practice of massive nitrogen fertilization was concluded to be impractical and was not recommended.

Length of Effect

The rate of residual fertilizer effect may depend upon the form of fertilizer used, or the rate applied. On flooded meadows in eastern Oregon, ammonium nitrate increased production by up to 2240 kg/ha, but residual effects were not apparent one year later (Cooper and Sawyer, 1954). Treble super-phosphate increased yields 750 kg/ha, and the second year yields were increased 450 kg/ha, exhibiting definite residual effect. In either case, fertilizer did not stimulate regrowth after harvest. In contrast, Baldwin et al(1974) reported a great amount of regrowth on Idaho fescue plants in plots fertilized with 2466 and 4932 kg/ha of 27-12-0

fertilizer. Some regrowth occurred on plots fertilized with 1233 kg/ha while practically none occurred on unfertilized plots. These authors also reported an increase of up to six weeks in length of green forage season as a result of fertilization. This effect has also been reported by Lorenz and Rogler (1973) in North Dakota, Holt and Wilson (1961) in Arizona, Conrad et al (1966) in California, and McCormick and Workman (1975) in Utah. Sometimes this effect is noted as a delay in maturity and drying in fall, but it is also manifested as earlier growth in spring, particularly with cool-season grass species. However, McCormick and Workman (1975) also cautioned that continued use of early-spring crested wheatgrass stimulated by fertilizers can lead to s tand depletion.

Residual effects have been reported from fertilization with manure. Smoliak (1965) found residual effects on production for up to eight years following application of manure, straw and manure, or straw and commercial fertilizer. Some of the effect noted was due to mulching by the straw. Heady (1952) reports that the effects of more than four applications of manure were apparent 12 years later, though no significant difference could be found for fewer than three applications. At the same site, Dolan and Taylor (1972) reported

that reduced clubmoss cover and increased forage cover were still apparent 30 to 40 years after the original treatments. Lodge (1959) reported that manure applications resulted in increased gross protein per acre the first year, and increased forage yields per acre the second year.

In Colorado, fertilization with a wide variety of minerals failed to produce quantitative responses in any of the plants grown on seven different soils in a five year study (Retzer, 1954). Elements tested included calcium, boron, magnesium, sulfur, iron, manganese, zinc, copper, cobalt, molybdenum, and sodium. Apparently, nitrogen and phosphorus are the main limiting nutrients on rangelands.

Soil Factors

Soil chemistry effects. The fate of fertilizer minerals applied to the soil could have long-term effects upon the vegetational composition of the site, depending upon their persistence and availability. Any effects on soil chemistry or soil physics could also have effects on vegetational composition. Nitrogen is subject to gaseous loss and is readily leached by water, while phosphorus is quickly fixed in the soil and is not as easily leached (Stoddart et al, 1979).

A study of soils of the Big Hole Valley, Montana,

showed that 336 kg/ha of ammonium nitrate applied annually did not vary total nitrogen level in the soils, although nitrifiable nitrogen was increased in the upper 7.6 cm (Houlton, 1958). No effects were found on soil pH, phosphorus content, organic matter content, or bulk density. Total pore space was not changed, although capillary pore space increased at the 7.6 to 15.2 cm level under fertilization. In eastern Montana, however, soil pH was decreased by fertilization (Black and Wight, 1972). Application of 1009 kg/ha of ammonium nitrate decreased pH in the upper 15.2 cm from 6.9 to 6.1 in one year, and from 6.9 to 6.5 the following year, even though the soil was strongly calcareous.

Nine years of annual ammonium nitrate fertilization at 34 and 101 kg/ha increased soil nitrogen in the surface 30.5 cm, but decreased nitrogen in the 61 to 91.4 cm zone in a North Dakota study (Smike et al, 1961). The decreases were thought to be due to increased root activity in that zone. Soil acidity in the surface 15.2 cm was increased 6.2 and 9.2 percent by the 34 and 101 kg treatments, respectively. The increased acidity led to an increase in available phosphorus in that zone. At deeper levels, less avaliable phosphorus was present, possibly due to increased root activity.

At Mandan, North Dakota, plant stands which had been fertilized with 90 kg/ha of nitrogen for six years were reduced greatly, with many dead or dwarfed plants of crested wheatgrass (Agropyron desertorum) (Rogler and Lorenz, 1969). The researchers found that soil conductivity was higher and pH lower in areas where plants were weakened. As a result, large areas of bare soil appeared, and summer cypress (Kochia scoparia) invaded the site. Plants were not reduced or killed on the control plots, but sites fertilized with only 45 kg/ha did have some mortality and damage.

Houston and Hyder (1975) traced the fate of nitrogen when applied once at rates of 224, 448, and 672 kg/ha. The first year, most of the applied nitrogen could be accounted for in the soils and top growth. The second and third years, only 55 to 77 percent, depending on the initial rate of applied nitrogen, could be accounted for. At the end of the third year, a significant part of the applied nitrogen was concentrated below the main root zone, where it was probably unavailable for further plant use.

In Utah, two range sites which responded significantly to nitrogen fertilization also exhibited second and third year carryover responses (Workman and McCormick, 1977.

In some years, inadequate soil moisture limits

fertilizer effectiveness in increasing plant growth. If some fertilizer remains in the root zone in a usable form, however, the effect may not be lost, but rather postponed (Westin et al, 1955).

Nitrate-nitrogen

Where a high proportion of forage nitrogen occurs as nitrates rather than as crude protein, nitrate poisoning may result as an undesirable side-effect of fertilization (Stoddart et al, 1975). A Wyoming study showed that all plant species and all plant groups accumulated nitrate-nitrogen in direct relation to the rate of applied nitrogen (Houston, Sabatka, and Hyder, 1973). Perennial grasses and forbs did not accumulate toxic levels of nitrate-nitrogen, but two annual forb species did. Due to high levels of nitrate-nitrogen in these two species, levels in the total herbage reached potentially hazardous levels. This effect could be expected to be particularly dangerous where high levels of nitrogen fertilizer are applied, or where nitrogen is applied annually. In Oregon, up to 4932 kg/ha of 27-12-0 fertilizer with four percent sulfur was applied, resulting in nitrate-nitrogen levels as high as 0.4 percent (Baldwin et al, 1974). Since levels above 0.21 percent are considered toxic (Fanning, 1969), the potential for serious problems from high level

nitrogen fertilization seems obvious. Sneva (1977) stated that annual application of 34 kg/ha or less ammonium nitrate did not significantly increase nitrate-nitrogen concentration in a semiarid soil in Oregon, while applications of 56 kg/ha or more did result in significant accumulations just above the cemented caliche layer. The risk of nitrate-nitrogen poisoning could necessitate annual weed control on fertilized areas (Houston et al, 1973), or incremental application of fertilizer throughout the growing season (Stoddart et al, 1975). Either treatment would greatly increase the cost and potential environmental impacts of fertilization.

Grazing Effects

Changes in vegetational composition of a rangeland could lead to changes in the diets or grazing habits of livestock or wildlife. In New Mexico, fertilization combined with a drought reduced grass production and led to increased use of forbs by cattle (Allison et al, 1977). Annual forbs made up 18 percent of the cattle diet on fertilized pastures, compared to only eight percent on an unfertilized pasture. In northern Utah, elk were observed to utilize fertilized sagebrush and bitterbrush more than unfertilized shrubs (Bayoumi and Smith, 1976). Twig growth, seed production, and

crude protein were higher for fertilized plants. In North Dakota, patchy grazing by cattle, with local overuse, was observed on fertilized pastures, but not on adjacent unfertilized areas (Rogler and Lorenz, 1969). Holt and Wilson (1961) found utilization of desert grassland sites in Arizona to be directly related to the rate of fertilization. Utilization at 28, 56, and 112 kg/ha of nitrogen was about 3, 4, and 5 times the utilization on the check plots, respectively. Drawe and Box (1969) in Texas and Baldwin et al (1974) in Oregon also found utilization by cattle to be related to rate of nitrogen fertilization.

CHEMICAL COMPOSITION

Crude Protein

The crude protein content of a feed is generally estimated by multiplying the nitrogen percentage by 6.25, except in special instances where percentage of nitrogen in the protein of a particular feed is known to be different than 16 percent. While protein content of feeds is often given too much relative importance, protein content is sometimes useful as an indirect measure of digestible energy (Crampton and Harris, 1969). Protein content of forages is

generally highest during early stages of growth. As plants mature, crude protein decreases and crude fiber increases. The result is generally a positive correlation between protein content and digestibility. However, Smoliak (1965) found that although crude protein increased significantly under fertilization by manure, straw, straw fertilizer, or chemical fertilizer, crude fiber was also increased by each treatment.

Generally, nitrogen fertilization increases nitrogen content and thus crude protein content of grasses. Legumes are depressed by nitrogen fertilization, but stimulated by phosphorus (Russell et al, 1965). Nitrogen fertilization may depress legume activity sufficiently to inhibit natural nitrification, leading to a decrease in soil nitrogen which fertilizer may or may not offset. Thus the effect of fertilization on botanical composition of the stand may have a great influence on nutritive value of forage produced.

Increasing levels of nitrogen fertilization led to increased nitrogen content of beardless wheatgrass in a study by Mason and Miltmore (1964). Application of 448 kg/ha of actual nitrogen doubled the yield and nitrogen content of the harvested grass. Rogler and Lorenz (1957) increased crude protein in the forage by fertilization with 101 kg/ha of nitrogen, but application of 34 kg/ha nitrogen resulted

(1967), Drawe and Box (1969), and Pettit and Deering (1974). In New Mexico, crude protein was increased during the growing season by fertilization, but not during the dormant season (Pieper, Kelsey, and Nelson, 1974). However, forage yield was increased, so total protein harvested was higher on fertilized than on unfertilized areas. Increases in crude protein as the resu lt of fertilization have also been reported in Nebraska (Burzlaff et al, 1968), Wyoming (Rauzi et al, 1968), Alberta (Johnston et al, 1968a), and Montana (Wight and Black, 1972).

Ash

Ash is the mineral component of the feed. Many minerals are known to be essential for animal life, but most are normally present in adequate amounts in range forage, and are thus of little concern to range managers (Stoddart et al, 1975). Sodium and chlorine are generally supplied to livestock as salt, and other minerals are supplemented as deficiencies are recognized. Calcium and phosphorus are by far the most important minerals, making up about three-fourths of the body mineral in farm animals, and over 90 percent of the skeletal minerals (Morrison, 1961). Phosphorus deficiencies are not uncommon on western rangeland, and several

methods of supplementation have been attempted, including range fertilization. In trials by Cosper and Thomas (1961), fertilization by nitrogen without additional phosphorus had no significant effect on phosphorus content of forage, while phosphorus fertilization alone significantly increased forage phosphorus levels. Where phosphorus and nitrogen were applied together, forage phosphorus was not as high as when phosphorus alone was used. In Nebraska, various rates of ammonium nitrate did not result in differences in percentage of phosphorus content of forage, but since yields were increased, phosphorus content in the surface 1.5 meters of soil decreased (Burzlaff et al, 1968). Williams (1953) showed increased forage phosphorus under nitrogen fertilization in May and June, but by August, forage phosphorus was not significantly different on nitrogen-treated plots. In this study, phosphorus fertilization had no significant effect on forage phosphorus levels throughout the growing season. Russell et al (1965) reported large increases in forage phosphorus contents as a result of phosphorus fertilication, apparently due to increases in phosphorus content of individual species, as well as legume stimulation. On mesquite (Prosopsis chilensis) grassland savannah in Texas, stocked at 1 cow per 12 to 16 acres, phosphorus deficiency in cows was prevented by feeding bone meal in self-feeders,

by adding disodium phosphate to drinking water with automatic regulators, or by phosphorus fertilization of the range (Reynolds et al, 1953). Unsupplemented cows produced 104 kg/ha of calf; bone-meal supplemented cows produced 130 kg/ha; cows supplemented with phosphated water, 160 kg/ha; and cows on fertilized range produced 197 kg/ha of calf. Unsupplemented cows had lower calf crops and weaned lighter calves than supplemented cows, regardless of the method of supplementation. Greatest net returns per acre and per cow over a five-year period were with phosphated water. Fertilization with triple superphosphate doubled phosphoric acid content of grasses, providing adequate phosphorus for range cattle in normal seasons. However, in drought years, carrying capacity would have to be reduced and other phosphorus supplements provided to livestock on fertilized range.

Ten years after single nitrogen applications from 28 to 504 kg/ha of ammonium nitrate in British Columbia, plants were analyzed for calcium, potassium, magnesium, zinc, manganese, and iron (Mason and Miltmore, 1972). Sharp declines were noted in calcium and zinc, but only minor changes were noted in other elements from increasing nitrogen levels. Reduced calcium and magnesium levels would have become critical if downward trends had continued, although the lowest levels recorded were still well above minimum levels required

by ruminants, indicating the need for zinc supplementation when high levels of nitrogen fertilizer are applied.

On the Texas coastal prairie, fertilization with up to 1009 kg/ha of ammonium sulfate alone and with 112 kg/ha treble superphosphate produced the following changes in chemical composition of grass two months later (Drawe and Box, 1969):

1) Percent nitrogen increased from 1.3 percent in the control to as much as 3.2 percent.

2) Percentage phosphorus did not change significantly except when phosphate fertilizer was added. This increased phosphorus content from 0.15 to 0.41 percent.

3) Percentage potassium was not significantly changed by any of the treatments tested.

4) Percentage calcium was not significantly changed by any of the treatments tested.

5) Parts per million (ppm) of maganese were increased significantly by all treatments tested. The largest increase was from 1009 kg/ha ammonium sulfate with 112 kg/ha treble superphosphate, which increased manganese from 11.7 ppm to 95.7 ppm.

6) Parts per million of iron were significantly decreased by all the treatments tested. The largest decrease

was from 98.3 ppm on the control to 68.3 ppm on the 1009 kg nitrogen/112 kg phosphorus treatment.

Calcium levels in mixed native herbage in Nebraska were not significantly affected by either phosphorus or nitrogen fertilization (Williams, 1953), while in Alberta (Smoliak 1965), significantly lower forage calcium was a result of fertilization with manure or chemical fertilizer. Ward (1959) reported that deficiencies of nitrogen, phosphorus, calcium, sulfur, or cobalt could be remedied by increased fertilization with these nutrients, and concluded:

> The relative balance of nutrients for plant growth influences the chemical composition of the forage. Balanced nutrient supply, whether at low or high level, usually results in forage of approximately the same mineral nutrient composition, varying only in yield. Imbalance of plant nutrients results in luxury consumption of the nutrient in abundant supply, with concurrent high level of that nutrient in the crop.

In New Mexico, Kelsey et al (1972) and Pieper et al (1974) reported decreased ash contents in forage as a result of fertilization.

Ether Extract

The ether extract of feeds consists of glycerides of fatty acids, free fatty acids, cholesterol, lecithin, chlorophyll, alkali substances, volatile oils, and resins (Crampton and Harris, 1969). Its nutritional significance is not

completely understood, but it does supply the essential fatty acid, linolenic acid, and functions as a specific source of energy.

Very little data in ether extract of fertilized forage has been reported, although Smoliak (1965) found that ether extract content was significantly lower on fertilized plots than on the control.

Crude Fiber

Crude fiber consists of cellulose and other carbohydrates which are not dissolved by weak acid and weak alkali. However, rumen microbes are able to break down cellulose for their own needed energy, and in so doing they produce acetic, butyric, and propionic acid, which supply energy to the ruminant (Crampton and Harris, 1969). Also the nondigestible fraction of the crude fiber provides necessary bulk.

In Alberta, fertilized forage contained a higher percentage of crude fiber than unfertilized forage (Smoliak, 1965). In Kansas, hemicellulose and neutral detergent fiber were increased by fertilization, while cellulose and lignin were unchanged (Woolfolk et al, 1975).

Nitrogen-free Extract

Nitrogen-free extract is an index of the non-cellulose portion of feed carbohydrates, and is primarily a non-

specific energy source (Crampton and Harris, 1969). It is the difference between the original weight of the forage sample and the sum of the water, ether extract, crude protein, crude fiber, and ash, as determined by proximate analysis.

Since nitrogen-free extract is determined by difference, variations already noted in other components of the proximate analysis from various studies would be expected to occur in the nitrogen-free extract as well. Smoliak (1965) reported that fertilized herbage was significantly lower in nitrogen-free extract th an herbage from unfertilized plots. In Kansas, nitrogen fertilization lowered the percentage of nitrogen-free extract, and increased percentage of crude fiber, lignin, and ash (Allen et al, 1976). This indicates a decrease in energy value due to fertilization.

Total Nonstructural Carbohydrates (TNC)

On native tallgrass in Kansas, application of nitrogen fertilizer in the spring lowered vigor and TNC reserves of big bluestem the following year, resulting in reduction of the plant's competitive ability (Rains, Owensby, and Kemp, (1975). TNC reserves were highest and nitrogen reserves lowest under burned conditions when there was no nitrogen fertilization during the growth and storage periods. TNC

w as higher on burned areas, regardless of whether the area was fertilized or not. Lowest TNC reserves occurred when the test area was unburned and fertilized.

Rogler and Lerenz (1969) reported that heavy nitrogen stimulated plant growth, thus lowering root reserves and increasing plant susceptibility to drought and winterkill. Grazing, of course, intensified the effect.

Digestibility

Kelsey et al (1972) reported an increase in the *in vitro* digestibility of dry matter and organic matter in fertilized blue grama. In Alberta, Johnston et al (1968) found little effect on digestibility or cellulose content as a result of phosphorus fertilization, while nitrogen or nitrogen plus phosphorus decreased the percentage of cellulose and increased the nutritive value index at all stages of growth, especially during the first year following fertilization. This effect was less evident in subsequent years. Generally, the higher the nitrogen or nitrogen plus phosphorus level, the higher was the nutritive value index and the lower the cellulose content. In Kansas, nitrogen fertilization treatment did not affect apparent dry matter digestibility significantly on bluestem range (Woolfolk et al, 1975).

Stoddart et al (1975) cited studies with conflicting conclusions of the effects of fertilization on forage digestibility. They concluded that documentation of fertilization effects on forage digestibility could prove extremely difficult due to such factors as stage of maturity and rankness of growth, which affect chemical composition, and the problems inherent in measuring digestibility and in sampling vegetation.

Palatability, Utilization, and Preference

Fertilization frequently alters botanical composition of a stand. Since different classes of livestock and game have definite preferences for some classes of vegetation over others, fertilization could be expected to alter palatability of a stand for a particular class of herbivore.

Fertilization often increases the lushness of vegetative growth, as well as the green growth period. Livestock and game animals alike tend to congregate on fertilized areas, often presenting the danger of local overuse. However, concentration on fertilized areas presents an opportunity to use fertilization to improve livestock distribution, particularly on mountain ranges. In northern Utah, nitrogen fertilization, when used with care, was successful in obtaining more uniform utilization (Hooper et al, 1969). Fertilizer was not recommended for areas where cattle normally congre-

gate, and fertilized areas should be over thirty acres to prevent heavy local use. Fertilizers should not be used to replace traditional methods of obtaining proper distribution, but rather should be coordinated with herding, salting, and water development. In Wyoming's Big Horn Mountains, aerial application of urea increased utilization from 15 percent to 73 percent on the area actually fertilized, and 55 percent in adjoining non-fertilized range (Smith and Lang, 1958).

Sixweeks fescue (Vulpia octoflora) is a problem grass in some areas of the southwest, where it occurs in mixed stands with blue grama. Cattle avoid sixweeks fescue, and use of blue grama is reduced as a consequence. Hyder and Bement (1964) tested nitrogen fertilization in an attempt to increase the use of blue grama ranges infested with sixweeks fescue, but found no increase in the apparent palatability of the fescue as a result of fertilization.

In Arizona, cattle showed marked preference for some grass species over others on unfertilized ranges, but on fertilized range there was no apparent preference for any particular species (Holt and Wilson, 1961).

Deer and elk apparently find fertilized forage more palatable than unfertilized. In Utah, elk preferred nitrogen

fertilized sagebrush and bitterbrush, although phosphorus fertilization had no effect on utilization (Bayoumi and Smith, 1976). In Washington, fertilized areas were used to attract game animals on winter range away from ranches and prevent conflicts with land owners (Brown and Mandery, 1962).

CONCLUSIONS

Range fertilization is a complex subject, and any generalizations made about it would invite controversy in certain circumstances. The wide variety of soil types, range vegetation types, management systems, climates, and related factors, as well as the combination of rates, timing, and types of fertilization which may be applied insure that a variety of responses will occur. Nevertheless, the following responses have been noted and may be considered reasonably predictable responses to rangeland fertilization:

1) Significant increases in herbage production may result from nitrogen, phosphorus, and nitrogen plus phosphorus fertilization. This herbage may or may not be useable as livestock forage.

2) Cool-season grass species, notably western wheatgrass, generally exhibit greater responses to nitrogen fertilization thando warm-season grasses.

3) In mixed stands, annual and perennial grasses may respond differently to fertilization depending upon the moisture supply.

4) Potentially deleterious changes in botanical composition of a rangeland may occur as a result of fertilization.

5) Nitrogen fertilization may stimulate grasses at the expense of legumes, while phosphorus fertilization may favor legumes to the detriment of grasses.

6) Decreases in dense clubmoss may be expected as a result of fertilization, with improvement in range condition.

7) Fertilization may be more beneficial than rest in accelerating successional changes in rangeland and improving range condition; however, in some instances the botanical composition changes already noted may lead to a degeneration of range condition.

8) Heavy nitrogen fertilization may lead to nitrate-nitrogen toxicity when nitrates are concentrated in forbs.

9) Fertilization may extend the green-growth period of grasses, partly by earlier initiation of growth in the spring, and sometimes by delaying maturity in the fall.

10. Nitrogen fertilization generally increases the crude protein content of grasses.

11) Phosphorus fertilization may lead to increased phosphorus content in the forage. Nitrogen fertilization generally has little effect on forage phosphorus.

12) Fertilization generally increases palatability of forage, and may increase forage utilization by livestock and wildlife.

While economic analysis of fertilization costs and returns is outside the scope of this paper, potential environmental impacts seem to necessitate a careful, systematic analysis of objectives, alternatives, and both environmental and economic costs and returns of any anticipated rangeland fertilization project.

LITERATURE CITED

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Allen, L.J., L.H. Harbers, R.R. Schalles, C.E. Owensby, and E.F. Smith. 1976. Range burning and fertilization related to nutritive value of bluestem grass. J. Range Manage. 29: 306-308.

Allison, C.D., R.D. Peiper, G.B. Donart, and J.D. Wallace. 1977. Fertilization influences cattle diets on blue grama range during drought. J. Range Manage. 30: 177-180.

Baldwin, D.M., N.W. Hawkinson, and E.W. Anderson. 1974. High-rate fertilization of native rangeland in Oregon. J. Range Manage. 27: 214-216.

Bayoumi, M.A. and A.D. Smith. 1976. Response of big game winter range vegetation to fertilization. J. Range Manage. 29: 44-48.

Binns, W.L., L.F. James, and A.E. Johnson. 1971. Control of larkspur with herbicides plus nitrogen fertilizer. J. Range Manage. 24: 110-113.

Black, A.L., and J.R. Wight. 1972. Nitrogen and phosphorus availability in a fertilized rangeland ecosystem of the Northern Great Plains. J. Range Manage. 25:456-460.

Bowns, J.E. 1972. Low level nitrogen and phosphorus fertilization on high elevation ranges. J. Range Manage. 25: 273-276.

Brown, E.R., and J.H. Mandery. 1962. Planting and fertilization as a possible means of controlling distribution of big game animals. J. Forestry 60: 33-35.

Burzlaff, D.F., G.W. Fick, and L.R. Rittenhouse. 1968. Effect of nitrogen fertilization on certain factors of a western Nebraska range ecosystem. J. Range Manage. 21: 21-24.

Conrad, C.E., E.J. Woolfolk, and D.A. Duncan. 1966. Fertilizer and management implications on California annual-plant range. J. Range Manage. 19: 20-26.

Cooper, C.S., and W.A. Sawyer. 1955. Fertilization of mountain meadows in eastern Oregon. J. Range Manage. 8: 20-22.

Cosper, H.R. and J.R. Thomas. 1961. Influence of supplemental runoff water and fertilizer on production and chemical composition of native range. J. Range Manage. 14: 292-297.

Cosper, H.R., J.R. Thomas, and A.Y. Alsayegh. 1967. Fertilization and its effect on range improvement in the Northern Great Plains. J. Range Manage. 20: 216-222.

Crampton, E.W., and L.E. Harris. 1969. Applied animal nutrition. Second edition. W.H. Freeman and Co., San Francisco. 753- pp.

Cronin, E.H., J.E. Bowns, and A.E. Johnson. 1977. Herbicides, nitrogen, and control of tall larkspur under aspen trees. J. Range Manage. 30: 420-422.

Currie, P.O. 1976. Recovery of ponderosa pine-bunchgrass ranges through grazing and herbicide or fertilizer treatments. J. Range Manage. 29: 444-448.

Dee, R.F., and T.W. Box. 1967. Commercial fertilizers influence crude protein content of four mixed prairie grasses. J. Range Manage. 20: 96-99.

Dobson, J.W., and E.R. Beaty. 1977. Forage yields of five perennial grasses with and without white clover at four nitrogen rates. J. Range Manage. 30: 461-465.

Dolan, J.J., and J.E. Taylor. 1972. Residual effects of range renovation on dense clubmoss and associated vegetation. J. Range Manage. 25: 32-37.

Drawe, D.L., and T.W. Box. 1969. High rates of nitrogen fertilizer influence Coastal Praire range. J. Range Manage. 22: 32-36.

Fanning, C.D. 1969. Nitrate levels in heavily fertilized forages in eastern Washington. Washington State Univ. Pamphlet EM 3287. Cited in Baldwin et al, 1974.

Freeman, B.N., and R.R. Humphrey. 1956. The effects of nitrates and phosphates upon forage production of a southern Arizona desert grassland range. J. Range Manage. 9: 176-180.

Gay, C.W., and D.W. Dwyer. 1965. Effects of one year's nitrogen fertilization on native vegetation under clipping and burning. J. Range Manage. 18: 273-277.

Goetz, H. 1969. Composition and yields of native grassland sites fertilized at different rates of nitrogen. J. Range Manage. 22: 384-390.

Goetz, H. 1970. Growth and development of Northern Great Plains species in relation to nitrogen fertilization. J. Range Manage. 23: 112-117.

Heady, H.F. 1952. Reseeding, fertilizing, and renovating in an ungrazed mixed prairie. J. Range Manage. 5: 144-149.

Holt, G.A., and D.G. Wilson. 1961. The effect of commercial fertilizers on forage production and utilization on a desert grassland site. J. Range Manage. 14: 252-256.

Hooper, J.F., J.P. Workman, J.B. Grumbles, and C.W. Cook. 1969. Improved livestock distribution with fertilizer--a preliminary economic evaluation. J. Range Manage. 22: 108-110.

Houlton, H.A. 1958. The effect of controlled water level and nitrogen fertilization on some physical and chemical characteristics of mountain meadow soils. M.S. Thesis (soils), Montana State College. 59 pp.

Houston, W.R., and D.N. Hyder. 1975. Ecological effects and fate of N following massive N fertilization of mixed-grass plains. J. Range Manage. 28: 56-60.

Houston, W.R., L.D. Sabatka, and D.N. Hyder. 1973. Nitrate-nitrogen accumulation in range plants after massive N fertilization on shortgrass plains. J. Range Manage. 26: 54-57.

Huffine, W.W., and W.C. Elder. 1960. Effect of fertilization on native grass pastures in Oklahoma. J. Range Manage. 13: 34-36.

Hyder, D.N., and R.E. Bement. 1964. Sixweeks fescue as a deterrent to blue grama utilization. J. Range Manage. 17: 261-264.

Johnston, A., L.M. Bezeau, A.D. Smith, and L.E. Lutwick. 1968a. Nutritive value and digestability of fertilized rough fescue. Can. J. Plant Sci. 48: 351-355.

Johnston, A., A.D. Smith, L.E. Lutwick, and S. Smoliak, 1968b. Fertilizer response of native and seeded ranges. Can. J. Plant Sci. 48: 467-472.

Johnston, A., S. Smoliak, A.D. Smith, and L.E. Lutwick. 1967. Improvement of southeastern Alberta range with fertilizers. Can. J. Plant Sci. 47: 671-678.

Jones, M.B., and S.S. Winans. 1967. Subterranian clover versus nitrogen fertilized annual grasslands: botanical composition and protein content. J. Range Manage. 20: 8-12.

Kay, B.L. 1966. Fertilization of cheatgrass ranges in California. J. Range Manage. 19: 217-220.

Kay, B.L. and R.A. Evans. 1965. Effects of fertilization on a mixed stand of cheatgrass and intermediate wheatgrass. J. Range Manage. 18: 7-11.

Kelsey, R.J., A.B. Nelson, G.S. Smith, R.D. Peiper, and J.D. Wallace. 1972. Effect of N-fertilization on blue grama parts. J. Animal Sci. 34: 899.

Klipple, G.E., and J.L. Retzer. 1959. Response of native vegetation of the Central Great Plains to applications of corral manure and commercial fertilizer. J. Range Manage. 12: 239-243.

Lorenz, R.J., and G.A. Rogler. 1967. Grazing and fertilization affect root development of range grasses. J. Range Manage. 20: 129-132.

Lorenz, R.J., and G.A. Rogler, 1973. Growth rate of mixed prairie in response to nitrogen and phosphorus fertilization. J. Range Manage. 26: 365-368.

Lodge, R.W. 1959. Fertilization of native range in the Northern Great Plains. J. Range Manage. 12: 277-280.

Martin, W.E., C. Pierce, and V.P. Osterli. 1964. Differential nitrogen response of annual and perennial grasses. J. Range Manage. 17: 67-68.

Mason, J.L., and J.E. Miltmore. 1964. Effects of nitrogen content of beardless wheatgrass on yield response to nitrogen fertilization. J. Range Manage. 17: 145-147.

Mason, J.L., and J.E. Miltmore. 1972. Ten year yield response of beardless wheatgrass from a single nitrogen application. J. Range Manage. 25: 269-272.

McCormick, P.W., and J.F. Workman. 1975. Early range readiness with nitrogen fertilizer: an economic analysis. J. Range Manage. 28: 181-184.

Miles, A.D. 1958. Natural sources of nitrogen and phosphorus for grass growth. J. Range Manage. 11: 125-128.

Morrison, F.B. 1961. Feeds and feeding, abridged. Ninth edition. Morrison Publishing, Clinton, Iowa. 696 pp.

Nichols, J.T. 1969. Range improvement practices on deteriorated dense clay wheatgrass range in western South Dakota. So. Dak. Agric. Exp. Sta. Bul. 552. 23 pp.

Nichols. J.T., and W.E. McMurphy, 1969. Pange recovery and production as influenced by nitrogen and 2,4-D treatments. J. Range Manage. 22: 116-119.

Patterson, J.K., and V.E. Youngman. 1960. Can fertilizers effectively increase our range land production? J. Range Manage. 13: 255-257.

Pettit, R.D., and D.W. Deering. 1974. Yield and protein content of sandyland range forages as affected by three nitrogen fertilizers. J. Range Manage. 27:211-213.

Pieper, R.D., R.J. Klesey, and A.B. Nelson. 1974. Nutritive quality of nitrogen fertilized and unfertilized blue grass. J. Range Manage. 27: 470-472.

P ower, J.F. 1972. Fate of fertilizer nitrogen applied to a Northern Great Plains rangeland ecosystem. J. Range Manage. 25: 367-371.

Rains, J.R., C.E. Owensby, and K.E. Kemp. 1975. Effects of nitrogen fertilization, burning, and grazing on reserve constituents of big bluestem. J. Range Manage. 28: 358-362.

Rauzi, F., R.L. Lang, and L.I. Painter. 1968. Effects of nitrogen fertilization on native rangeland. J. Range Manage. 21: 287-291.

Reardon, P.O., and D.L. Huss. 1965. Effects of fertilization on a little bluestem community. J. Range Manage. 18: 238-241.

Retzer, J.L. 1954. Fertilization of some range soils in the Rocky Mountains. J. Range Manage. 7: 69-73.

Reynolds, E.B., J.M. Jones, J.F. Fudge, and R.J. Eleberg, Jr. 1953. Methods of supplying phosphorus to range cattle in Texas. Texas Agric. Exp. Sta. Bul. 773. 16 pp.

Rogler, G.A., and R.J. Lorenz. 1957. Nitrogen fertilization of Northern Great Plains rangeland. J. Range Manage. 10: 156-160.

Rogler, G.A., and R.J. Lorenz. 1969. Pasture productivity of crested wheatgrass as influenced by nitrogen fertilization and alfalfa. U.S. Dep. of Agric. Tech. Bul. 1402. 33 pp.

Russell, J.S., E.M. Brouse, H.F. Rhoades, and D.F. Burslaff, 1965. Response of sub-irrigated meadow vegetation to application of nitrogen and phosphorus fertilizer. J. Range Manage. 18: 242-247.

Ryerson, D.E., J.E. Taylor, L.C. Baker, H.A.R. Houlton, and D.W. Stroud. 1970. Clubmoss on Montana rangelands. Distribution. Control. Range Relationships. Mont. Agric. Exp. Sta. Bul. 645. 116 pp.

Smika, D.E., H.J. Haas, G.A. Rogler, and R.J. Lorenz. 1961. Chemical properties and moisture extraction in rangeland soils as influenced by nitrogen fertilization. J. Range Manage. 14: 213-216.

Smith, D.R., and R.L. Lang. 1958. The effect of nitrogenous fertilizers on cattle distribution on mountain range. J. Range Manage. 14: 213-216.

Smith, D.P., and R.L. Lang. 1962. Nitrogen fertilization of upland range in the Big Horn Mountains. Wyo. Agric. Exp. Sta. Bul. 388. 10 pp.

Smoliak, S. 1965. Effects of mamure, straw, and inorganic fertilizers on Northern Great Plains ranges. J. Range Manage. 18: 11-15.

Sneva, F.A. 1977. Soil nitrogen levels in a semiarid climate following long-term nitrogen fertilization. J. Range Manage. 30: 328-330.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. Third edition. McGraw-Hill, New York. 532 pp.

Vallentine, J.F. 1971. Range developments and improvements. Brigham Young University Press, Provo, Utah. 516 pp.

W ard, G.M. 1959. Effect of soil fertility upon the yield and nutritive value of forages. J. Dairy Sci. 42: 277-297.

Welch, N.H., E. Burnett, and E.B. Hudspeth. 1962. Effect of fertilizer on seedling emergence and growth of several grass species. J. Range Manage. 15: 94-98.

Westin, F.C., G.J. Guntley, and B.L. Brage. 1955. Soil fertility. In Agricultural Research at the Range Field Station, South Dakota State College Experiment Station, Cottonwood, S.D. So. Dak. Agric. Exp. Sta. Circ. 116. pp. 12-18.

Wight, J.R., and A.L. Black. 1972. Energy fixation and precipitation-use efficiency in a fertilized rangeland ecosystem of the Northern Great Plains. J. Range Manage. 25: 376-380.

Wight, J.R. 1976. Range fertilization in the Northern Great Plains. J. Range Manage. 29: 180-185.

Williams, J.S. 1953. Seasonal trends of minerals and proteins in prairie grasses. J. Range Manag. 6: 100-108.

Wilson, A.M., G.A. Harris, and D.H. Gates. 1966. Fertilization of mixed cheatgrass-bluebunch wheatgrass stands. J. Range Manage. 19: 134-137.

Woolfolk, J.S., E.F. Smith, R.R. Schalles, B.M. Brent, L.H. Harbers, and C.E. Owensby. 1975. Effects of nitrogen fertilization and late-spring burning of bluestem range on diet and performance of steers. J. Range Manage. 28: 190-193.

Workman, J.P., and P.W. McCormick, 1977. Economics of carry-over response to nitrogen fertilization of rangelands. J. Range Manage. 30: 324-327.