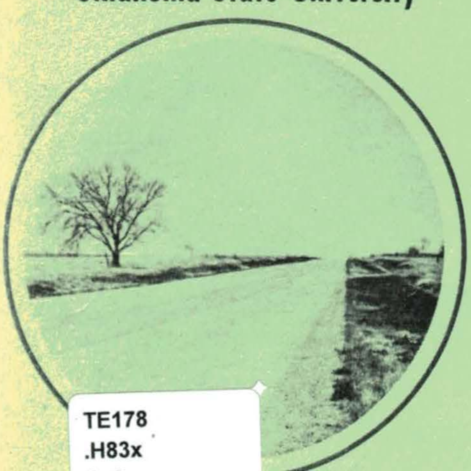
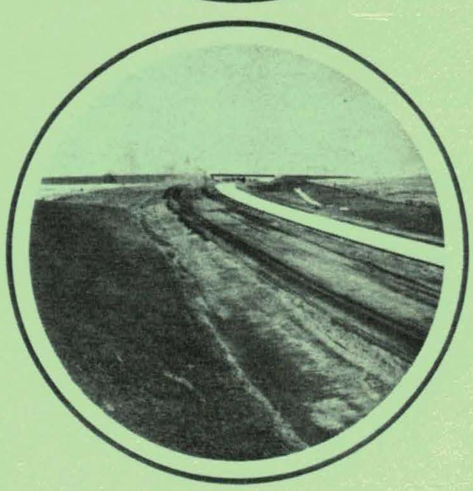
Roadside Development and Erosion Control





May 1974
Miscellaneous Publication MP-93
Agricultural Experiment Station
Oklahoma State University





ROADSIDE DEVELOPMENT AND EROSION CONTROL

by

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in cooperation with

The Oklahoma Department of Highways

and

The United States Department of Transportation

Federal Highway Administration

Bureau of Public Roads

Oklahoma Agricultural Experiment Station

Oklahoma State University

Stillwater, Oklahoma

TABLE OF CONTENT

ACKNOWLEDGEMENTS

The research personnel from Oklahoma State University working on this project express their appreciation to the personnel of the Oklahoma Department of Highways and the Bureau of Public Roads for their continued interest and cooperation in these investigations. Special recognition is due Mr. R. T. Sutton, Mr. H. B. McDowell, and Mr. B. C. Hartronft of the Oklahoma Highway Department, and Mr. J. E. Stewart of the Bureau of Public Roads.

"The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Oklahoma Department of Highways or the Bureau of Public Roads."

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* In order that the information in this publication may be more useful, it was sometimes necessary to use tradenames of products, rather than complicated chemical identifications. As a result it is unavoidable in some cases that similar products which are on the market under other tradenames may not be cited. No endorsement of named products is intended, nor is criticism implied of similar products which are not mentioned.

PART I

CAUSES AND CONTROL OF SOIL EROSION

Consultation and close cooperation among engineers and agronomists in the design, construction, and maintenance of the highway system results in a satisfactory and economical solution to erosion control, better highways, and beautification.

CAUSES AND CONTROL OF SOIL EROSION

RECOMMENDATIONS

DESIGN

1. Flatten backslopes and fills as much as possible. Avoid slopes steeper than 3:1 if possible where a vegetative ground cover is to be used for erosion control. If 2:1 backslopes must be designed as on urban roadways particularly, plans for permanent supplemental irrigation should be initiated at the time.

2. Provide for interceptor ditches at the top of cut slopes particularly, and on the berms of deep cuts, to facilitate the orderly removal of excess water that pours down from terrace outlets or watersheds above, or that falls on the slope itself.

3. Utilize a physical barrier along the outer side of the shoulder on long slopes particularly, and on the inside of curves for the purpose of concentrating and removing excess water in an orderly fashion that otherwise would result in excessive erosion of fill slopes.

EROSION CONTROL

1. Apply no more starter fertilizer than 200 pounds of 13-13-13 per acre at the time of seeding for optimum germination and establishment of the desired grasses.

2. Weeping lovegrass seems to be more widely adapted and easier to establish for erosion control in Oklahoma than other species tested. Its use in western, central, and eastern Oklahoma is to be encouraged until such time a more satisfactory grass becomes available.

3. The use of high-grade hay or excelsior for vegetative mulch is strongly recommended. No more than a trace of weeds (preferably none) with mature seeds should be present in the vegetative mulch. Low-grade vegetative mulch composed of undesirable weedy annuals, or perennial johnsongrass should be avoided without exception.

4. Based on limited research data no significant benefit could be detected from the incorporation of lime into the soil, or tillage either by disking or with a chisel, prior to seeding bermudagrass for erosion control on a north or west facing backslope. These practices are not to be encouraged until and unless future research proves them beneficial under other conditions or for other plants.

INTRODUCTION

Over $4 million are spent each year for erosion control on Oklahoma highways and roads. The cost per mile for erosion control increased approximately 45 percent from 1965 to 1966. With more than 12,000 miles of federal and state highways in Oklahoma now, and more being constructed each year, the need for determining the causes of soil erosion and the most satisfactory and economical methods for control becomes obvious.

FACTORS RESPONSIBLE FOR SOIL EROSION

Many factors are responsible for soil erosion on the highway system. Some are more universal than others, but each contributes to the total cost for control.

The principal causes of soil erosion are wind, water, and man. It is when man steps in and alters the balance of nature that erosion becomes destructive and expensive to maintain.

To ultimately develop a program for the satisfactory and economical control of soil erosion on Oklahoma highways and roads, the cause of factors most frequently involved first had to be determined. Investigations in all divisions of the highway system repeatedly turned up some factors of erosion that were generally common to all areas.

CAUSES OF SOIL EROSION ON OKLAHOMA HIGHWAYS

The major causes of soil erosion on all areas of the highway system, but especially on cut and fill slopes, generally were found to be improper design, or maintenance, or both. The factors responsible for failure in stand establishment, or to persist after successful establishment generally were found to be as follows:

1. The use of weedy, low-grade vegetative mulch. On newly seeded cut and fill slopes the vegetative (hay) mulch frequently was composed largely of annual grasses and weeds, or was so heavily contaminated with seeds of these rapidly growing, undesirable plants that the slower growing, seeded perennials died or failed to become successfully established because of the competition for moisture, nutrients, and space. The results from the use of poor-quality, weedy vegetative mulch on newly seeded areas can be illustrated by Figure 1.1.

2. Improper use of maintenance equipment. The operation of mowers particularly, on highly erosive cut and fill slopes is the most destructive force currently acting upon the erosion control vegetative ground cover. The protective vegetative cover is not only destroyed by the improper practice of mowing too short and too frequently, but also by being physically torn from the soil by the shearing action of the tractor sliding as it attempts to traverse the slope generally

in a horizontal direction (Figure 1.2), or from the spinning wheels in ascending the steep slopes, or as they slide in an attempt to stop or turn as they descend (Figure 1.3).

The "blading-off" of established vegetative ground cover especially native grasses, on the highway shoulders, or soil removal from the top or slopes of stabilized cuts for repairs on fill slopes adds greatly to the cost of erosion control in the highway system.

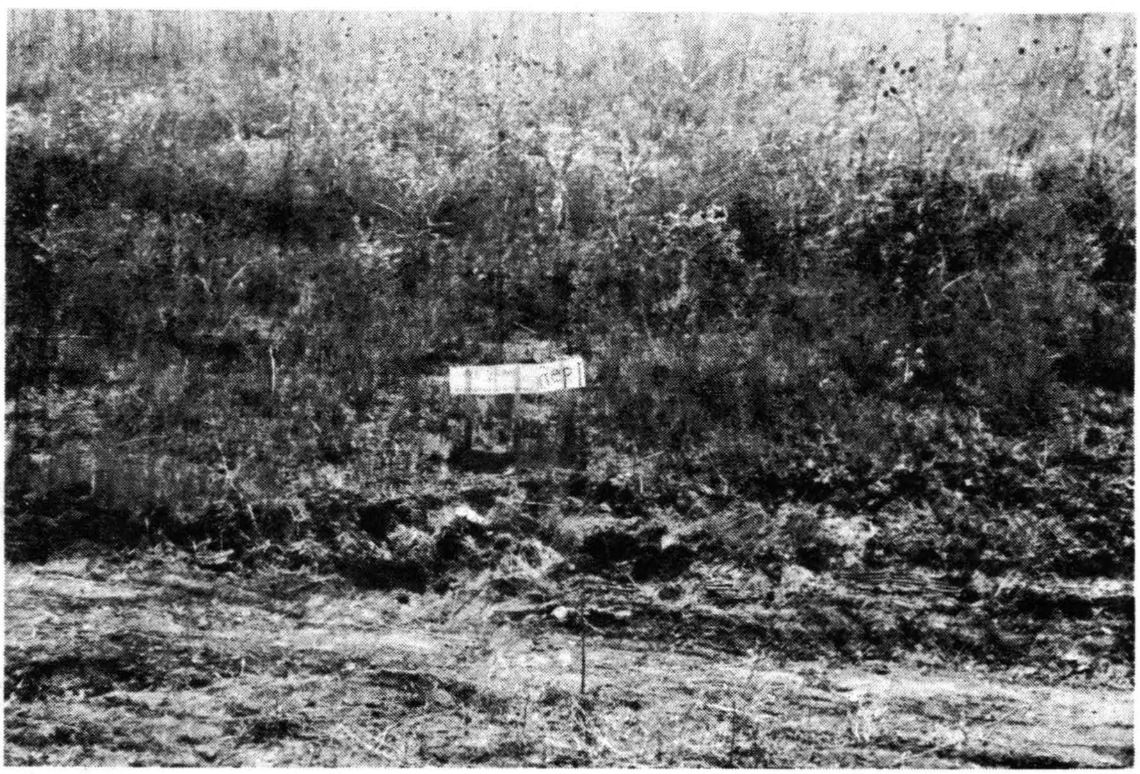

Figure 1.1. Trashy, low-grade vegetative mulch composed largely of annual grasses and weeds, or mature johnsongrass is frequently the cause of a failure in stand establishment of perennial grasses seeded for erosion control

Figure 1.2. The operation of maintenance equipment, mowers particularly, on highly erosive cut (top photo) and fill (bottom photo) slopes destroys the vegetative cover and accelerates soil erosion by physically tearing the grass from the soil as the tractor slides in traversing the slope.

Figure 1.3. Soil erosion is greatly accelerated by the destruction of grass and the creation of ruts as the mower wheels spin as they ascend or slide in an attempt to stop or turn on the way down.

3. Decline in soil fertility. Failure to provide maintenance levels of fertilizer to well established bermuda, weeping love, or native grass covers has led to a thinning (Figure 1.4) or complete destruction of the vegetative cover resulting in certain soil erosion and costly repairs.

4. Improper highway design. Failure to acquire adequate rights-of-way for the construction of interceptor ditches on the top of cut slopes particularly, to facilitate the orderly removal of excess water has resulted in serious erosion from water pouring down the slope from terrace outlets or watershed above (Figure 1.5).

Previously, many backslopes were designed with a 3:1 slope, and some cases even 2:1 which created a droughty, difficult condition first for the establishment of the erosion control vegetative ground cover, and second for the maintenance over a period of time. Frequently, through the expenditure of considerable funds a satisfactory ground cover for erosion control was established only to decline in density and protective ability because of the droughty soil created by steepness of the slope preventing good water penetration and accompanying winter kill from deep penetration in the soil of cold air because of a lack of water in the soil pores to slow or prevent damaging effects of low temperatures.

The lack of a physical barrier along the outer side of the shoulder from near the crest of a slope to the bottom for the purpose of concentrating and removing excess water in an orderly fashion has resulted in excessive erosion of fill slopes. Erosion of this type occurs primarily because of superelevation, highway slope is designed to the outside, and the accumulation of gravel on the shoulder that tends to concentrate the runoff water along the dike until a sufficient volume accumulates to break through the gravel ridge and down the fill slope.

Figure 1.4. The decline in soil fertility following the successful establishment of a grass, particularly bermuda, results in a thinning or complete loss of the vegetative cover, soil erosion and costly repairs.

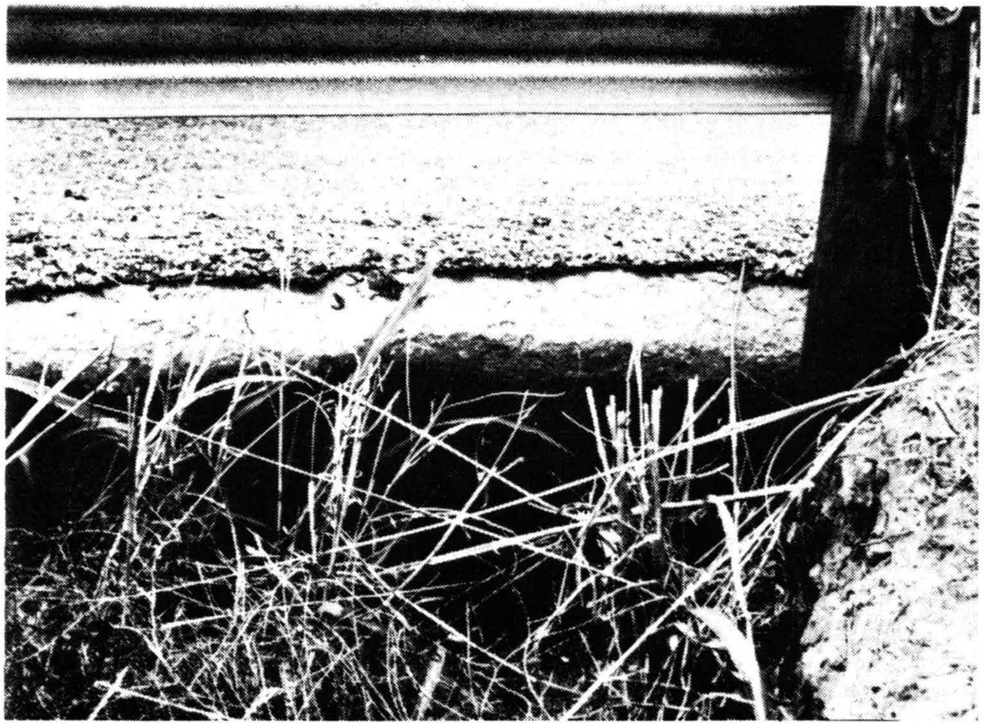

Figure 1.5. Soil erosion occurs as a result of improper design through omission of a physical barrier along the shoulder to concentrate and remove excess water (top photo), and because of inadequate rights-of-way interceptor ditches could not be constructed on top of cut slopes particularly for the orderly removal of excess water (bottom photo) from terrace outlets, or adjacent watershed.

CONTROL OF SOIL EROSION

The principal objectives of this part of the research project were to find satisfactory and economical methods for the prevention and control of soil erosion along Oklahoma highways. To achieve these objectives several factors were to be evaluated. The principal factors involved in erosion control are plant species, soils and soil fertility, slope and exposure, and cultural practices best suited for the establishment and maintenance of permanent vegetation.

FINDINGS AND CONCLUSIONS

1. Laboratory analyses of soil samples taken from all research locations, including samples taken every six inches from top to bottom of 23 feet high (33 percent) backslope in central Oklahoma[1]- indicate a need for supplemental fertilization for optimum growth of grasses for erosion control. Levels of available phosphate ranged from a low of 0.0 pounds on the above mentioned backslope in central Oklahoma to a high of 32.1 pounds per acre at another location. The levels of available potassium ranged from a low of 90 pounds to a high of 380 pounds per acre. The soil pH ranged near or above neutral in all samples tested. Based upon these tests no lime would be required for neutralizing the soil pH in central and western Oklahoma.

2. Laboratory investigations of the effect of bulk density and soil water pressure on grass seedling emergence indicate that moisture is the most important factor influencing the emergence of common bermudagrass and weeping lovegrass seedlings for the range of bulk density and soil water pressures studied[2]. Both grasses gave approximately the same emergence at the -1/3 and -1 bar soil water pressures.

3. Weeping lovegrass (Eragrostis curvula Nees.) is one of the most widely adapted, easily established grasses tested for the control of soil erosion on Oklahoma Highways. Its use in western, central, and eastern Oklahoma is to be encouraged.

Successful seedings of weeping lovegrass were made on sandy soils and clays, and on north facing slopes as well as those that faced south. Seedings made on highly erosive cut slopes in western Oklahoma near Elk City showed weeping lovegrass mulched with either asphalt or Turfiber[3] provided more cover initially

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[1] Bailey, Richard E. 1966. Evaluation of Grass Species and Mulches for Erosion Control on Oklahoma Highways. Unpublished M.S. Thesis. Oklahoma State University.

[2] Hughes, Tom D. 1966. The Effect of Bulk Density and Soil Water Pressure on Grass Seedling Emergence. M.S. Thesis. Oklahoma State University. (Published in Agron. Jour. 58:549-553. 1966.)

[3] Product of International Paper Company.

for erosion control (Figures 1.6 and 1.7) than any other grass in the test. Heavy rains from the south occurred the week after seeding and caused severe loss of soil, seed, and mulch from the south facing slope that largely accounts for the decline in plant protection (Figure 1.7).

Bermudagrass (Cynodon dactylon (L.) Pers.) responded to the warmer temperatures of the south facing cut slope in north-central Oklahoma east of Stillwater, and provided slightly more protection from soil erosion the year after seeding than did weeping lovegrass as determined by actual plant count (Figure 1.8). The effect of a north exposure on bermudagrass was quite evident with a decline in plant population one year after seeding, whereas the number of weeping lovegrass plants increased more than 55 percent (Figure 1.9).

Benefits for the Oklahoma Department of Highways derived either partly or entirely from this research includes a savings of about $11.00 per acre for seedings made in central Oklahoma from the use of only 8 pounds of weeping lovegrass per acre compared to the previous practice of almost 40 pounds of seed from a mixture of 5 grasses. In southeast Oklahoma the savings are even greater amounting to $14.00 per acre from the seeding of 8 pounds of lovegrass, or $14.20 saved per acre if 15 pounds of common bermudagrass is seeded per acre instead of 40 pounds of seed from a mixture of 4 grasses.

4. The type, or kind of mulch seemed to make no real difference in the germination, or plant population of weeping lovegrass so long as it offered no competition by contamination with weedy annuals, or perennial johnsongrass. Good prairie hay (with no mature weed seeds) used as a mulch for new seedings was comparable to excelsior slope mats in the number of weeping lovegrass plants that became established on a sandy fill-slope in southwestern Oklahoma near Rush Springs, and both were only slightly better than baled excelsior blown on as a mulch (Figure 1.10).

5. In the production of a protective bermudagrass cover on a droughty, geological soil as found on a deep, west-facing back-slope in central Oklahoma the most effective method studied was the incorporation of 2 percent hydrated lime (20 tons/acre) in the spring, followed seven months later with a mid-winter seeding of unhulled common bermudagrass and fertilized in late June after germination and substantial growth of the bermuda with 400 pounds of 12-12-12 per acre.

To determine whether tillage, lime, or fertilizers would aid satisfactorily in the establishment and production of a protective bermudagrass cover, four tillage and lime combinations, and two fertilizer treatments were applied on a deep, west-facing cut slope, seeded to bermuda, and mulched with prairie hay in central Oklahoma, north of Guthrie.

In the first year after seeding fertilizer was the only treatment that significantly increased the protective cover of bermudagrass (Figure 1.11). Two years after seeding, a very noticeable and significant increase in bermuda was produced on those areas that had been treated with hydrated lime, disked, and fertilized. Fertilizer alone was not enough to provide maximum growth of the bermudagrass two years after seeding. The application of quick lime combined with disking seemed no better than a no lime, no disking treatment so long as both were fertilized. The long range effects of these treatments on the establishment and growth of bermudagrass can only be determined with time.

6. In seeding for erosion control on Oklahoma highways and roads no more starter fertilizer than 200 pounds of 13-13-13 should be applied per acre for optimum germination and establishment of the desired grasses.

Seedings made prior to the initiation of this research project called for 400 pounds of 13-13-13 per acre. As a direct result of this research 200 pounds of 13-13-13 was found to be adequate as a starter. The 200 pound reduction of 13-13-13 fertilizer applied per acre in all seedings at a cost of $100.00 per ton results in a savings to the Oklahoma Department of Highways of $10.00 per acre. On a two-lane road with 100 feet of rights-of-way having about 7 acres per mile to be seeded, this would amount to a savings of approximately $7,000.00 every 100 miles.

7. Vegetative mulch composed of undesirable weedy annuals, or perennial johnsongrass was found to be responsible for many failures in the establishment of desired grasses for erosion control.

Competition for available soil moisture, space, and nutrients accounts for the decline and ultimate failure in the establishment of perennial grasses that are slow in their rate of growth the first year, and the abundance of undesirable, short-lived, rapidly growing annuals.

No vegetative mulch should be used on erosion control seedings that contain seed or live vegetative parts of johnsongrass, or more than a trace of other weeds, either annual or perennial with mature seeds.

8. Soil moisture primarily determines whether a protective vegetative cover can be successfully established on the highway system. In the absence of adequate soil moisture germination of the seeded grass is delayed and consequently the length of the growing season is correspondingly reduced until such time even though excellent germination is obtained the seedling plants are unable to survive the rigors of the first winter.

Seedings were made in the early summer of 1965 on east and west facing cut slopes in central Oklahoma near Chandler. Fertilizer at the rate of 200 pounds of 12-12-12 per acre, and a soil conditioner (Humicite[4]) at the rate of 1.1 gallons per acre was applied to this area, seeded with five grasses and mulched with 1.7 tons of Turfiber per acre. Three days after seeding a supplemental watering of 6,000 gallons (equivalent to about 0.22 inch) per acre was made in an attempt to increase germination and stand establishment. The grasses included common bermudagrass, giant (NK-37) bermudagrass, weeping love, King Ranch bluestem, and a mixture of native grasses (mostly little bluestem).

Common bermudagrass produced more protective ground cover on both the east and west facing cut slopes than any other grass in the test. The soil conditioner (Humicite) had no influence on the growth of these grasses. As a result of the dry soil conditions that prevailed none of these seedings were considered satisfactory, and practically all plants died the first winter.

High temperatures and inadequate soil moisture in 1965 caused the complete failure of seedings made in July near Meeker in central Oklahoma. Five grasses and two mulches, an asphalt emulsion (AE-5) and Turfiber were included in this investigation.

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[4] Product of South Texas Soil Conditioner Service, Inc.

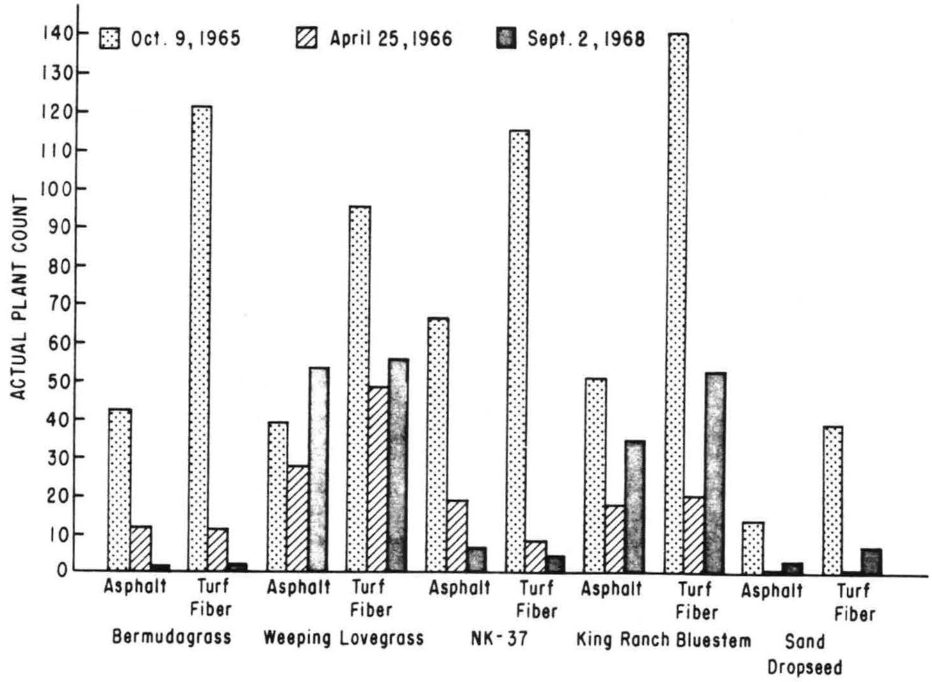

Figure 1-6. The evaluation of five grasses and two mulches for erosion control on a north facing cut slope seeded and mulched June 9, 1965, on SH-6 four miles west of US-66 intersection west of Elk City, Oklahoma. This area was fertilized with 200 lbs. 10-20-10 per acre on June 9, 1965, and again on March 17, 1966 and evaluated on the above dates.

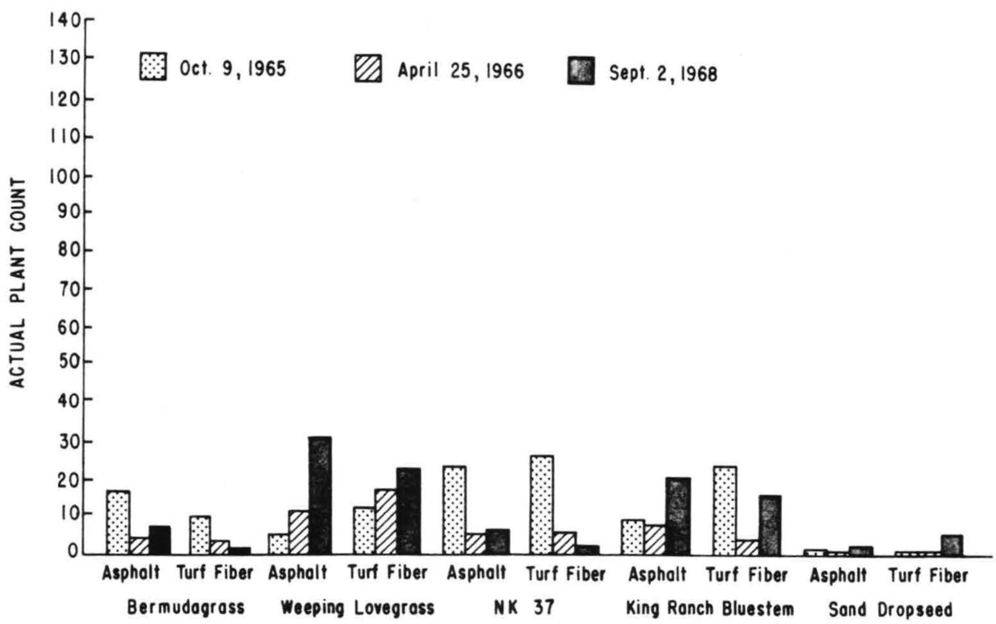

Figure 1-7. The evaluation of five grasses and two mulches for the control of erosion on a south facing cut slope seeded and mulched June 9, 1965, on SH-6 four miles west of US-66 intersection west of Elk City, Oklahoma. This area was fertilized with 200 pounds 10-20-10 per acre on June 9, 1965, and again on March 17, 1966 and evaluated on the above dates.

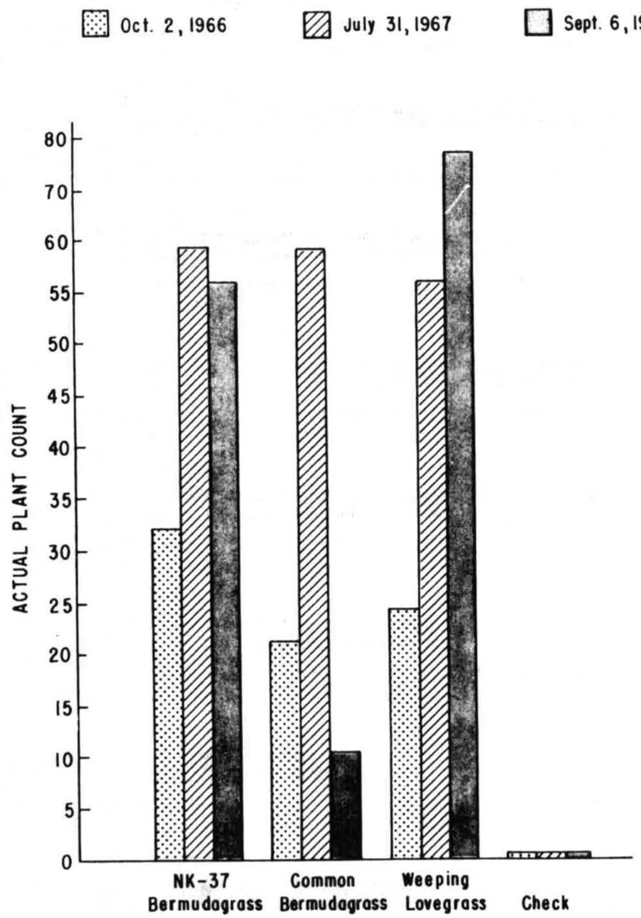

Figure 1-8. A comparison of three grasses for erosion control on a south facing cut slope east of Stillwater, Oklahoma, on SH-51 four miles east of SH-108 seeded and hay mulched May 4, 1966, and fertilized with 435 lbs./acre of 10-20-10 on May 23, 1967 and evaluated on the above dates.

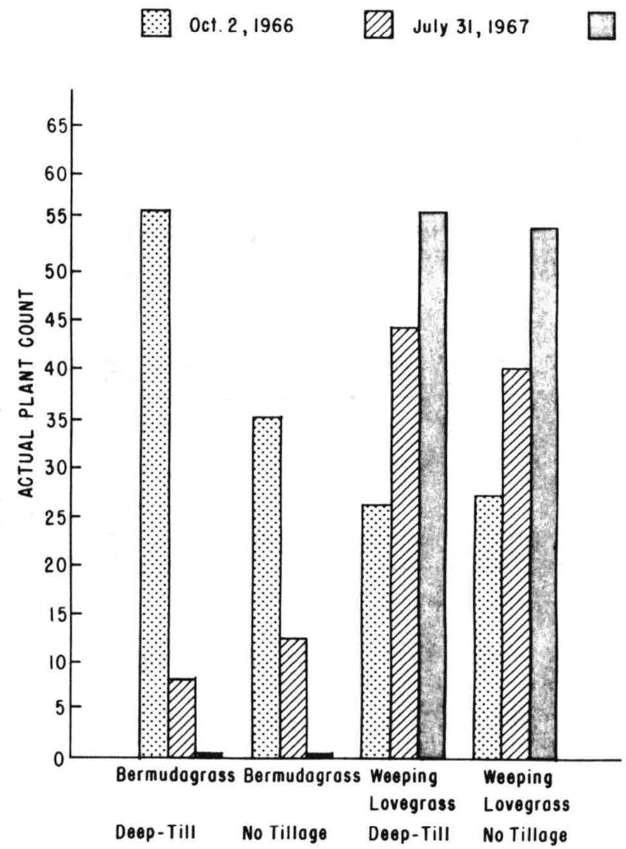

Figure 1-9. The effect of a deep-tillage operation on the establishment of bermudagrass and weeping lovegrass seeded and hay-mulched May 4, 1966, and fertilized with 435 lbs./acre of 10-20-10 May 23, 1967, on a north facing cut slope east of Stillwater, Oklahoma on SH-51 four miles east of SH-108. Evaluated on the above dates.

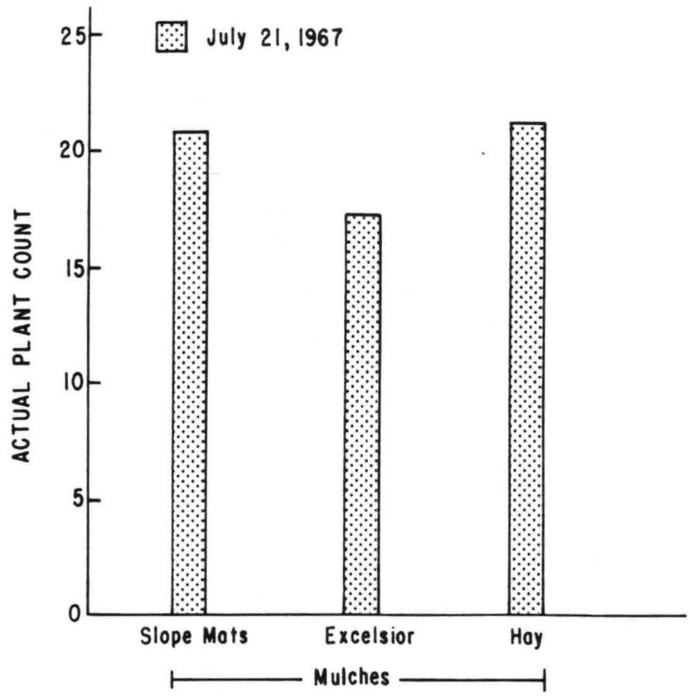

Figure 1-10. The effect of various mulching materials on the establishment of weeping lovegrass seeded May 4, 1966, on an east facing fill slope on US-81 north of Rush Springs, Oklahoma. Evaluation on the above date.

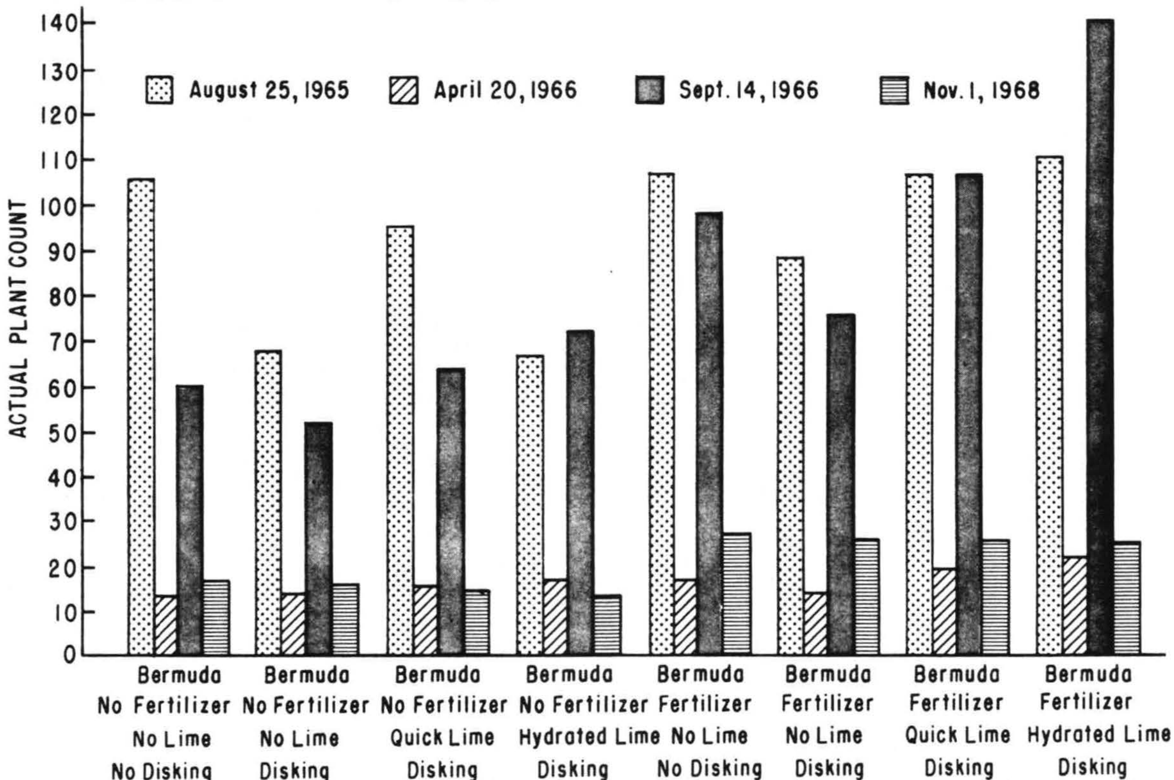

Figure 1-11. The effect of lime, fertilizer, and disking on the establishment of common bermudagrass on a west facing cut slope one mile north of SH-33 on I-35 east of Guthrie, Oklahoma. Lime was applied June 18, 1964, the area seeded February 3, 1965, and fertilized June 24, 1965, with 400 lbs. of 12-12-12 per acre and were evaluated on the above dates.

PART II

MAINTENANCE OF VEGETATIVE GROUND COVERS

Erosion resistant vegetative covers may be restored or maintained on highway slopes with proper fertilization (top photo), or they may be relentlessly destroyed with the decline in soil fertility (bottom photo) after their initial successful establishment.

MAINTENANCE OF VEGETATIVE GROUND COVERS

ON

OKLAHOMA HIGHWAYS

RECOMMENDATIONS

The complete evaluation of plant response to fertilizer treatments can only be made with time. The plant, soil, and weather complex interact differently from one year to the next, but over a period of time, maybe 10 or 15 years, a trend or pattern evolves upon which recommendations can be made with greater confidence and reliability. The time interval involved in these research evaluations spans a period of less than five years. Recommendations based upon such cursory investigations must be subject to revision with the accumulation of additional data. The preliminary responses of several erosion resistant grasses to various fertilizer treatments on cut and fill slopes serve as the basis for these recommendations.

MAINTENANCE

1. MOWING

   a. DO NOT MOW CUT AND FILL SLOPES.

   b. AREAS OTHER THAN SLOPES that must be mowed, should not be clipped lower than 4 to 6 inches above the soil surface, and then no more frequently than 60 day intervals. Clipping native grasses once during the winter dormant season is the least damaging, but even this will injure switchgrass in a vegetative cover.

2. GRADING

   a. DO NOT "BLADE-OFF" ESTABLISHED VEGETATIVE GROUND COVER FROM THE HIGHWAY SHOULDERS, ESPECIALLY THE NATIVE TALLGRASSES.

   b. DO NOT BORROW SOIL from the top or slopes of stabilized cuts to repair fill slopes, or topdress cut slopes for turfing.

3. FERTILIZATION

   a. East of US-81

      1) General for ALL GRASS MIXTURES ON ALL SLOPES. Apply 100-17-16 pounds of <u>actual</u> nitrogen, phosphorus, and potassium

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respectively per acre per application once every 2 to 3 years, especially when bermudagrass is present. Commercial fertilizers that will supply 100-17-16 pounds of elemental N-P-K would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

17 pounds elemental phosphorus = 195 pounds 0-20-0
or, = 86 pounds 0-45-0

2) Predominately WEEPING LOVEGRASS COVERED SLOPES. Apply 50-17-16 pounds of actual nitrogen, phosphorus, and potassium respectively per acre per application once every 2 to 3 years. Commercial fertilizers that will supply 50-17-16 pounds of elemental N-P-K would include among others:

NITROGEN:

50 pounds elemental nitrogen = 250 pounds ammonium sulfate
or, = 150 pounds ammonium nitrate
or, = 112 pounds urea

PHOSPHORUS:

17 pounds elemental phosphorus = 195 pounds 0-20-0
or, = 86 pounds 0-45-0

POTASSIUM:

16 pounds elemental potassium = 32 pounds 0-0-60

3) Predominately BERMUDAGRASS COVERED SLOPES. Apply 100-17-16 pounds of actual nitrogen, phosphorus, and potassium respectively per acre per application once every 2 to 3 years. Commercial fertilizers that will supply 100-17-16 pounds of elemental N-P-K would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

17 pounds elemental phosphorus = 195 pounds 0-20-0
or, = 86 pounds 0-45-0

POTASSIUM:

16 pounds elemental potassium = 32 pounds 0-0-60

4) Predominately BERMUDAGRASS COVERED SHOULDERS and ALL LEVEL AREAS. Apply 100-17-16 pounds of actual nitrogen, phosphorus, and potassium respectively per acre per application once every 2 to 3 years. Commercial fertilizers that will supply 100-17-16 pounds of elemental N-P-K would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

17 pounds elemental phosphorus = 195 pounds 0-20-0
or, = 86 pounds 0-45-0

POTASSIUM:

16 pounds elemental potassium = 32 pounds 0-0-60

5) Switchgrass in a vegetative mixture responds to an application of 50-17-16 pounds of actual nitrogen, phosphorus, and potassium respectively per acre per application once every 2 to 3 years. These rates are the same as for weeping lovegrass. See paragraph 3a(2).

6) King Ranch bluestem in a vegetative mixture has indicated no response to supplemental fertilization, therefore none is recommended. It has persisted as well or increased in abundance in the unfertilized experimental areas, as in the areas that received the maximum rates of fertilizer.

b. West of US-81

1) General for ALL GRASS MIXTURES ON ALL SLOPES. Apply 100 pounds of actual nitrogen per acre per application once every 2 to 3 years, especially when sideoats grama, switchgrass and bermuda are present. Commercial fertilizers that will supply 100 pounds of elemental nitrogen would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

2) Predominately WEEPING LOVEGRASS COVERED SLOPES. Apply 100-34-0 pounds of actual nitrogen, and phosphorus respectively per acre, per application once every 2 to 3 years. Commercial fertilizers that will supply 100-34-0 pounds of elemental N-P would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

34 pounds elemental phosphorus = 389 pounds 0-20-0
or, = 172 pounds 0-45-0

3) Predominately BERMUDAGRASS COVERED FILL SLOPES. Apply 100-34-0 pounds of actual nitrogen, and phosphorus respectively per acre, per application once every 2 to 3 years. Commercial fertilizers that will supply 100-34-0 pounds of elemental N-P would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

34 pounds elemental phosphorus = 389 pounds 0-20-0
or, = 172 pounds 0-45-0

4) Sideoats grama in a vegetative mixture responds to an application of 100-17-16 pounds of actual nitrogen, phosphorus, and potassium respectively per acre per application once every 2 to 3 years. Commercial fertilizers that will supply 100-17-16 pounds of elemental N-P-K would include among others:

NITROGEN:

100 pounds elemental nitrogen = 500 pounds ammonium sulfate
or, = 300 pounds ammonium nitrate
or, = 223 pounds urea

PHOSPHORUS:

17 pounds elemental phosphorus = 195 pounds 0-20-0
or, = 86 pounds 0-45-0

POTASSIUM:

16 pounds elemental potassium = 32 pounds 0-0-60

5) Buffalograss in a vegetative mixture responds to an application of 100 pounds of actual nitrogen per acre per application once every 2 to 3 years. Commercial fertilizers that will supply 100 pounds of elemental nitrogen would include among others:

NITROGEN:

100 pounds elemental nitrogen	=	500 pounds ammonium sulfate
or,	=	300 pounds ammonium nitrate
or,	=	223 pounds urea

6) Switchgrass in a vegetative mixture responds to an application of 50 pounds of actual nitrogen per acre, per application once every 2 to 3 years. Commercial fertilizers that will supply 50 pounds of elemental nitrogen would include among others:

NITROGEN:

50 pounds elemental nitrogen	=	250 pounds ammonium sulfate
or,	=	150 pounds ammonium nitrate
or,	=	112 pounds urea

4. WEED CONTROL

a. All of Oklahoma

The application of a post-emergence herbicide for broadleaf weed control, such as Banvel* (dicamba) at the rate of 1 pound of actual material per acre (commercial material contains 4 pounds of actual ingredient per gallon) following the first application and perhaps subsequent ones, of fertilizer would permit more efficient use of the plant nutrients by the desired grasses.

5. GRASSES

a. East of US-81

1) Weeping lovegrass is better adapted for use on all slopes in this area than any other grass tested.

2) Bermudagrass is better adapted for use on south facing slopes than any other grass tested.

3) Weeping lovegrass is better adapted for use on north facing slopes than any other grass tested.

4) Bermudagrass is better adapted for use on east or west facing slopes than any other grass tested.

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*Tradename of Velsicol Chemical Corporation.

b. West of US-81

1) Sideoats grama is better adapted for use on all slopes in this area than any other grass tested.

2) Weeping lovegrass is equally well adapted as sideoats grama for use on south facing slopes of all the grasses tested.

3) Switchgrass is equally well adapted as sideoats grama generally east of the panhandle, for use on north facing slopes of all the grasses tested.

4) Buffalograss is better adapted for use on east or west facing slopes of all the grasses tested.

5) Bermudagrass is better adapted for use on all except north facing fill slopes of all the grasses tested.

INTRODUCTION

Statistical records indicate more than $3 million was spent each year in fiscal 1963, 1964, and 1965 for erosion control on Oklahoma roads and highways. The cost of erosion control in 1965 was $15,900.00 per mile, and one year later (fiscal 1966) the cost had risen to $23,000.00 per mile, an increase of approximately 45 percent. The construction of more roads and highways each year added to the more than 12,000 miles now in Oklahoma makes the need for satisfactory and economical means of maintenance even more urgent.

FACTORS RESPONSIBLE FOR THE LOSS OF ESTABLISHED GROUND COVERS

The lack of proper maintenance is the most common reason for the loss of established ground covers. The direction of exposure and degree of slope also contribute to the decline and ultimate loss of some vegetative covers.

The factors most commonly involved in the loss of established ground covers are as follows:

1. The lack of maintenance applications of fertilizer. Historically, an abundance of fertilizer is applied at the time of seeding or sodding for the initial erosion control on the highway system. Once the initial planting is made generally no additional fertilizer is applied regardless of the need of the plants. Unfortunately, areas successfully stabilized initially with erosion resistant grasses, particularly bermuda (*Cynodon dactylon* (L.) Pers.) soon eroded so severly major repairs and replanting had to be done primarily as a direct result of the decline in soil fertility. The plants become weak, the vegetative cover becomes thin and ultimately ceases to exist altogether as the available plant nutrients disappear.

Soil erosion becomes more destructive as the vegetative ground cover weakens and dies with the decline in soil fertility.

2. Improper mowing. In those areas where the grasses were able to persist after establishment because of the inherent soil fertility they were commonly denuded by frequent, improper mowing. The height of clip for the taller, slow-growing bunchgrasses such as little and big bluestems (Andropogon scoparius Michx. and A. gerardi Vitman), indiangrass (Sorghastrum nutans (L.) Nash), switchgrass (Panicum virgatum L.), and weeping lovegrass (Eragrostis curvula Nees.) generally was the same as that for the shorter, fast-growing sodgrass bermuda. The frequent, low-mowing of the tall grasses reduced the depth of root penetration just as the tops were shortened and prevented a buildup of stored food by the plants to enable them to resist the low temperatures of winter and the hot, dry conditions of summer, so eventually they died.

Considerable research has been done on response of native grasses to clipping. Weeping lovegrass has somewhat the same habit of growth as the natives. The growth and vigor of the vegetation appear to be inversely related to frequency of clipping. Likewise numerous investigations have shown a decline in the production of roots of native grasses with frequent clipping. A study conducted at the Oklahoma Agricultural Experiment Station showed the stand density of nativegrass and plant vigor decreased, and broadleaved weeds and annual bromes increased under increased frequency of clipping.[1]

[1] Dwyer, Don D., W. C. Elder and G. Singh. 1963. Effects of Height and Frequency of Clipping on Pure Stands of Range Grasses in North Central Oklahoma. Okla. Agric. Expt. Sta. Bull. B-614.

The operation of mowers on highly erosive cut and fill slopes is one of the most destructive practices imposed on the protective grass cover. The vegetative cover is not only destroyed by the improper practice of mowing too short and too frequently, but also by being physically torn from the soil by the shearing action of the tractor sliding as it attempts to traverse the slope generally in a horizontal direction, or from the spinning wheels in ascending the steep slopes, or as they slide in an attempt to stop or turn as they descend.

3. The common practice of "blading-off" the established vegetative ground cover especially the native tallgrasses on the highway shoulders, and in borrowing soil from the top or slopes of stabilized cuts to repair fill slopes, or topdress cut slopes for turfing, destroys much protective plant material and adds greatly to the cost of erosion control in the highway system.

4. Lack of research information on plant adaptation to man-made sites. THIS IS EQUALLY IMPORTANT AS A CAUSE OF SOIL EROSION REPORTED IN PART I OF THIS REPORT ON "CAUSES AND CONTROL OF SOIL EROSION ON OKLAHOMA HIGHWAYS."

Plants that are known to be well adapted to a particular area under natural conditions may be completely unsuited to sites developed by man that creates an entirely different environment. A high fill or back-slope with a north exposure creates an entirely different environment for plant growth than a similar site facing south. North exposures at this latitude tend to be cooler in summer and much colder in winter than those that face south. Too, the intensity and amount of direct sunlight is less on north exposures which greatly influences plant growth and persistence. A west facing slope tends to be hotter, and drier in summer than one facing east.

The steepness of slope on cuts and fills tend to make these soils drier than those nearby. It is known dry soils permit faster and greater changes in temperature in a short period of time than soils that are moist. Therefore, the strong, cold winds of winter inflict the greatest damage to those plants on slopes that face north.

FERTILITY REQUIREMENTS FOR IMPROVEMENT AND MAINTENANCE OF VEGETATIVE GROUND COVERS

The principal objectives of this part of the research project were to find satisfactory and economical methods to maintain a good vegetative ground cover after its successful establishment, and to restore a protective plant cover on areas where turf failure has occurred principally from a decline in soil fertility. To achieve these objectives several factors were to be evaluated. The major items of concern were:

The "blading-off" of established vegetative cover particularly the native grasses, and borrowing soil from the top of stabilized cuts destroys the protective ground cover and adds greatly to the cost of erosion control.

1. The influence of design on the successful and economical establishment and maintenance of vegetative ground covers on cut and fill slopes.

2. The establishment of fertility requirements for maintenance of vegetatively stabilized slopes.

3. The effect of plant competition on maintenance of the desired vegetation.

FINDINGS AND CONCLUSIONS

Although plant response to fertilizers is generally rapid on low fertility soils, the determination of the most effective and economical treatments is slow because of the numerous variables involved. Weather is one of the most influential variables in field studies. In a five year period, no two years will necessarily have the same weather conditions. Since weather occurs daily and its long-time average is climate, time is required for the reliable evaluation of fertilizer treatments and application frequency for satisfactory and economical erosion control by vegetative means.

An excavation area of raw shale and sand with a 5 percent slope, located on US-69 near Eufaula, was seeded initially in May 1965 with bermudagrass (*Cynodon dactylon*), buffalograss (*Buchloe dactyloides*), little hop clover (*Trifolium dubium*) and mulched with weeping lovegrass (*Eragrostis curvula*) hay.[2] The area was fertilized at the time of seeding with 200 pounds 12-12-12 per acre, and then top dressed with 100 pounds of ammonium nitrate per acre in September 1965. In April 1966 three levels of gypsum were applied on the experimental area, followed by four levels of nitrogen-phosphorus fertilizers applied in late May 1966. The next month a post-emergence herbicide for broadleaf weed control was applied with a surfactant to one-half of each experimental unit. A fair stand of bermuda with traces of lovegrass and buffalo were present initially. The responses from the grasses to these treatments in the first two years of the investigation are shown in Figures 2.1 through 2.12. These data indicated a highly significant increase in the bermudagrass cover from nitrogen fertilization. The same results were obtained in similar experiments at Buffalo and Shawnee. The response to phosphorus fertilization, gypsum, or herbicide treatment was not significant early, but later there were definite indications of significant increases in the percent ground cover of bermuda and weeping lovegrass from a combination nitrogen-phosphorus fertilization and gypsum treatments. The real effects from phosphorus applications and gypsum treatments would show up more distinctly in plant survival during severe winters, and persistence through periods of moisture stress. These benefits will be more fully realized with time. The herbicide effect through broadleaf weed control was probably overwhelmingly masked at this particular location by the highly significant response to nitrogen fertilization particularly.

To investigate the fertility requirement of erosion resistant grasses and the effect of alternate year applications, six fertilizer treatments were applied to a vegetative ground cover previously established on a US-270 cut slope near Holdenville. The 3:1 slope, composed of a sandy loam soil with shale outcropping near the bottom, was rather well protected with about 65 percent ground cover, mostly bermudagrass, when the experiment started in 1964. The results of these treatments are shown in Figures 2.13 through 2.18.

Without fertilizer the bermudagrass ground cover declined about 30 percent, while K. R. bluestem increased 1 1/2 times that amount as shown in Figure 2.18. With only three years of data the complete evaluation of fertilizer response, and application frequency cannot be made. Within a five or ten year period real differences should manifest themselves based on the early trend in the nonfertilized treatment.

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[2] Maddux, Larry Dean. 1967. The Effect of Fertilizer, Gypsum, and Herbicide on Establishment and Maintenance of a Vegetative Ground Cover for Erosion Control on Oklahoma Highways. Unpublished M. S. Thesis. Oklahoma State University.

Just across the road (US-270) south from the afore mentioned experiment is an exact duplication with the exception of a north exposure as shown in Figures 2.19 through 2.24. Weeping lovegrass was the predominant ground cover under all treatments. Bermudagrass declined in abundance, or remained in about the same small area on this north facing slope as at the beginning of the investigation three years earlier. Again, a complete evaluation of fertilizer response, and application frequency could not be made in the brief elapsed time of the experiment. The addition of fertilizer, particularly nitrogen, resulted in a distinct increase in weeping lovegrass, but only a slight increase in switchgrass, and practically no change in the amount of K. R. Bluestem. There is an indication however, that weeping lovegrass is better adapted for use in erosion control on north facing slopes than bermuda.

A duplicate experiment of the above was initiated in 1964 on US-270 about 3 1/2 miles further west on a sandy loam, 3:1 backslope. The preliminary results of these fertilizer treatments are shown in Figures 2.25 through 2.30. Initially a good stand of bermudagrass and weeping love were the dominant grasses on the south facing slope with bermuda providing 5 to 20 percent more ground cover than weeping love. After three years weeping lovegrass had increased in abundance, particularly where fertilized, to the point it provided 15 to 40 percent more ground cover than bermuda which had declined in density even when fertilized, and was completely gone in those areas that had not been fertilized. In the non-fertilized areas weeping lovegrass further exhibited its usefulness in erosion control by increasing 22 percent in the amount of ground cover. However, the greatest increase in ground cover on these unfertilized sites was provided by K. R. bluestem which was essentially nonexistant in 1964, and then three years later furnished a cover for 44 percent of the soil surface.

Immediately south, across US-270, a duplicate investigation was conducted except for a north exposure. The initial, but incomplete results of these fertilizer treatments are shown in Figures 2.31 through 2.36. On this north facing slope, initially seeded to bermudagrass, weeping love, switchgrass, and K. R. bluestem the bermuda has completely disappeared while weeping love increased in all treatments even without fertilization, to the point of providing ground cover for about 70 percent or more of the backslope area. Switchgrass increased under nitrogen fertilization, particularly at the higher rates, and furnished about 20 percent coverage of the soil surface.

The use of fertilizers as an effective and rather inexpensive means of restoration and/or maintenance of a bermudagrass cover for the protection of cut and fill slopes particularly is not without some problems on a few sites. Just as fertilizer stimulates the growth of bermudagrass, weeds are stimulated also if the plants or seeds are present and uninhibited. Consequently, a weed control program must be initiated simultaneously with fertilization of some areas for maximum benefits from the plant nutrients provided.

In April 1964 six fertilizer treatments were applied to an east-facing 2:1 cut slope of loamy soil, on US-270 near Shawnee in central

Oklahoma. The slope had approximately a 40 percent cover of bermudagrass with a heavy infestation of winter annual grasses at the start of the experiment. One year later in May 1965 one-half of each research plot was treated with the herbicide Banvel[3] at the rate of 1 lb. actual ingredient/acre for the control of western ragweed (Ambrosia psilostachya) and annual sunflower (Helianthus annuus) primarily. Fertilizer was reapplied in June 1966 and a retreatment with herbicide was made one year later in June 1967. The preliminary results of these combination fertilizer-herbicide treatments are shown in Figures 2.37 to 2.39.

Bermudagrass declined in percent ground cover in all plots except one unless the weeds were controlled with a herbicide. The greatest increase in bermudagrass ground cover was that treatment of 50-17-16 actual/acre combined with a post-emergence weed control program of 1 lb. actual Banvel per acre.

Two experiments designed to determine the fertilizer requirements for restoration and maintenance of vegetative ground covers on previously established areas were initiated in 1964 on Interstate 35 just south of SH-51 in north-central Oklahoma. The bermudagrass cover extended over approximately 38 percent of the east-facing 2:1 backslope composed of a clay loam soil with only moderate erosion. The fertilizer treatments were reapplied in June the next two years. The initial results of these fertilizer experiments are shown in Figures 2.40 and 2.41. A 70 percent ground cover from bermudagrass is considered to be adequate for protection and soil stabilization on most backslopes in this area.

Three annual applications, each of 100-17-16 lbs. actual fertilizer per acre yielded the greatest increase in bermudagrass cover in this investigation. At the end of the third year after the initial treatment, almost 83 percent of the backslope was covered with bermudagrass. Almost to the arbitrary level of satisfactory ground cover was the area treated with 50-17-16 lbs. of actual fertilizer elements per acre in each of three successive years. The application of 50 lbs. actual nitrogen per acre in each of these three years almost produced a satisfactory level of bermudagrass cover.

On the hotter, west-facing slope on I-35 across from the above experiment a duplicate investigation was initiated in 1964. Only 33.5 percent of the backslope was covered with bermudagrass when these experiments started. The preliminary results of these fertilizer experiments are shown in Figures 2.42 and 2.43.

All fertilizer treatments with one exception produced more than 70 percent vegetative cover at this location in three years time. The annual application of 50 lbs. nitrogen per acre for three years was approaching the arbitrary level of satisfactory cover at the end of the third year. The unfertilized portion of this area maintained about the same bermudagrass cover throughout this brief period of time. Only about 40 percent of the backslope was protected by a bermudagrass cover when no fertilizer was applied. This is considered to be definitely inadequate for erosion control on cut and fill slopes in Oklahoma!

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[3] A product of Velsicol Chemical Company.

In 1964 six fertilizer treatments were applied to a north facing backslope on Interstate 40 near Hydro in western Oklahoma. The vegetative cover was mostly sideoats grama (Bouteloua curtipendula), switchgrass (Panicum virgatum), and weeping lovegrass in that order. The loamy soil was moderately eroded and the vegetation was in poor condition. The percent ground cover from all grasses declined during this short period of time in the unfertilized areas but had increased at the end of three years from all fertilizer treatments. The greatest increase in percent ground cover occurred in those areas that received only nitrogen. The preliminary results of these fertility treatments are shown in Figures 2.44 through 2.49. Sideoats grama made its greatest increase in percent ground cover when fertilized with the high rate of nitrogen, phosphorus, and potassium. The 100-34-32 (pounds of actual) fertilizer produced twice as much ground cover from sideoats grama as did 100 pounds of nitrogen alone. Weeping lovegrass however, just as all grasses combined, produced the most ground cover when fertilized with only nitrogen.

On a north-facing fill slope one-half mile west of the above experiment on I-40, bermudagrass declined in percent ground cover from June 1964 to October 1966 in all except one fertilizer treatment. The preliminary evaluations of these six fertilizer treatments on the growth and persistence of bermudagrass are shown in Figures 2.50 and 2.51. The fill soil is a sandy loam, with an occassional ditch beginning to form when the investigation started in 1964. Considerable water from the elevated slope of the highway pours down over the fill surface. The application of 100-17-16 pounds of actual N-P-K per acre in each of the three years 1964 to 1966, increased the percent ground cover slightly, whereas all other treatments showed a definite decline in the amount of bermuda. These data tend to indicate that the application of a complete, high analysis fertilizer is not enough to maintain bermudagrass (a full-sun loving grass), on the shaded, colder slopes of a north-facing fill area.

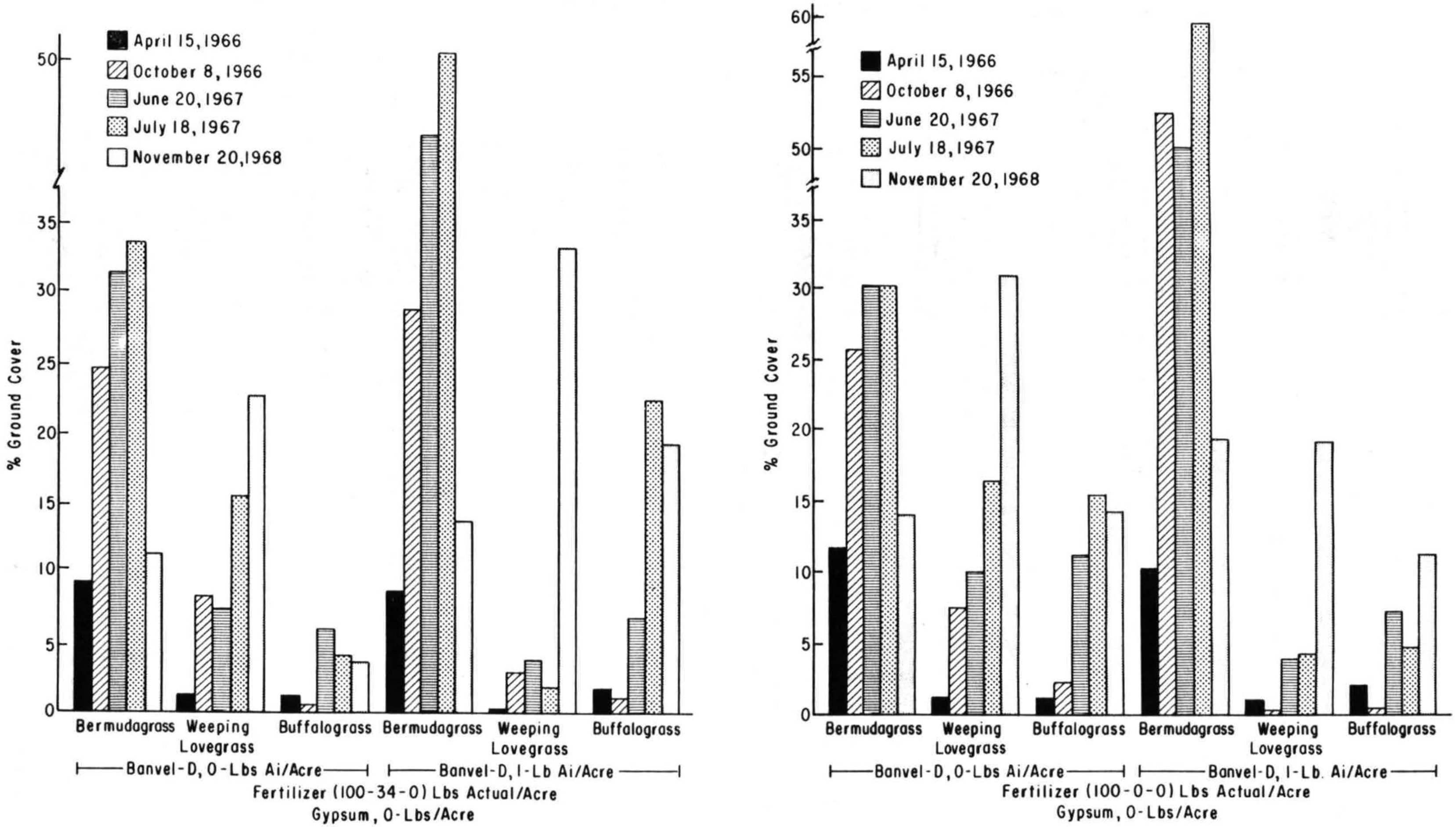
Further west about one-quarter mile from the above experiment on I-40, six fertilizer treatments were applied initially in May 1964 on a moderately eroded 3:1 backslope with a fair, but inadequate cover of sideoats grama, weeping love, and switchgrass. The soil is a sandy loam with some sandstone exposed near the bottom of the slope. The incomplete evaluations of these fertilizer treatments applied each of the three years 1964 to 1966 on the percent vegetative ground cover are shown in Figures 2.52 through 2.57. The greatest increase in percent ground cover from all grasses resulted from the application of 100 pounds of actual nitrogen in each of three successive years. Sideoats grama showed more increase in ground cover than either of the other two grasses measured. The two grasses, sideoats and switch each showed an increase in percent ground cover in all treatments except one. Switchgrass declined in abundance in the unfertilized area. Weeping lovegrass maintained its original ground cover, or declined slightly in all treatments. These data tend to indicate the adaptability of sideoats grama and switchgrass for erosion control on north-facing backslopes of this type in western Oklahoma, especially when fertilized periodically with 100 pounds of nitrogen per acre.

Across the road north from the above investigation on I-40 near Hydro (in western Oklahoma), a duplicate experiment was initiated in

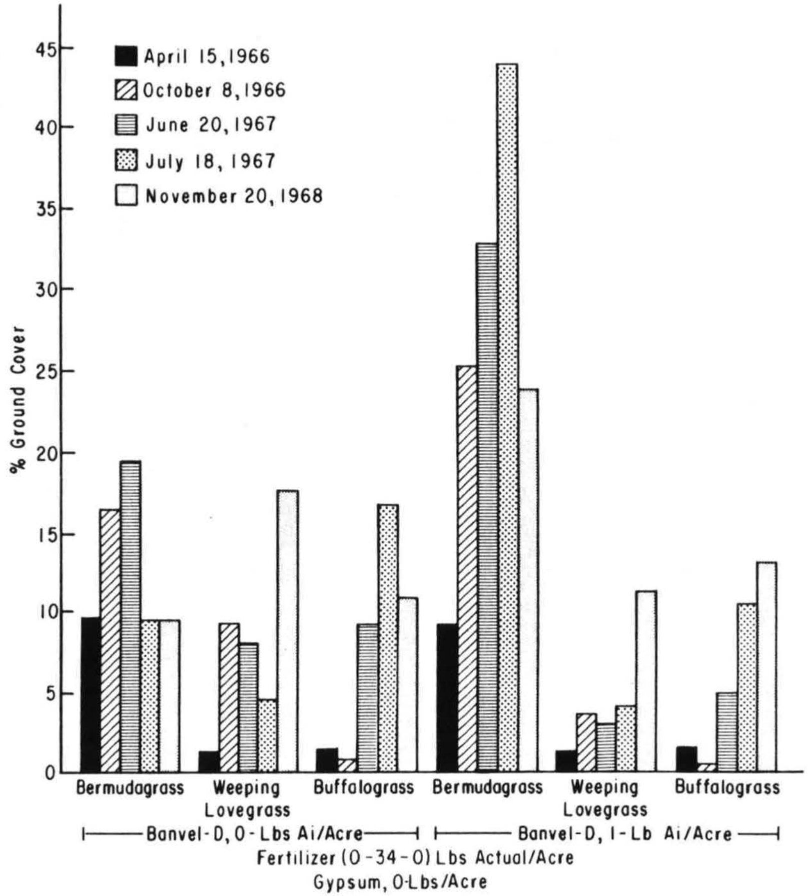
May 1964, with the exception of a south-facing slope. The sandy-loam backslope had several ditches that were starting to form at the time this investigation started and the existing vegetation was found to be in a generally poor to fair condition. The degree of erosion was considered to be moderate to severe. The incomplete evaluations of these six fertilizer treatments on the percent ground cover are shown in Figures 2.58 through 2.63. Just as was found in the duplicate investigation across the road, sideoats grama showed the greatest increase in percent ground cover of the three principal grasses. The application of 50 pounds of nitrogen per acre in each of three successive years produced the largest increase in ground cover from all grasses of the six treatments evaluated. Weeping lovegrass and switchgrass tended to persist in about the same area throughout the experimental period regardless of the fertility treatment. These data further indicate the desirable erosion control features of sideoats grama for western Oklahoma on sights of this type.

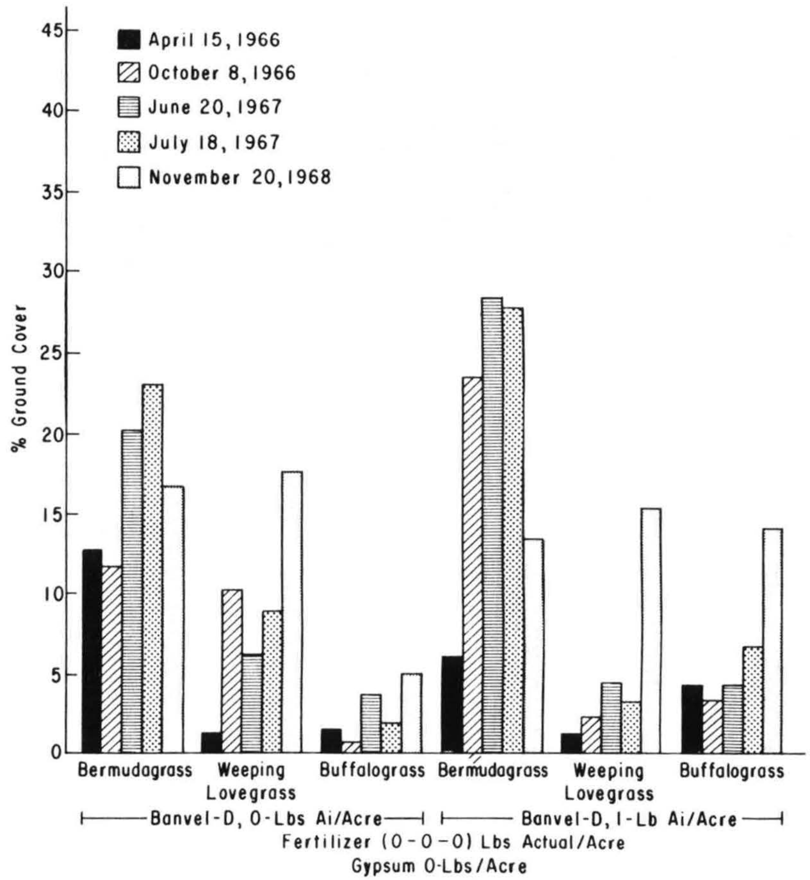
Four fertilizer treatments and four application periods were included in duplicate experiments, with the exception of slope exposure, on sandy loam backslopes in northwest Oklahoma on State Highway 34 (some seven miles north of US-64 intersection), northeast of Buffalo. The east and west facing slopes were originally seeded in the summer of 1964 when 200 pounds of 13-13-13 per acre was applied, and the area was seeded with weeping lovegrass and mulched with hay. A sparse and chlorotic stand of weeping lovegrass and sideoats grama existed on the slopes at the start of this investigation in 1966. The preliminary evaluations of fertilizers, and frequency of application, for maintenance and erosion control of vegetative ground covers are shown for the west-facing backslope in Figures 2.64 through 2.67, and in Figures 2.68 through 2.71 for the area on the opposite side of the road with an east exposure. Neither weeping lovegrass, nor sideoats grama showed a significant increase in percent ground cover from two applications of nitrogen, one in each of the two years 1966 and 1967. The complete evaluation of these fertilizer treatments and planned frequency of application could not be achieved in the brief period of only two years. Neither the east or west slope exposure exhibited a significant influence on the vegetative cover in the first two years of the experiment.

In the same area as the above experiments on SH-34, but on east and west facing fill slopes sprigged to bermudagrass in 1964, four fertilizer treatments were applied initially in July 1966, and re-applied in June 1967. The sandy loam soil used in the fill exhibited only slight traces of erosion when this experiment started. The bermudagrass, at that time, was thin and slightly chlorotic, but showing signs of spreading. The incomplete evaluations of these fertility treatments are shown for the east-facing fill slope in Figure 2.72, and for the duplicate treatments on a west exposure in Figure 2.73. The application of 100 pounds of nitrogen per acre significantly increased the percent ground cover of bermudagrass the first year it was applied in both experiments but showed only a slight, although definitely important increase from a similar application the second year. Neither the east or west slope exposure exhibited any influence on the vegetative cover on these fill slopes in this short period of time.

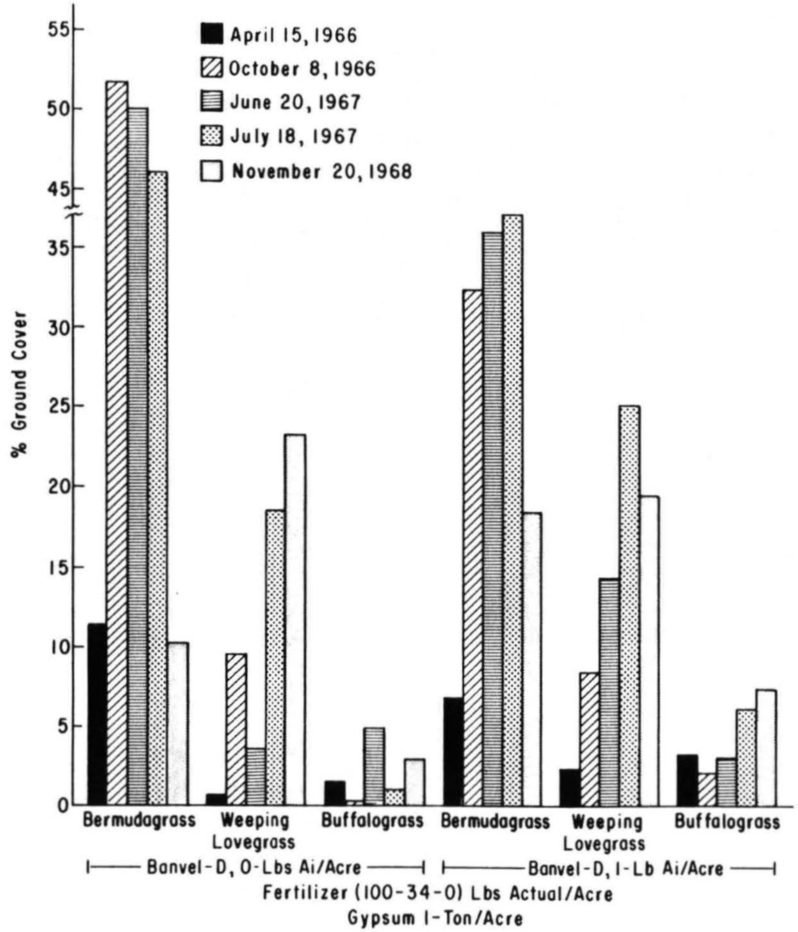


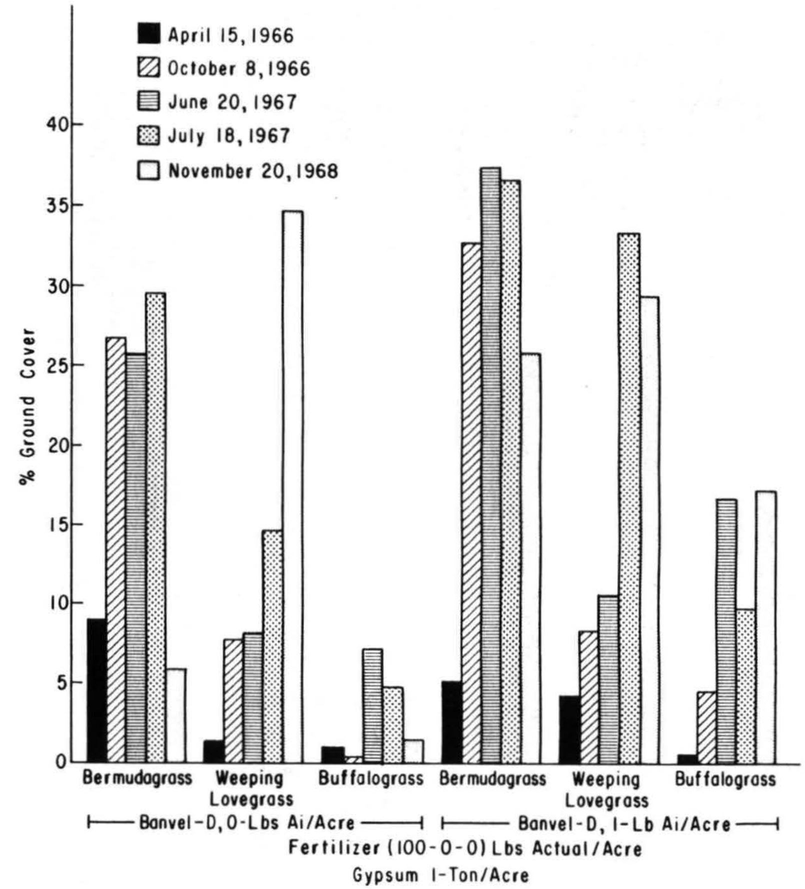
Figures 2-1 and 2-2. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth of three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.



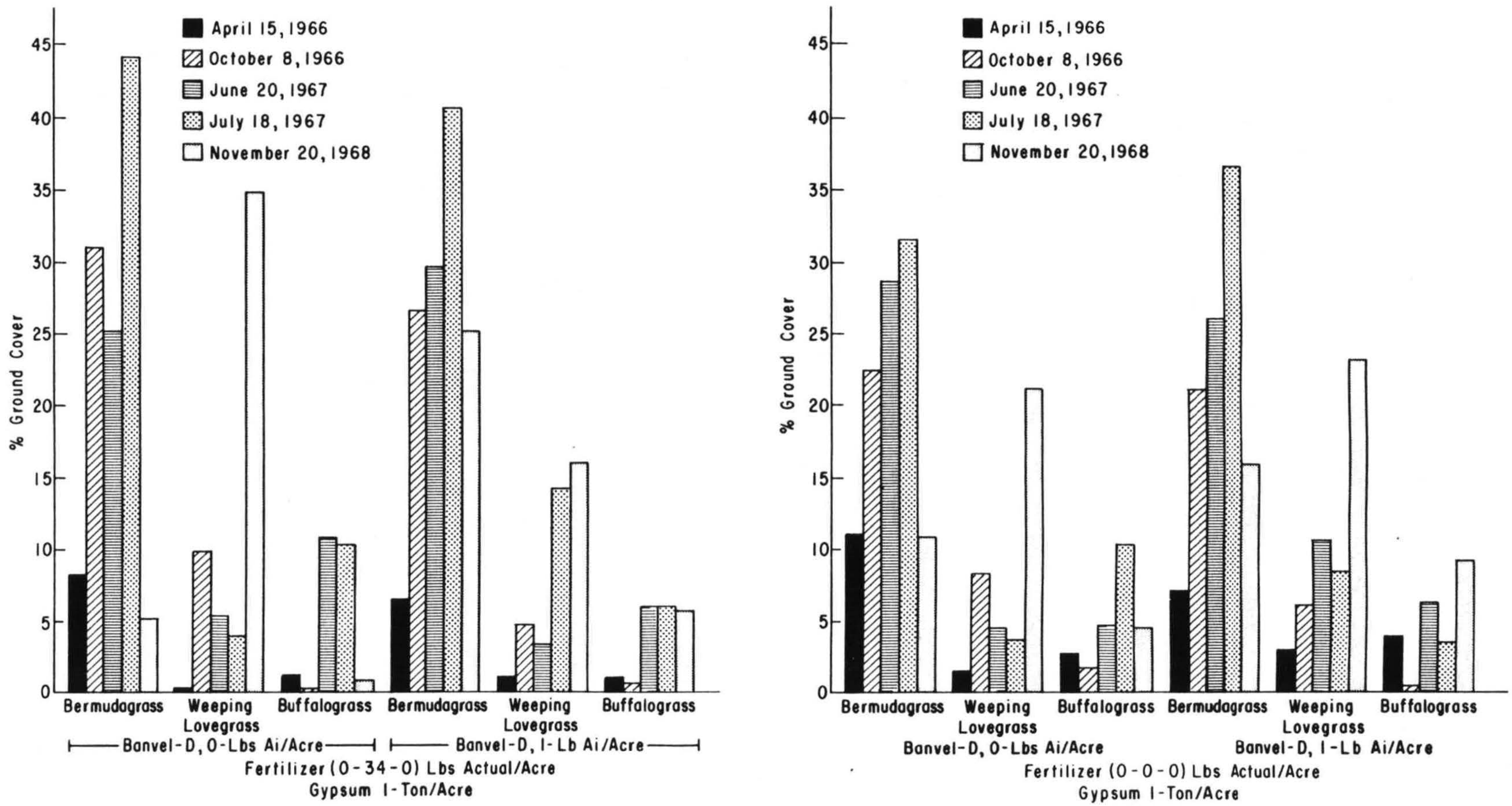


Figures 2-3 and 2-4. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth of three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.

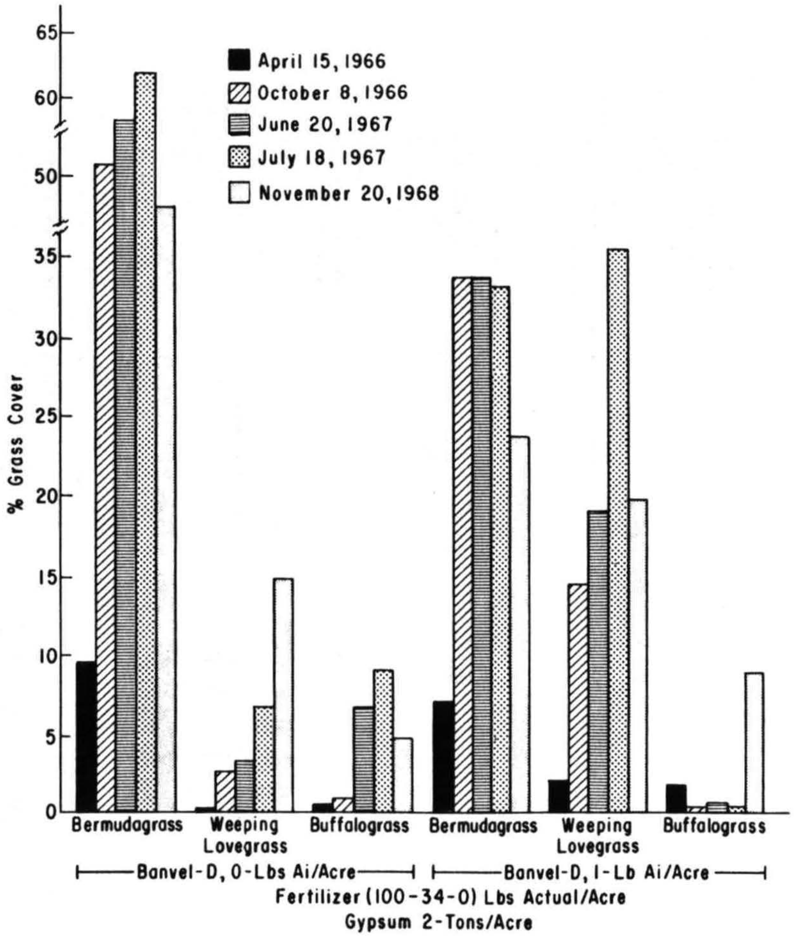


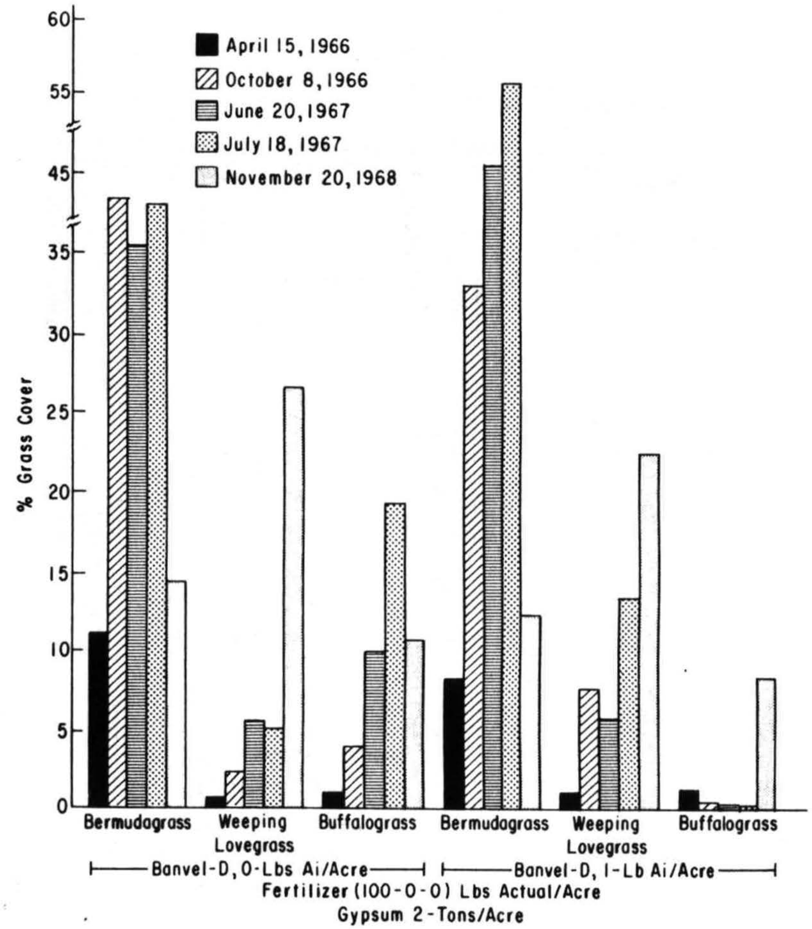


Figures 2-5 and 2-6. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth of three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.

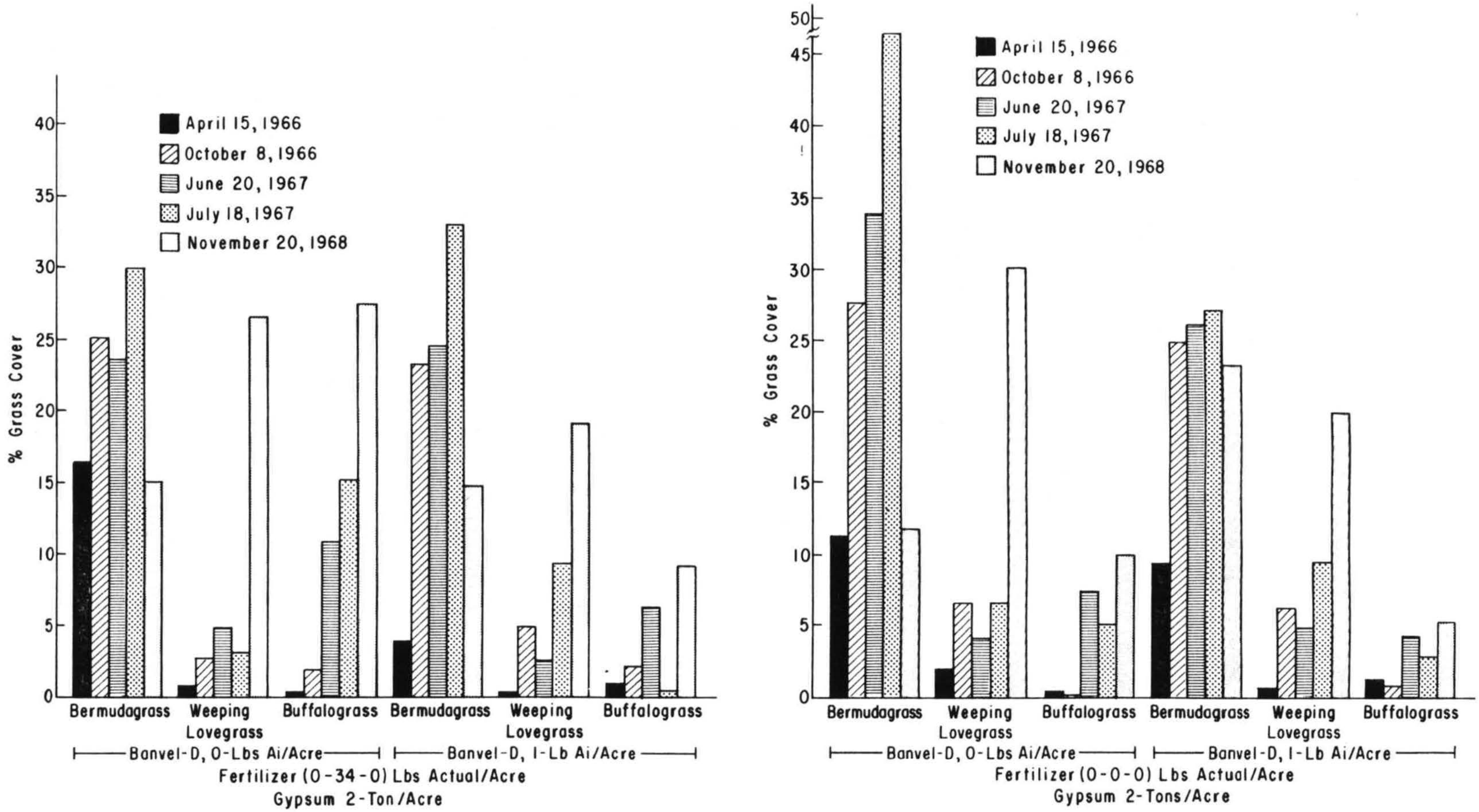


Figures 2-7 and 2-8. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth of three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.

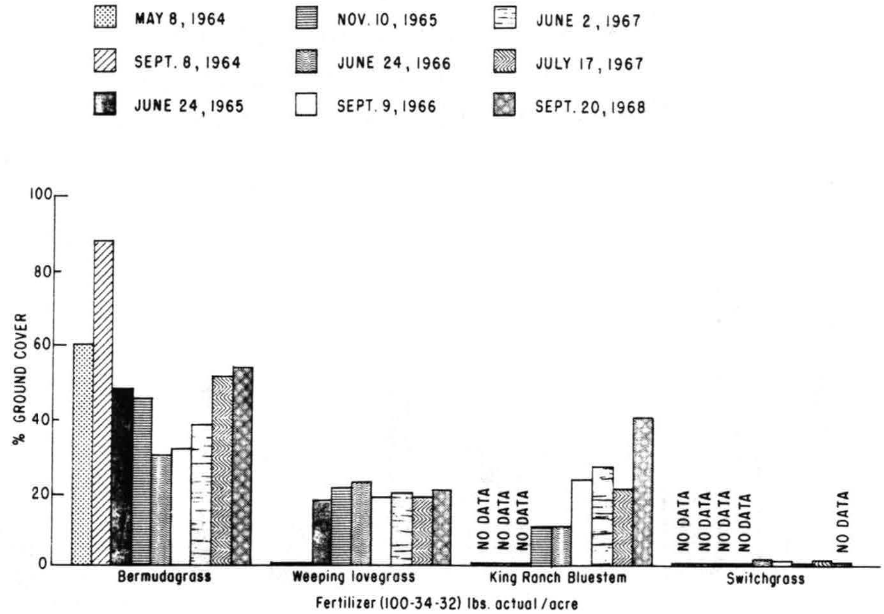


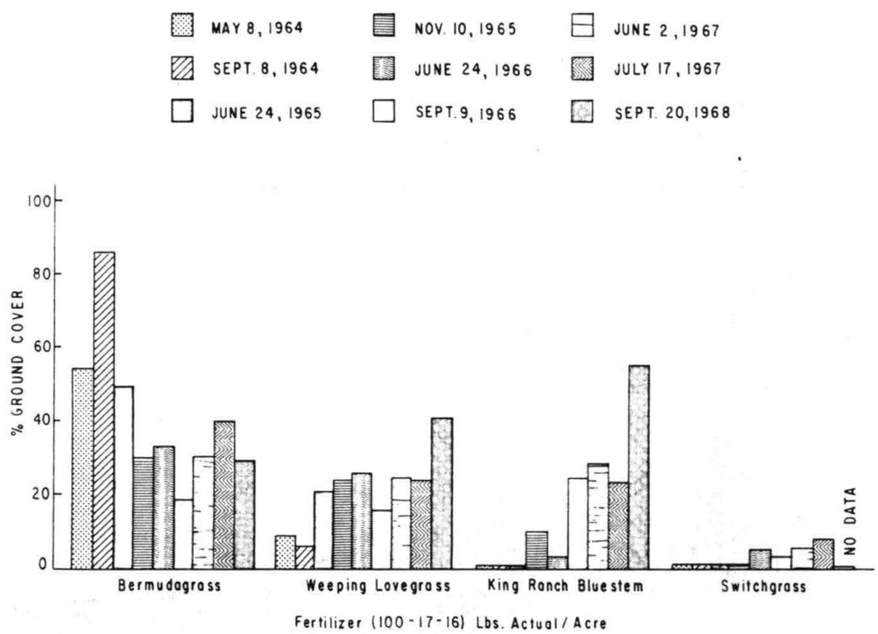


Figures 2-9 and 2-10. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.

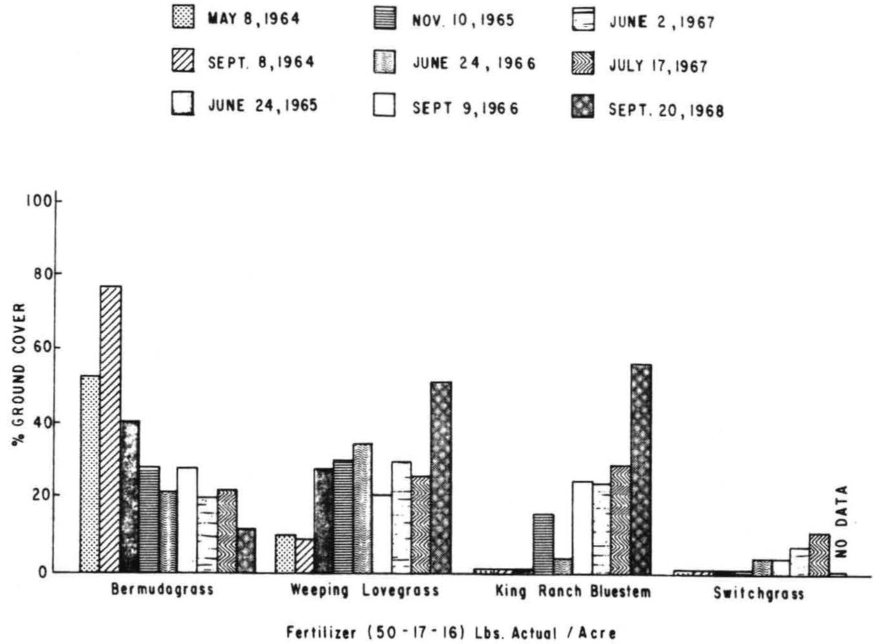


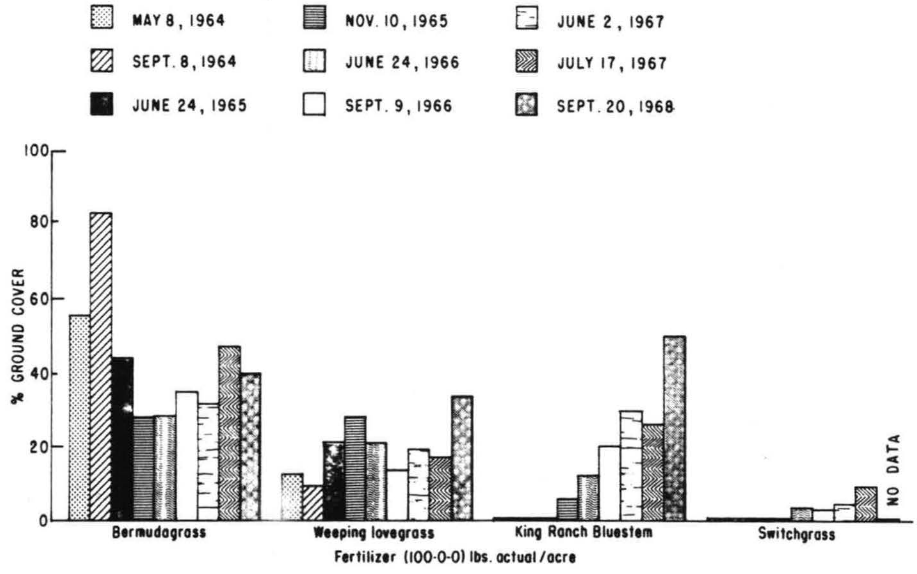
Figures 2-11 and 2-12. The effect of four rates of fertilizer, three rates of gypsum, and one rate of Banvel herbicide on the growth three grasses on US-69 north of Eufaula, Oklahoma, at the junction of US-69 Business Route as evaluated on the above dates.



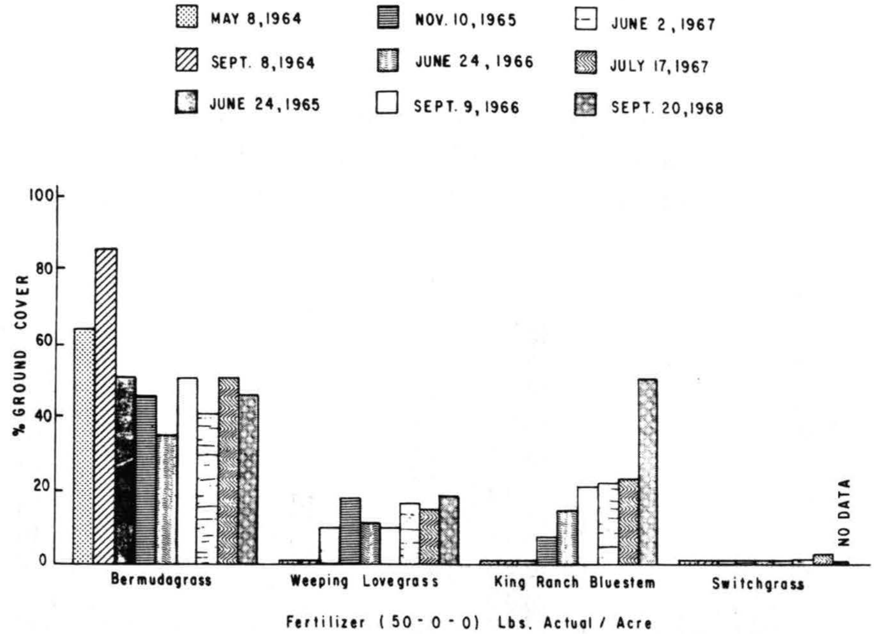


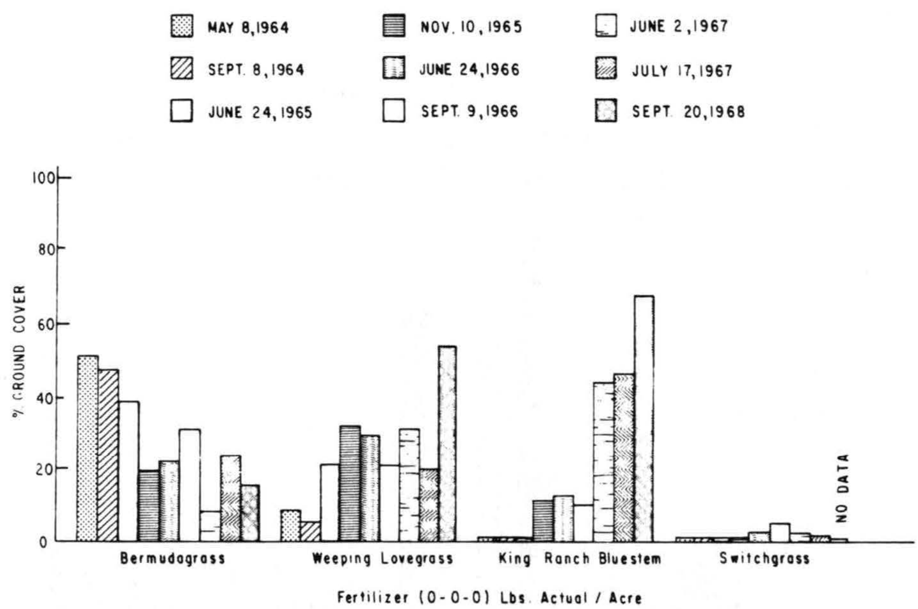
Figures 2-13 and 2-14. The effect of various fertilizers applied April 22, 1964, and retreated June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



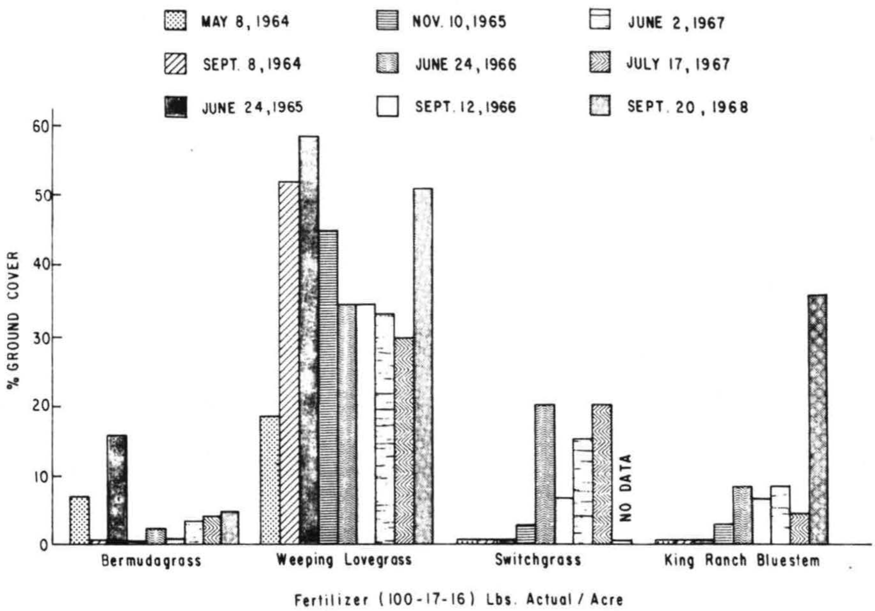


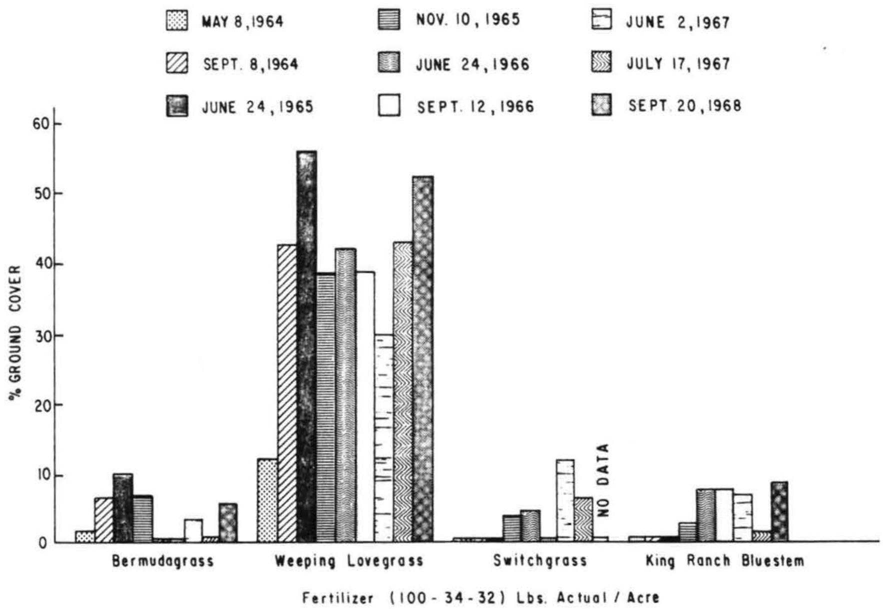
Figures 2-15 and 2-16. The effect of various fertilizers applied April 22, 1964, and retreated June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



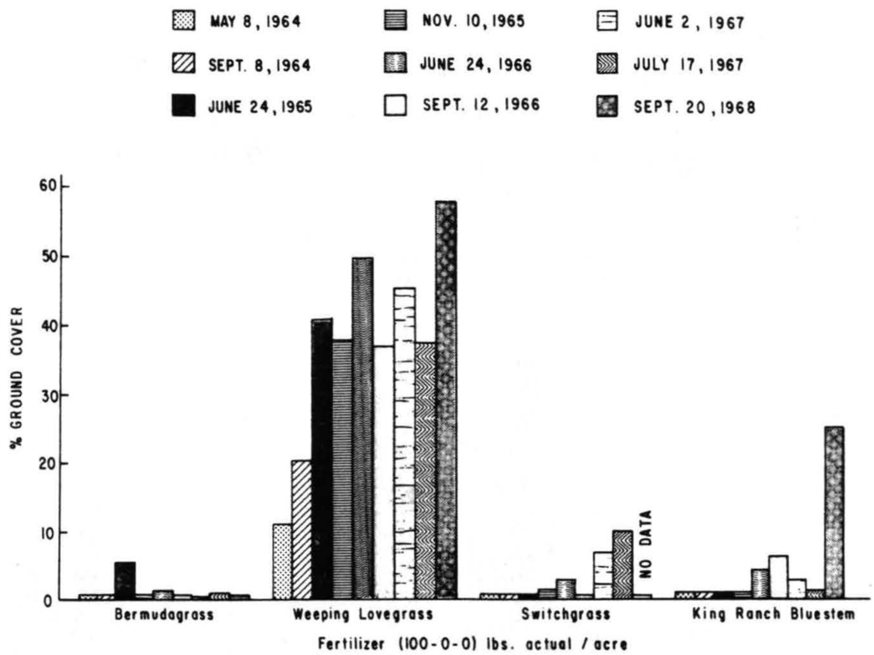


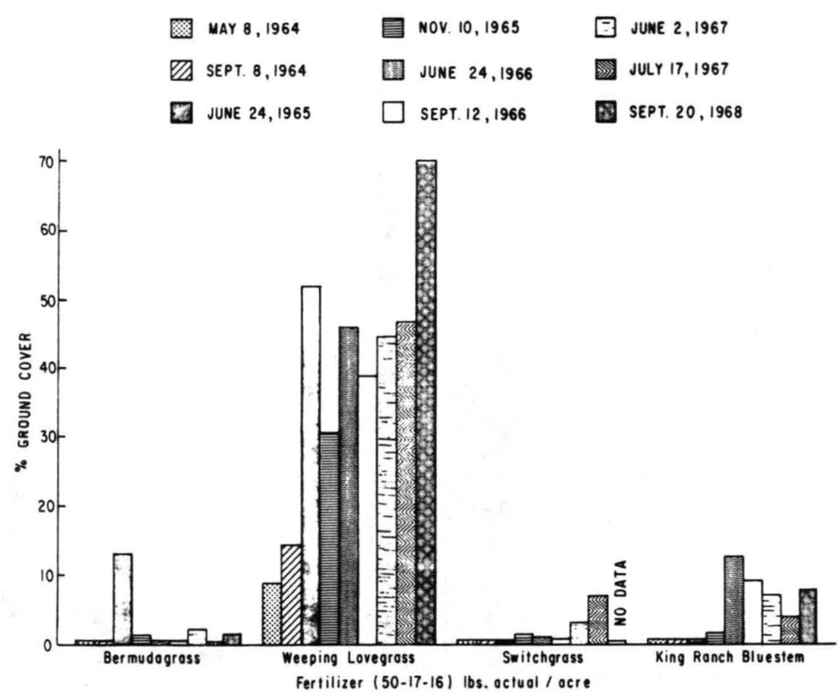
Figures 2-17 and 2-18. The effect of various fertilizers applied April 22, 1964, and retreated June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



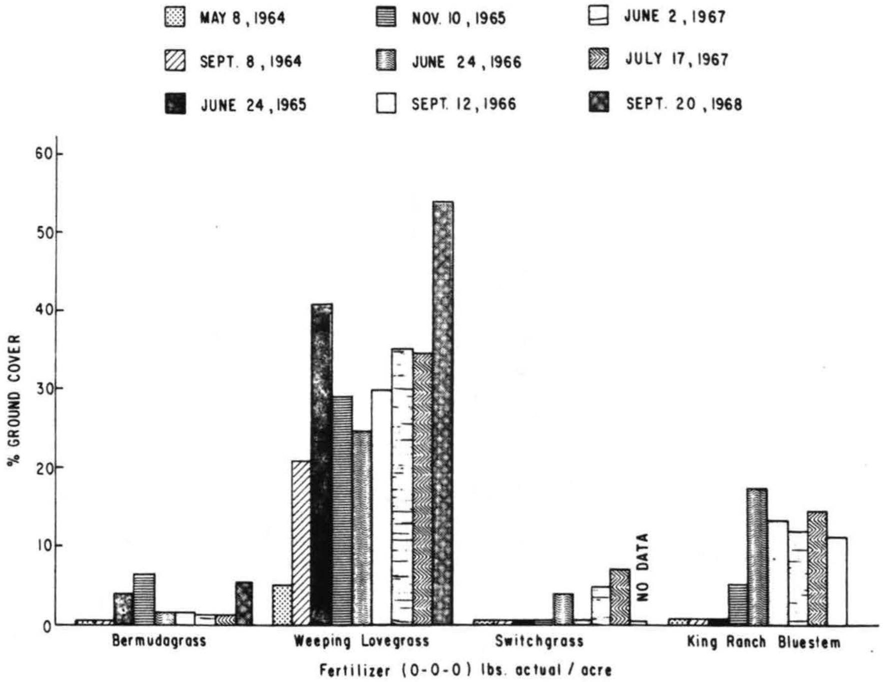


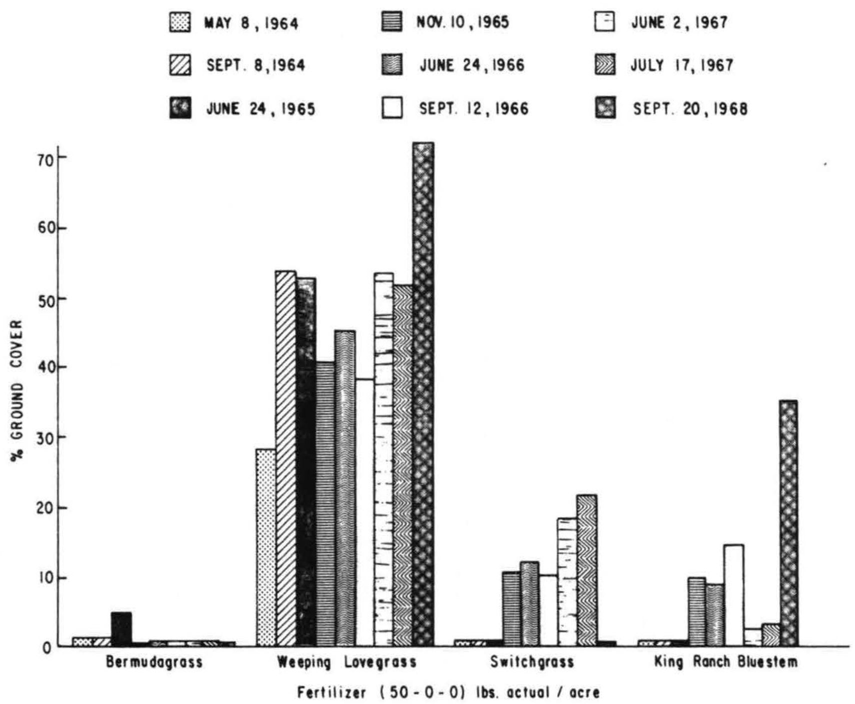
Figures 2-19 and 2-20. The effect of various fertilizers applied April 22, 1964, and retreated May 6, 1965, and June 7, 1966, on the growth of four grasses on a north facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



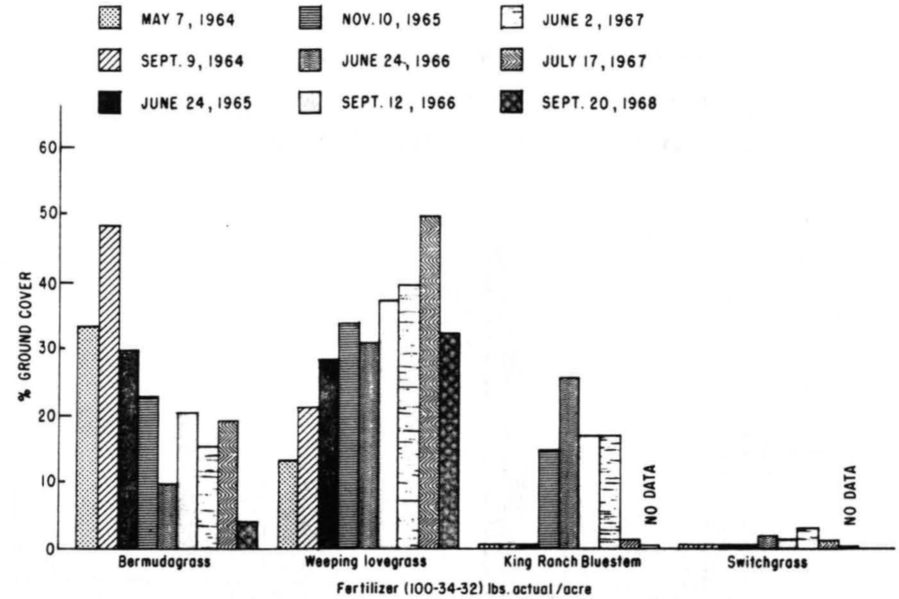


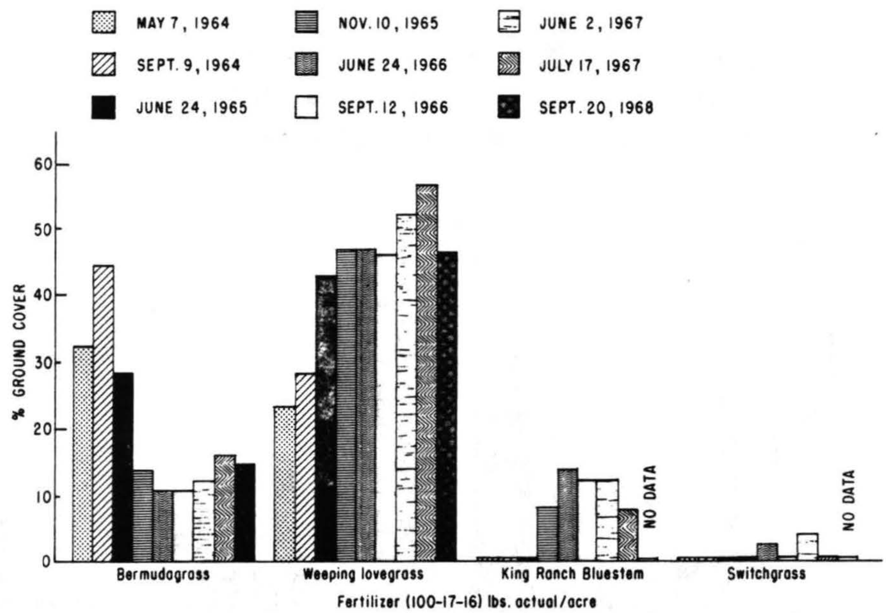
Figures 2-21 and 2-22. The effect of various fertilizers applied April 22, 1964, and retreated May 6, 1965, and June 7, 1966, on the growth of four grasses on a north facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



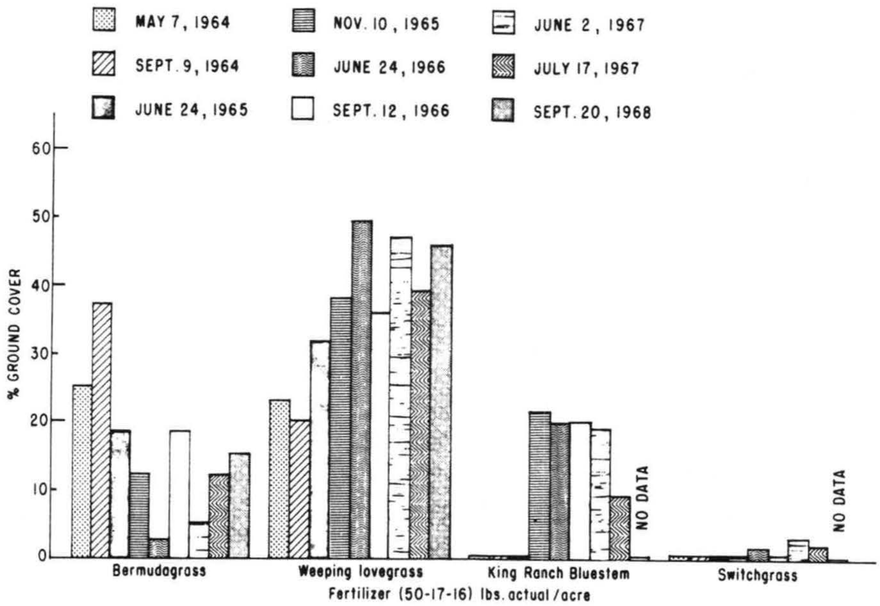


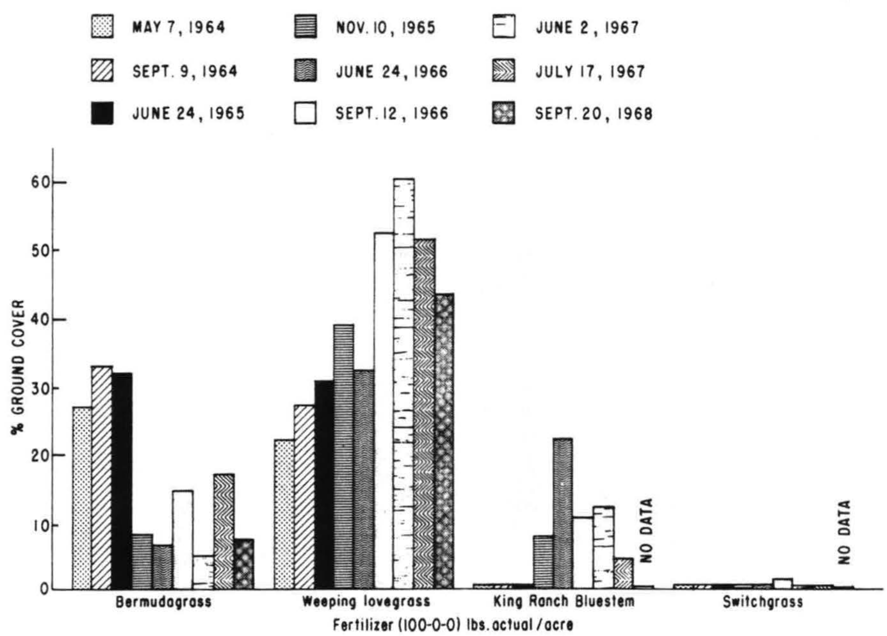
Figures 2-23 and 2-24. The effect of various fertilizers applied April 22, 1964, and retreated May 6, 1965, and June 7, 1966, on the growth of four grasses on a north facing cut slope on US-270 one and one-half miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



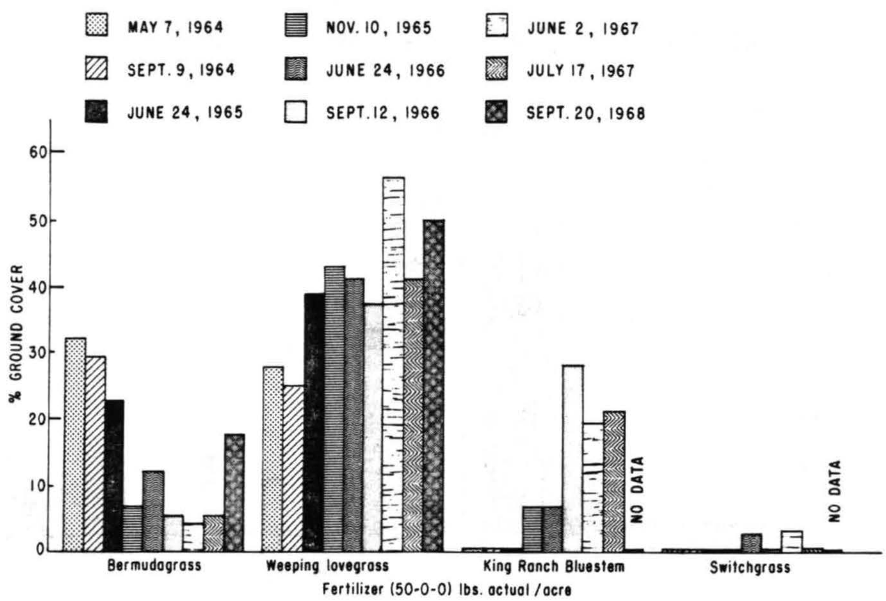


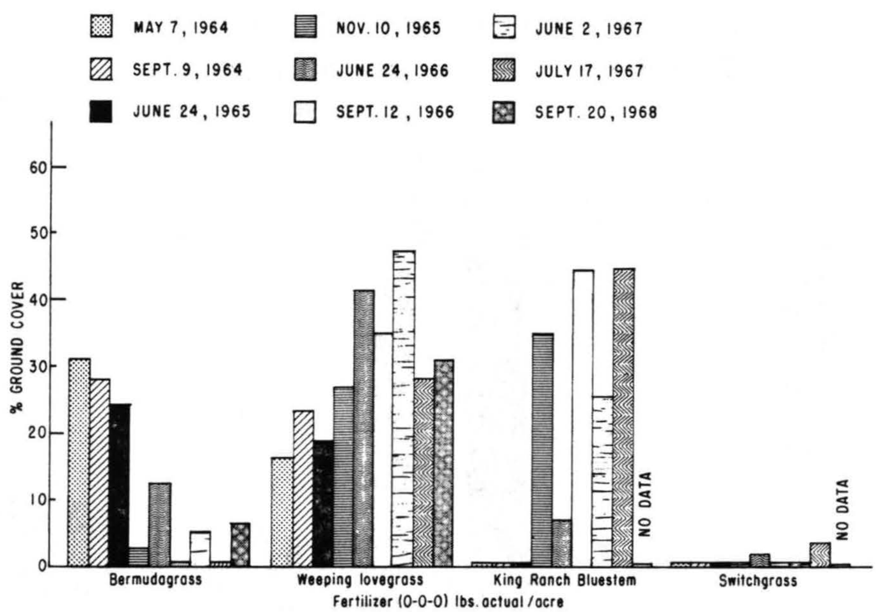
Figures 2-25 and 2-26. The effect of various fertilizers applied April 24, 1964, and retreated May 7, 1965, and June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



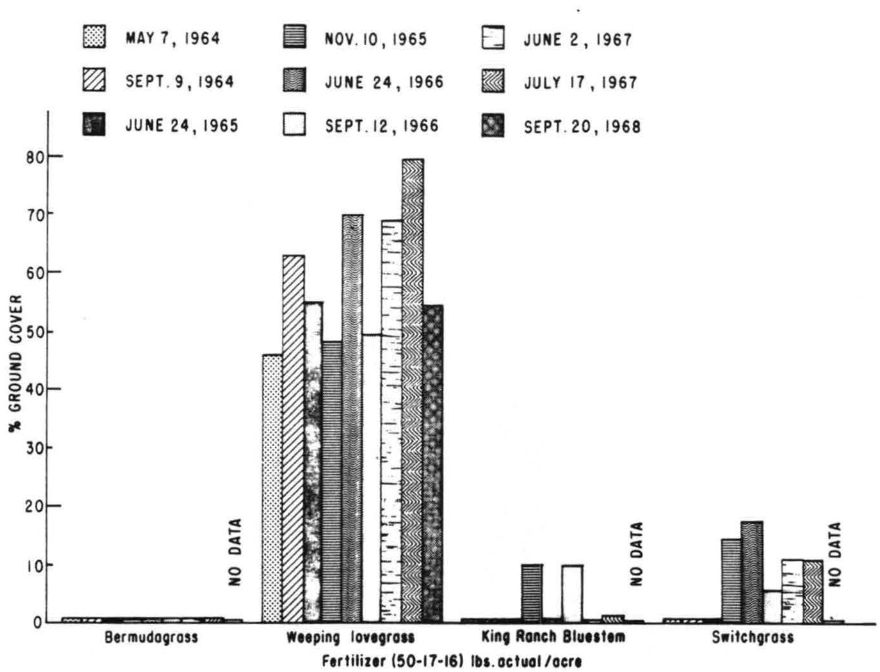


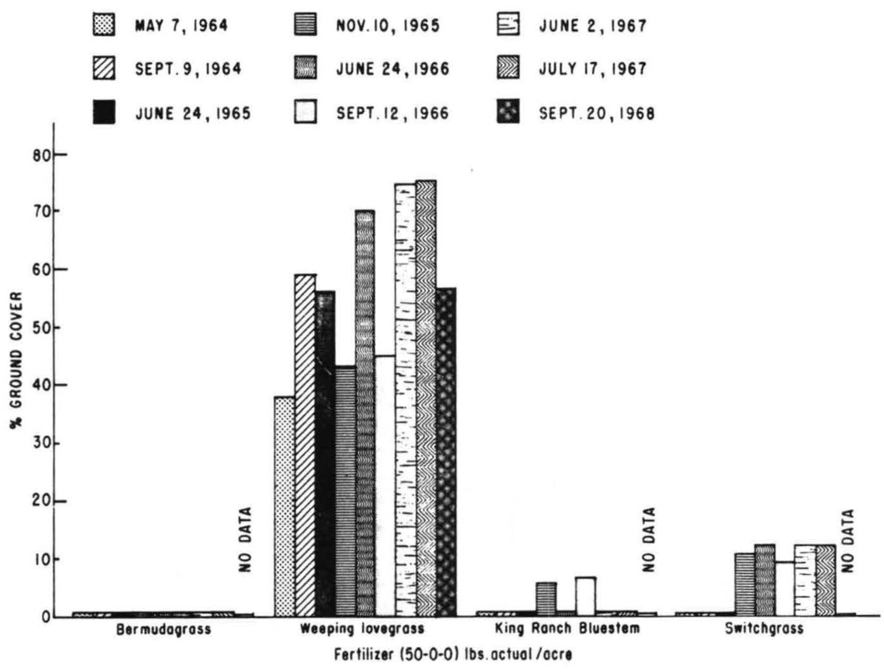
Figures 2-27 and 2-28. The effect of various fertilizers applied April 24, 1964, and retreated May 7, 1965, and June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



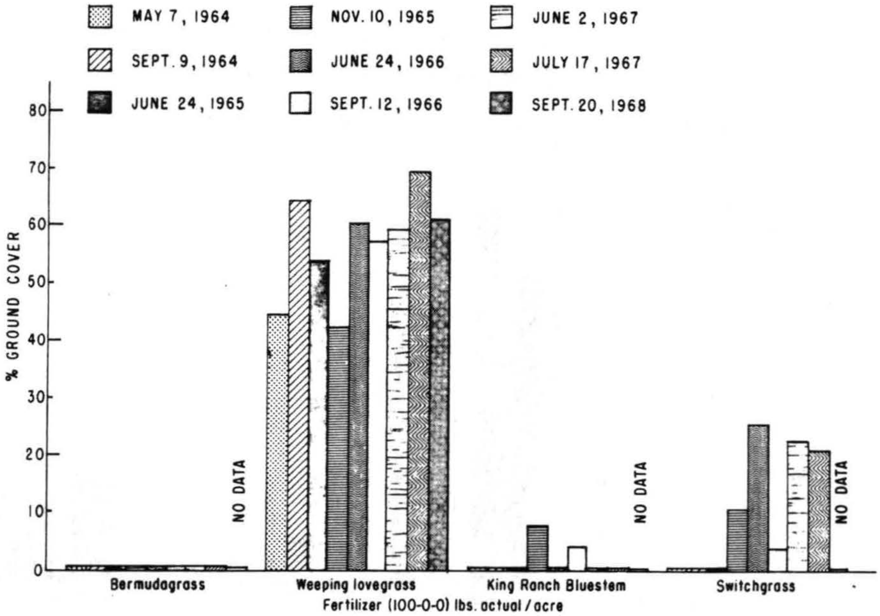


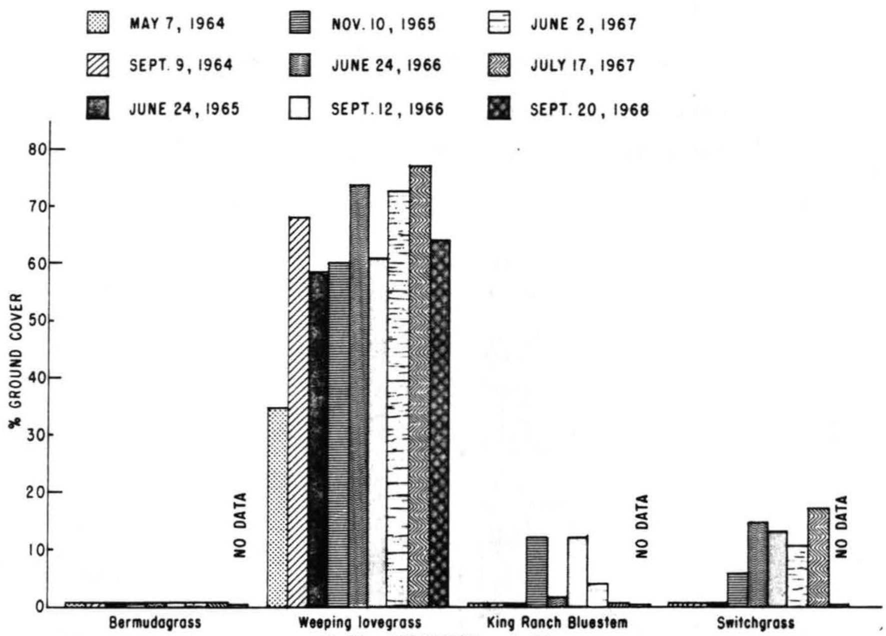
Figures 2-29 and 2-30. The effect of various fertilizers applied April 24, 1964, and retreated May 7, 1965, and June 17, 1966, on the growth of four grasses on a south facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



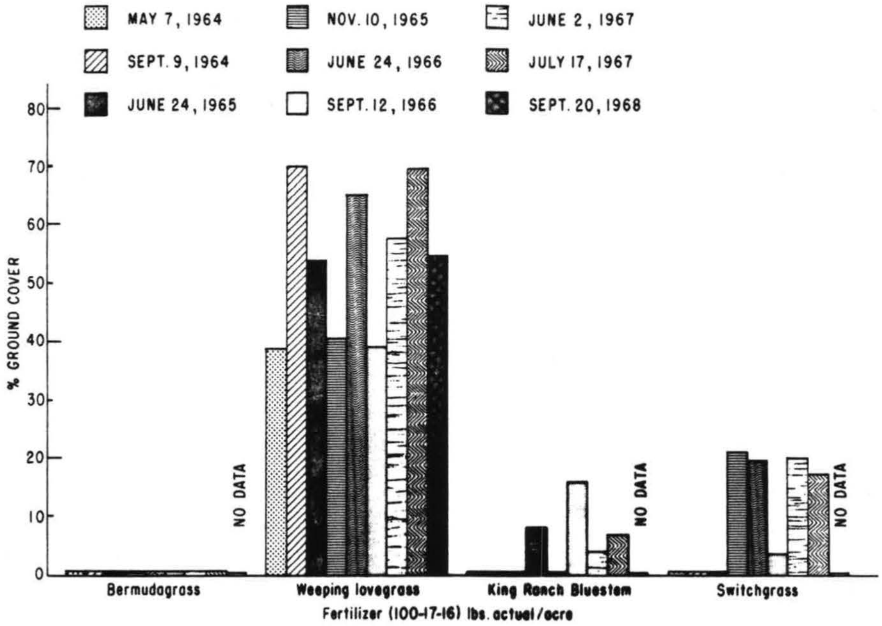


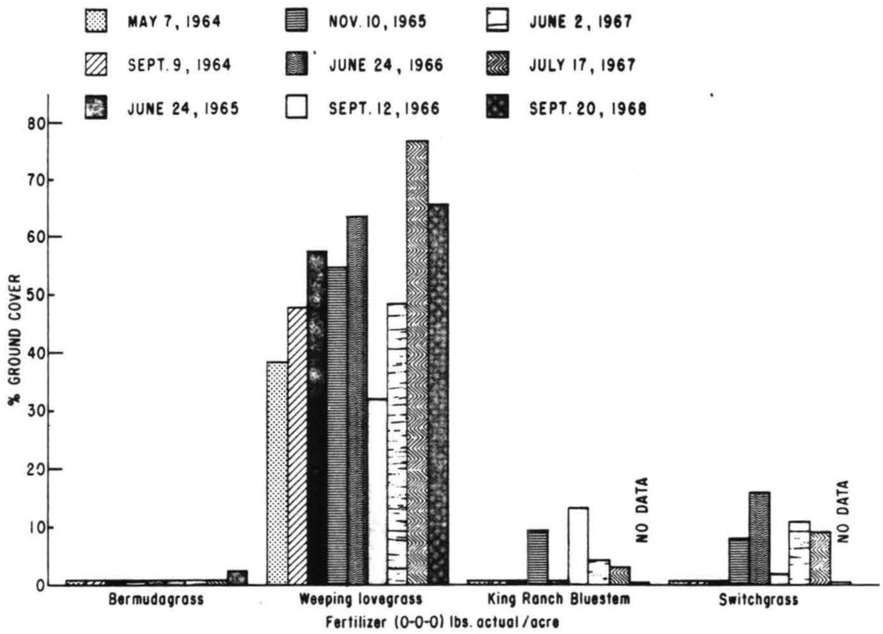
Figures 2-31 and 2-32. The effect of various fertilizers applied April 24, 1964, and retreated June 17, 1966, on the growth of four grasses on a north facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.



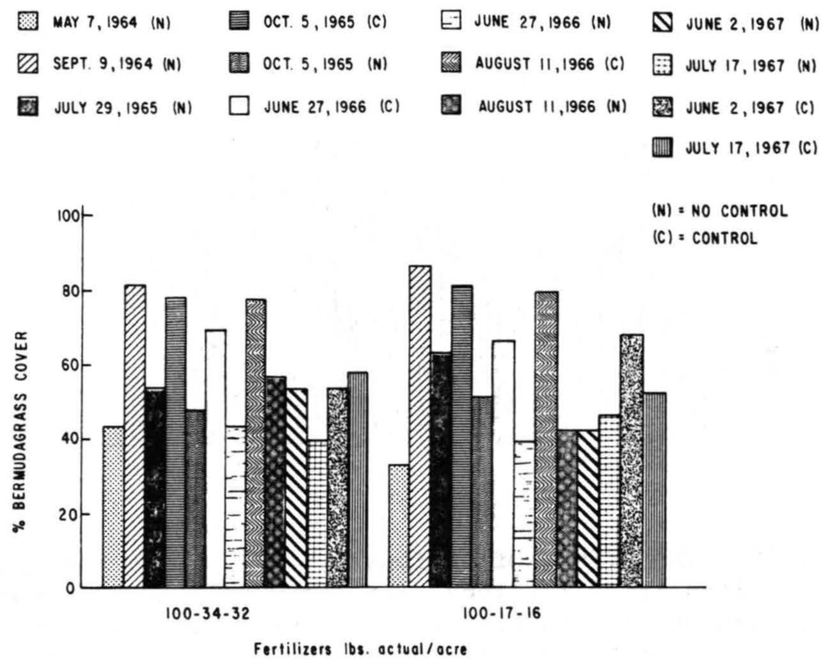


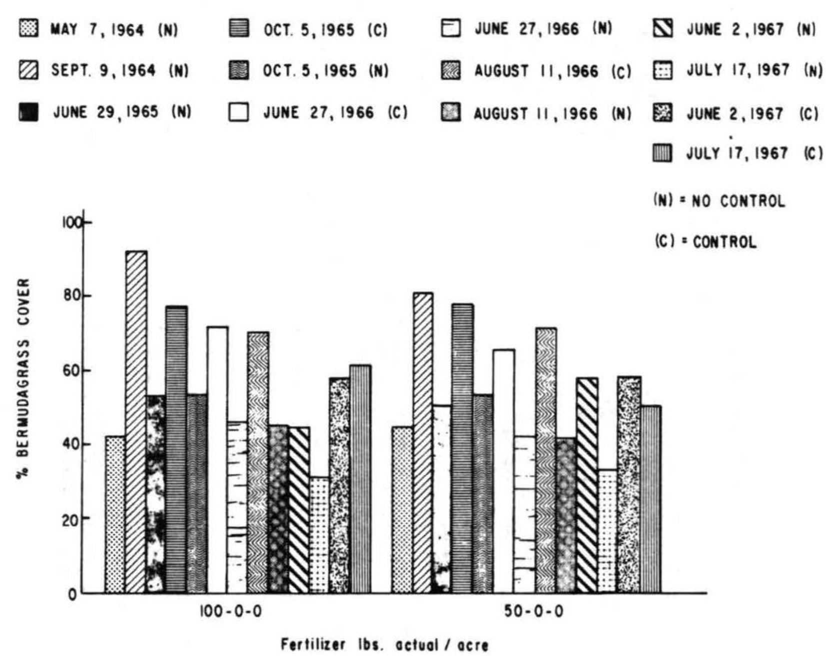
Figures 2-33 and 2-34. The effect of various fertilizers applied April 24, 1964, and retreated June 17, 1966, on the growth of four grasses on a north facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.





Figures 2-35 and 2-36. The effect of various fertilizers applied April 24, 1964, and retreated June 17, 1966, on the growth of four grasses on a north facing cut slope on US-270 four miles west of SH-48 near Holdenville, Oklahoma as evaluated on the above dates.





Figures 2-37 and 2-38. The effect of various fertilizers on the growth of bermudagrass applied April 24, 1964, and again on June 21, 1966 combined with a post-emergence herbicide treatment on May 22, 1965, and again on June 22, 1967 for broadleaf weed control on an east facing cut slope on US-270 south of Shawnee, Oklahoma as evaluated on the above dates.

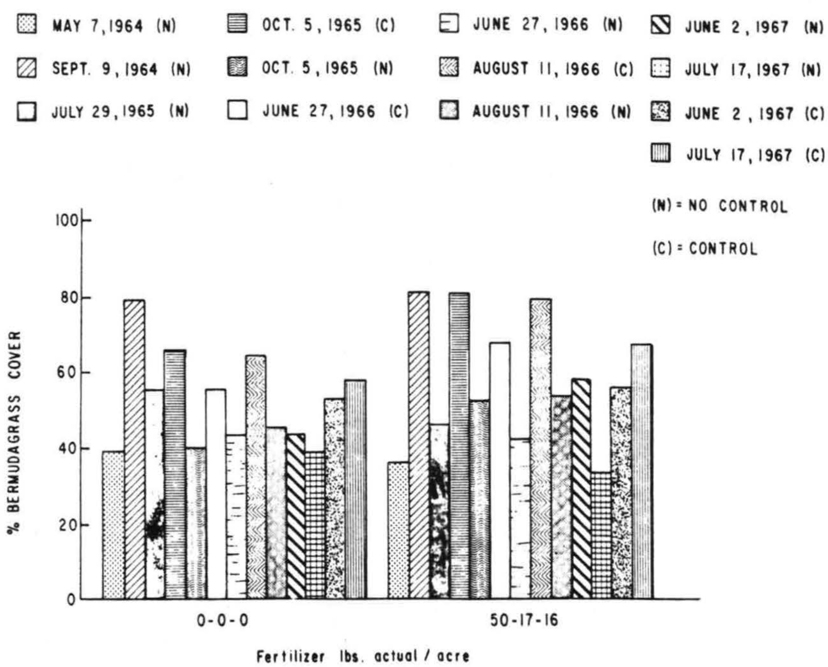


Figure 2-39. The effect of various fertilizers on the growth of bermudagrass applied April 24, 1964, and again on June 21, 1966, combined with a post-emergence herbicide treatment on May 22, 1965, and again on June 22, 1967, for broadleaf weed control on an east facing cut slope on US-270 south of Shawnee, Oklahoma as evaluated on the above dates.

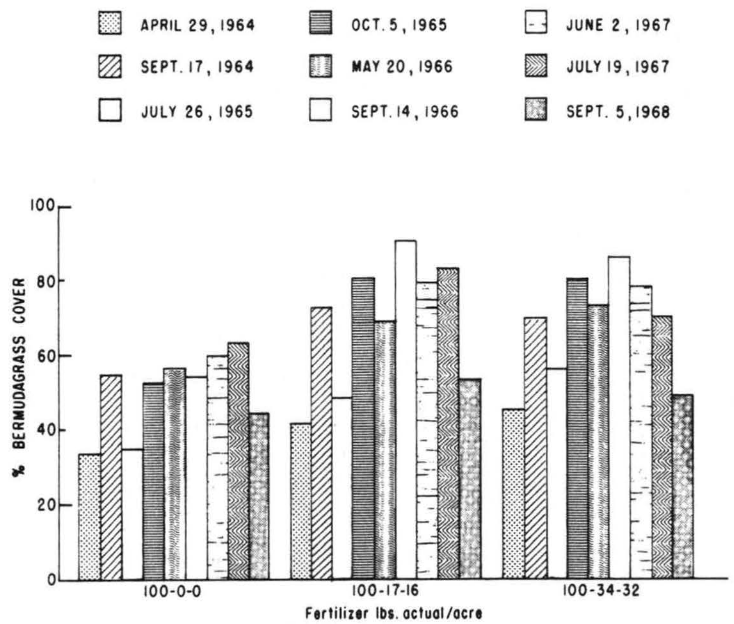


Figure 2-40. The effect of various fertilizers applied April 17, 1964, and retreated June 3, 1965, and June 3, 1966, on the growth of bermudagrass on an east facing cut slope on I-35 three-fourths of a mile south of SH-51 as evaluated on the above dates.

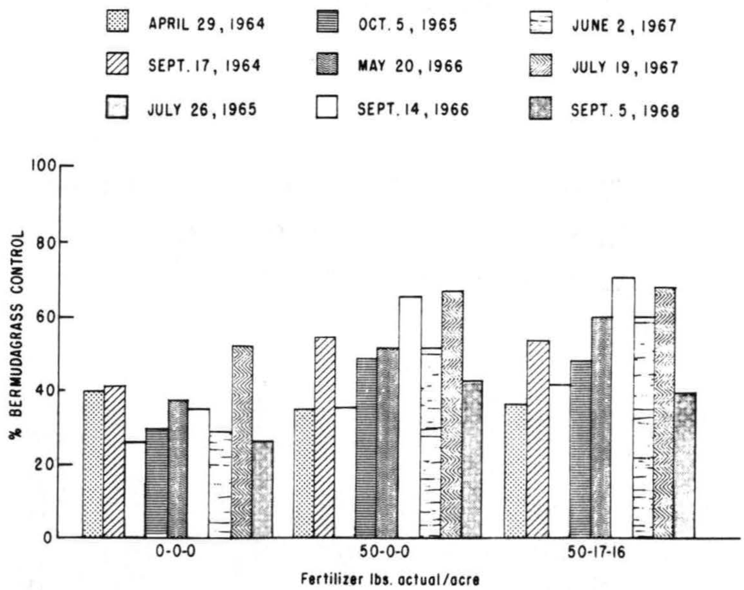


Figure 2-41. The effect of various fertilizers applied April 17, 1964, and retreated June 3, 1965, and June 3, 1966, on the growth of bermudagrass on an east facing cut slope on I-35 three-fourths of a mile south of SH-51 as evaluated on the above dates.

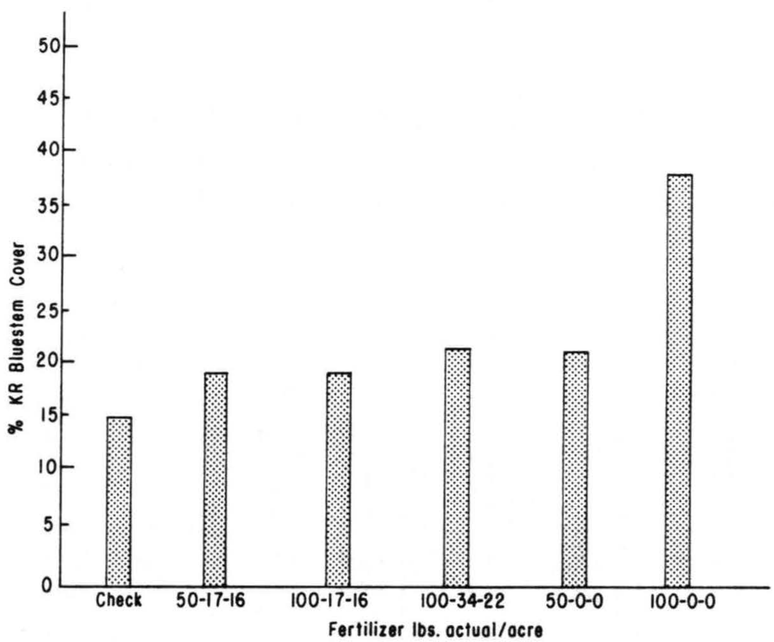
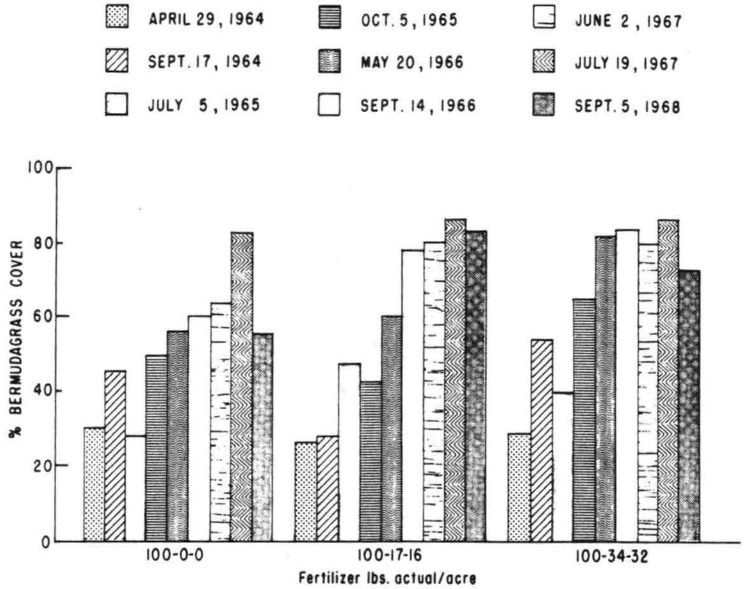
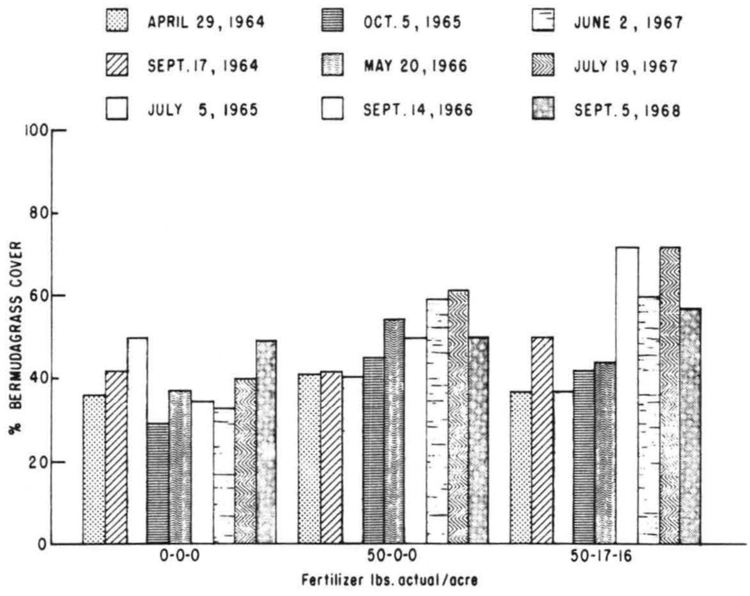


Figure 2-41A (Supplemental to Fig. 2-40 and 2-41). The effect of various fertilizers applied April 17, 1964, and retreated June 3, 1965, and June 3, 1966, on the growth of KR bluestem on an east facing slope on I-35 three-fourths of a mile south of SH-51, as evaluated September 5, 1968.





Figures 2-42 and 2-43. The effect of various fertilizers applied April 18, 1964, and retreated June 3, 1965, and June 3, 1966, on the growth of bermudagrass on a west facing cut slope on I-35 three-fourths of a mile south of SH-51 junction as evaluated on the above dates.

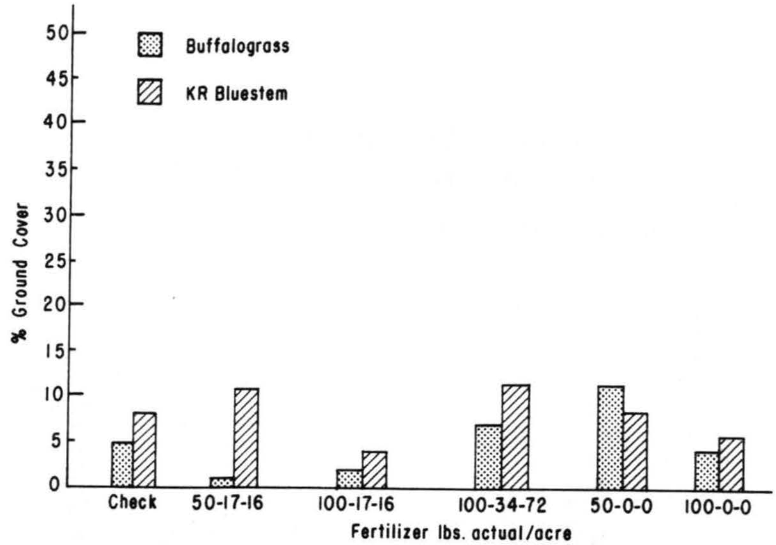


Figure 2-43A (Supplemental to Fig. 2-42 and 2-43). The effect of various fertilizers applied April 18, 1964, and retreated June 3, 1965, and June 3, 1966, on the growth of buffalograss and KR bluestem on a west facing cut slope on I-35 three-fourths of a mile south of SH-51 junction as evaluated September 5, 1968.

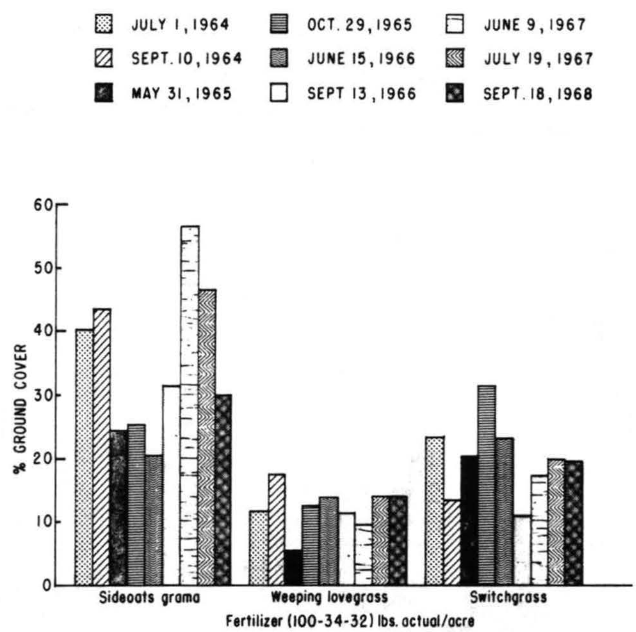
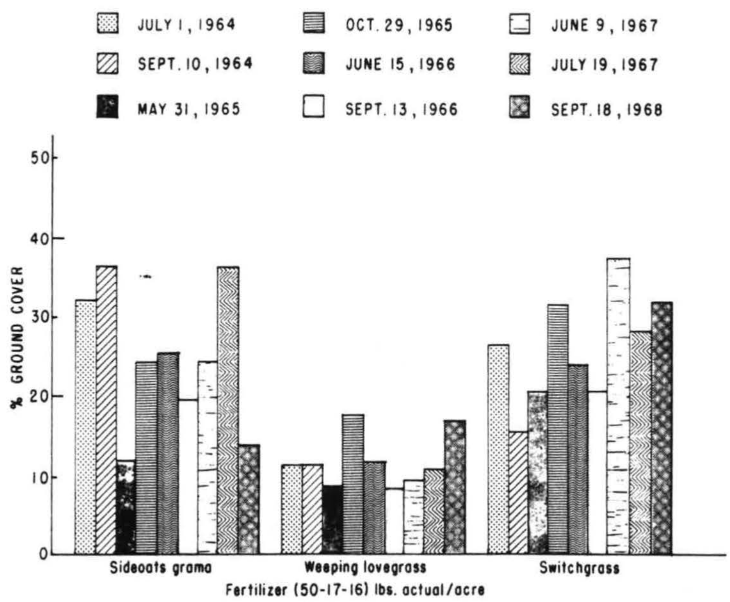
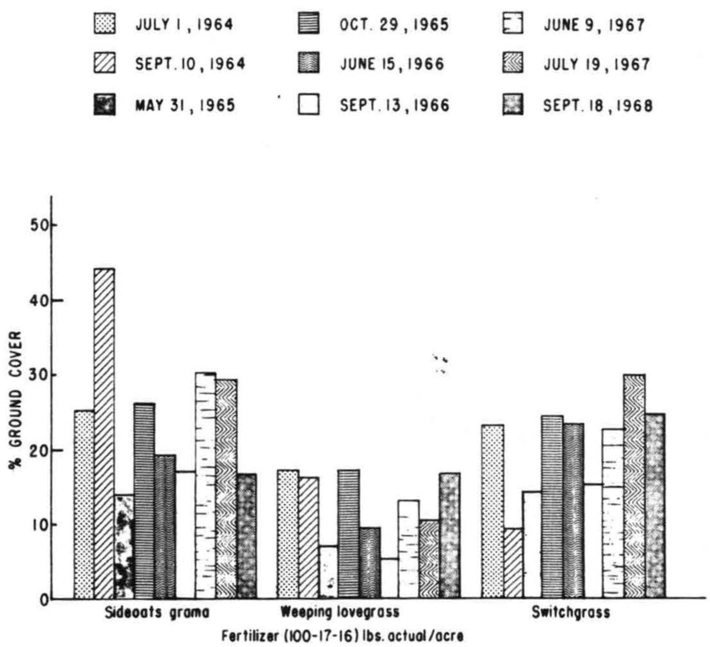
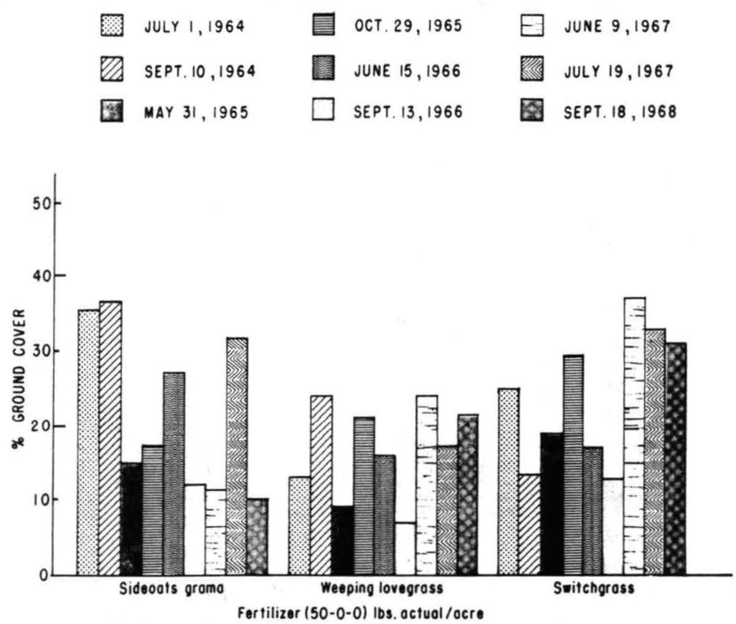


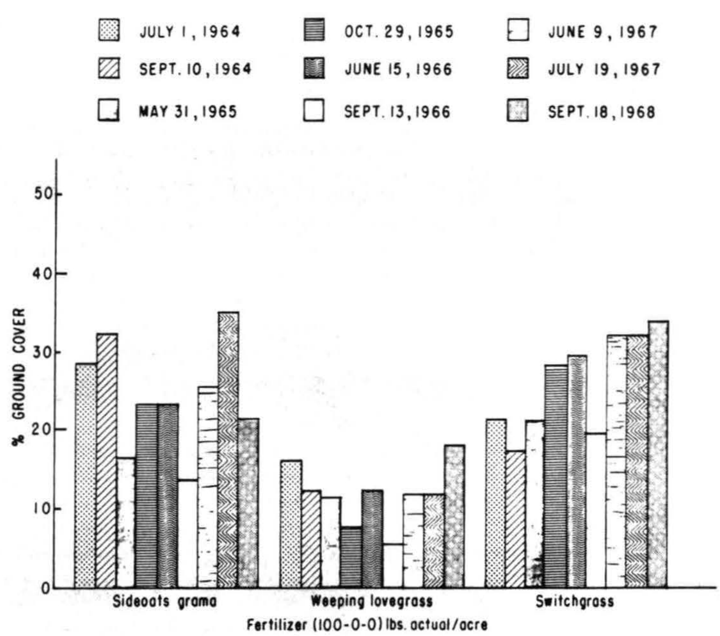
Figure 2-44. The effect of various fertilizer rates applied May 13, 1964, and retreated June 2, 1965, and June 15, 1966 on the growth of three grasses on a north facing cut slope 3.6 miles east of SH-58 on I-40 near Hydro, Oklahoma as evaluated on the above dates.





Figures 2-45 and 2-46. The effect of various fertilizer rates applied May 13, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 3.6 miles east of SH-58 on I-40 near Hydro, Oklahoma as evaluated on the above dates.





Figures 2-47 and 2-48. The effect of various fertilizer rates applied May 13, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 3.6 miles east of SH-58 on I-40 near Hydro, Oklahoma as evaluated on the above dates.

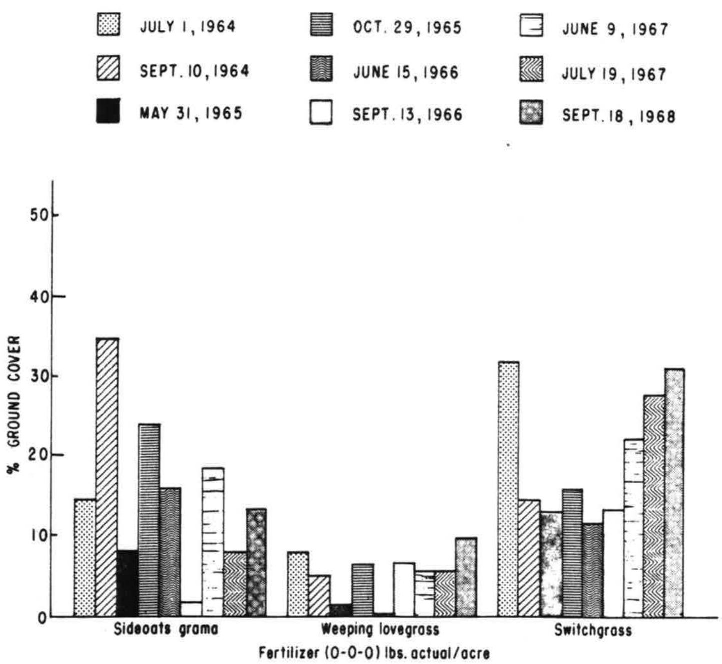


Figure 2-49. The effect of various fertilizer rates applied May 13, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 3.6 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

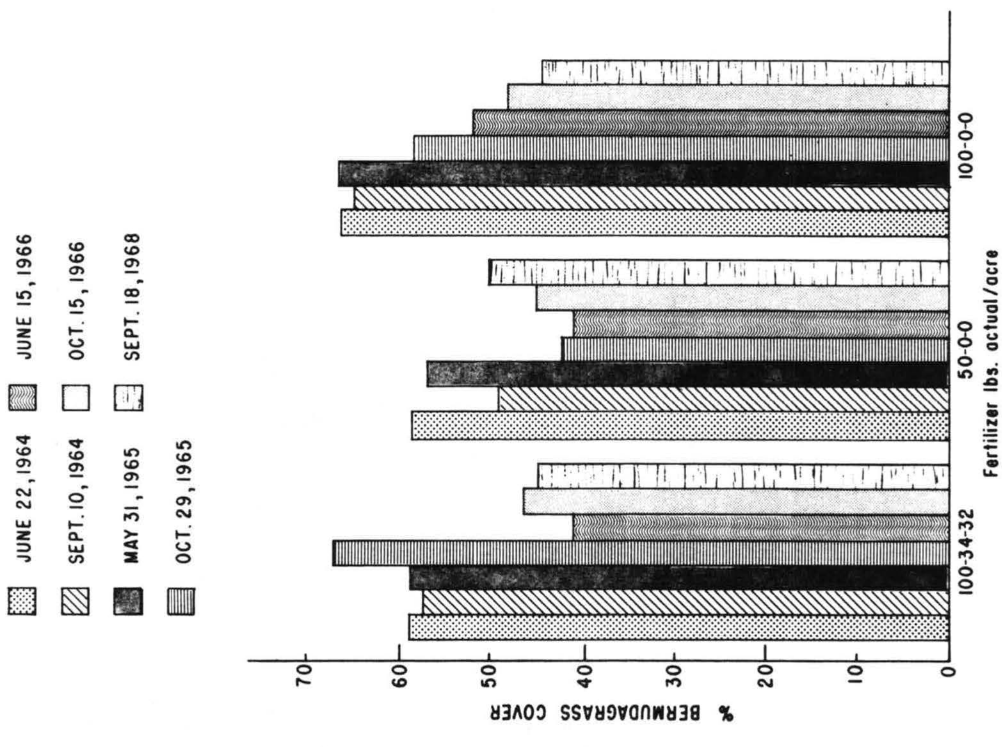


Figure 2-50. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of bermudagrass on a north facing fill slope 4.2 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

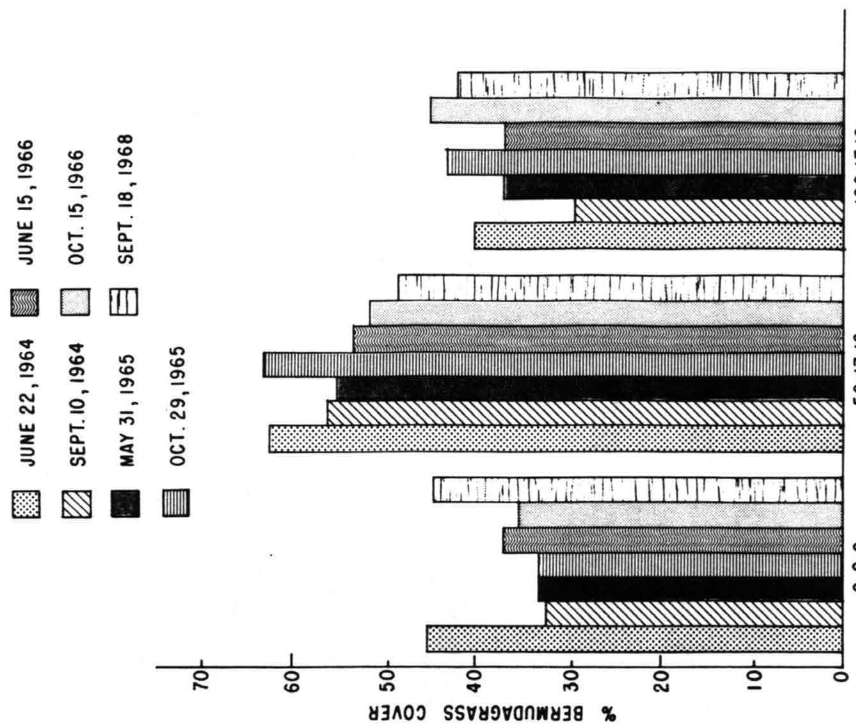


Figure 2-51. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of bermudagrass on a north facing fill slope 4.2 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

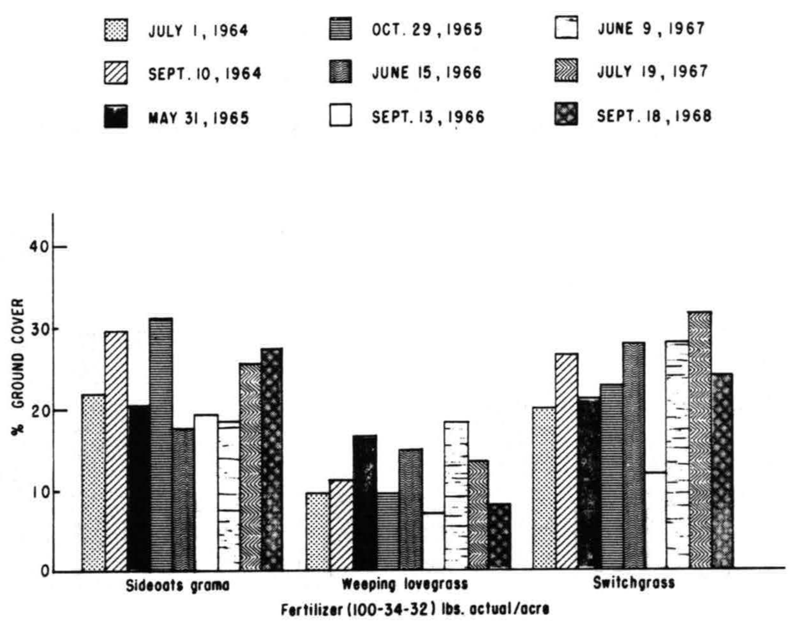
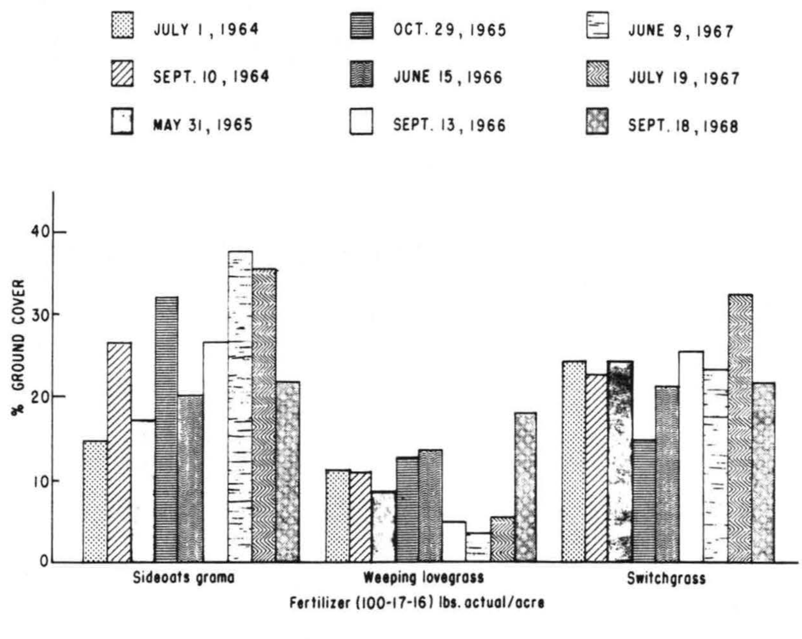
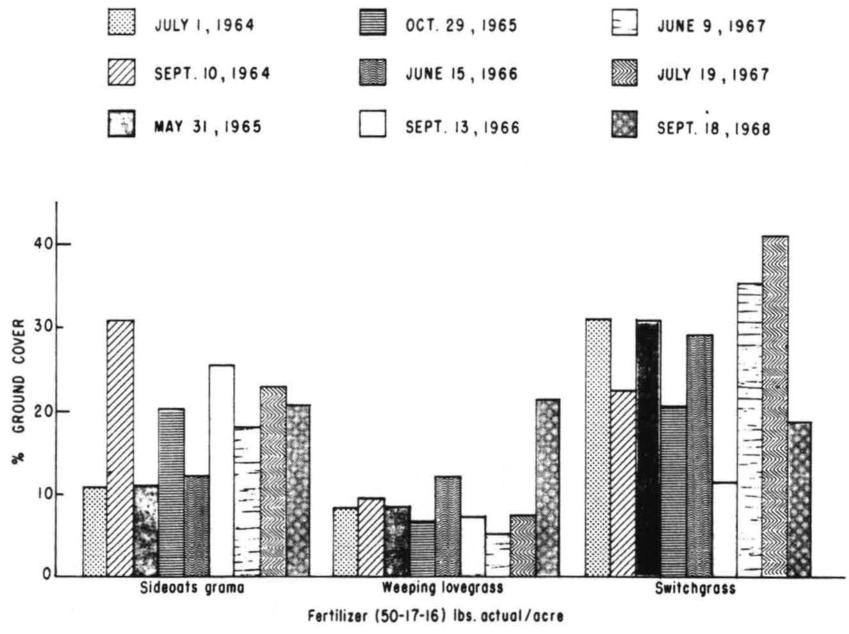
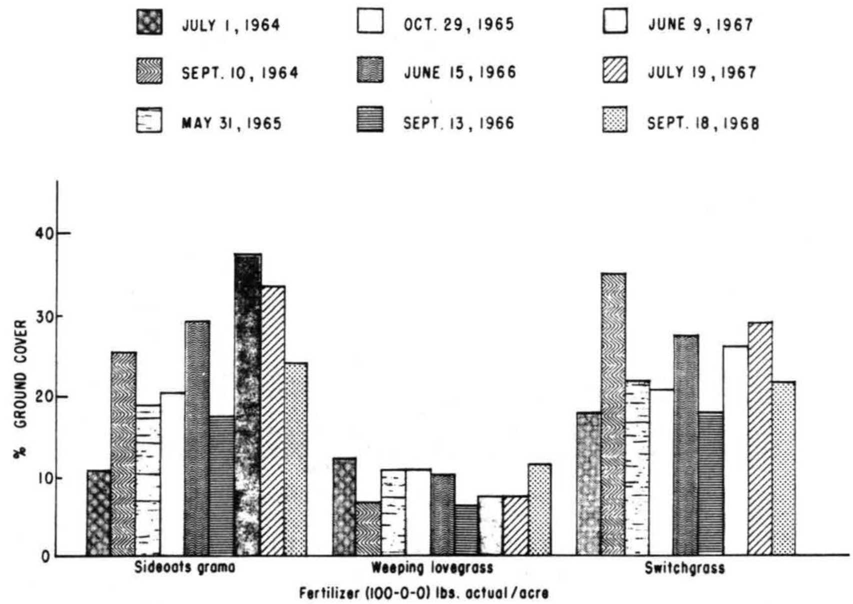


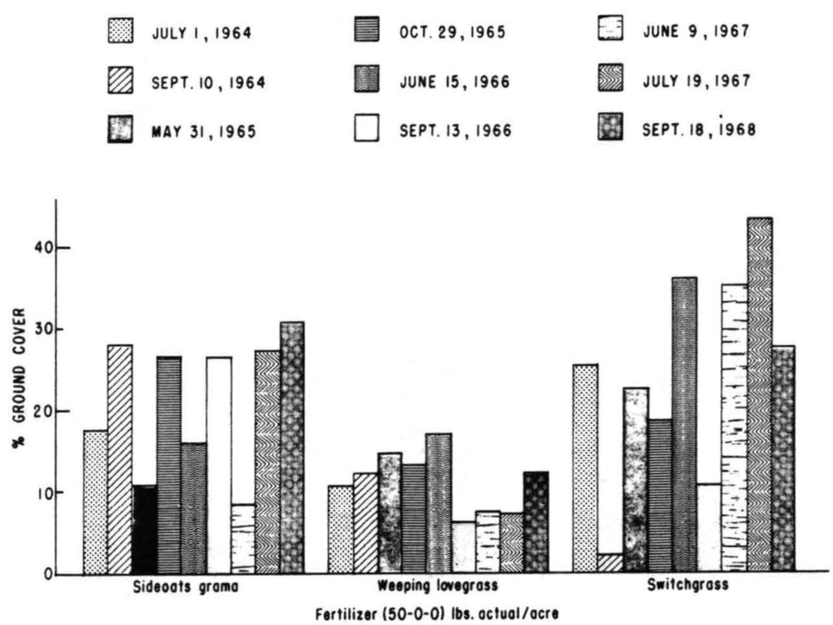
Figure 2-52. The effect of various fertilizer rates applied May 13, 1964, and retreated June 3, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.





Figures 2-53 and 2-54. The effect of various fertilizer rates applied May 13, 1964, and retreated June 3, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.





Figures 2-55 and 2-56. The effect of various fertilizer rates applied May 13, 1964, and retreated June 3, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

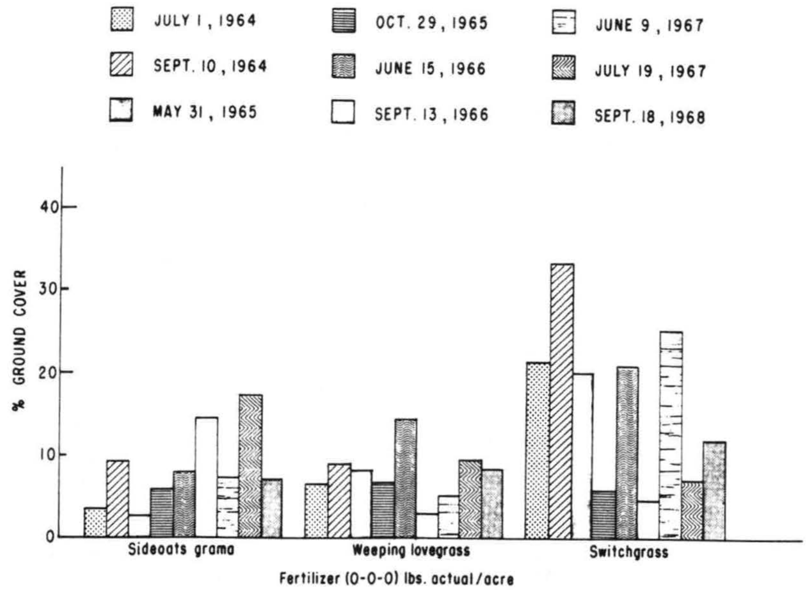


Figure 2-57. The effects of various fertilizer rates applied May 13, 1964, and retreated June 3, 1965, and June 15, 1966, on the growth of three grasses on a north facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

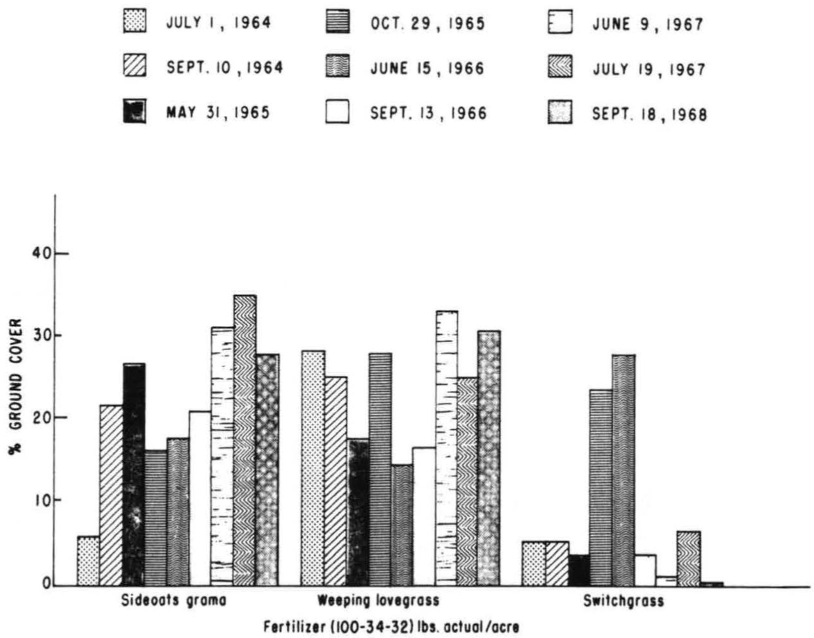
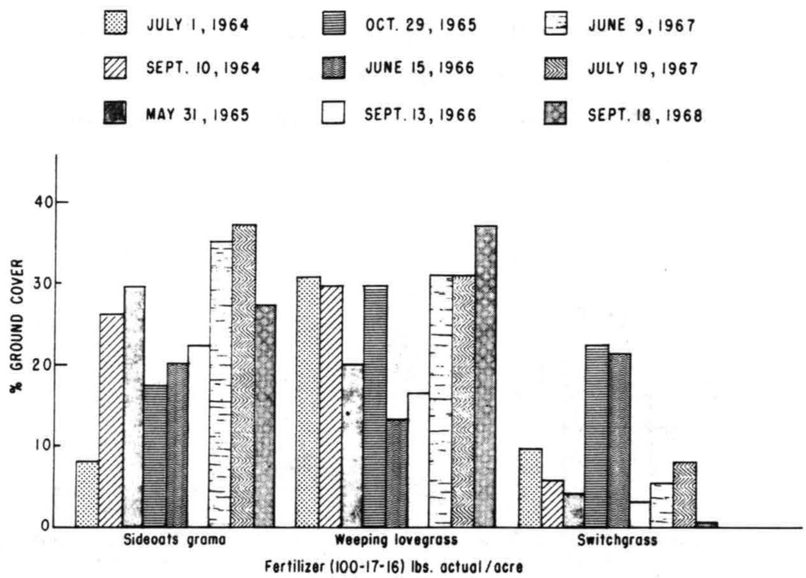
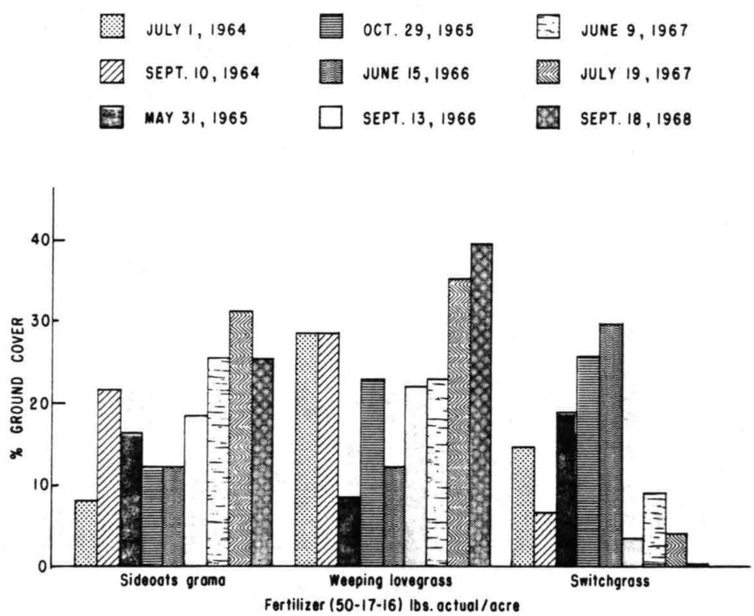
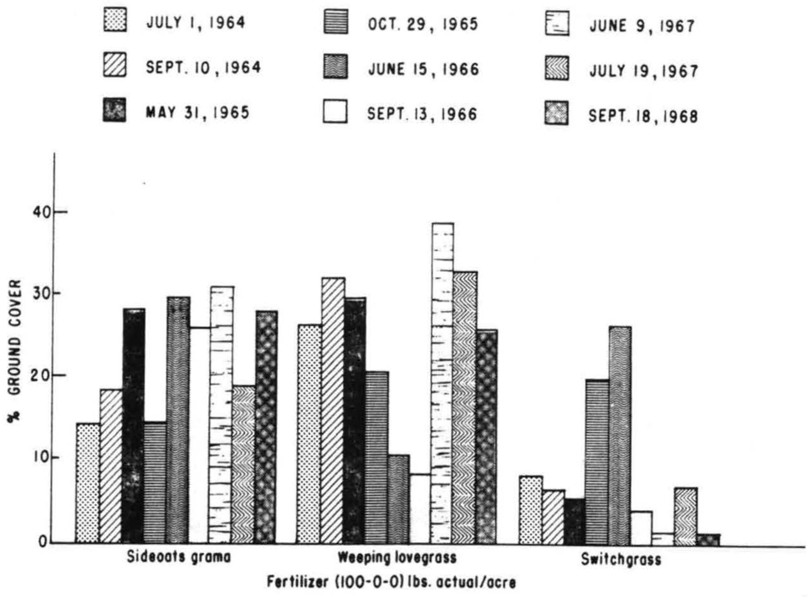


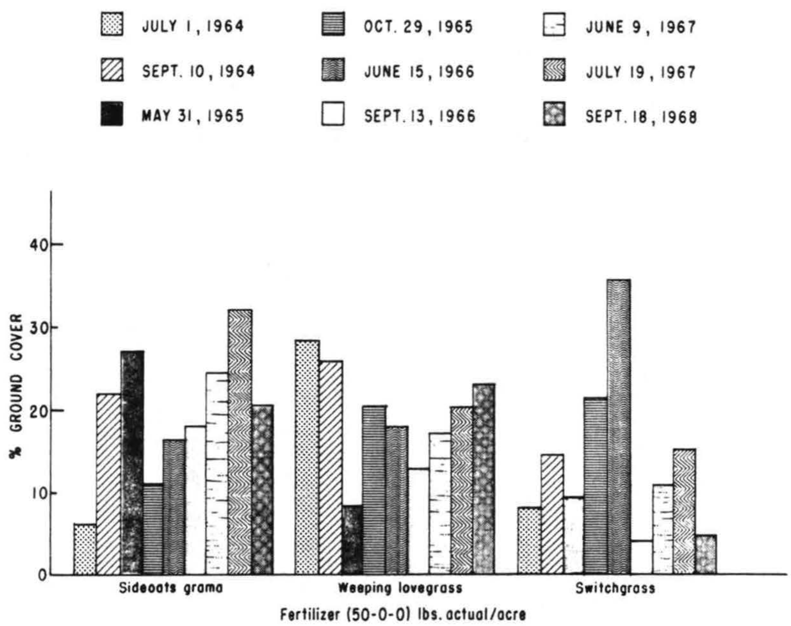
Figure 2-58. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a south facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.





Figures 2-59 and 2-60. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a south facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.





Figures 2-61 and 2-62. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a south facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

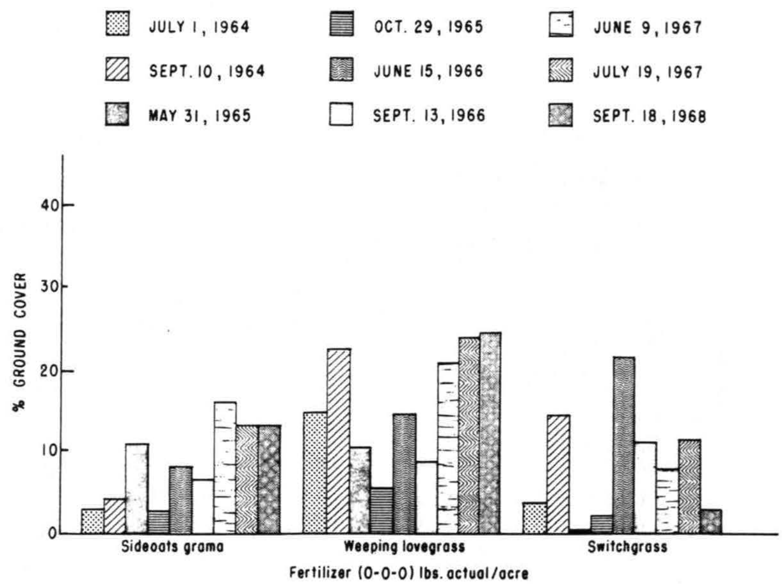


Figure 2-63. The effect of various fertilizer rates applied May 20, 1964, and retreated June 2, 1965, and June 15, 1966, on the growth of three grasses on a south facing cut slope 4.5 miles east of SH-58 on I-40 near Hydro, Oklahoma and evaluated on the above dates.

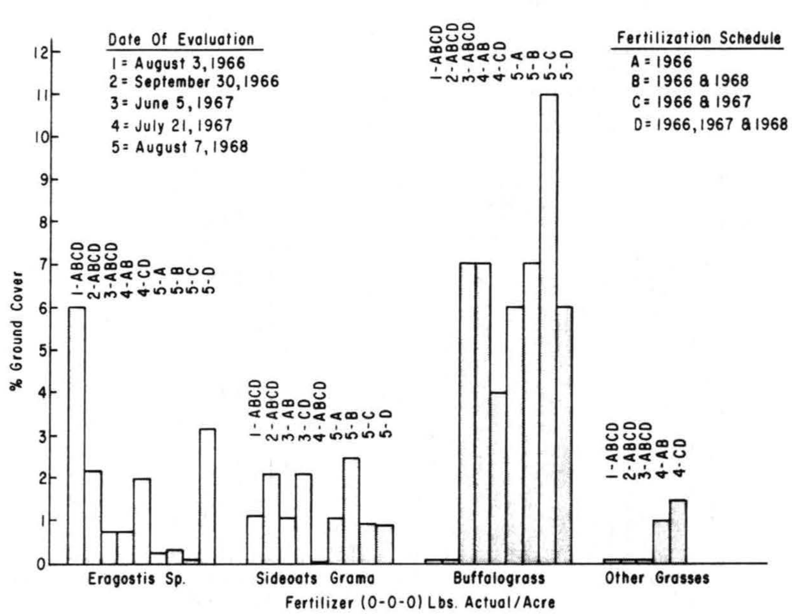
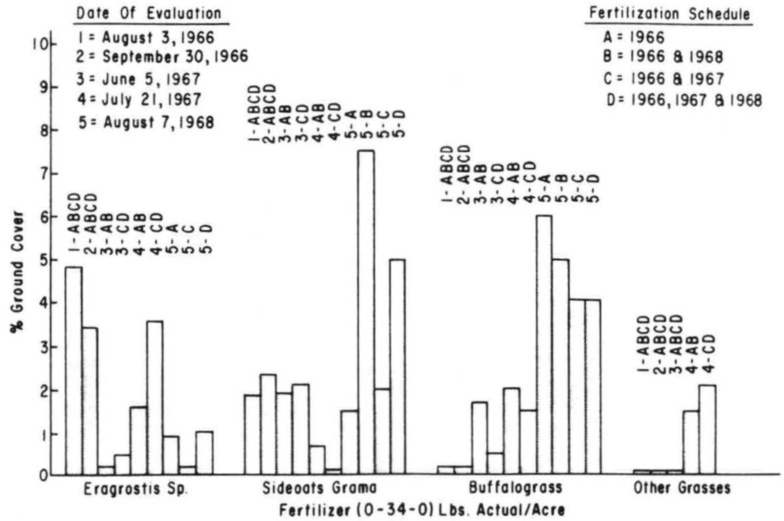
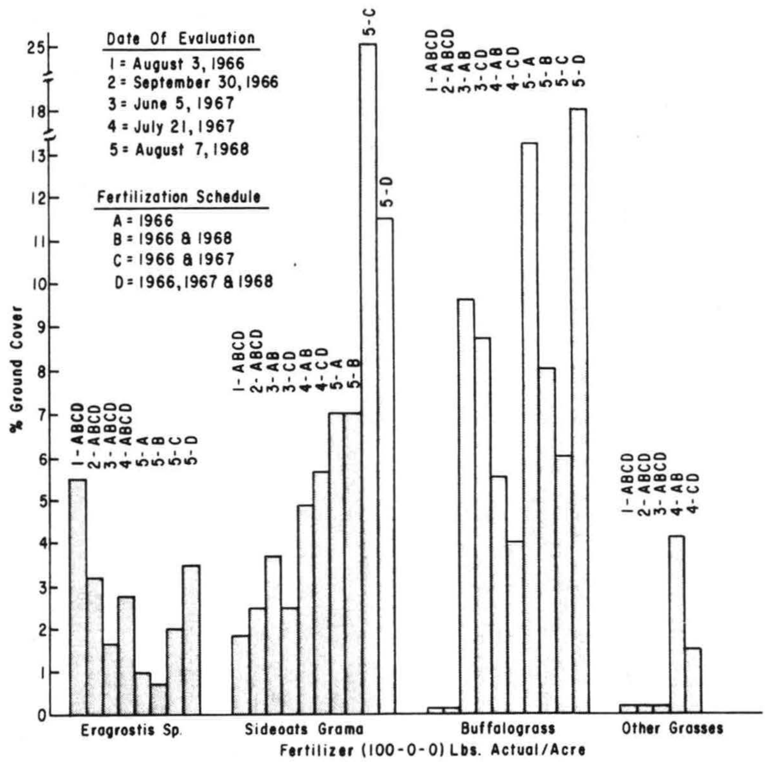


Figure 2-64. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on a west facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again July 21, 1967 and evaluated on the above dates.





Figures 2-65 and 2-66. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on a west facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again July 21, 1967 and evaluated on the above dates.

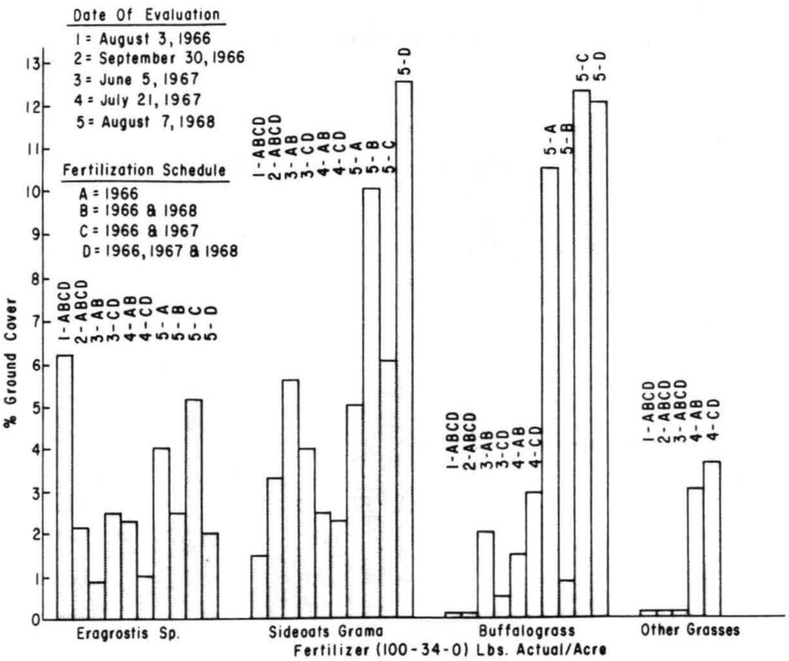


Figure 2-67. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on an west facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again on July 21, 1967 and evaluated on the above dates.

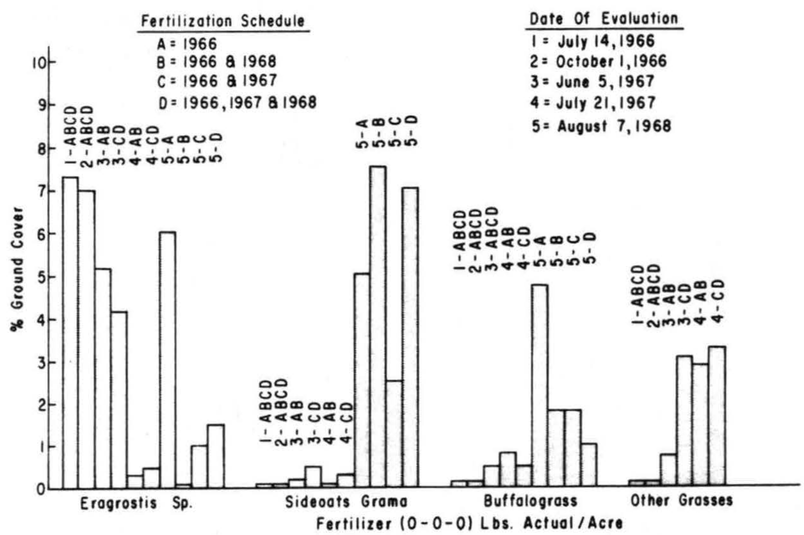
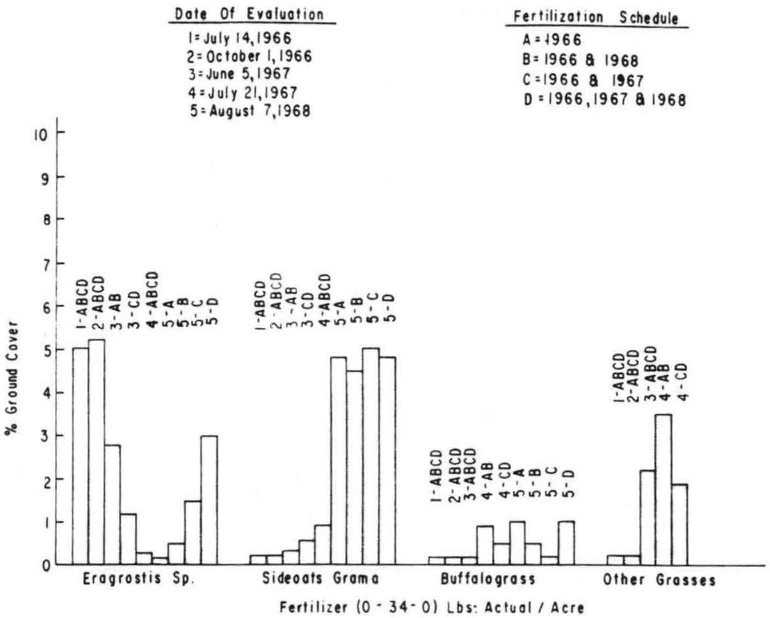
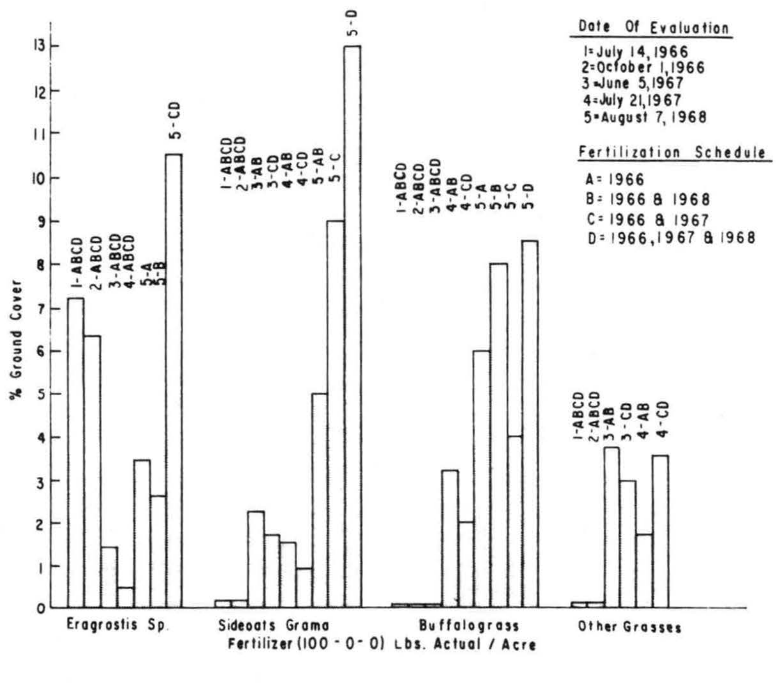


Figure 2-68. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on a east facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again July 21, 1967 and evaluated on the above dates.





Figures 2-69 and 2-70. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on an east facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again on July 21, 1967 and evaluated on the above dates.

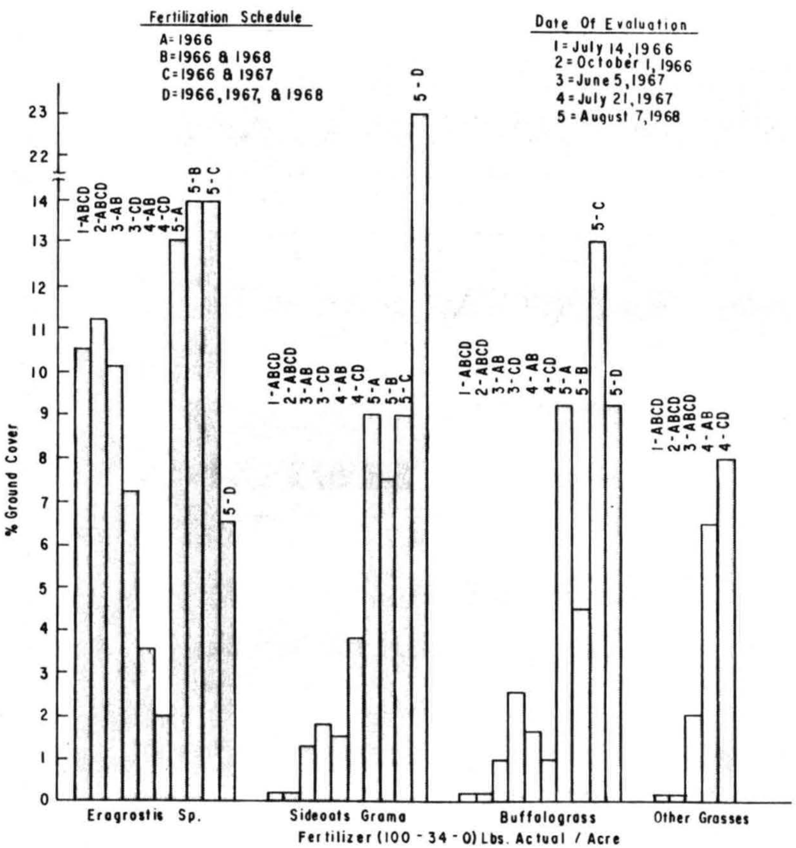


Figure 2-71. The effect of various fertilizer rates and frequency of application on the growth of several grasses for erosion control on SH-34 on an east facing cut slope seven miles north of US-64 west of Alva, Oklahoma. Fertilizers were applied July 14, 1966, and again on July 21, 1967 and evaluated on the above dates.

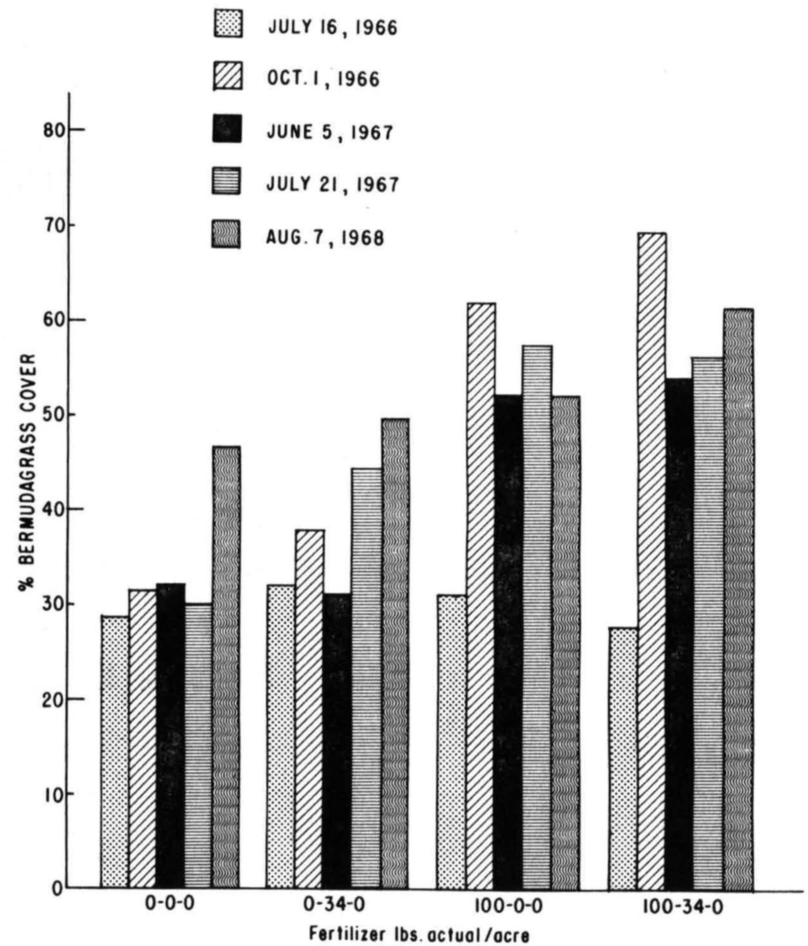


Figure 2-72. The effect of various fertilizers applied July 14, 1966, and again on July 21, 1967, on the growth of bermudagrass on an east facing fill slope on SH-34, 6.8 miles north of US-64 west of Alva, Oklahoma as evaluated on the above dates.

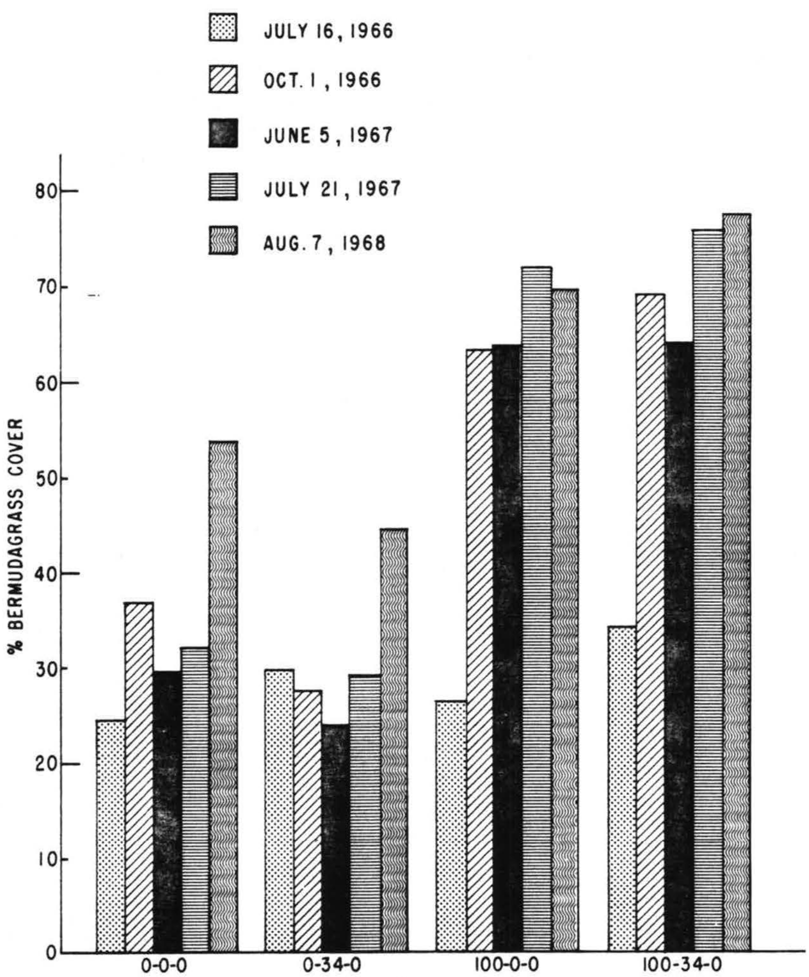


Figure 2-73. The effect of various fertilizers applied July 14, 1966 and again on July 21, 1967, on the growth of bermudagrass on a west facing fill slope on SH-34, 6.8 miles north of US-64 west of Alva, Oklahoma as evaluated on the above dates.

PART III

WEED CONTROL AND ERADICATION

WEED CONTROL AND ERADICATION
ON OKLAHOMA HIGHWAYS

RECOMMENDATIONS

The evaluation of herbicides for the most effective and economical means of weed control on the highway system is a continuous process. Numerous herbicides currently available and combinations of these have been only partially evaluated, some of which could be more effective and economical than the ones currently recommended. Each year new herbicides are developed and should be evaluated immediately if maximum efficiency and economy in weed control on the highway system is to be achieved.

Recommendations for weed control and eradication based upon these initial findings must be subject to revision with the accumulation of additional data. The evaluations of various herbicides for weed control and eradication on Oklahoma highways obtained in these preliminary investigations serve as the bases for these recommendations. All chemicals currently recommended for weed control and eradication on Oklahoma highways are listed in the tables at the end of this section.

BROADLEAF WEED AND ANNUAL GRASS CONTROL

1. Sanbur control. The post-emergence herbicides ammonium methanearsonate (AMA), calcium acid methyl arsonate (CMA), monosodium acid methanearsonate (MSMA), and disodium methanearsonate (DSMA) each with one retreatment 7 to 20 days after the initial application are equally effective in the control of sandburs on Oklahoma highways. A surfactant should be added at the rate of one percent by volume to those materials that do not contain a surfactant in the manufacturers formulation. These herbicides should be applied in enough water to make 40 gallons of solution per acre plus 0.4 gallon of surfactant as needed. In these experiments only MSMA was formulated with a surfactant by the manufacturer. Based upon actual plant count in these investigations, although not statistically different AMA consistently seemed to be more effective than the other organic arsonates. If competitive with the other herbicides in cost per acre, AMA would be suggested for sandbur control on Oklahoma highways.

2. General Broadleaf Weed and Annual Grass Control. The pre-emergence application of atrazine is recommended first for the control of both broadleaf weeds and annual grasses commonly found on Oklahoma highways. Diuron, although not as widely effective in these experiments, is the second pre-emergence herbicide recommended for both broadleaf weed and annual grass control. To control only broadleaf weeds the herbicides Banvel (dicamba), 2,4-D amine, and 2,4,5-T amine are recommended. Based on cost per acre for effective broadleaf weed control 2,4-D generally would be the least expensive. Caution should be exercised in the use of the phenoxy compounds particularly such as 2,4-D, and 2,4,5-T in areas where sensitive crops or trees are growing to avoid drift. It would be advisable to apply these

herbicides when there is no wind or at least when the wind velocity is less than 10 miles per hour.

3. Alfalfa and Sweetclover Control. The herbicides recommended for the control of these plants on the highway system are 2,4-D amine, 2,4,5-T amine, and Banvel (dicamba).

JOHNSONGRASS CONTROL

The organic arsonate herbicides disodium methanearsonate (DSMA), and monosodium acid methanearsonate (MSMA) are recommended for the selective control of johnsongrass on Oklahoma highways. These herbicides should be applied two or three times per year in enough water to make 40 gallons of solution per acre plus a surfactant at the rate of one percent by volume with those materials that do not contain a surfactant in the manufacturers formulation. In these experiments 0.4 gallon of surfactant was added to the DSMA solution only as MSMA was formulated with a surfactant by the manufacturer. Plants that appear the year following treatment are primarily from seed and will require repeated applications of the herbicide as before for control. The most effective control of johnsongrass will be obtained with these herbicides when the plants are treated when 12 to 18 inches tall and actively growing, and when the sun is bright and the temperature is 80° F or higher.

SOIL STERILIZATION

The herbicides recommended for the suppression of all plant growth especially bermudagrass on shoulders and under guardrails of the Oklahoma highway system are bromacil, borocil, prometone, TCA Inhibited, Borea T-10, and a combination of TCA and bromacil.

Table 1. Suggested Chemicals for Broadleaf Weed and Annual Grass Control.

Herbicide	Chemical	Form[1]	% Active Ingredient	Pounds or gallons of Commercial Material Per Acre
Atrazine+++ (Pre-Em)	2-chloro-4-Ethyl-amino-6-isopropyl-amino-5-triazine	WP	80	3.75 lbs.
Picloram+ (Tordon) (Pre-Em)	4-Amino-3,5,6-trichloropicolinic acid	L	4 lbs./gal.	1 pint
Diuron+++ (Pre-Em)	3(3,4-dichlorophenyl)-1,1-dimethylurea	WP	80	3.75 lbs.
Banvel+ (Post-Em)	2-methoxy-3,6-di-chlorobenzoic acid	L	4 lbs./gal.	1 quart
2,4-D Amine+	Dimethylamine salt of 2,4-dichlorophenoxy acetate	L	4 lbs./gal.	1 quart
2,4,5-T Amine+	Triethylamine salt of 2,4,5-trichlorophenoxy acetate	L	4 lbs./gal.	1 quart
CMA++	Calcium acid methanearsonate	L	1 lb./gal.	3.7 gal.
MSMA++	Monosodium acid methanearsonate	L	2 lbs./gal.	1 gal.
AMA++	Ammonium methanearsonate	L	1.4 lbs./gal.	2.7 gal.
DSMA++	Disodium methanearsonate	WP	63	4.0 lbs.

[1] L = Liquid
WP = Wettable Powder

All herbicides are to be applied in 40 gallons of solution per acre.

\+ Broadleaf weed control
++ Annual grass control
+++ Broadleaf weed and annual grass control

Table 2. Suggested Chemicals for Complete Plant Supression on Oklahoma Highway Rights-of-Way.

Herbicide	Chemical	Form[1]	% Active Ingredient	Amount of Commercial material Acre	Foot Mile
Borocil	Disodium Tetraborate Pentahydrate, & Disodium tetraborate decahydrate, and Bromacil	G	98	334 lbs.	40.4 lbs.
Bromacil	(5-bromo-3-sec-butyl-6-methyluracil)	WP	Hyvar X-Ws 50	48 lbs.	5.8 lbs.
			Hyvar X 80	30 lbs.	3.6 lbs.
TCA Inhibited	Sodium Trichloroacetate	SP	91	165 lbs.	20.0 lbs.
TCA & Bromacil	(See Above)	SP & WP	(See Above)	88 & 20 (of 50%) lbs.	10.6 & 2.4 lbs.
				88 & 12.5 (of 80%) lbs.	10.6 & 1.5 lbs.
Borea T-10	Sodium metaborate and monuron	WP	58	862 lbs.	104.3 lbs.
Prometone	2-methoxy-4-6-bis-(isopropylamino)-S-triazine	L	2 lbs./gal.	20 gal.	2.5 gal.

[1] G = Granular
WP = Wettable Powder
SP = Soluble Powder
L = Liquid

All herbicides are to be applied in a minimum of 100 gallons of water per acre.

Table 3. Cost Per Acre or Foot Mile of Recommended Herbicides Based on Current Wholesale Prices for Small Quantities[1].

Herbicide	Percent Active	Amount of Commercial Material/Application: Acre	Amount of Commercial Material/Application: Foot Mile	Cost: Acre	Cost: Foot Mile
SELECTIVE WEED CONTROL[2]					
Atrazine	80%	3.75 pounds		$ 9.26	
Picloram	4 lbs./gal.	1.0 pints		$ 7.75	
Diuron	80%	3.75 pounds		$ 9.56	
Banvel	4 lbs./gal	1.0 quart		$ 6.25	
2,4-D amine	4 lbs./gal	1.0 quart		$ 0.75	
2,4,5-T amine	4 lbs./gal.	1.0 quart		$ 2.41	
CMA	1 lb./gal.	3.7 gallons		$ 12.40	
MSMA	4 lbs./gal.	3.0 quarts		$ 3.56	
AMA	1.4 lbs./gal.	2.7 gallons		$ 16.17	
DSMA	63%	4.0 pounds		$ 1.44	
SOIL STERILANTS[3]					
Borocil	98%	334 lbs.	40.4 lbs.	$140.28	$16.97
Bromacil	Hyvar X-WS 50%	48 lbs.	5.8 lbs.	$165.60	$20.01
	Hyvar X 80%	30 lbs.	3.6 lbs.	$154.50	$18.54
TCA Inhibited	91%	165 lbs.	20.0 lbs.	$ 58.58	$ 7.10
TCA & Bromacil	(See above)	88 lbs. & 20 lbs. 50%	10.6 lbs. & 2.4 lbs. 50%	$ 31.24 & $69.00 = $100.24	$ 3.76 + $8.28 = $12.04
		88 lbs. & 12.5 lbs.80%	10.6 lbs. & 1.5 lbs. 80%	$ 31.24 & $64.38 = $95.62	$ 3.76 & $7.73 = $11.49
Borea T-10	58%	862 lbs.	104.3	$214.98	$26.06
Prometone	2 lbs./gal.	20 gallons	2.5 gallons	$165.00	$20.63

[1] Cost per pound generally is much less when purchases are made of truckload, carload, or tank car lots.
[2] These herbicides should be applied in enough water to make 40 gallons of solution per acre.
[3] These herbicides should be applied in water in a minimum of 100 gallons of solution per acre or 12.1 gallons per foot mile.

INTRODUCTION

The highway program in Oklahoma requires modern, efficient methods of establishment and maintenance of desirable vegetation on the rights-of-way if it is to provide maximum services with a minimum of expenditure. Herbicides are being used successfully in most areas to minimize hand labor in the maintenance programs around guardrails and signposts, to reduce the frequency of mowing, and to improve the effectiveness and reduce the costs of weed control on grass-covered areas. Current maintenance programs in some states utilize herbicides for the control of broadleaved plants and weedy grasses, sometimes in combination with growth inihibitors. These modern programs commonly reduce maintenance costs while improving the stand of grass.

A problem common to many states is the infestation of roadsides with johnsongrass (Sorghum halepense L.). This plant, considered a noxious weed on most crop land, spreads by seeds and underground stems (rhizomes), and is detrimental to both the appearance of roadsides and the drivers' safety. To combat this problem highway maintenance divisions frequently employ mechanical mowing of johnsongrass as a means of control. Mowing newly established lawns regularly with a lawn mower and at the usual low height of clip, will require one or more years to effectively reduce or eliminate johnsongrass from the area. Such a frequency of mowing applied to the vast highway system would make the cost for the control of johnsongrass prohibitive in most cases even with maximum effectiveness.

Soil sterilization, or complete plant suppression, is currently employed in many highway maintenance programs for more effective and economical maintenance of guardrails and shoulders. The complete suppression of plant growth is used for the protection of highways where severe damage could result if plant growth in the asphaltic surface or shoulders were not controlled.

METHODS OF WEED CONTROL

Two methods are generally available for the control of weeds in grass-covered areas, these are mechanical or chemical. Both methods have been used with success. The principal objective here is to use the most satisfactory and economical method for weed control on the various highway areas.

Successful weed control by mechanical methods generally is restricted to those weeds that perpetuate themselves by seed. With careful timing of the mowing operations to coincide with the flowering periods of the many weeds, the repeated removal of the flowers, preventing seed production should ultimately eliminate the weeds from an area. Failure to remove all flowers, however, enables the common roadside weeds to produce enough seed to perpetuate the problem for many years. Weeds that reproduce vegetatively must be mowed frequently enough to prevent flowering, and the normal production and accumulation of foodstuffs to ultimately lead to starvation and death of the plant while preventing seed production for future infestation. A proposed mowing schedule for weed control on Oklahoma highways where mechanical methods are deemed best is included in the appendix.

The improper use of mechanical equipment for supposedly weed control purposes adds greatly to the maintenance costs of the highway system. The exposure of bare soil on slopes from the tearing action of the tractor, and the destruction of desirable grasses on the flats from frequent and low mowings, permits and encourages weed invasion and growth along the highway. Soil erosion is accelerated by these practices also.

Weed control with chemicals has become a common practice in recent years. Generally this is the most satisfactory and economical method of weed control. These weed-killing chemicals, or herbicides are classified according to their effects on plants. Contact herbicides kill those plant parts that are covered with the chemical. They are effective against annual weeds but only burn off the tops of perennial plants. Herbicides such as 2,4-D that can be absorbed by either the roots or above-ground parts and moved throughout the plant system upsetting the plant's growth and metabolic processes are referred to as systemic herbicides, growth regulators, or translocated herbicides. Chemicals that prevents the growth of green plants when present in the soil are referred to as soil sterilants.

WEED CONTROL AND ERADICATION

The principal objectives of this part of the research project were to find the most satisfactory and economical methods to control weeds on the Oklahoma highway system. To achieve these objectives several factors were to be evaluated. The major items of concern involved chemical and mechanical means of weed control, and were to concentrate on:

A. Chemical control of weeds.

1. The evaluation of selective herbicides for weed control.
2. The evaluation of non-selective herbicides for soil sterilization.
3. The evaluation of chemical growth regulators as a substitute for mowing.

B. Mechanical control of weeds.

1. Determination of proper time to mow for weed control in each geographical area of the state.
2. Determination of height and frequency of mowing required for weed control in various highway areas.

FINDINGS AND CONCLUSIONS

The research results in this report, even though involved with a common investigation, will be presented as three separate studies for the purpose of clarity and convenience.

SECTION I

BROADLEAF WEED AND ANNUAL GRASS CONTROL

More than 12,000 miles of state and federal highways and roads are presently maintained by the Oklahoma Department of Highways. Mowing represents one of the major maintenance costs annually for this highway system. In the five-year period 1960-1964 an average of 244,608 acres were mowed annually at an average cost of more than $843,000.00 per year. The loss of life in mowing accidents each year is of even greater importance.

The availability of herbicides that are effective in the selective control of many plants, offers possibilities for their successful and economical use in the maintenance of Oklahoma's highways. The use of chemicals for weed control in combination with an effective fertilization program (see Part I, "Causes and Control of Soil Erosion on Oklahoma Highways," and Part II of this research report, "Maintenance of Vegetative Ground Covers on Oklahoma highways") would enhance soil stabilization for erosion control and beautification while substantially reducing costs of highway maintenance.

With tourism being encouraged in Oklahoma, all aspects of our highway system must be considered if the program is to be successful. As our state and federal roads and highways are increasingly used, the rest areas and roadside parks will be visited more frequently. Roadsides also will be utilized to a greater extent either from intentional rest stops or for emergency purposes.

Weeds which are to be found on the highway rights-of-way generally detract from the overall beauty of the area, or may inflict physical pain if brought into contact with a person. One such plant of this nature is the sandbur (*Cenchrus pauciflorus* Benth.) which produces numerous spiny burs that virtually renders an area unusable by man or animal.

In 1966 the first of several experiments was initiated to evaluate pre-emergence and post-emergence herbicides and their combinations for the selective control of sandburs on the roadside in bermudagrass turf.[1] The results of these herbicides evaluations for the selective control of sandburs in bermudagrass turf are shown in Figures 3.1 through 3.5.

The post-emergence herbicides were significantly more effective than the pre-emergence materials tested, or a combination of the two for sandbur control as shown in Figure 3.5. The organic arsonates, AMA (ammonium methanearsonate) at 3.8 pounds active ingredient (a.i.)/acre showed complete sandbur control with MSMA (monosodium acid methanearsonate) at 2.0 lbs., DSMA (disodium methanearsonate) at 2.5 lbs., and CMA (calcium acid methyl arsonate) at 3.7 lbs. a.i./acre equally as effective.

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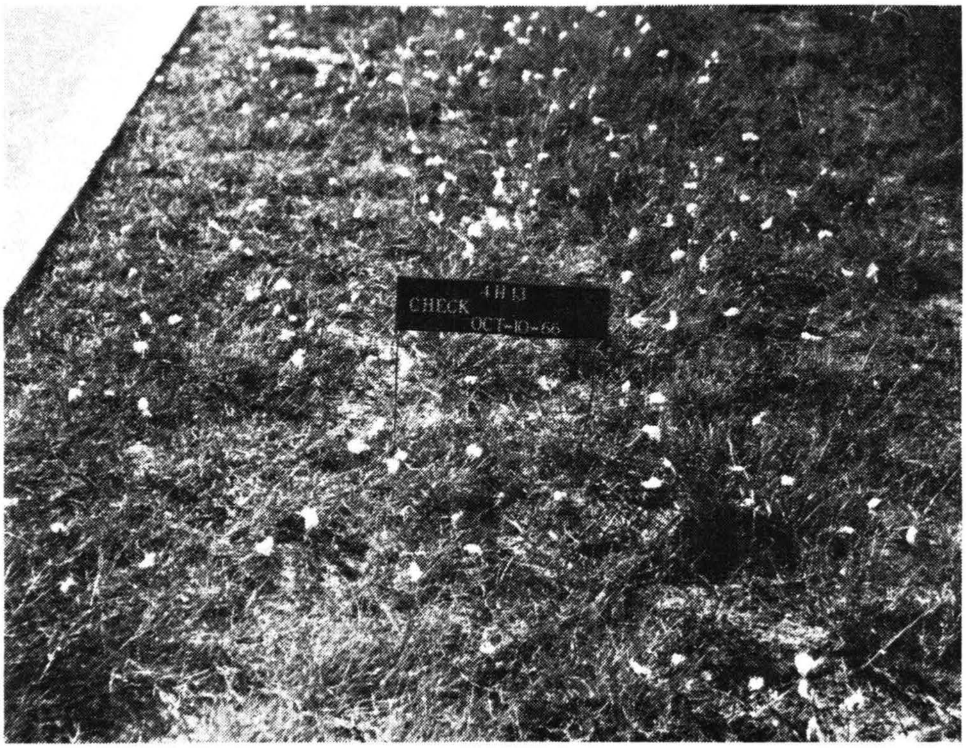
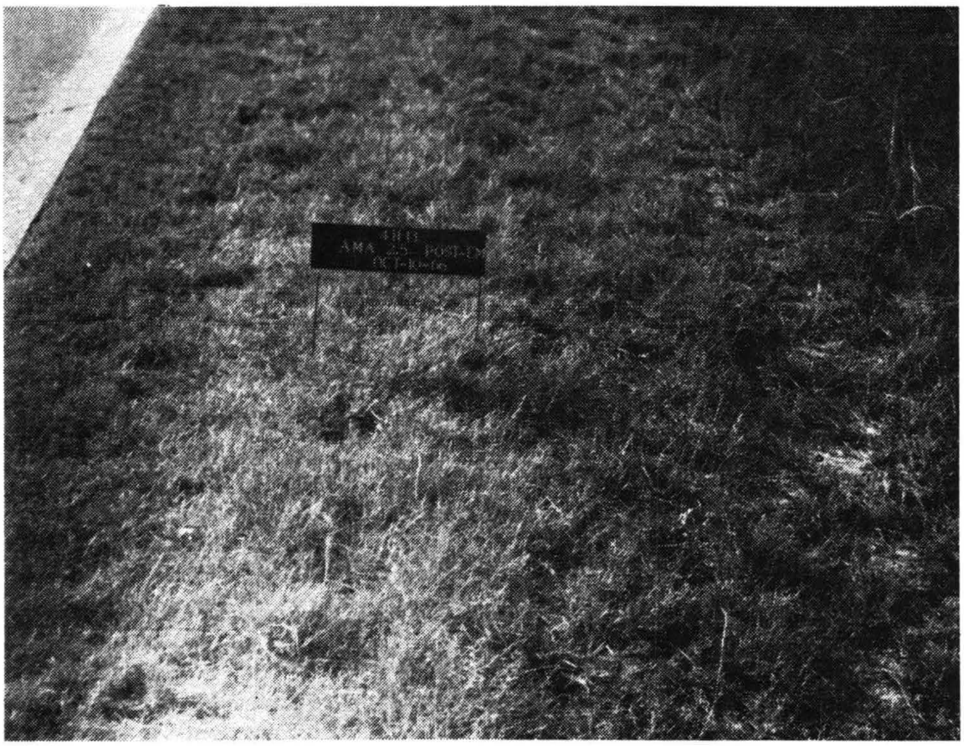
[1] Roach, Gary W. 1968. Herbicide Evaluation for the Selective Control of Sandbur in Bermudagrass Turf. Unpublished M.S. Thesis. Oklahoma State University.





Sandburs (white marks in top photo) that infest roadsides and rest areas can be effectively controlled (bottom photo) with selective herbicides that permits the erosion resistant bermudagrass to take over.

Broadleaf weeds and annual grasses (top photo) can be effectively controlled on the highway system (bottom photo) with selective herbicides that permits the erosion resistant grasses to thrive and reduces the total costs of maintenance.

Only the post-emergence herbicides from the initial investigation were evaluated in subsequent studies along with two other post-emergence materials, another organic arsonate DSMA (disodium methanearsonate) at 2.5 lbs., and Monex (MSMA plus Diuron [3(3,4-dichlorophenyl)-1,1 dimethylurea] at 1.2 lbs. a.i./acre. The post-emergence herbicides used in 1966 and 1967 were all satisfactory in the control of sandburs in bermudagrass turf with only slight differences indicated between materials or rates.

An experiment was initiated in 1966 to evaluate several pre-emergence and post-emergence herbicides for the control of broadleaf weeds and annual grasses in central Oklahoma at the intersection of US-177 and US-62 west of Meeker. The results of this investigation are shown in Figures 3.6, 3.7, and 3.8. The pre-emergence herbicides Tordon (picloram), Tritac-D, Diuron, Fenac, and Simazine applied in March 1966, and the post-emergence material Banvel (dicamba) applied two months later in May produced more than 75 percent control of all broadleaf weeds when evaluated several months later in mid-August. The control of annual grasses was not as good as expected with a 72 percent control with Diuron at 3 lbs. a.i./acre as the most effective treatment.

A similar experiment to the one described above was started a year earlier (1965) on US-270 near Shawnee. The objectives of this experiment were to evaluate pre-emergence and post-emergence herbicides for broadleaf weed and annual grass control, and to measure residual activity if any of the herbicides to determine the application frequency required for satisfactory weed control. Each experimental unit or plot was entirely treated with its respective herbicide in 1965, but in 1966 only two-thirds of the original area was treated making a total of two treatments for this portion and in 1967 one-third of the original treatment area was retreated making a total of three successive annual treatments on this part. The results of these evaluations are shown in Figures 3.9 through 3.21. The treatments were evaluated twice in each of the years 1965 (two bars at the left for each entry), and 1966 (two center bars), but only once in 1967 as indicated by the one bar at the extreme right for each entry. An arbitrary figure of 90 percent was established as the minimum for satisfactory broadleaf weed and annual grass control.

Atrazine at 3 lbs. a.i./acre applied as a pre-emergence herbicide in early April as shown in Figure 3.9, provided about 96 percent control of all broadleaf weeds and 97 percent control of the annual grasses as shown by the bar graph at the left for each plant group when first evaluated in May 1965. Some seven weeks later 92 percent of the broadleaf plants and 96 percent of the annual grasses had been controlled as shown by the second bar graph from the left for each plant group. One year later this herbicide still controlled 55 percent of the broadleaf weeds and 62 percent of the annual grasses when evaluated on May 23, 1966 as shown by the lower portion of the center bar graph for each entry. That portion of the experimental unit (two-thirds of the original area) that was retreated about six weeks earlier provided control for 95 percent of the broadleaves and 88 percent of the annual grasses as shown by the upper portion of the central bar graph. When these two areas were again evaluated in August 1966 that area treated 16 months earlier showed 67 percent control of the broadleaf weeds and 87 percent of the annual grasses as shown by the lower portion of the second bar graph from the right. The retreated portion of this plot provided 93 percent control each for the broadleaf plants and the annual grasses as shown in the upper portion of the second bar graph from the right.

In 1967 the area treated two years before still exhibited about 73 percent broadleaf weed control and 61 percent of the annual grasses as shown in the lower portion of the right-hand bar graph. The area treated in April of the two previous years showed a control of 74 percent of the broadleaves and 83 percent of the annual grasses as depicted by the middle portion of the bar graph on the right. Treatment in April for three consecutive years provided 93 percent control of the broadleaf weeds and 89 percent of the annual grasses as shown by the upper portion of the right-hand bar graph.

The pre-emergence application of atrazine at 3.0 lbs. a.i./acre generally is adequate for the control of 90 percent or more broadleaf weeds and annual grasses as indicated by these data. A possibility exists of building-up enough residual activity after 3 or more annual treatments to permit treatments on alternate years or perhaps even less frequently. The full evaluation of the residual activity of these herbicides could not be achieved in the three years of this experiment. Picloram at the rate of 0.5 lbs. a.i./acre will provide 90 percent or better control of the broadleaf weeds commonly found on the highway system as indicated by these data. After three consecutive applications of atrazine at 1.5 lbs. a.i./acre, simazine at 3.0 lbs., or diuron at 4 lbs. a control of 90 percent or more of the broadleaf weeds was attained just as produced by one application of atrazine at 3.0 lbs. a.i./acre, or 0.5 lbs., of picloram. Two of the most effective herbicides for the selective control of broadleaf plants and weedy grasses that Sinkler[2] found in his preliminary investigation, tritac and tritac-D were closely approaching the 90 percent level of broadleaf weed control after three annual applications of 2.0 lbs. a.i./acre. The post-emergence application of those herbicides at the rates evaluated in this experiment was generally not satisfactory for the control of broadleaf weeds or annual grasses on the highway system.

The weeds found to be most common in early spring in the experiment on US-270 near Shawnee in central Oklahoma were henbit (*Lamium amplexicaule*), woolly plantain (*Plantago purshii*), and vetch (*Vicia* spp.). The weeds most commonly found in mid-summer at this location were perennial ragweed (*Ambrosia psilostachya*), haplopappus (*Haplopappus ciliatus*), lespedeza (*Lespedeza japonica*), buttonweed (*Diodia teres*), conyza (*Conyza canadensis*), Buffalo bur (*Solanum rostratum*), annual bromegrasses (*Bromus* spp.), hairy crabgrass (*Digitaria sanguinalis*), and triple-awned grass (*Aristida oligantha*).

[2] Sinkler, Max Dee, 1966. Herbicide Evaluation for Weed Control on Oklahoma Highways. Unpublished M.S. Thesis. Oklahoma State University.

Two plants that are common in appearance on the roadsides and medians of numerous Oklahoma highways are alfalfa (Medicago sativa), and yellow sweetclover (Melilotus officinalis). These important forage and pasture legumes are becoming weed problems for the Highway Department and serve to justify frequent and costly mowing of the highway system.

In 1967 two investigations were initiated to evaluate several herbicides for the selective control of alfalfa and sweetclover.[3] One experiment was located on SH-51 west of Stillwater in north-central Oklahoma, the other was on SH-81 south of Kingfisher. The materials found to be most effective in this preliminary investigation for the control of alfalfa and sweetclover were 1.0 lb. a.i./acre of 2,4-D or 2,4,5-T, 7.5 lbs. of Fenac, or 0.75 lbs. of Banvel (dicamba).

In summary, the herbicides found to be most effective for the control of sandburs on the Oklahoma highway system are the post-emergence materials the organic arsonates, AMA (ammonium methanearsonate) at 3.8 lbs. a.i./acre. MSMA (monosodium methanearsonate) at 2.0 lbs. a.i./acre, DSMA (disodium methanearsonate) at 2.5 lbs. a.i./acre, and CMA (calcium acid methyl arsonate) at 3.7 lbs. a.i./acre. These herbicides must be reapplied at least once at a 7 to 20 day interval for the most effective control.

The pre-emergence application of atrazine at the rate of 3.0 lbs. a.i./acre was found to be effective for the control of both broadleaf weeds and annual grasses commonly found on Oklahoma highways. Broadleaf weeds were effectively controlled also with the pre-emergence herbicides picloram (Tordon) at 0.5 lbs. a.i./acre, and diuron at 3.0 lbs. a.i./acre. The post-emergence herbicide dicamba (Banvel) at 1.0 lbs. a.i./acre, was effective in the control of broadleaf weeds in these experiments. Diuron applied as a pre-emergence herbicide at the rate of 3.0 lbs. a.i./acre was found to be effective in the control of annual grasses on the highway system.

Alfalfa and sweetclover were effectively controlled with the post-emergence applications of 1.0 lb. a.i./acre of 2,4-D or 2,4,5-T, 7.5 lbs. a.i./acre of Fenac, or 0.75 lbs. a.i./acre of dicamba (Banvel).

SECTION II

SOIL STERILIZATION

Soil sterilization is commonly used in several state highway maintenance programs for more efficient and economical maintenance of guardrails, signposts, and shoulders. In these areas all plant growth is suppressed for the safety of the motoring public, and the preservation of the highway through the protection of the asphaltic shoulders. The potential benefits of these chemicals are offset in some cases by the improper application of the materials, or by the downslope movement from

[3] Bhrommalee, Narong. 1968. The Effect of Six Herbicides on the Control of Alfalfa and Sweetclover on Oklahoma Highways. Unpublished M.S. Thesis. Oklahoma State University.

Vegetative growth in asphaltic shoulders (top photo) and under guardrails can be effectively controlled with herbicides (bottom photo) that sterilize the soil.

the place of application, killing all vegetation, thereby leaving the soil exposed to erosion and perhaps ultimate loss of the highway at that point.

The plant species commonly found and oftentimes quite difficult to control on Oklahoma highways are common bermudagrass (Cynodon dactylon) and johnsongrass (Sorghum halepense). These become troublesome on the highway shoulders particularly when the rhizomes or shoots break through the asphaltic surface and open a channel for water penetration into the roadbed.

Six experiments were conducted to evaluate various soil sterilants for the elimination of all vegetation, especially bermudagrass on highway shoulders and around guardrails. These investigations were located generally through the central portion of the state. One experiment was located near Chickasha on the shoulders of SH-92. Twelve chemicals were applied initially in March 1965 and the plots retreated in June 1966 at one-half the initial rate. The results of this investigation are shown in Figures 3.22 through 3.28. Although the complete evaluation of these chemicals could not be made in the brief period of this investigation the results tend to indicate the most effective materials for the suppression of bermudagrass are: bromacil at the rate of 24 lbs. a.i./acre, TCA at 150 lbs., urox at 300 lbs., Monobor-chlorate at 1740 lbs., borocil at 327 lbs., Borea T-10 at 500 lbs., and a combination of 80 lbs. a.i./acre of TCA and 5 lbs. of bromacil. These data are generally in agreement with those obtained by Sinkler who found the most promising herbicides for soil sterilization to be chlorea, Monobor-chlorate, ureabor, Borea T-10, borocil, prometone, and TCA. He also noted that lateral movement from the treated band occurred consistently with chlorea, Borea T-10, monuron, bromacil, urox, and ureabor.

An evaluation of chemicals for the complete suppression of plant growth under guardrails was initiated in June 1964 on US-270 near Wewoka. The results of these evaluations are shown in Figures 3.29 through 3.36. Little precipitation occurred at this location in 1964 until August, after which a total of 15 inches was recorded by the middle of November. These data although only preliminary for the complete evaluation of these materials indicate those treatments and rates that were most effective in the kill of bermudagrass also moved downslope killing an area larger than the originally intended band of soil sterilization with the exception of TCA at the rate of 250 lbs./acre. The chemicals that seemed to be the most effective were Borea T-10 at 250 lbs. a.i./acre, urox at 300 lbs., monuron at 52 lbs., ureabor at 1200, bromacil at 20 lbs., boracil at 218 lbs., and a combination of 65 lbs. of TCA and 8 lbs. a.i./acre of bromacil.

An experiment was initiated in June 1964 to evaluate various chemicals as soil sterilants for the control of bermudagrass principally on SH-51 west of Stillwater in north-central Oklahoma. The results of these evaluations are shown in Figures 3.37 through 3.49. Although the chemicals have not been fully evaluated the most effective materials as indicated by these data were: bromacil at 24 lbs. a.i./acre, urox at 300 lbs., prometone 40 lbs., ureabor 1200 lbs., chlorea 1920 lbs., borocil

218 lbs., the combination of 80 lbs. TCA and 10 lbs. bromacil, and TCA alone at 300 lbs. a.i./acre.

A similar investigation to the one described above was initiated in June 1964 on the shoulders of SH-99 near Drumright. The results of these evaluations are shown in Figures 3.50 through 3.54. Although these chemicals were not fully evaluated these data tend to indicate even though effective in killing bermudagrass in the treated band, the herbicides chlorea, borocil, and urox at all rates tested and the high rate of 1740 lbs. a.i./acre of Monobor-chlorate, monuron, Borea T-10, bromacil, ureabor, prometone, and the combination of bromacil and TCA would be arbitrarily considered unsatisfactory for use on highway shoulders because of the excessive downslope movement that created potential erosion problems. In this experiment prometone at 49 lbs. a.i./acre, urox at 398 lbs., monuron at 24 lbs., and a combination of 12.3 lbs. a.i./acre of bromacil and 98.7 lbs. of TCA all exhibited good plant suppression two years after the initial application.

Another experiment was initiated on SH-99 in June 1965, this one near Wynona in north-central Oklahoma to evaluate several herbicides for use as soil sterilants on highway shoulders. A second application of these materials at one-half the original rate was made in 1966, one year later. The results of these evaluations, although not complete are shown in Figures 3.55 through 3.65. These data indicate the most effective herbicides for the control of bermudagrass particularly in this area are TCA at 150 lbs., urox at 300 lbs., and bromacil at 24 lbs. a.i./acre. The downslope movement of urox at this rate was considered excessive and would be undesirable on slopes such as these.

In December of 1965 an experiment was initiated on US-177 about five miles south of the intersection with US-66 west of Chandler in central Oklahoma to evaluate several chemicals as soil sterilants on highway shoulders and their application in mid-winter. The results of these evaluations although not complete are shown in Figures 3.66 through 3.71. These data indicate the most effective herbicides for the eradication of bermudagrass when applied near the first of the year are Urox HX at 16 lbs. a.i./acre, bromacil at 24 lbs., borocil at 327 lbs., monuron at 64 lbs., and ureabor at 800 lbs. The most downslope movement of chemicals seemed to occur with Borea T-10, ureabor, bromacil, borocil, monuron, urox, and prometone. Sinkler reported chemical movement downslope similar to that found in this experiment.

The herbicides found to be the most effective in the suppression of plant growth especially bermudagrass on shoulders and under guardrails of the Oklahoma highway system are bromacil at 24 lbs. a.i./acre, boracil at 327 lbs., TCA at 150 lbs., Borea T-10 at 500 lbs., and a combination of 80 lbs. TCA and 10 lbs. bromacil. These chemicals and rates alone and in combination possibly will change with further evaluation.

SECTION III

JOHNSONGRASS CONTROL

The abundance of johnsongrass seems to increase each year along Oklahoma highways. When allowed to grow, the plants may become so tall and dense as to restrict the drivers' view on curves, crossings, and intersections. In addition to the driving hazards that may be created by johnsongrass, the plants detract from the general beauty of the area, and serve as a source of infestation into adjacent cropland of this noxious weed. A substantial portion of the mowing costs on Oklahoma highways is expended for the intended control of johnsongrass. Even though this could be accomplished eventually by frequent mowing at low heights, the expense would be prohibitive. The rhizomes ordinarily become extensive and repeatedly send new growth above ground for a long period even when the plants are mowed.

The nature of the rhizomes (underground stems) of johnsongrass is such as to make the plant a persistant perennial. It spreads both by seeds and rhizomes. The control of johnsongrass with a herbicide would normally require either that the herbicide be translocated throughout the plant system, or that the soil be completely sterilized. Although there are several soil sterilants which will kill the rhizomes of johnsongrass, they also will kill the desirable erosion resistant bermudagrass commonly found growing in close association even though sparse.

Two experiments were initiated in August 1963 to evaluate three herbicides for the selective control of johnsongrass on the Oklahoma highway system. The herbicides Monobor-chlorate-D at the rates of 643 and 1089 lbs. a.i./acre, dalapon at 10 and 15 lb. rates, and DSMA at 1.9 and 3.2 lbs. a.i./100 gallons of water applied at a rate to completely wet the foilage were used in the experiments on I-35 south of SH-51 near Mulhall, and on SH-33 west of US-177 intersection near Coyle, both in north central Oklahoma. These were retreated four times in 1964 as deemed necessary for the most effective control. The chemicals and rates used in each experiment are shown in Table 4. In 1964 two additional experiments were initiated. One that was discarded before evaluations could be made was located on SH-18 north of SH-51 intersection near Pawnee in north central Oklahoma. The other was located on US-64 west of Sand Springs in the northeast part of the state. One retreatment was made in the fall of 1964 on the experiment located near Sand Springs. None was made on the experiment located near Pawnee.

The results of these preliminary evaluations of herbicides for the selective control of johnsongrass are shown in Tables 5, 6, and 7. These data as reported by Sinkler indicate the most effective control of johnsongrass was obtained with treatments of Monobor-chlorate, or Monobor-chlorate-D. All herbicide treatments tended to cause a substantial reduction in johnsongrass stands at the end of the treatment period. Mowing did not consistently enhance or inhibit the effectiveness of these herbicides.

Table 4. Dates of Herbicide Application and Surfactants used in 1963 for the Control of Johnsongrass Along State Highway 33 and Interstate 35.

Application Date	Herbicide	Rate/Acre Lbs. A.I.	Surfactant	Rate	Experiment
Aug. 22-25, 1963	Monobor-chlorate-D	643 & 1089/acre	None	--	SH-33
	Dalapon	10 & 15/acre	Dow's Dynawet	0.5%	SH-33
	DSMA	1.9 & 3.2/100 gal.	Dow's Dynawet	0.37%	SH-33
Aug. 26-28, 1963	Same herbicides	Same rates	Same	Same	I-35
October 6, 1963	Dalapon	1/10 gal.	Dow's Dynawet	1%	I-35
	DSMA	1.9/100 gal.	Dow's Dynawet	0.32%	I-35
October 11, 1963	Same	Same	Same	Same	SH-33
May 16, 1964	Dalapon	1/10 gal.	Dow's Dynawet	1%	SH-33
	DSMA	1.9/100 gal.	Dow's Dynawet	0.37%	SH-33
June 23, 1964	DSMA	1.9 & 3.2/100 gal.	Dow's Dynawet	0.37%	I-35
	Dalapon	10 & 15/acre or spot treatment	Dow's Dynawet	1%	I-35
August 6, 1964	DSMA	1.9 & 3.2/100 gal.	Depester Herbicide Surf.	0.2%	SH-33
	Dalapon	10 & 15/acre or spot treatment	Depester Herbicide Surf.	1%	SH-33
	Monobor-chlorate	Spot treatment	None	--	SH-33
August 8, 1964	Same as SH-33	Same as SH-33	Same as SH-33	--	I-35
Sept. 16, 1964	DSMA	1.9 & 3.2/100 gal.	Dow's Dynawet	0.2%	I-35
Sept. 17, 1964	Dalapon	10 & 15/acre	Dow's Dynawet, except plots 1, 13, & 24 with Depester Herbicide Surf.	1%	I-35 & SH-33
	Monobor-chlorate	214 & 428/acre	None	--	I-35 & SH-33
Sept. 22, 1964	DSMA	1.9 & 3.2/100 gal.	Depester Herbicide Surf.	0.2%	SH-33
October 17, 1964	DSMA	1.9 & 3.2/100 gal.	Emulsifying Agent A	1%	I-35 & SH-33
	Dalapon	1 & 2/10 gal.	Emulsifying Agent A	1%	I-35 & SH-33

Table 5. The Effect of Three Herbicides on the Relative Stand of Johnsongrass Reported in Percent in Mowed and Unmowed Plots Following Retreatments in 1964 (Two Retreatments with Dalapon and DSMA, and One with CBM) as Scored on September 18, 1964 in the Test on I-35 near Mulhall Road.

HERBICIDE	RETREATMENT RATE LBS. A.I./ACRE AUGUST 6 & 8, 1964	RELATIVE DENSITY IN PERCENT[1]	
		MOWED	UNMOWED
Check	--	100	81
DSMA	1.9 lbs./acre	75	58
DSMA	3.2 lbs./acre	92	67
Dalapon	10 lbs./acre	67	50
Dalapon	15 lbs./acre	67	33
CBM	Spot treatments	62	69
CBM	Spot treatments	25	50

[1] Treatment differences are significant at the one percent level of probability.

Table 6. The Effect of Three Herbicides on the Relative Stand of Johnsongrass Reported in Percent in Mowed and Unmowed Plots Following Retreatments in 1964 (Two Retreatments with Dalapon and DSMA, and One with CBM) as Scored on September 22, 1964 in the Test on SH-33 near Coyle.

HERBICIDE	RETREATMENT RATE AUGUST 6, 1964 LBS. A.I./ACRE	RELATIVE DENSITY IN PERCENT[2]	
		MOWED	UNMOWED
Check	--	20[1]	43
DSMA	1.9 lbs./100 gal.	22	30
DSMA	3.2 lbs./100 gal.	13	33
Dalapon	10 bls./acre or spot	20	9
Dalapon	15 lbs./acre or spot	12	22
CBM	Spot treatment	10	1
CBM	Spot treatment	8	4

[1] Only two plots, one of which was damaged in 1963.
[2] The treatment differences are significant at the one percent level of probability.

Table 7. The Effect of Four Herbicides on the Relative Stand of Johnsongrass Reported in Percent in Mowed and Unmowed Plots on October 15, 1964, Folowing One Retreatment with Dalapon, DSMA and CMA on October 7, 1964, in the Test on US-64 near Sand Springs.

HERBICIDE	INITIAL RATE LBS. A.I./ACRE	RELATIVE DENSITY IN PERCENT	
		MOWED	UNMOWED
Check	--	100	93
DSMA	1.9 lbs./100 gal.	108	6
DSMA	3.2 lbs./100 gal.	88	7
Dalapon	10 lbs./acre	4	2
Dalapon	15 lbs./acre	1	0
CBM	643 lbs./acre	5	1
CBM	1089 lbs./acre	3	0
CMA	1.5 lbs./acre	100	10
CBM	2.5 lbs./acre[1]	100	4

[1] There are only two replications.

In June 1965 three additional experiments were initiated to further evaluate these and other chemicals for the selective control of johnsongrass. One was located in central Oklahoma on US-177 near Meeker, another near Fort Gibson on SH-80 in eastern Oklahoma, and one on US-64 near Alva in northwest Oklahoma. Two similar investigations were begun in August 1965, one in southeast Oklahoma near Ada on SH-3, and the other in south central Oklahoma on US-270 near Texoma. In June 1966 an experiment was initiated on SH-51 west of Stillwater to evaluate combinations of Monobor-chlorate and bromacil as possible materials for selective, long-lasting control of johnsongrass while permitting the erosion-resistant bermudagrass to survive. The chemicals used and dates of application since 1965 at each location are shown in Table 8.

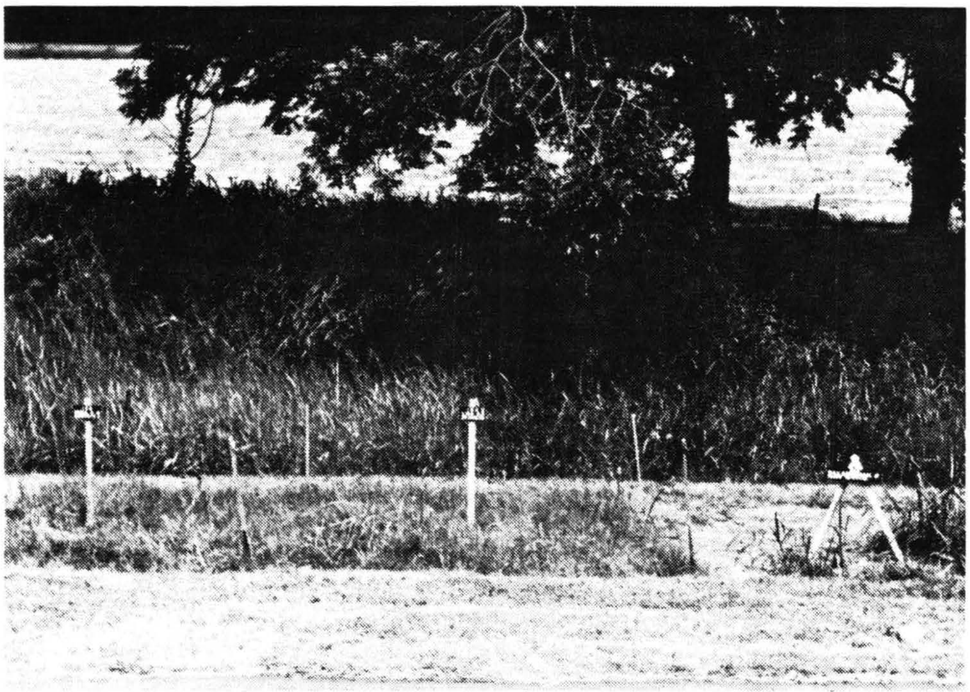
The results of these evaluations of chemicals for the selective control of johnsongrass indicate that many of the herbicide treatments used, such as DSMA, MSMA, dalapon, Monobor-chlorate, and the bromacil-Monobor-chlorate combination produced significant control of johnsongrass, but when considered on the basis of toxicity to the bermudagrass, it was concluded from these data that the organic arsonate herbicides DSMA and MSMA are best suited for the selective control of johnsongrass on Oklahoma highways. The effectiveness of these materials is shown in Table 9. These materials caused only a brief yellowing of the bermudagrass that soon disappeared as new growth was produced.[4] The herbicides DSMA plus 1 percent surfactant, applied at the rate of 2.5 lbs a.i./acre, or MSMA at 3 lbs. a.i./acre, each applied two or three times per year, will produce 90 percent or more control of the existing johnsongrass plants. The plants that appear the year or more after the area was treated are primarily from seed and will require repeated applications of the herbicide as before for control. Bermudagrass that was present even though sparse under the johnsongrass cover and in adjacent areas began to flourish soon after the johnsongrass foliage had been removed. The most effective control of johnsongrass will be obtained when the plants are treated, when 12 to 18 inches tall and actively growing, and when the sun is shining and the temperature is 80° or higher.

[4] Schneider, Richard John. 1968. The Evaluation of Various Herbicides for the Selective Control of Johnsongrass (Sorghum halepense L.) on Oklahoma Highways. Unpublished M.S. Thesis. Oklahoma State University.

Table 8. Herbicides and Rates Used at Ten Locations Since 1965.

HERBICIDE	RATES LBS. A. I.	LOCATION[1]	YEARS APPLIED 1967	1966	1965
Bromacil & MBC	12 & 960/A	Alva		*	*
MBC	500 & 1000/A	Fort Gibson	*	*	*
DSMA	2.5 & 5.0/A	Meeker	*	*	*
Dalapon	10 & 15/A				
CMA	1.5 & 2.5/A				
Diuron	2.0 & 4.0/A				
Prometone 25E	40/A	Ada	*	*	
Dalapon & TCA	12.5/A	Texoma	*	*	
Dalapon	7.5/A				
DSMA	2.5 & 5.0/A				
MSMA	2 & 3/A				
Bromacil & DSMA	3 & 5/A				
Bromacil & MSMA	3 & 3/A				
Diuron & DSMA	3 & 5/A				
Diuron & MSMA	3 & 3/A				
Bromacil & MBC	0 & 250/A	Stillwater		*	
Bromacil & MBC	2 & 250/A				
Bromacil & MBC	4 & 250/A				
Bromacil & MBC	6 & 250/A				
Bromacil & MBC	8 & 250/A				
Bromacil & MBC	0 & 500/A				
Bromacil & MBC	2 & 500/A				
Bromacil & MBC	4 & 500/A				
Bromacil & MBC	6 & 500/A				
Bromacil & MBC	8 & 500/A				
DSMA	3 & 5/100 gal.	Mulhall			*
Dalapon	10 & 15/A	Perkins			*
MBC	1.5 & 2.5/100 sq. ft.				
CMA	1.5 & 2.5/A	Pawnee		*	*
DSMA	3 & 5/100 gal.	Sand Springs			*
Dalapon	10 & 15/A				
MBC	1.5 & 2.5/100 sq. ft.				

[1] All herbicides in each group were applied at each location in the years shown.



Johnsongrass (top photo) commonly found in some areas of the highway system can be effectively controlled with selective herbicides (bottom photo) that permits the erosion resistant bermudagrass to grow up and take over (left center-lower photo).

Table 9. The Percent Control of Johnsongrass Produced by the Two Rates of DSMA for One or More Years at Nine Locations.

LOCATION	RATE A.I.	MOWED			UNMOWED		
		1967	1966	1965	1967	1966	1965
Ada	2.5/A	92			65		
	5.0/A	98			94		
Alva	2.5/A		70	78		82	86
	5.0/A		93	87		62	85
Fort Gibson	2.5/A	93	68	89	99	90	79
	5.0/A	99	92	85	99	94	76
Mulhall	3/100 gal.		55	56		16	63
	5/100 gal.		52	78		36	73
Meeker	2.5/A	95	97	93	88	98	77
	5.0/A	90	99	91	90	98	83
Sand Springs	3/100 gal.		49	54		13	55
	5/100 gal.		41	44		56	59
Pawnee	2.5/A		82	88		88	86
	5.0/A		91	74		88	77
Perkins	3/100 gal.		55	53		52	41
	5/100 gal.		64	81		53	70
Texoma	2.5/A	72	88		57	53	
	5.0/A	93	93		89	81	

PUBLICATIONS

1. Sinkler, Max D., Wayne W. Huffine and Paul W. Santelmann. 1965. Evaluation of Four Herbicides for the Selective Control of Johnsongrass (Sorghum halepense) on Oklahoma Highways. Proc. SWC Abstracts. p. 417.

2. Roach, Gary W., and Wayne W. Huffine. 1967. Herbicide Evaluation for the Selective Control of Sandbur in Bermudagrass Turf. Amer. Soc. Agron. Abstracts p. 57.

FILM

HIGHWAY MAINTENANCE. Description of Maintenance problems created by mowing, and suggested means of selective weed control and soil sterilization based upon research findings. Methods are presented for herbicide applications and the calibration of equipment. (25 minutes on sound. Black & White. 16 mm.).

APPENDIX

Table I. Some Chemicals Included in the Weed Control Experiments.

Herbicide	Chemical, Form, and Concentration
Urox	3-(p-chlorophenyl)-1,1-dimethylurea trichloroacetate
Urox HX	Bromacil (5-bromo-3 sec-butyl-6-methyluracil) granular 4%
Urox-22	(Same as urox) granular 22%
Tordon	4-amino-3,5,6-trichloropicolinic acid liquid 2 lbs. per gallon
Betasan 4E	S-(0,0-diisopropyl phosphorodithioate) of N-(2-mercaptoethyl) benzenesulfonamide liquid 4 lbs. per gallon
Betasan	(Same as Betasan 4E) granular
Banvel	2-methoxy-3,6-dichlorobenzoic acid liquid 4 lbs. per gallon
Chlorea	Sodium chlorate 40% Sodium metaborate 51% Monuron 2.4% granular 93.4%
Prometone	2-methoxy-4,6-bis-(isopropylamino)-S-triazine liquid 2 lbs. per gallon
Dacthal	dimethyl 2,3,5,6,-tetrachloroterephthalate wettable powder 75%
Atrabor 8p	atrazine granular
Fenac	2,3,6-trichlorophenylacetic acid liquid 2 lbs. per gallon
TCA	trichloroacetic acid soluble powder to be applied with water Inhibited 91%
Simazine	2-chloro-4,6-bis (ethylamino)-S-triazine wettable powder 80%
Atrazine	2-chloro-4-ethylamino-6-isopropylamino-S-triazine wettable powder 80%

Appendix Table I. (continued)

Monuron	3-(4-chlorophenyl)-1,1-dimethylurea wettable powder 80%
Diuron	3-(3,4-dichlorophenyl)-1,1-dimethylurea wettable powder 80%
Dalapon	2,2-dichloropropionic acid wettable powder 85%
Casoron	2,6-dichlorobenzonitrile granular
MSMA	Monosodium acid methanearsonate liquid 2 lbs. per gallon
MBC	Sodium metaborate 68% Sodium chlorate 30% (Boron trioxide 23%)
Ureabor	Disodium tetraborate pentahydrate 63.2% Disodium tetraborate decahydrate 30.0% (Boron trioxide 41.4%) Monuron 2%
Borocil	Disodium tetraborate pentahydrate 71.2% Disodium tetraborate pentahydrate 22.8% Bromacil 4.0% granular
Borea T-10	Sodium metaborate 50% Monuron 8% granular
AMA	Ammonium methanearsonate liquid 1.4 lbs. per gallon
DSMA	Disodium methanearsonate wettable powder 63%
2,4D	Dimethylamine salt of 2,4-dichloroacetic acid liquid 4 lbs. per gallon
2,4,5T	Triethylamine salt of 2,4,5-trichloroacetic acid liquid 4 lbs. per gallon

APPENDIX

Table II. Proposed Mowing Schedule for Mechanical Weed Control.

The flowering dates for many common weeds along Oklahoma Highways are in the months of May to September. Weed control solely by mechanical means perhaps would be a questionable practice from the practical and economical standpoint, but when judiciously used could compliment other weed control practices. It is suggested that 2 or 3 mowings a summer be used where weed control is to be done in part by mechanical means.

Since the majority of the plants listed will flower in 2 or more of the months of June, July and August it is suggested that mowing of the highway rights-of-way be scheduled for at least 2 and preferably all 3 months to clip off the flowers before seed can be produced. This practice along with other maintenance operations such as periodic fertilization to stimulate growth of the desired grass and chemical weed control should produce a more weed-free roadside area within a short period of time. It must be remembered that weeds are not the cause of poor turf but are the result of!! All maintenance practices for good turf must be employed at the same time. MOWING ONCE IN EACH OF THE MONTHS OF JUNE AND JULY AND AUGUST IF POSSIBLE WILL PREVENT MOST SEED-SET AND IN TIME WILL LEAD TO A PRACTICALLY WEED-FREE ROADSIDE.

Appendix Table II. (continued)

Common Names Scientific Names	Duration	Mowing Dates[1] April	May	June	July	Aug.	Sept.	Method of Propagation	Division Infested
Dogbane Apocynum cannabimum	perennial			X	X	X	X	Seeds, roots, or rhizomes	all
Stiff Goldenrod Solidago rigida	perennial				X	X	X	Seeds	all
Common Ragweed Ambrosia elatior	annual				X	X	X	Seeds	all
Giant Ragweed Ambrosia trifida	annual				X	X	X	Seeds	all
Ironweed Vernonia baldwinii	perennial				X	X	X	Seeds	all
Tall Ironweed Vernonia altissima	perennial				X	X	X	Seeds	all
Rough Buttonweed Diodia teres	annual				X	X	X	Seeds	all
Velvetleaf Abutilon theophrasti	annual				X	X	X	Seeds	all
Flower-of-the-Hour Hibiscus trionum	annual				X	X	X	Seeds	all
Russian Thistle Salsola kali	annual				X	X	X	Seeds	3,4,5,6,7
Cocklebur Xanthium pennsylvanicum	annual				X	X	X	Seeds	all
Prickly Lettuce Lactuca scarriola	annual or winter annual				X	X	X	Seeds	all

[1] These correspond essentially with flowering dates.

Appendix Table II. (continued)

Common Names Scientific Names	Duration	Mowing Dates April	May	June	July	Aug.	Sept.	Method of Propagation	Division Infested
Woolly Plantain Plantago purshii	annual	X	X	X				Seeds	all
Western Ragweed Ambrosia psilostachya	perennial			X	X	X	X	Seeds	all
Snow-on-the-Mountain Euphorbia marginata	annual				X	X	X	Seeds	all
Blackeyed Susan Rudbeckia hirta	perennial		X	X	X	X		Seeds	all
Russian Knapweed Centaurea repens	perennial			X	X	X		Seeds & Roots	6
Curled Dock Rumex crispus	perennial			X	X	X	X	Seeds	all
Sand sunflower or Plains sunflower Helianthus petiolaris	annual			X	X	X	X	Seeds	all
Mare's Tail or Horseweed Erigeron canadensis	annual			X	X	X	X	Seeds	all
Prickly Poppy Argemons intermedia	annual		X	X	X	X	X	Seeds	all
Wild Blue Lettuce or Perennial Lettuce Lactuca pulchella	perennial			X	X	X		Seeds & creeping roots	6
Rugel or Blackseed Plantago Plantage rugelii	perennial			X	X	X	X	Seeds	1,2,3,4,8
Stinging Nettle Vroica procera	perennial			X	X	X	X	Seeds or under- ground rootstock	1,2,3,4,8

Appendix Table II. (continued)

Common Names Scientific Names	Duration	Mowing Dates April	May	June	July	Aug.	Sept.	Method of Propagation	Division Infested
Rough Pigweed Amaranthus retroflexus	annual			X	X	X	X	Seeds	all
Lamb's Quarters Chenopodium album	annual		X	X	X	X	X	Seeds	all
Bracted Plantain Plantago aristata	annual or winter annual			X	X	X	X	Seeds	1,2,3,4,7,8
Horsenettle Solanum carolinense	perennial		X	X	X	X	X	Seeds	all
Prickly Pear Opuntia species	perennial		X	X	X			Seeds & Stems	all
Fleabane or Daisy Fleabane Erigeron strigosus	annual or biennial winter annual	X	X	X	X			Seeds	all
Buckhorn Plantain Plantago lanceolata	perennial		X	X	X	X	X	Seeds	8
Ground Cherry Phsalis Heterophylla	perennial		X	X	X	X		Seeds	all
Silverleaf Nightshade Solanum elaeagnifolium	perennial		X	X	X	X		Seeds	all
Buffalo Bur Solanum rostratum	annual			X	X	X		Seeds	all
Peppergrass Lepidium virginianum	annual or winter annual	X	X	X	X			Seeds	all

Appendix Table II. (continued)

Common Names Scientific Names	Duration	Mowing Dates April	May	June	July	Aug.	Sept.	Method of Propagation	Division Infested
Wild Pumpkin or Wild Gourd Cucurbita foetidissima	perennial		X	X	X	X	X		4,5,6,7
Prickly Sida Sida spinosa	annual		X	X	X	X	X	Seeds	1,2,3,4,8
Carolina Cranesbill Geranium carolinianum	annual	X	X					Seeds	all
Evening Primrose Cenothera spp.	perennial	X	X					Seeds	all
Curlycup Gumweed Grindelia squarrosa	biennial		X	X				Seeds	all
Western Yarrow Achillea lanulosa	perennial			X	X	X	X	Seeds & under-ground rootstocks	all
Mullen Verbascum thapsus	biennial			X	X	X	X	Seeds	1 & 8
Prairie Rose Rosa suffulta	perennial			X	X	X		Seeds & under-ground roots	8
Woolly Croton Croton capitatus	annual				X	X	X	Seeds	all
Field Thistle or Tall Thistle Cirsium altissimum	perennial			X	X	X	X	Seeds	1,2,4,5,6
Kochia, Burning Bush or Mexican Fireweed Kochia scoparis	annual			X	X	X	X	Seeds	5,6,4,8

Appendix Table II. (continued)

Common Name Scientific Name	Duration	Mowing Dates						Method of Propagation	Division Infested
		April	May	June	July	Aug.	Sept.		
Salt Bush or Orache Atriples patula	annual				X	X		Seeds	4,5,6
Spiny Pigweed Amaranthus spinosus	annual				X	X	X	Seeds	all
Pennsylvania Smartweed Polygonum pennsylvanicum	annual			X	X	X	X	Seeds	all
Wild Sunflower Helianthus annus	annual			X	X	X	X	Seeds	all
Erect Knotweed Polygonum erectum	annual			X	X	X	X	Seeds	all
Yellow Sweet Clover Melilotus officinalis	biennial		X	X	X	X		Seed	all
White Sweet Clover Melilotus alba	biennial		X	X	X	X		Seed	all
Jerusalem Artichoke Helianthus tuberosus	perennial					X	X	Seeds, rhizomes & tuber	1,2,3,4,8
Thoroughwort Eupatorium altissimum	perennial					X	X	Seeds	1,2,3,4,7,8

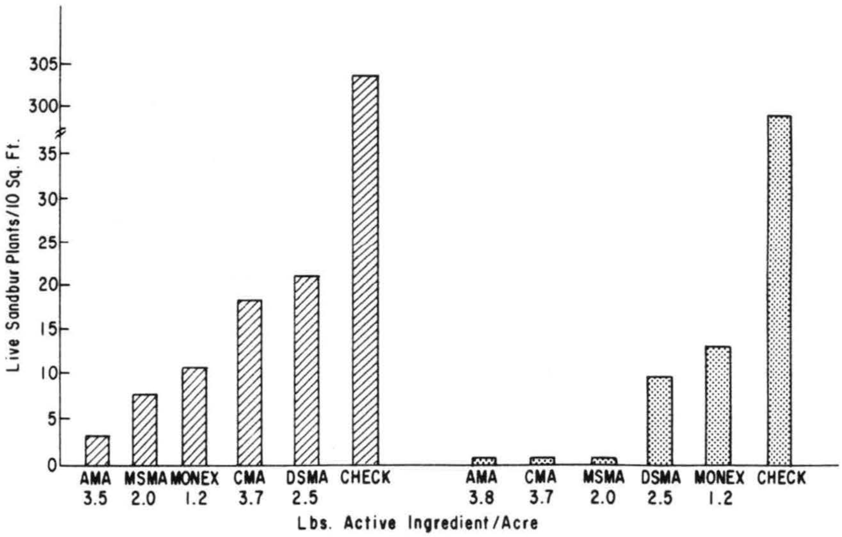


Figure 3-1. The effect of various post-emergence herbicides on the control of sandbur in established bermudagrass on SH-152 shoulders west of Binger, Oklahoma.

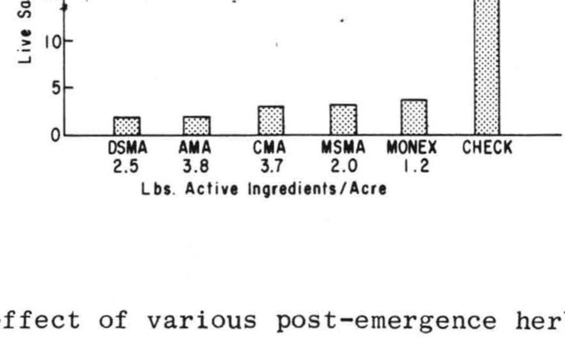


Figure 3-2. The effect of various post-emergence herbicides applied June 15, 1967 and retreated July 10, 1967, on the control of sandbur in established bermudagrass on SH-33 shoulders 3.5 miles west of US-177 near Perkins, Oklahoma, on July 24, 1967.

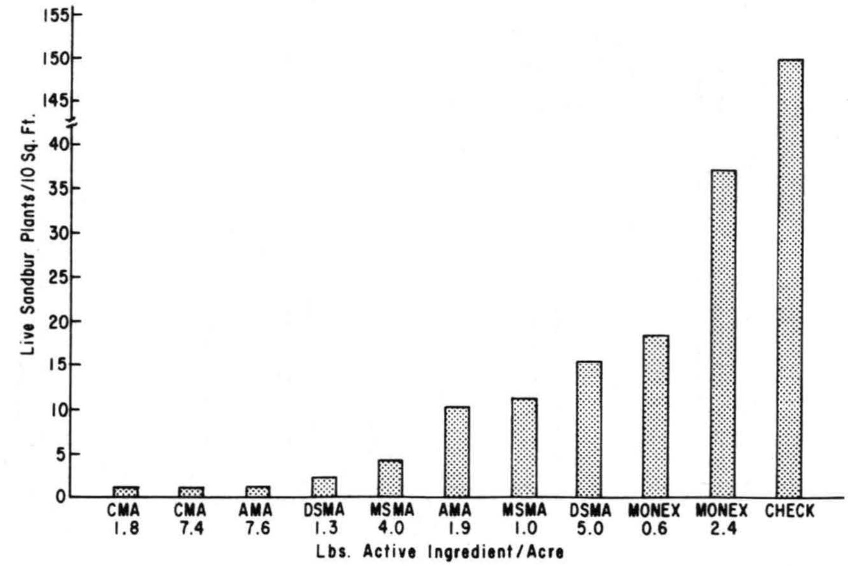


Figure 3-3. The effect of various post-emergence herbicides applied June 21, 1967, and retreated June 30, 1967, on the control of sandbur in established bermudagrass on SH-152 shoulders nine miles west of Binger, Oklahoma, on August 16, 1967.

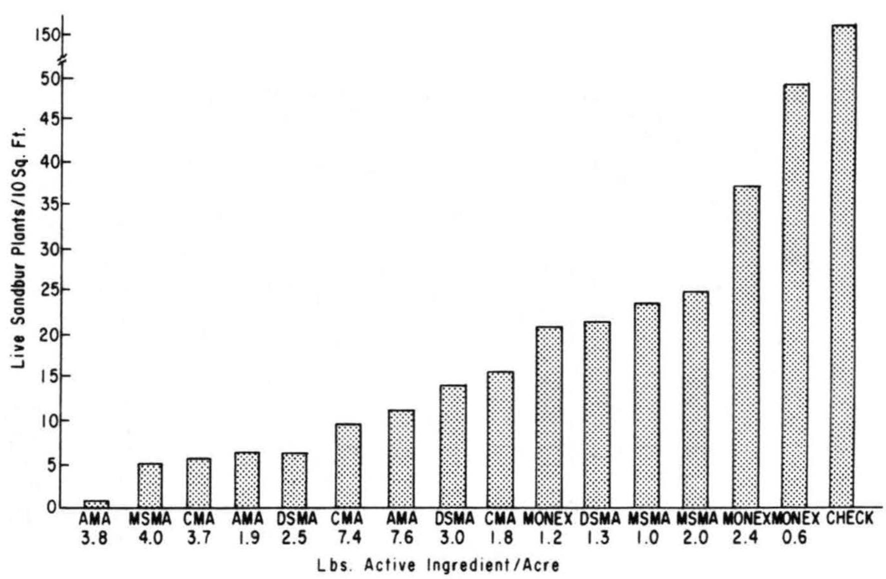


Figure 3-4. The effect of various post-emergence herbicides applied August 25, 1967, on the control of sandbur in established bermudagrass on SH-152 shoulders nine miles west of Binger, Oklahoma on September 7, 1967.

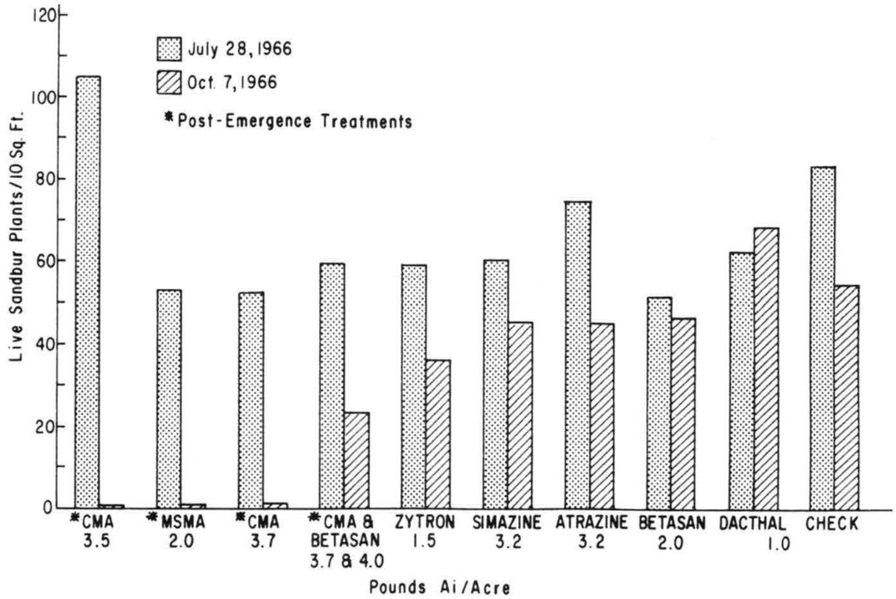


Figure 3-5. The effect of various herbicides applied pre-emergence March 30, 1966, and post-emergence May 25, September 1, and September 19, 1966, on the control of sandbur on SH-33 shoulders 7.8 miles west of US-177 near Coyle, Oklahoma.

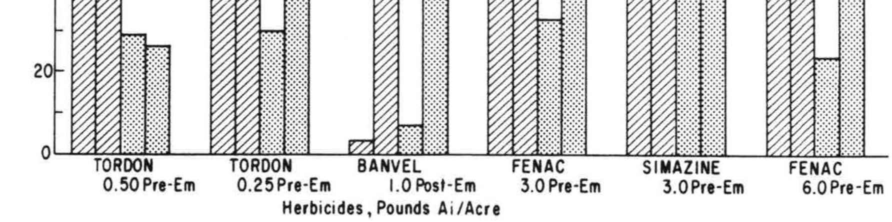
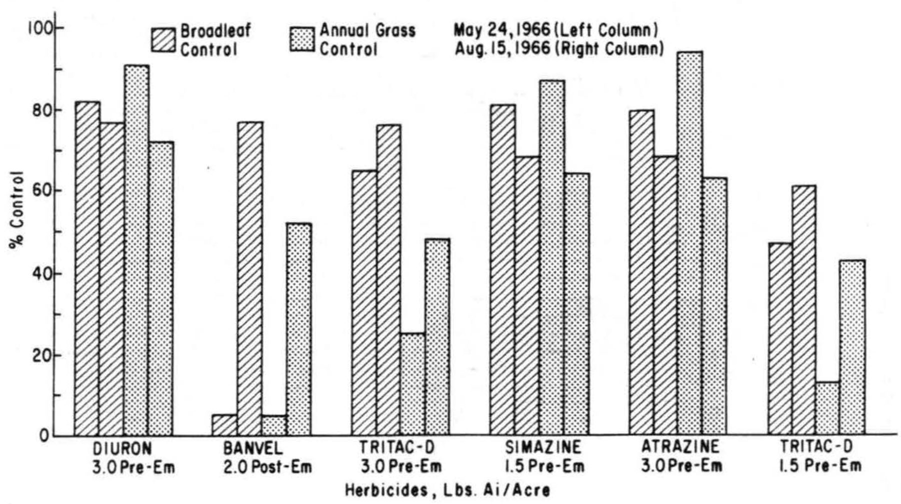
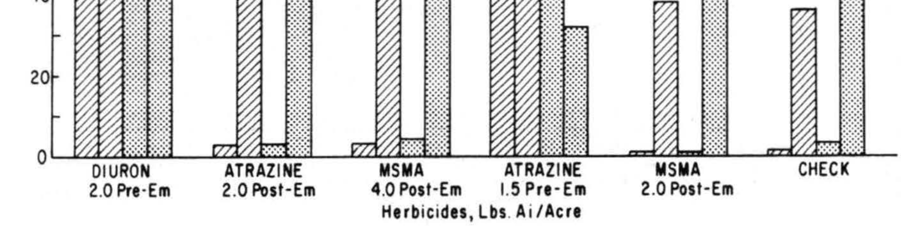
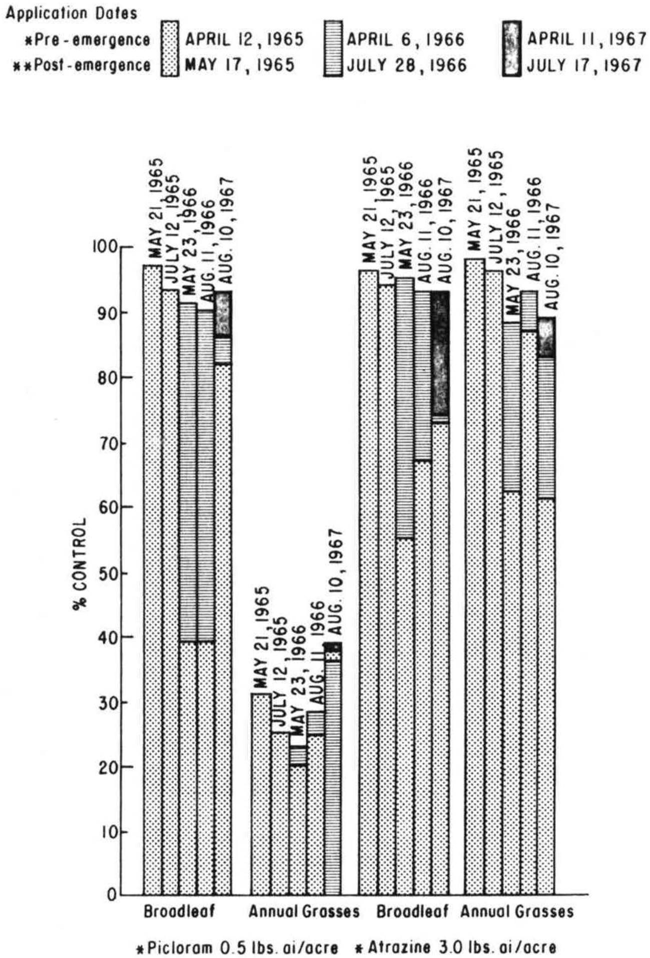


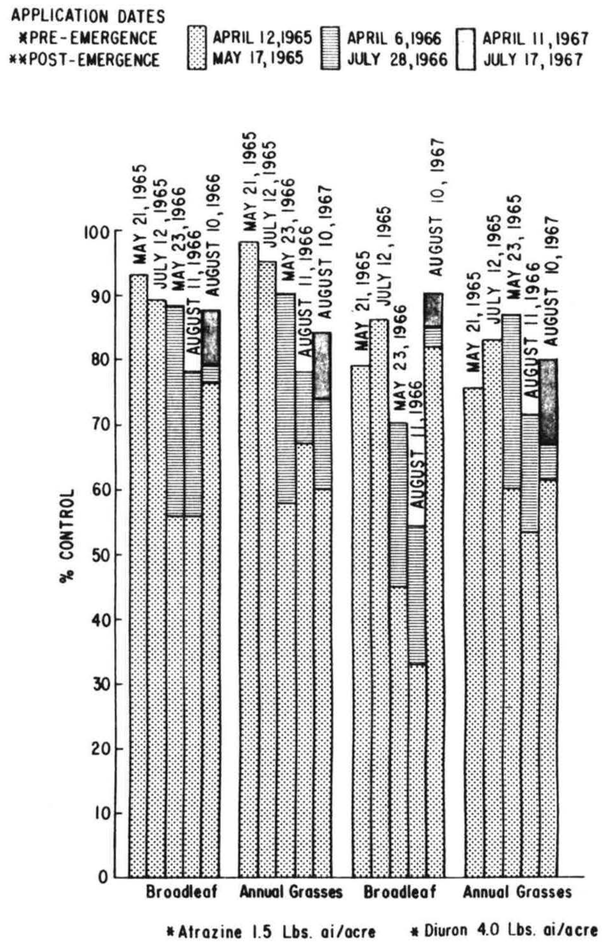
Figure 3-6. The effect of various chemicals applied March 29, 1966 (Pre-emergence) and May 25, 1966 (Post-emergence) on the control of broadleaf weeds and annual grasses near the junction of US-177 and US-62 west of Meeker, Oklahoma.



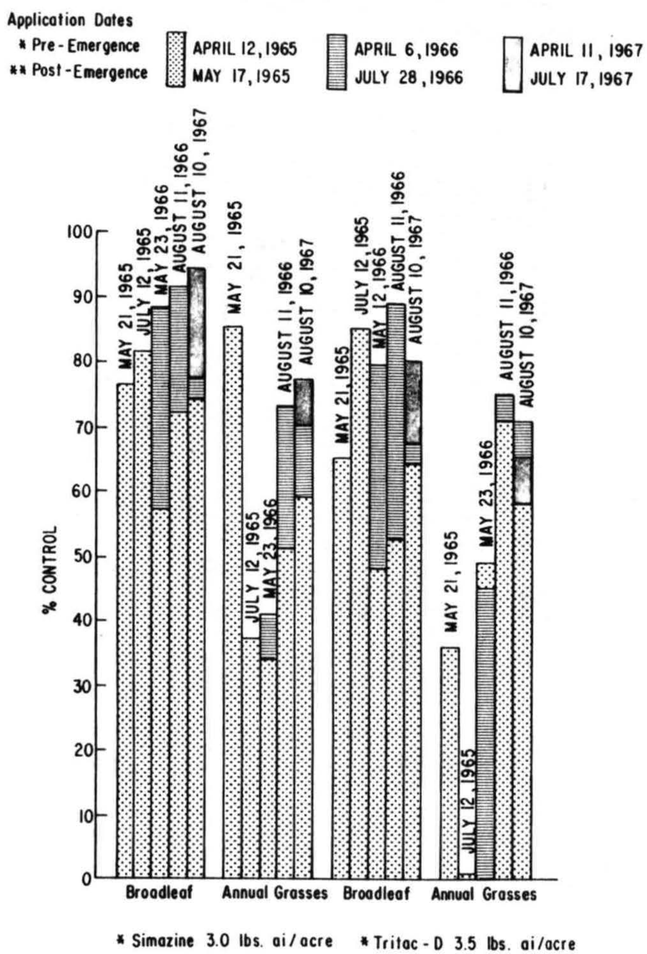


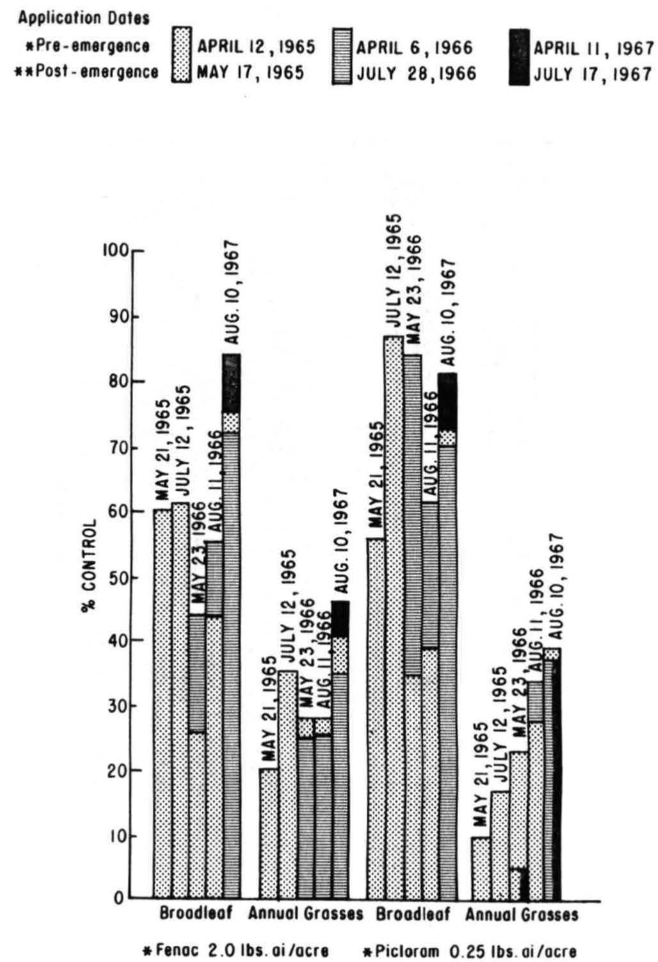
Figures 3-7 and 3-8. The effect of various chemicals applied March 29, 1966 (Pre-emergence) and May 25, 1966 (Post-emergence) on the control of broadleaf weeds and annual grasses near the junction of US-177 and US-62 west of Meeker, Oklahoma.



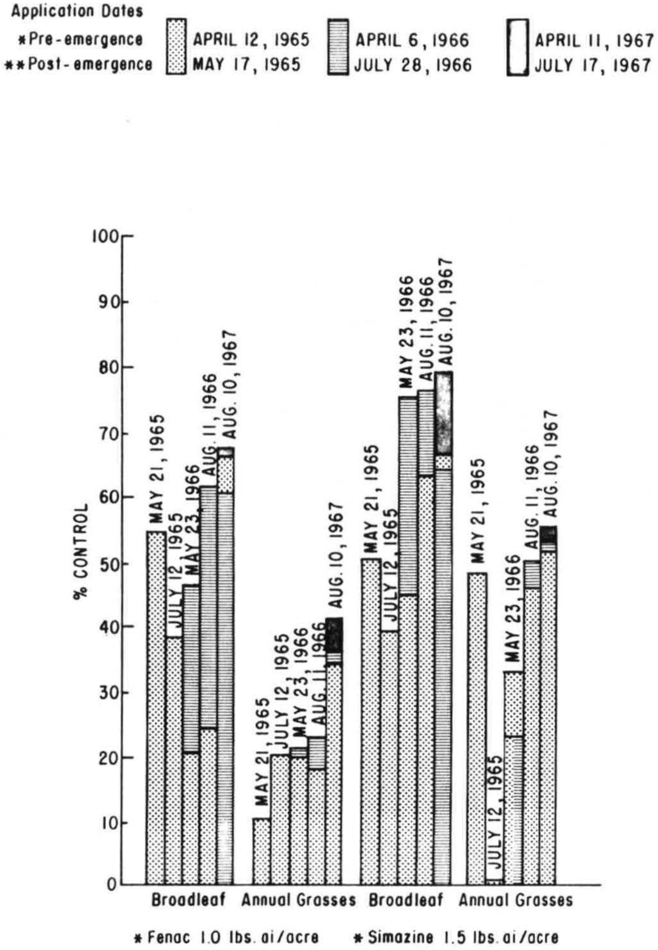


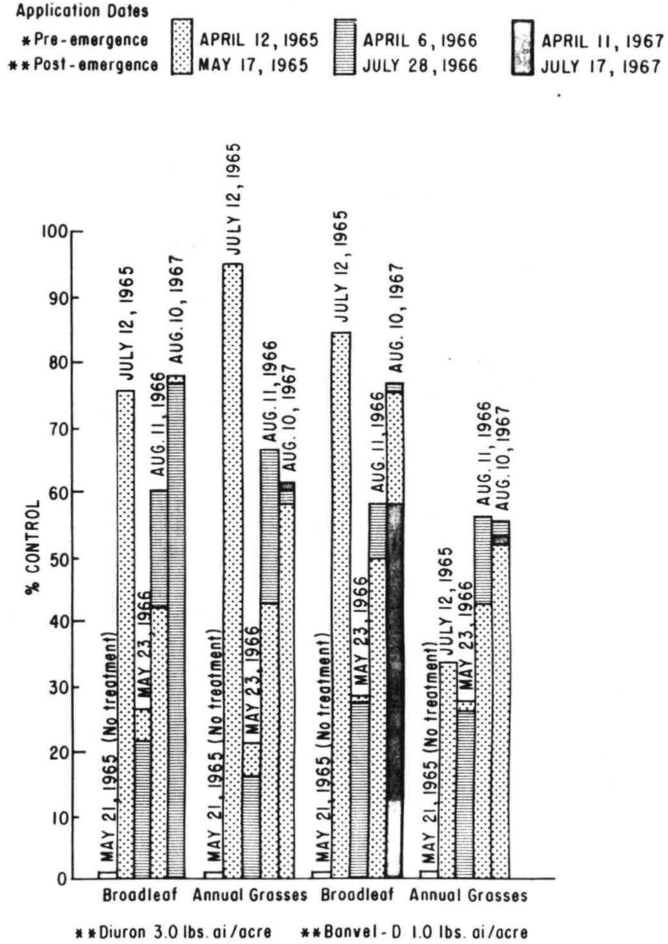
Figures 3-9 and 3-10. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.



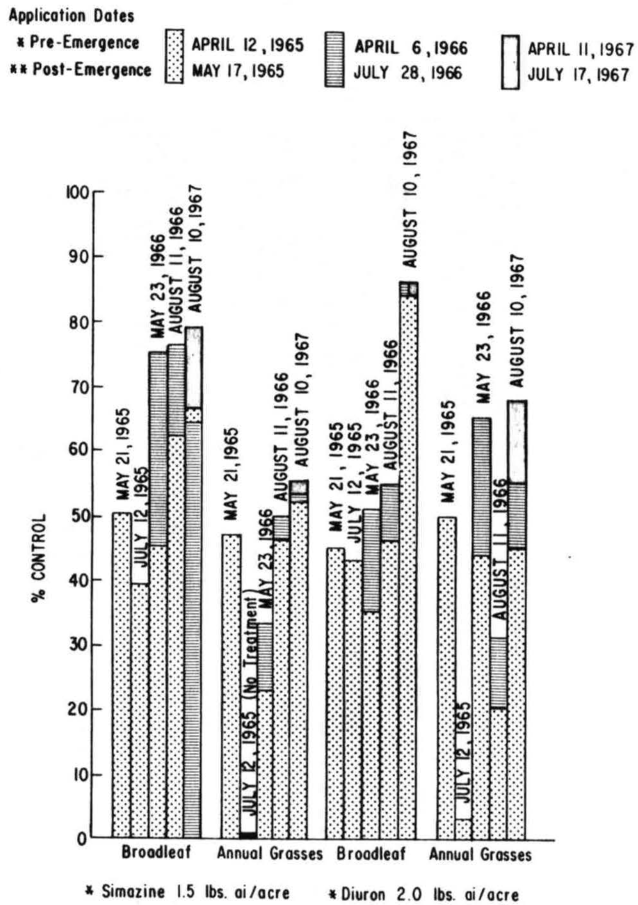


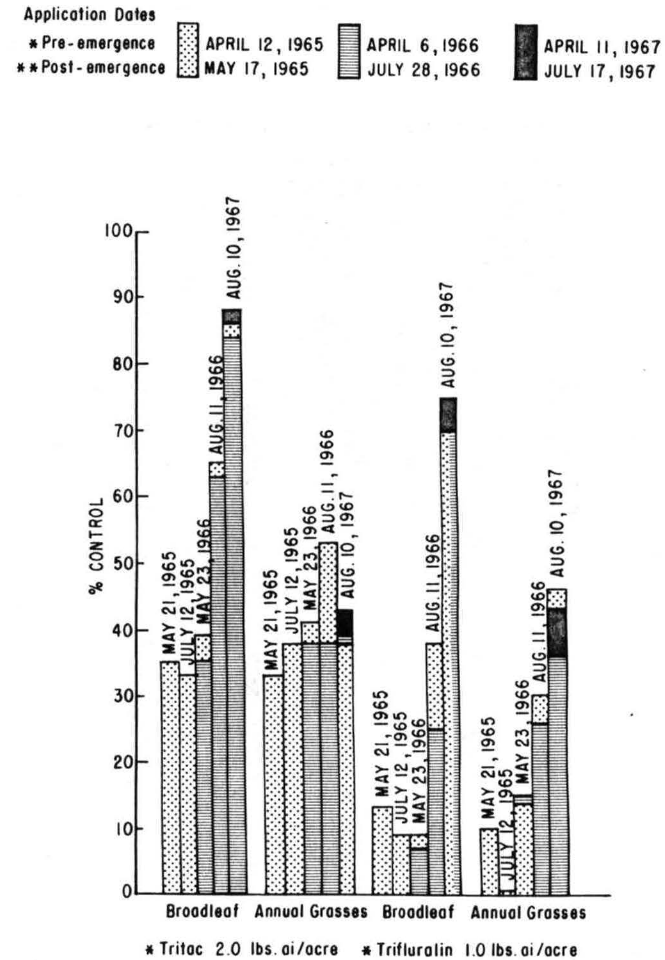
Figures 3-11 and 3-12. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.



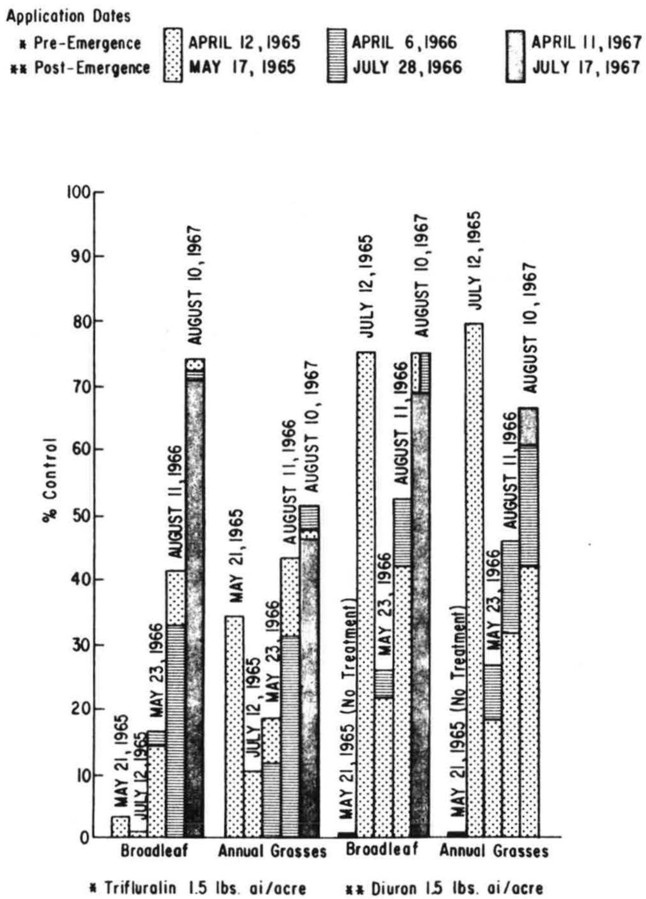


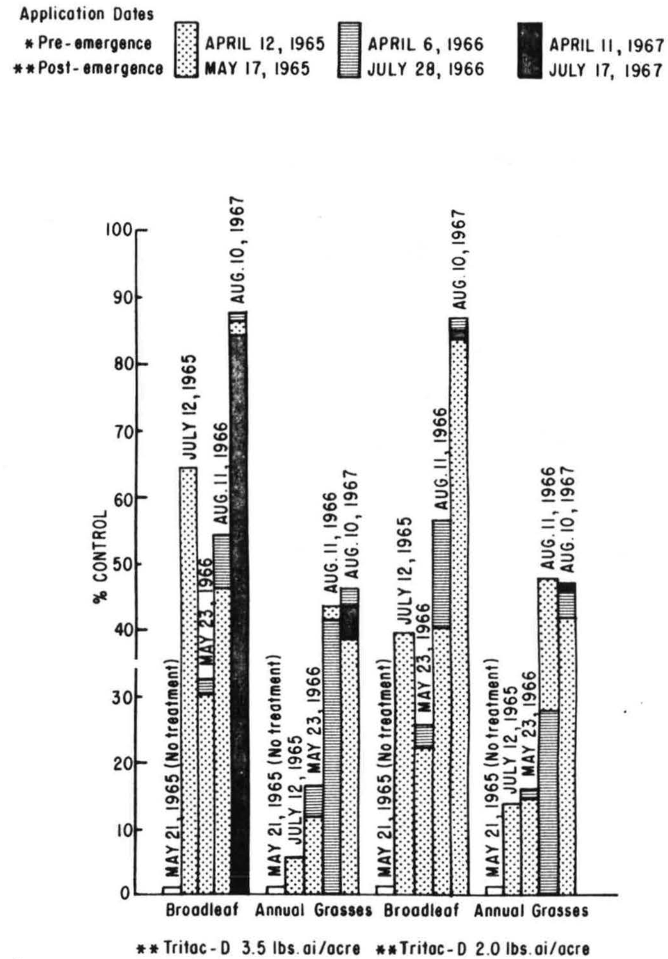
Figures 3-13 and 3-14. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967 on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.



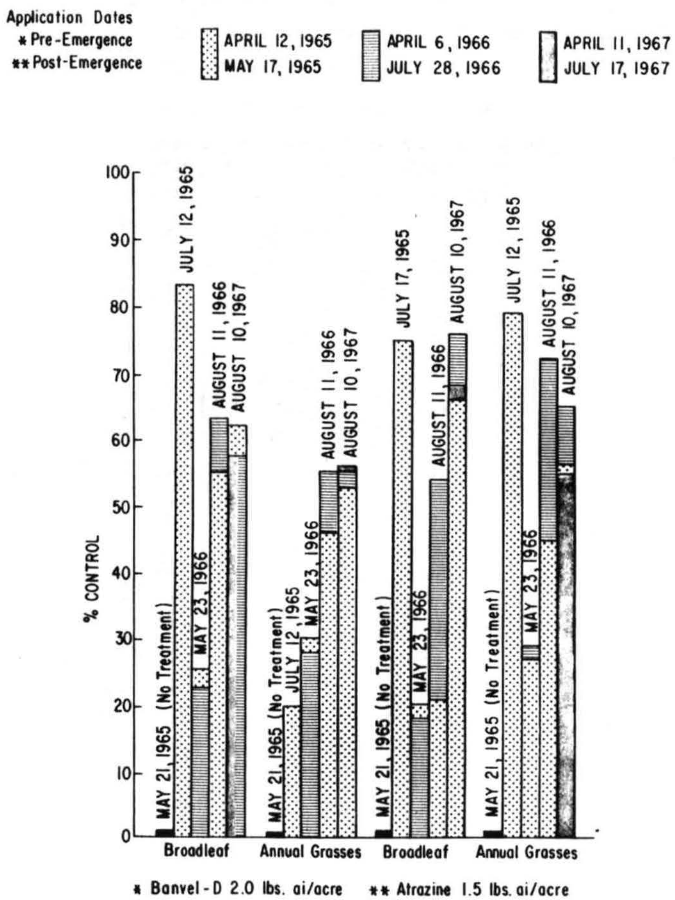


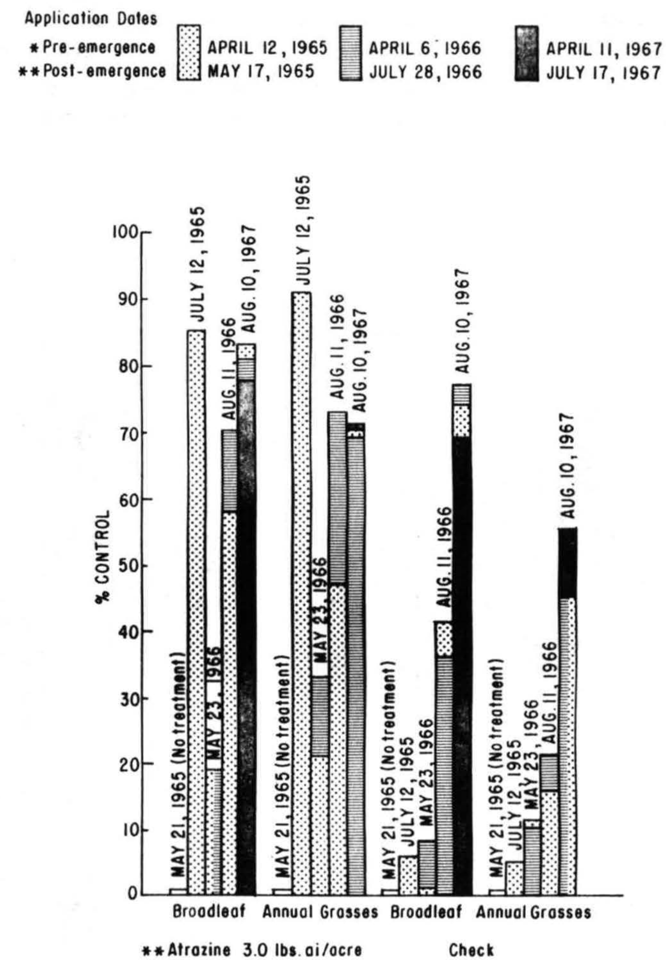
Figures 3-15 and 3-16. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966 and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.





Figures 3-17 and 3-18. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.





Figures 3-19 and 3-20. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.

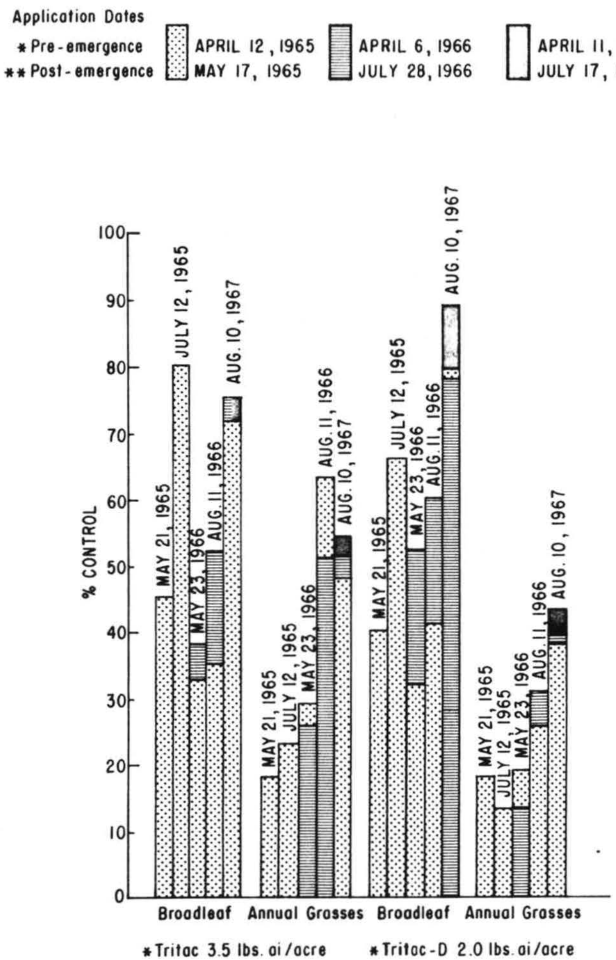


Figure 3-21. The effect of various herbicides and their residual activity on the control of broadleaf weeds and annual grasses applied pre-emergence on April 12, 1965, April 6, 1966, and April 11, 1967, and the post-emergence treatments on May 17, 1965, July 28, 1966, and July 17, 1967, on US-270 just south of I-40 near Shawnee, Oklahoma as evaluated on the above dates.

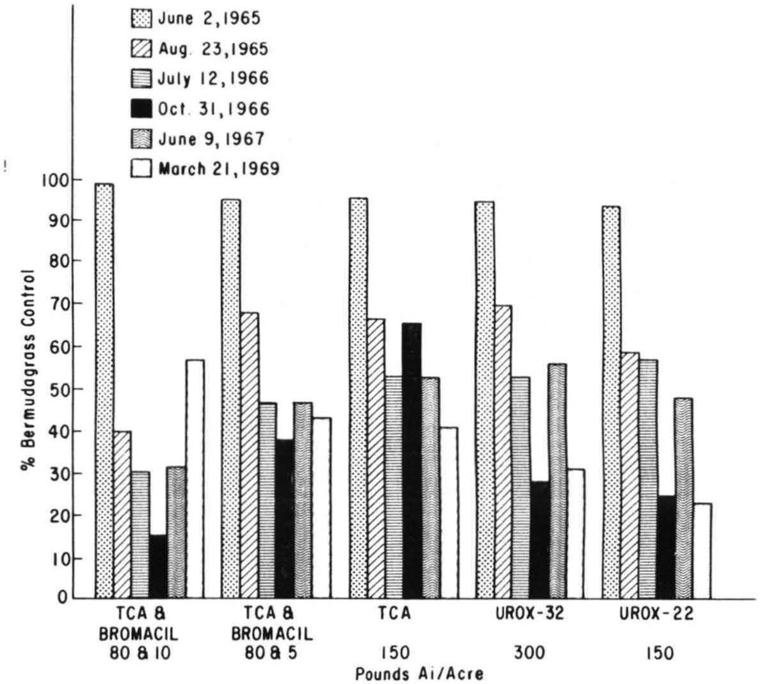
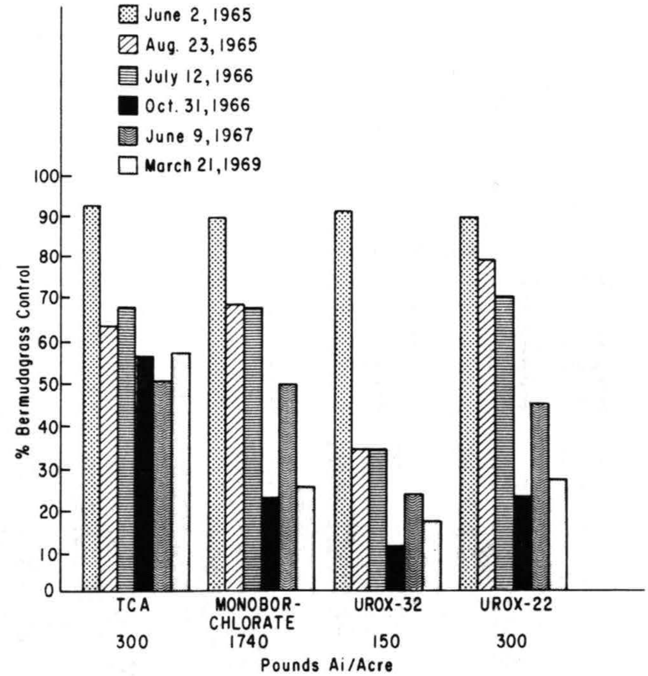
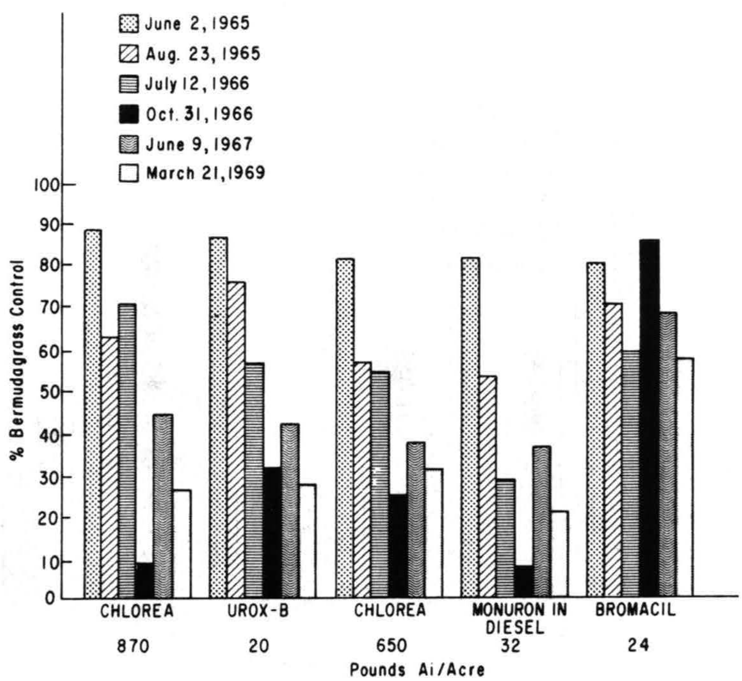
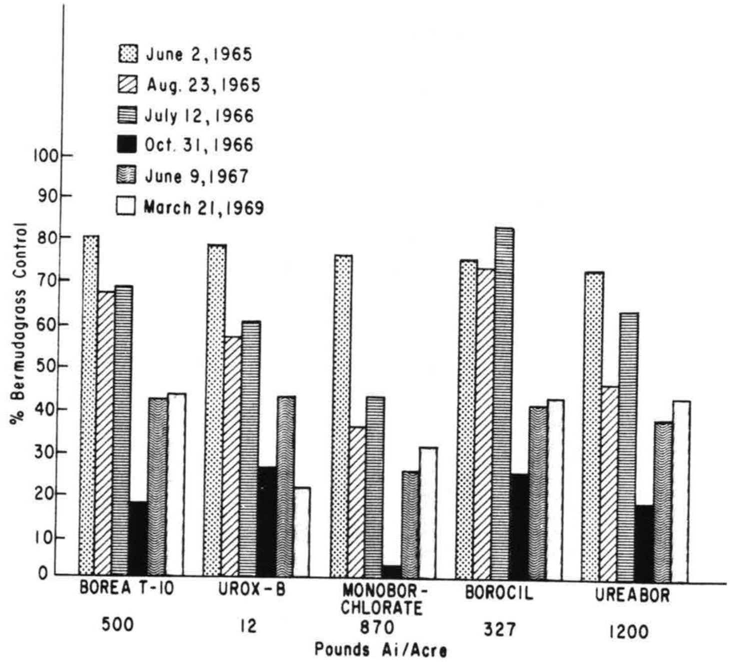


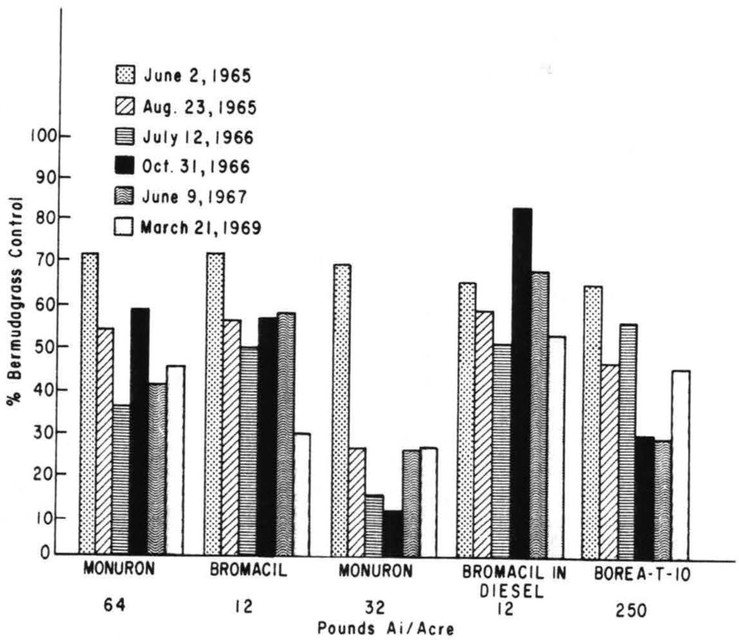
Figure 3-22. The effect of various chemicals applied on March 26, 1965, and retreated at one-half rate June 17, 1966, in the control of bermudagrass on SH-92 shoulders near Chickasha, Oklahoma as evaluated on the above dates.



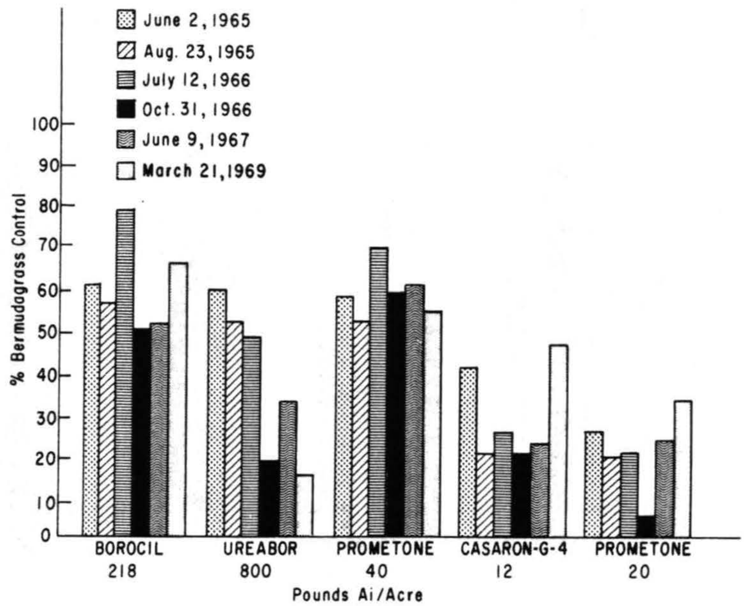


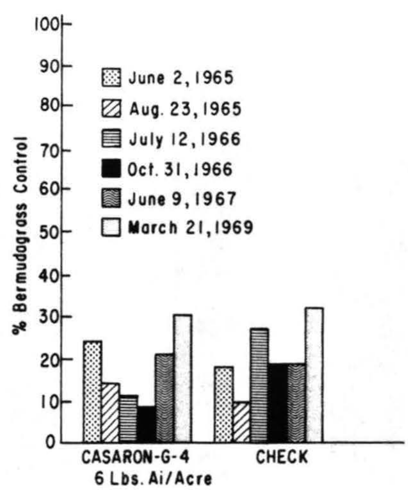
Figures 3-23 and 3-24. The effect of various chemicals applied on March 26, 1965, and retreated at one-half rate June 17, 1966, in the control of bermudagrass on SH-92 shoulders near Chickasha, Oklahoma as evaluated on the above dates.



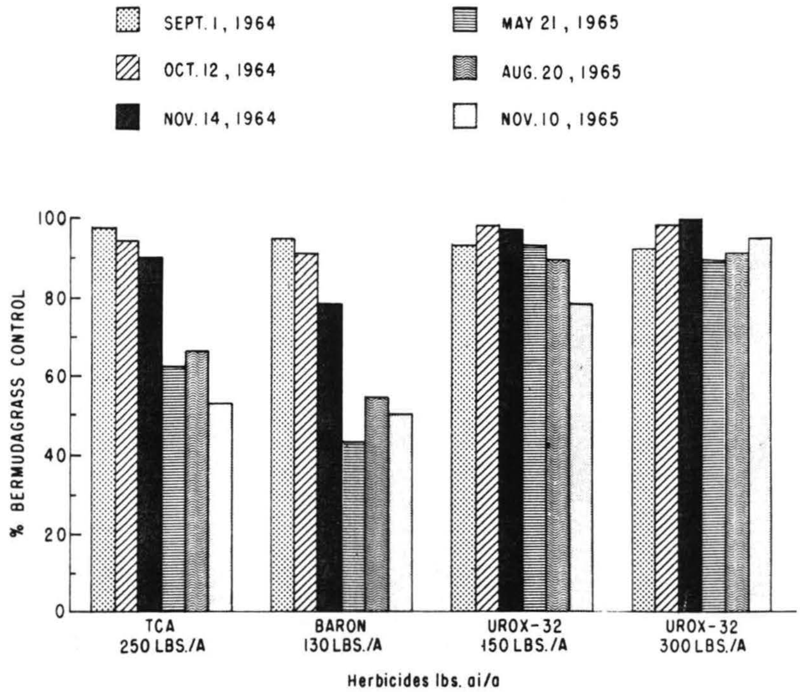


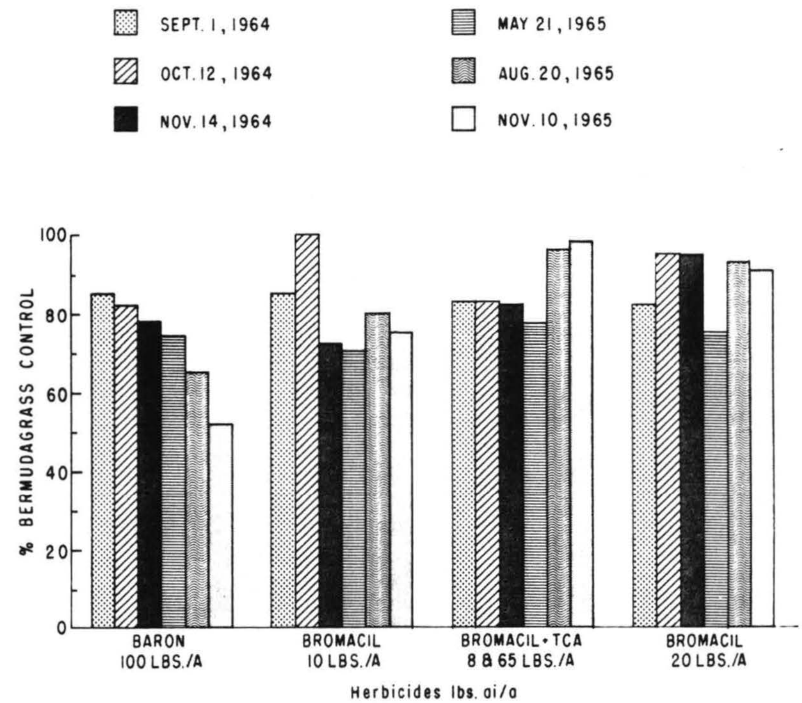
Figures 3-25 and 3-26. The effect of various chemicals applied on March 26, 1965, and retreated at one-half rate June 17, 1966, in the control of bermudagrass on SH-92 shoulders near Chickasha, Oklahoma as evaluated on the above dates.



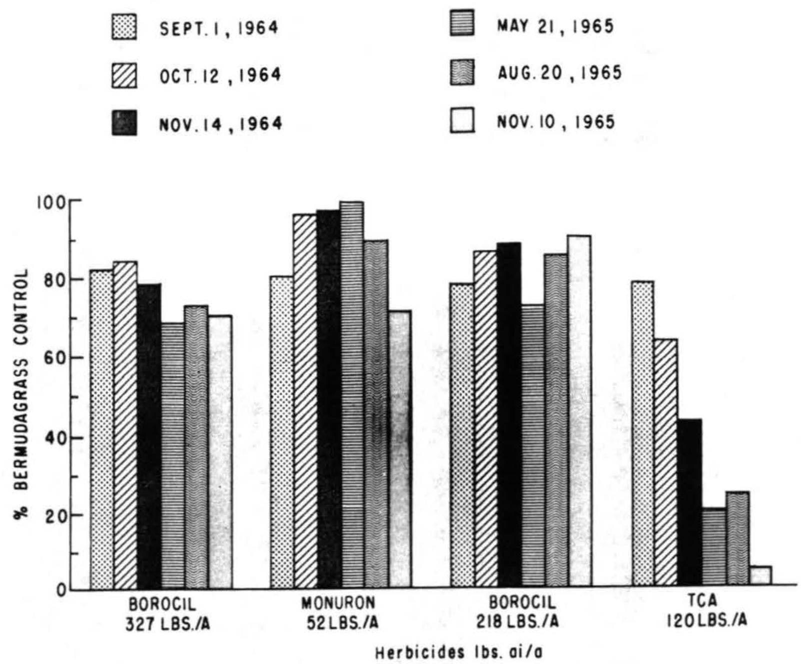


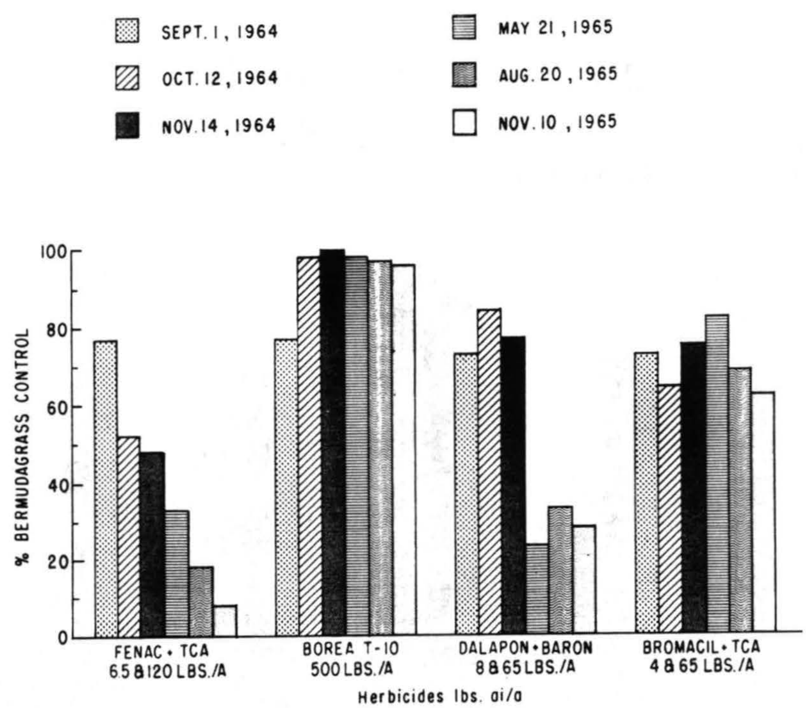
Figures 3-27 and 3-28. The effect of various chemicals applied on March 26, 1965, and retreated at one-half rate June 17, 1966, in the control of bermudagrass on SH-92 shoulders near Chickasha, Oklahoma as evaluated on the above dates.



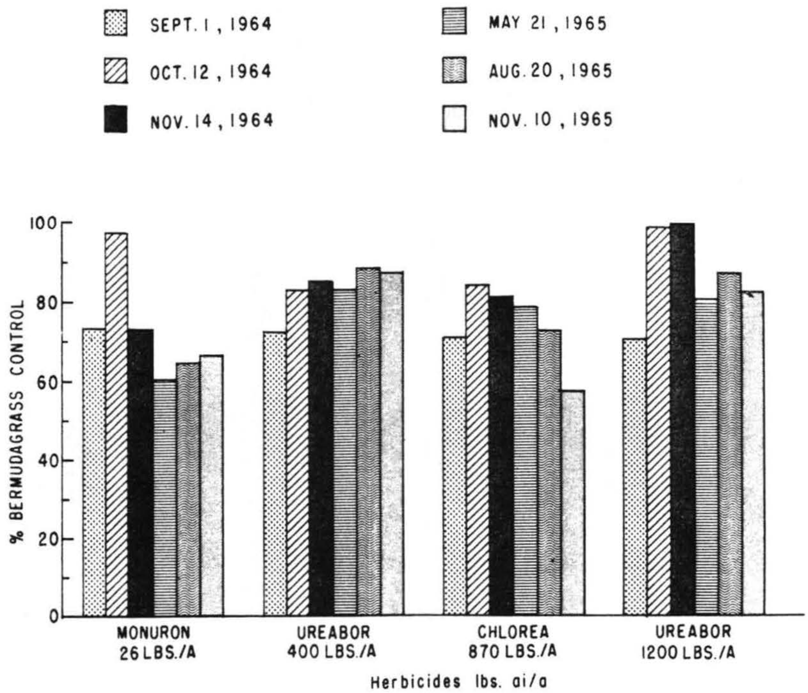


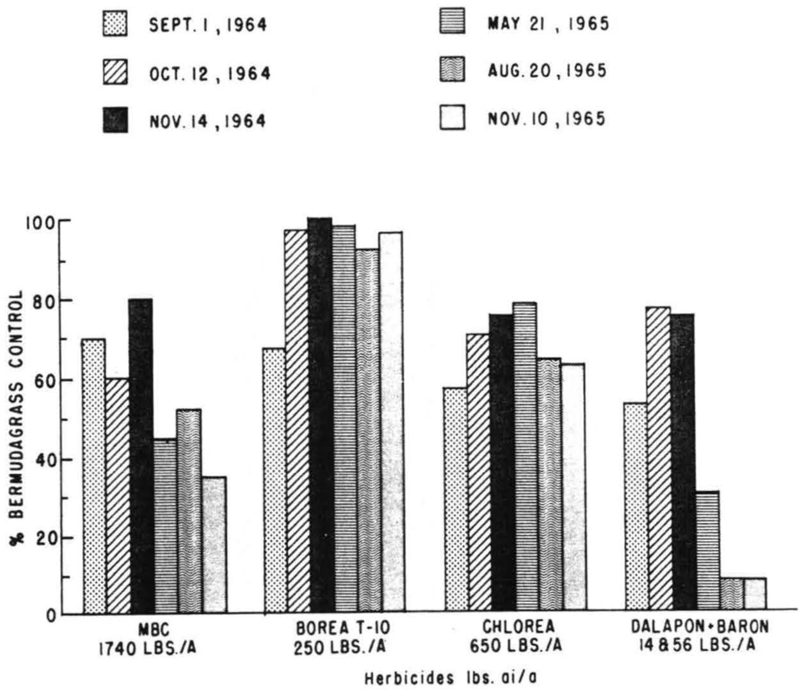
Figures 3-29 and 3-30. The effect of various chemicals applied June 29, 1964, on the control of bermudagrass around guardrails on US-270 near Wewoka, Oklahoma as evaluated on the above dates.



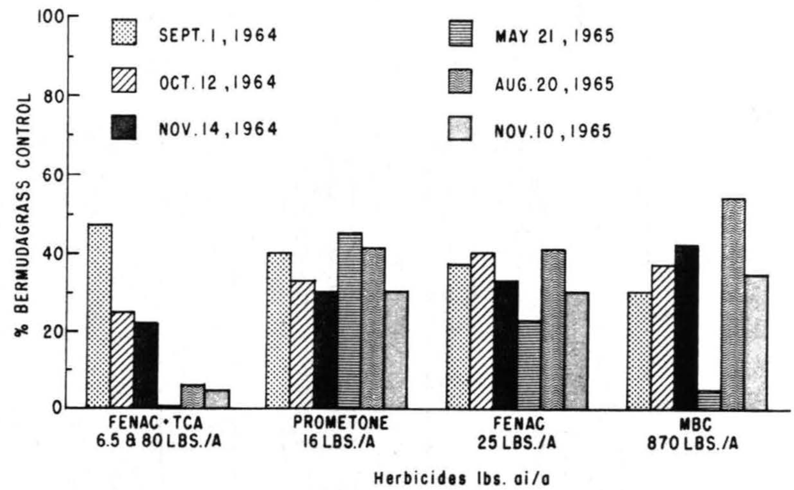


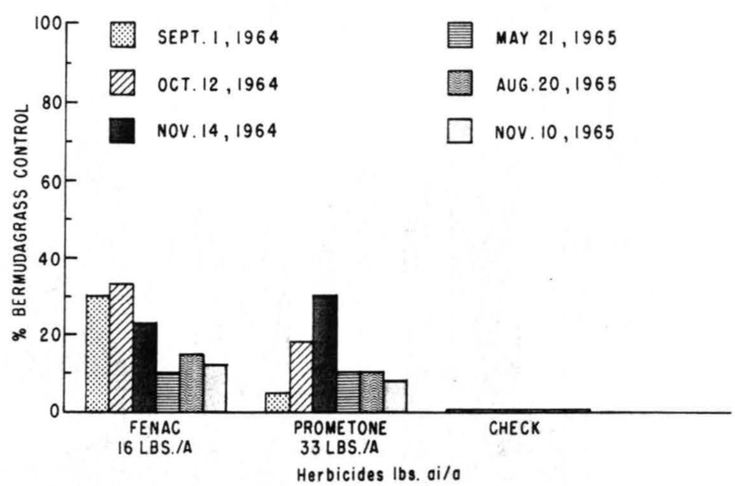
Figures 3-31 and 3-32. The effect of various chemicals applied June 29, 1964, on the control of bermudagrass around guardrails on US-270 near Wewoka, Oklahoma as evaluated on the above dates.



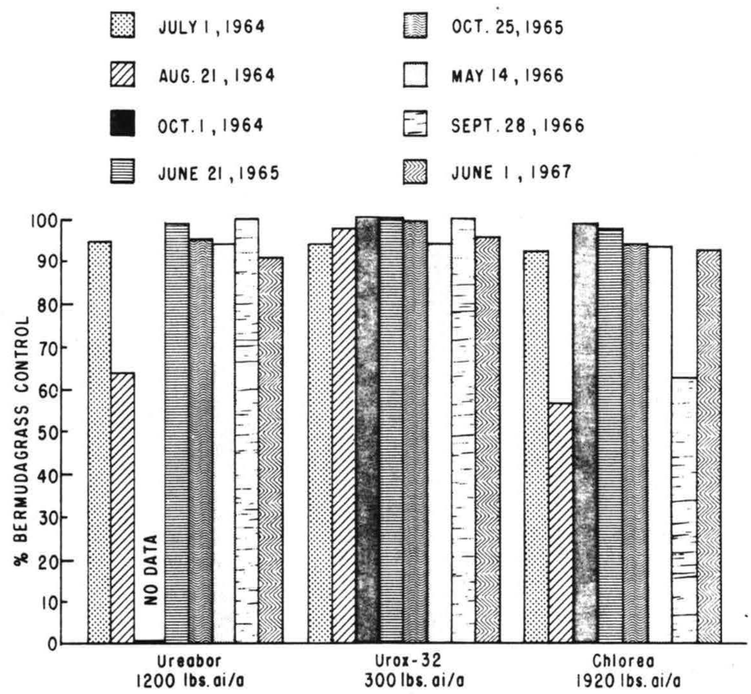


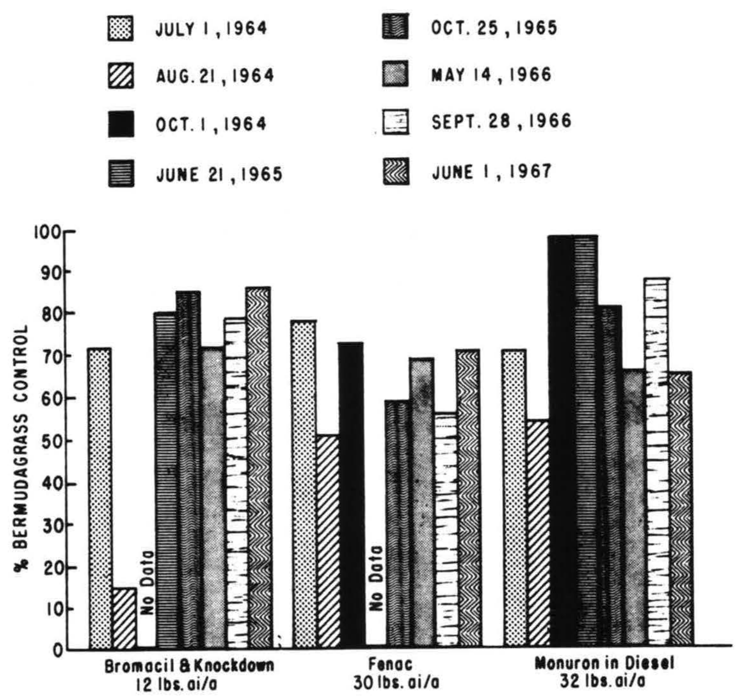
Figures 3-33 and 3-34. The effect of various chemicals applied June 29, 1964, on the control of bermudagrass around guardrails on US-270 near Wewoka, Oklahoma as evaluated on the above dates.



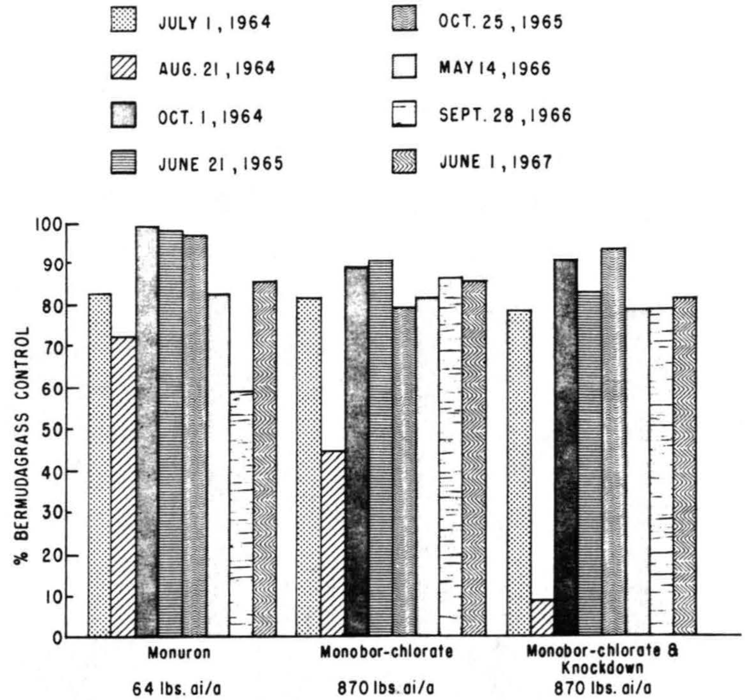


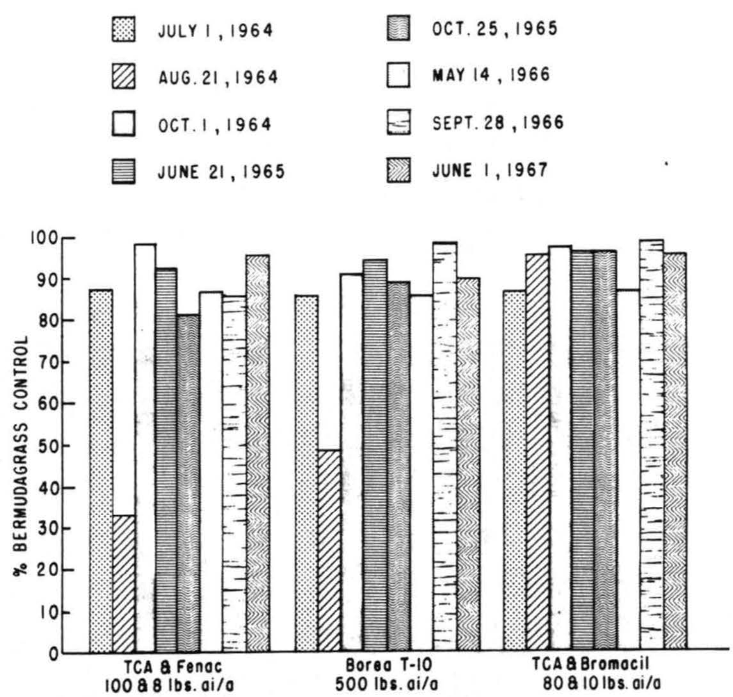
Figures 3-35 and 3-36. The effect of various chemicals applied June 29, 1964, on the control of bermudagrass around guardrails on US-270 near Wewoka, Oklahoma as evaluated on the above dates.



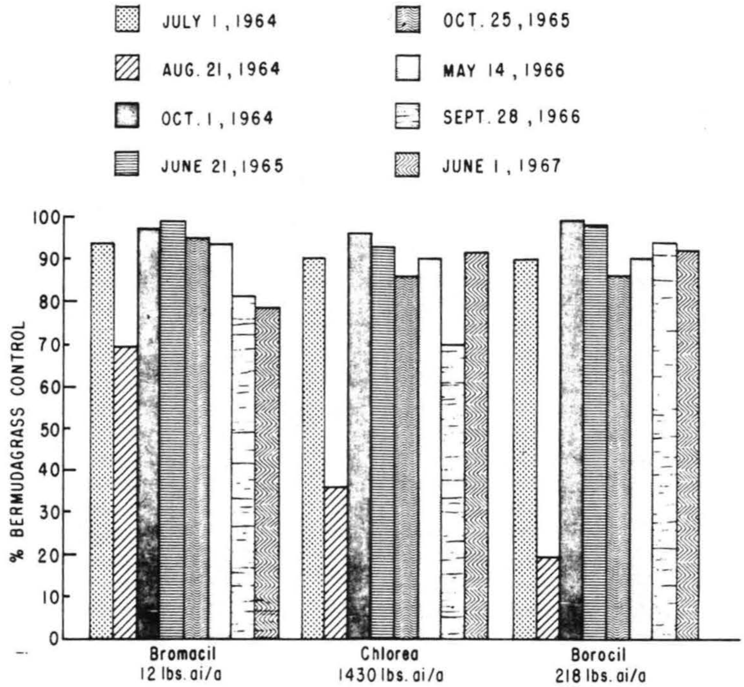


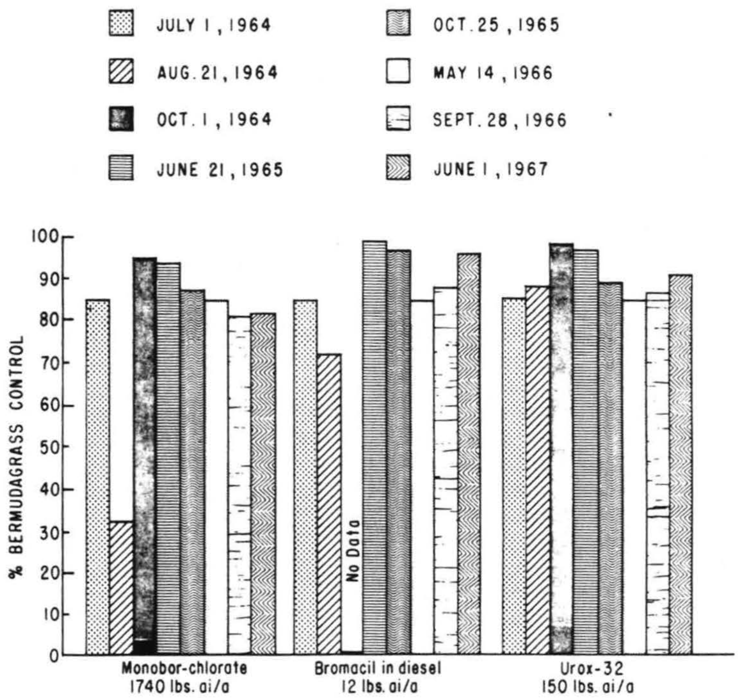
Figures 3-37 and 3-38. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.



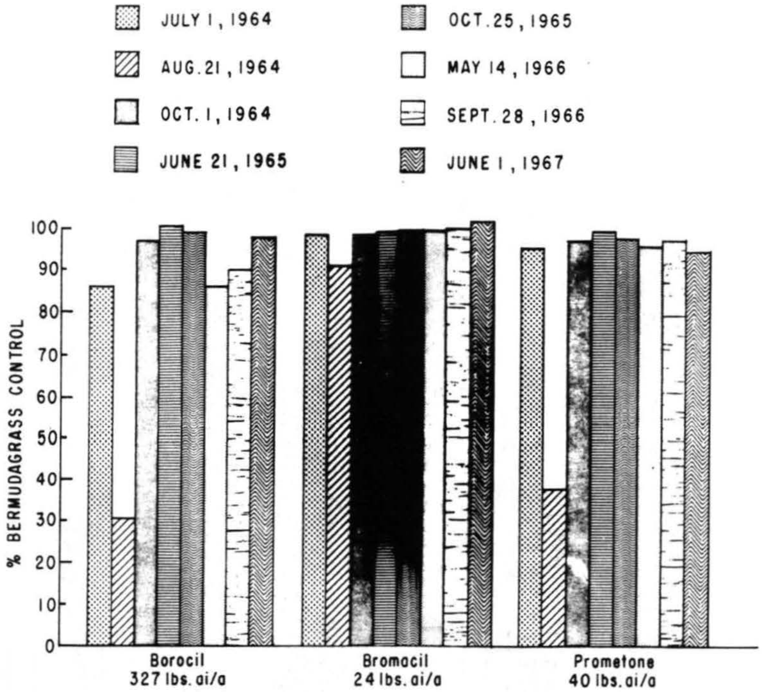


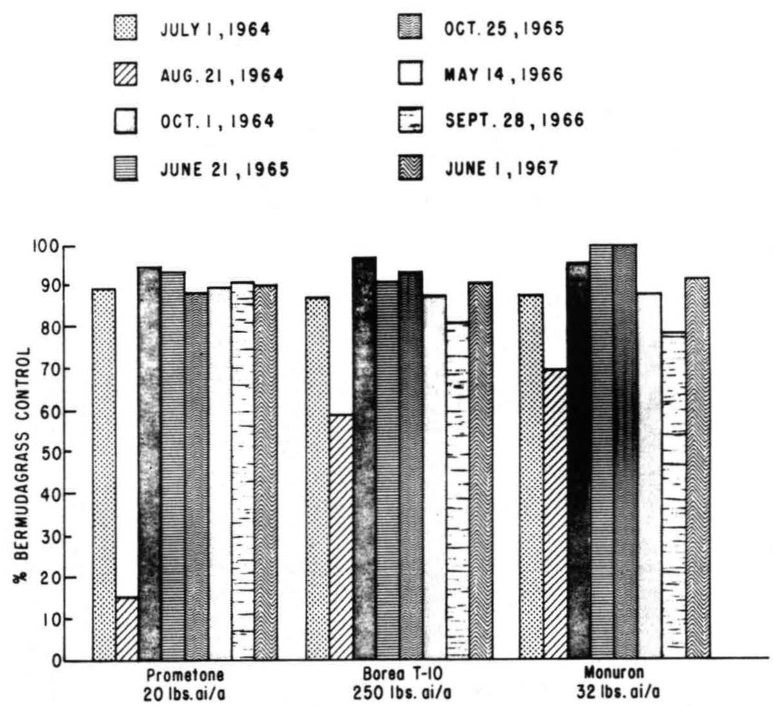
Figures 3-39 and 3-40. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.



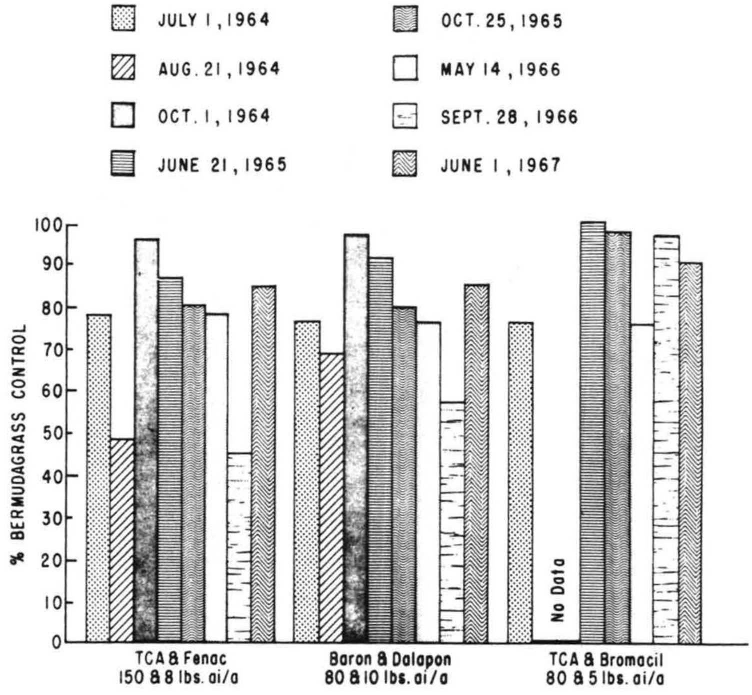


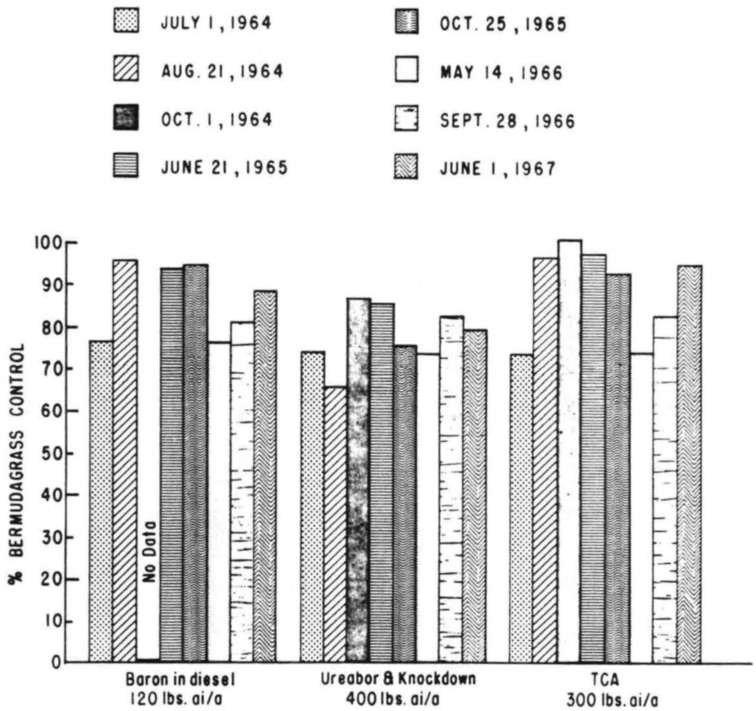
Figures 3-41 and 3-42. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.



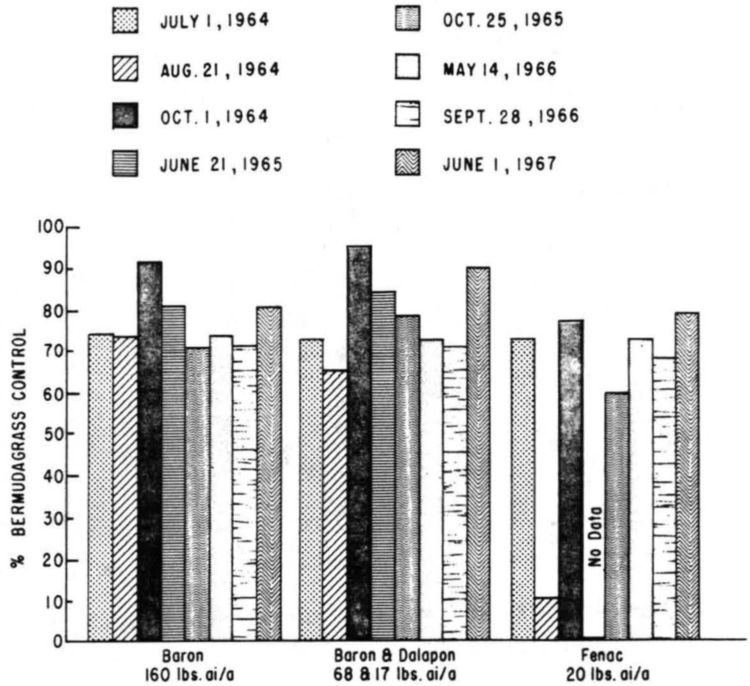


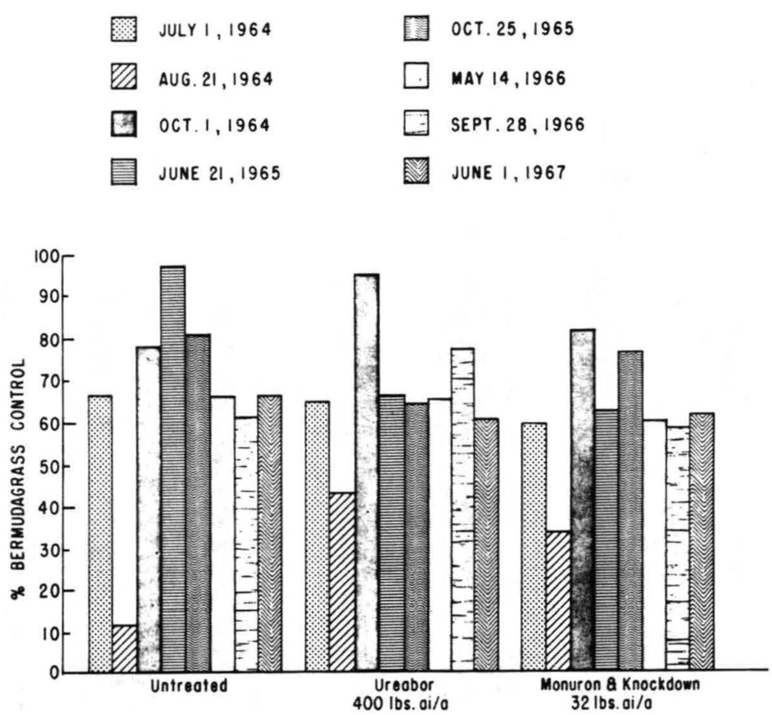
Figures 3-43 and 3-44. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.





Figures 3-45 and 3-46. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.





Figures 3-47 and 3-48. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.

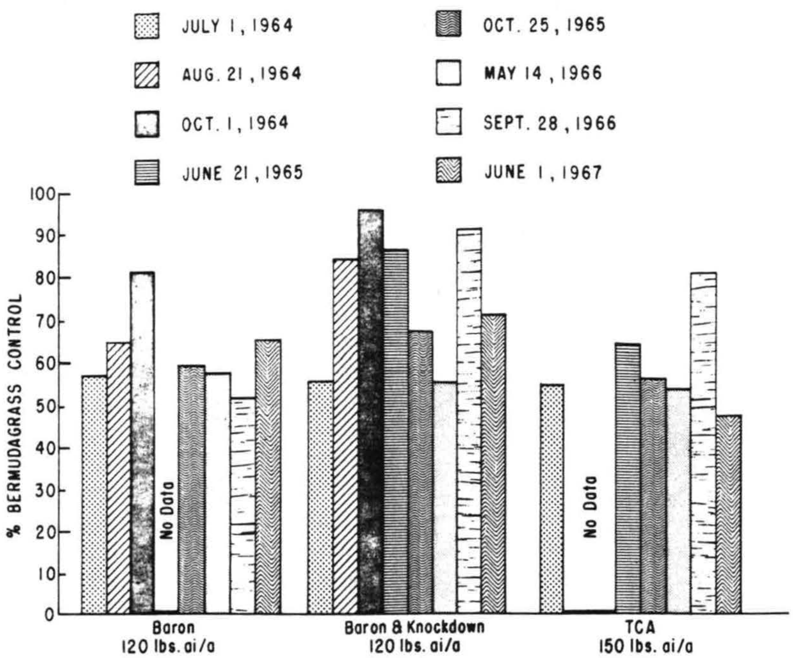


Figure 3-49. The effect of various chemicals applied June 10, 1964, on the control of bermudagrass on SH-51 shoulders 13 miles west of Stillwater, Oklahoma as evaluated on the above dates.

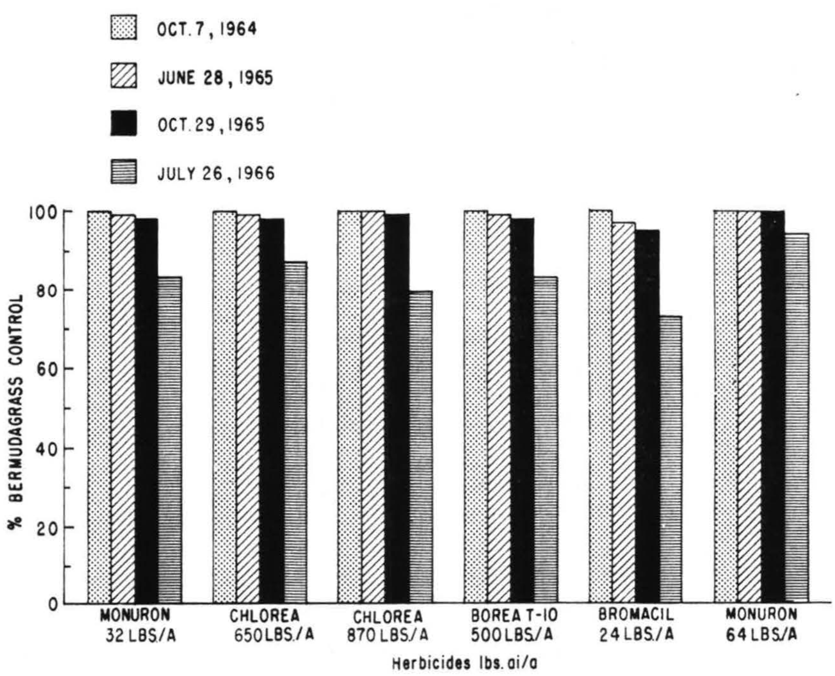
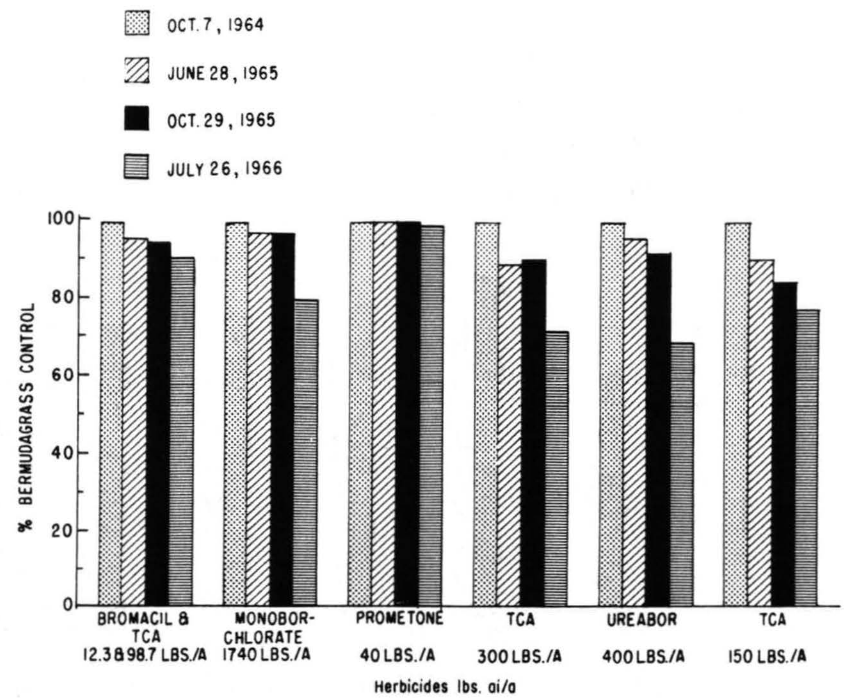
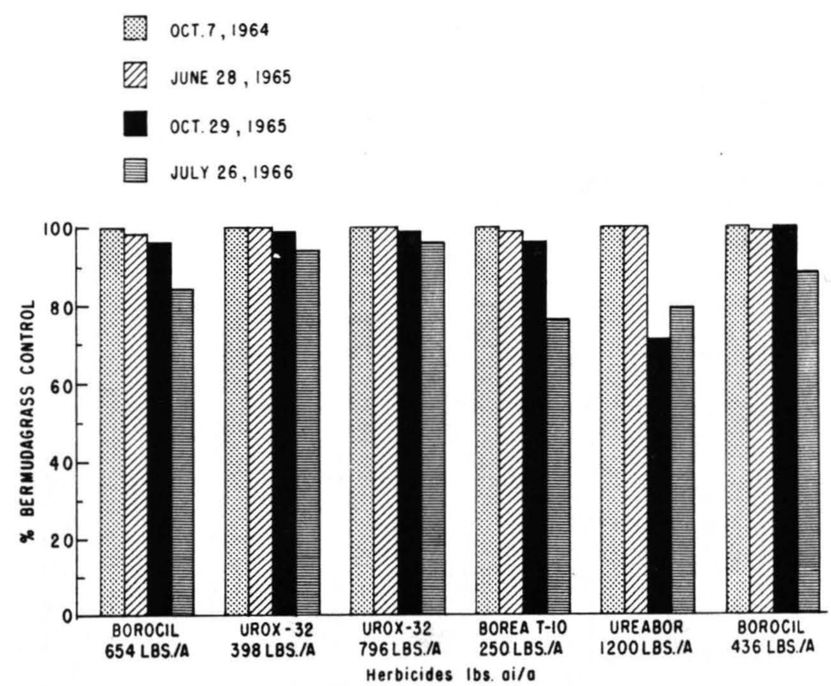
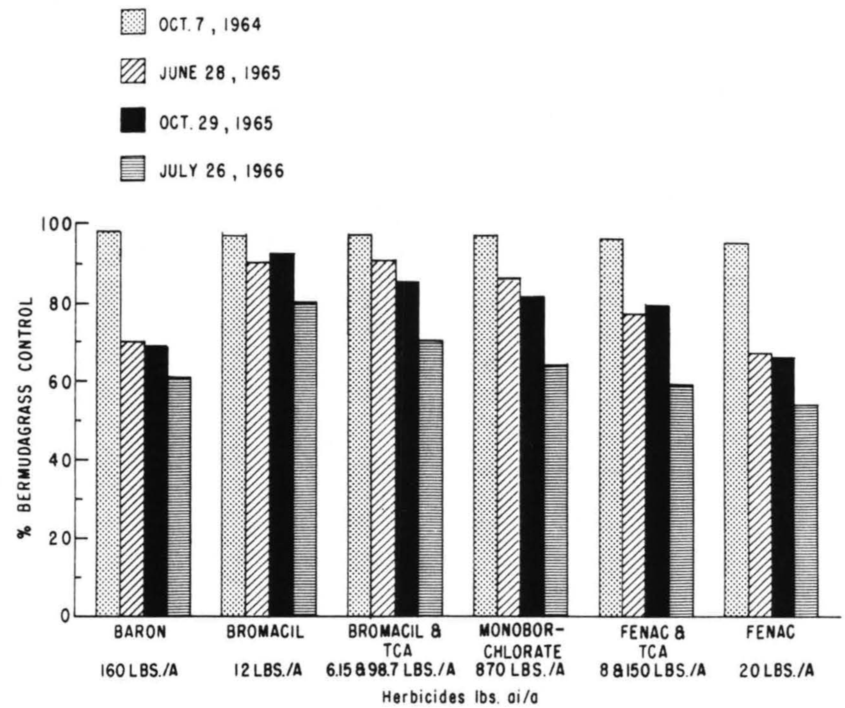


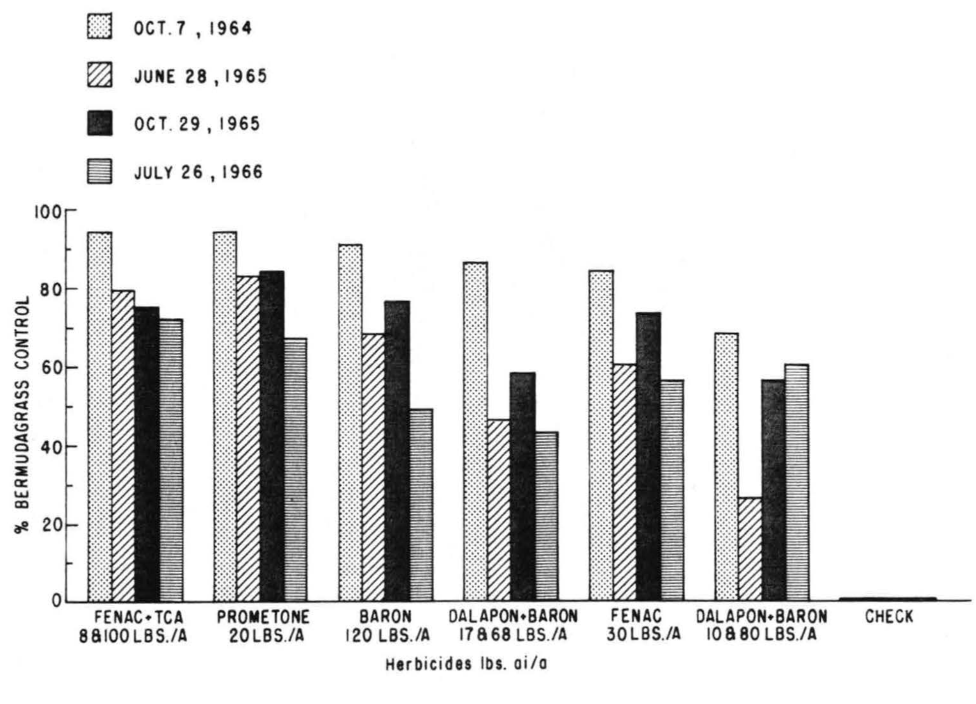
Figure 3-50. The effect of various chemicals applied on June 2, 1964, in the control of bermudagrass on SH-99 shoulders near Drumright, Oklahoma as evaluated on the above dates.



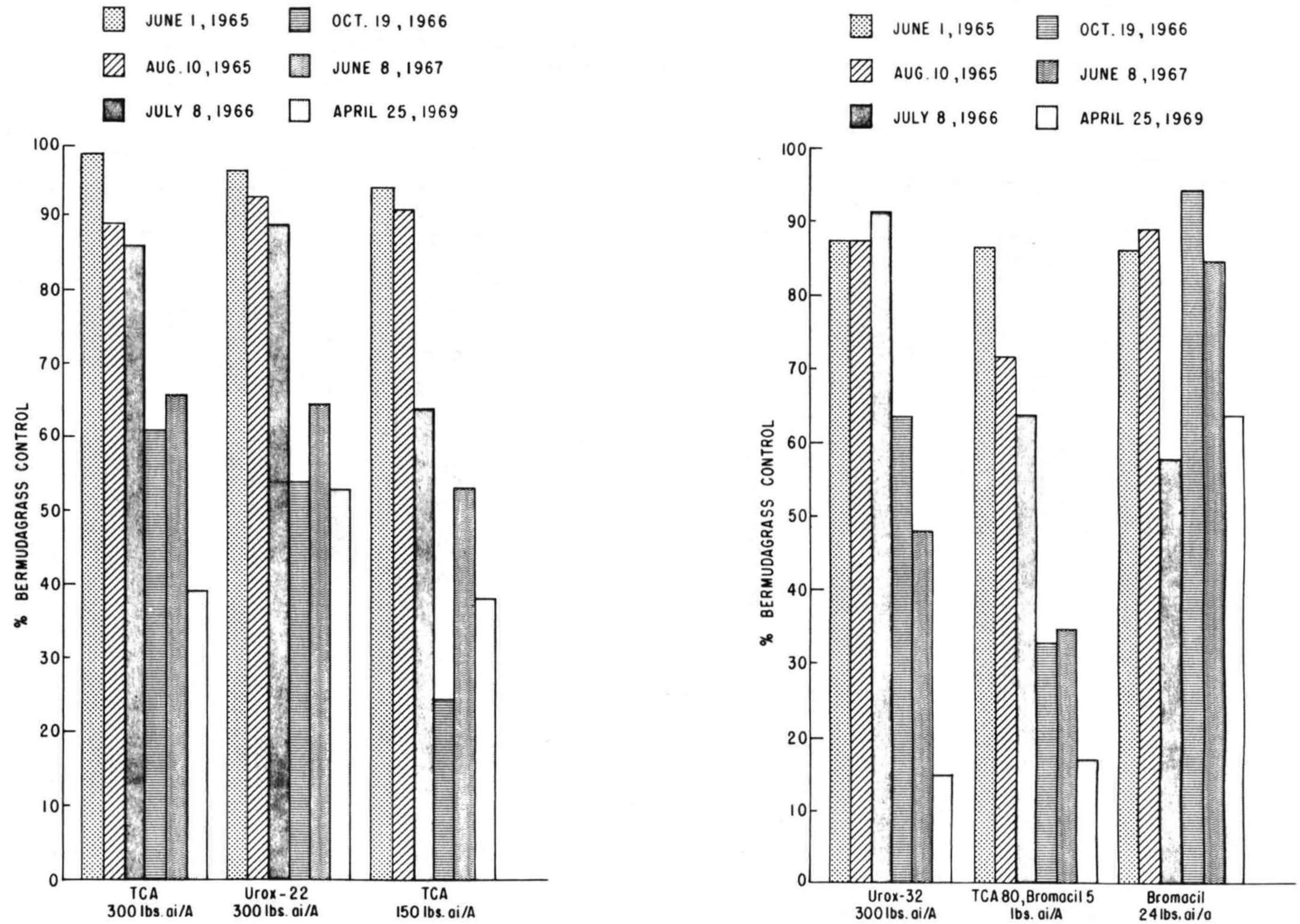


Figures 3-51 and 3-52. The effect of various chemicals applied on June 2, 1964, in the control of bermudagrass on SH-99 shoulders near Drumright, Oklahoma as evaluated on the above dates.

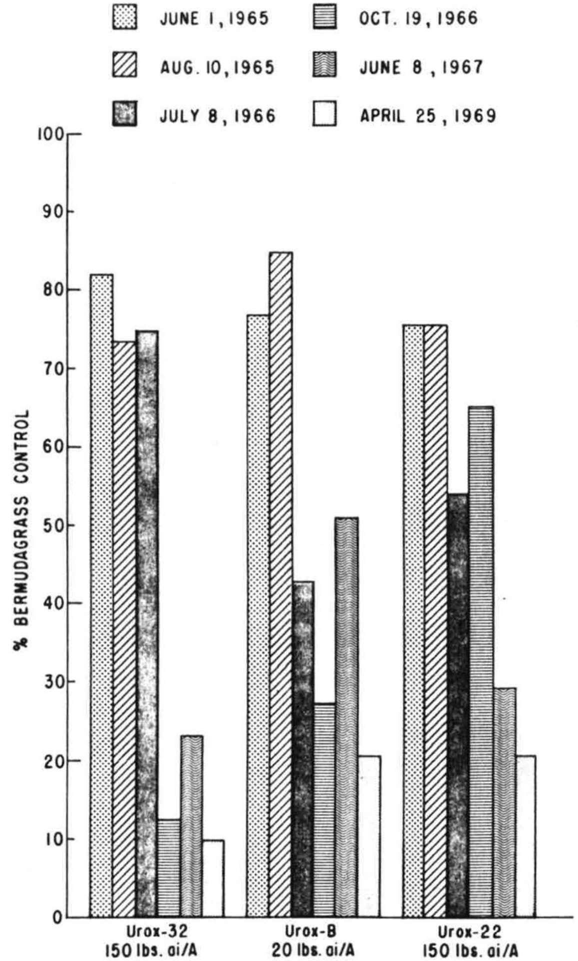


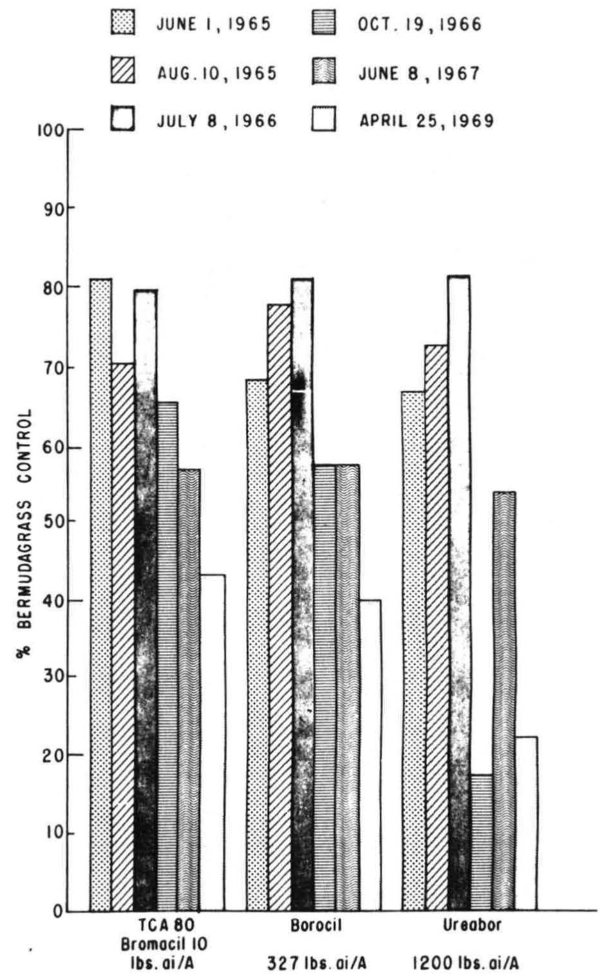


Figures 3-53 and 3-54. The effect of various chemicals applied on June 2, 1964, in the control of bermudagrass on SH-99 shoulders near Drumright, Oklahoma as evaluated on the above dates.

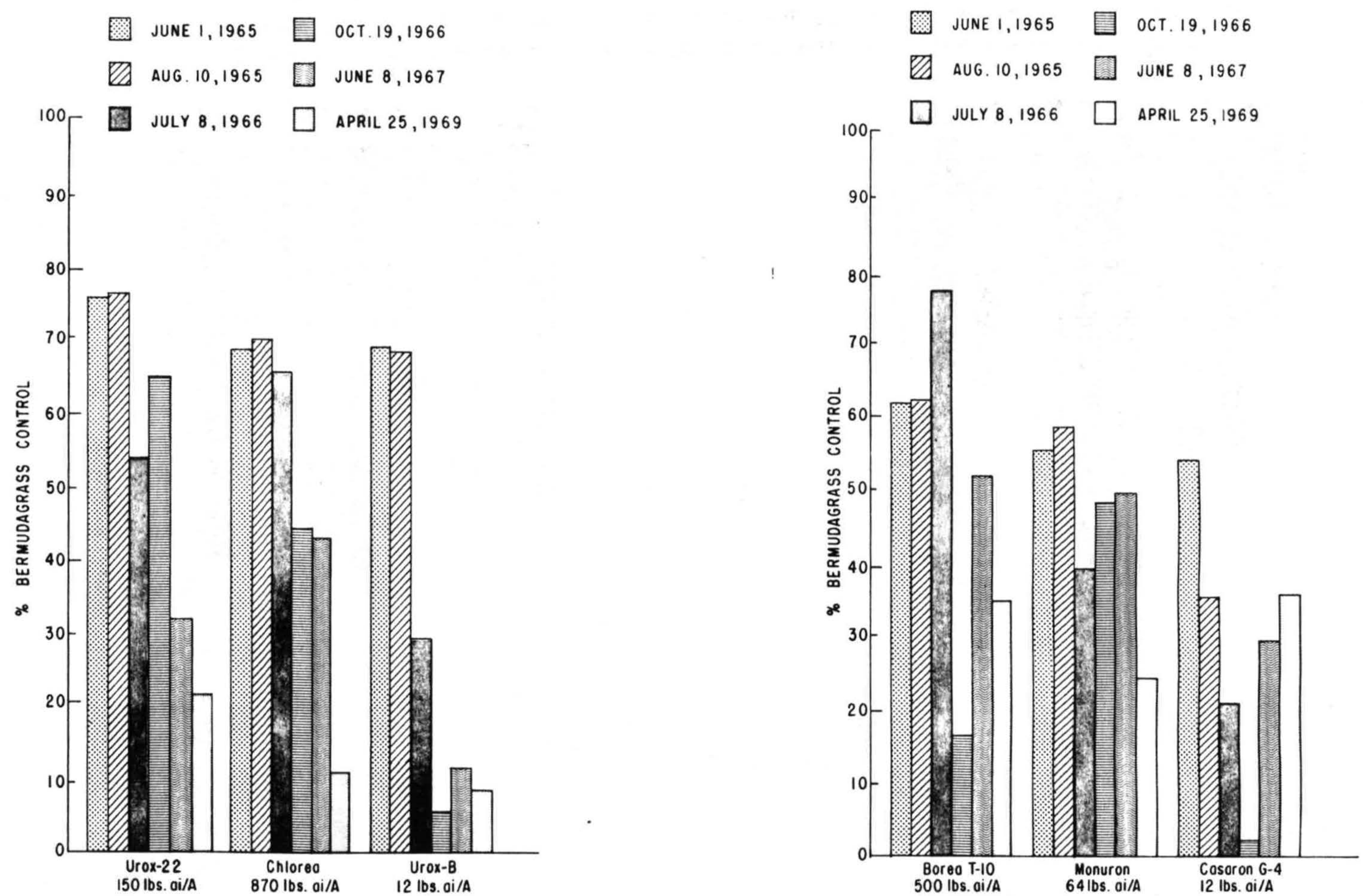


Figures 3-55 and 3-56. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.

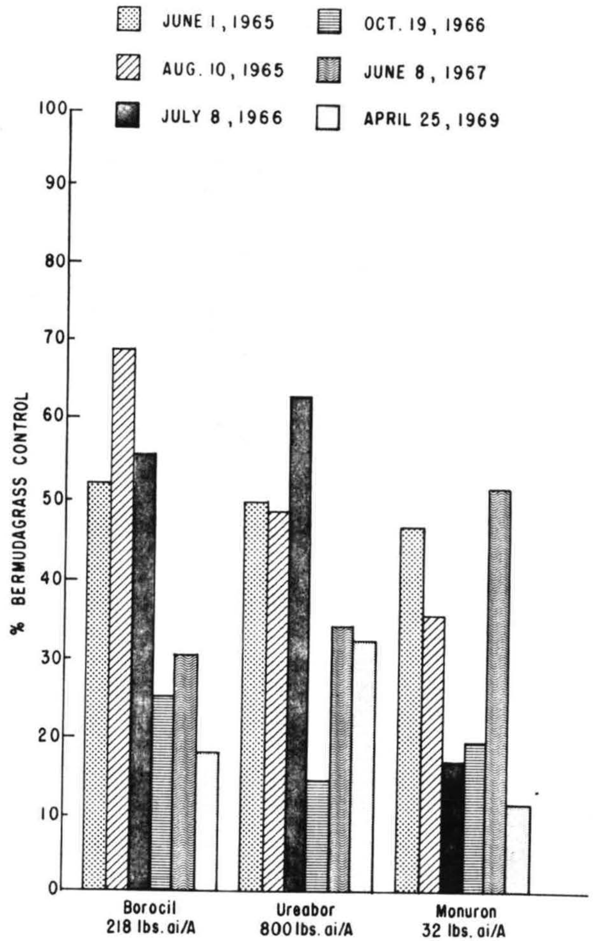


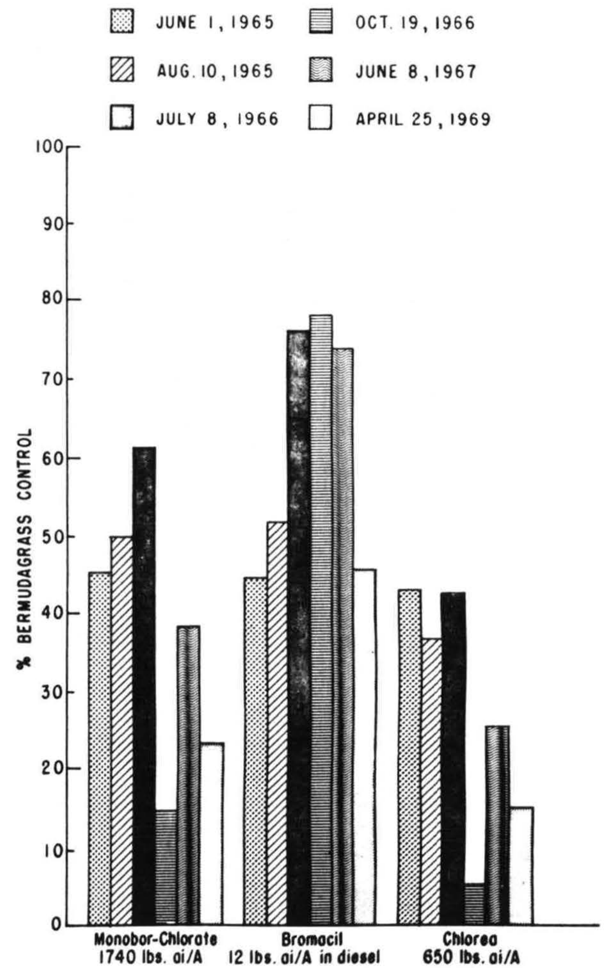


Figures 3-57 and 3-58. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.

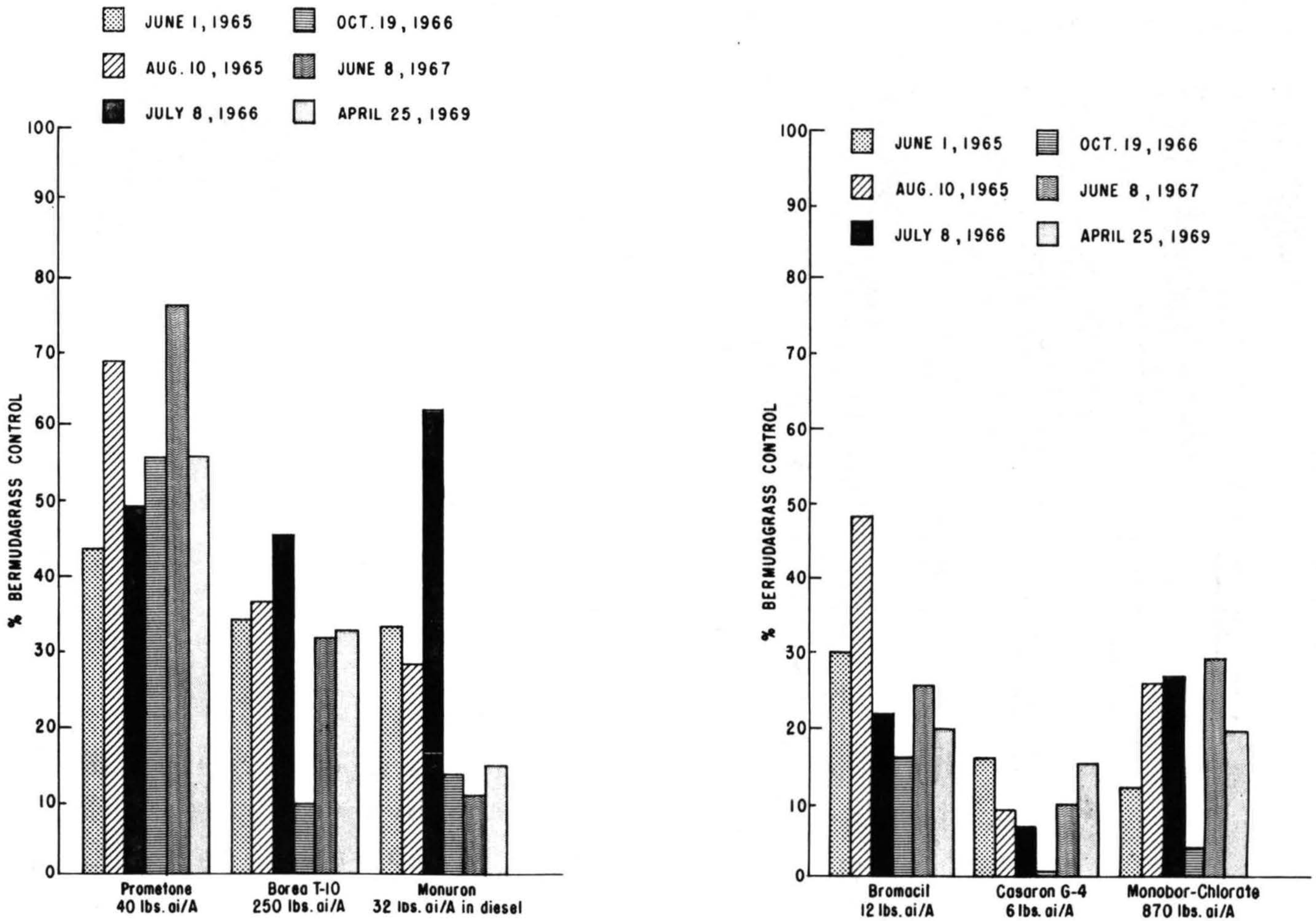


Figures 3-59 and 3-60. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.





Figures 3-61 and 3-62. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.



Figures 3-63 and 3-64. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.

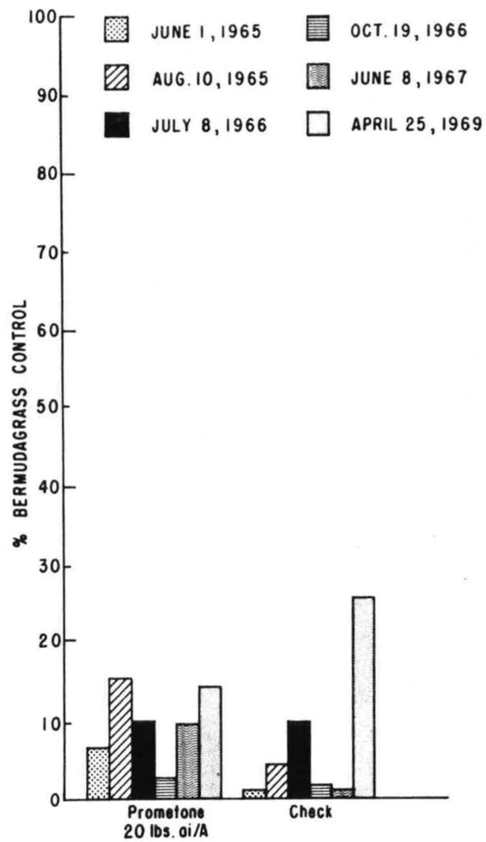


Figure 3-65. The effect of various chemicals applied on March 30, 1965, and retreated at one-half rate June 15, 1966, in the control of bermudagrass on SH-99 shoulders near Wynona, Oklahoma as evaluated on the above dates.

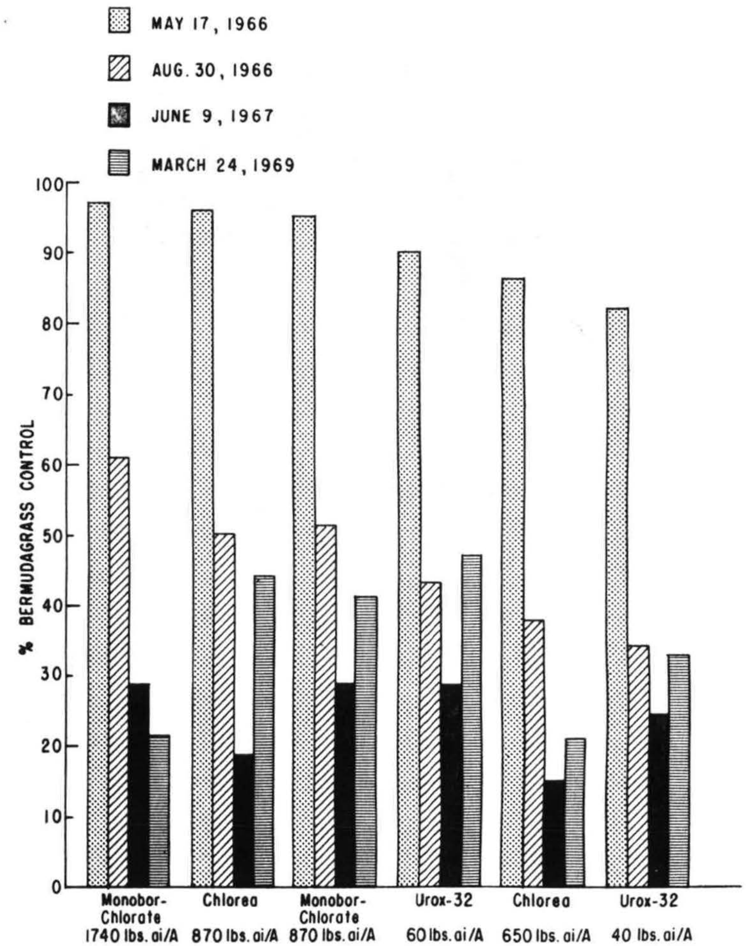
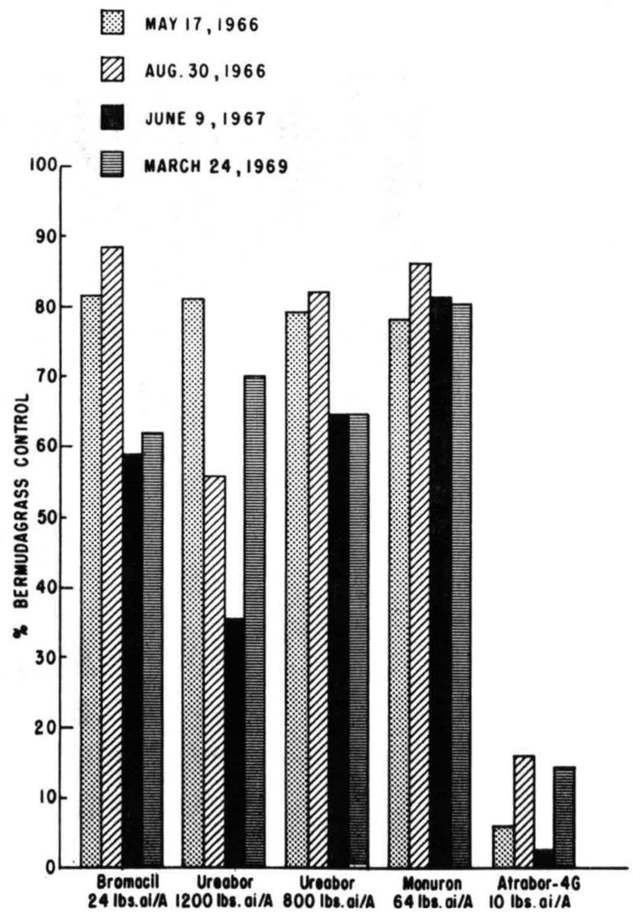
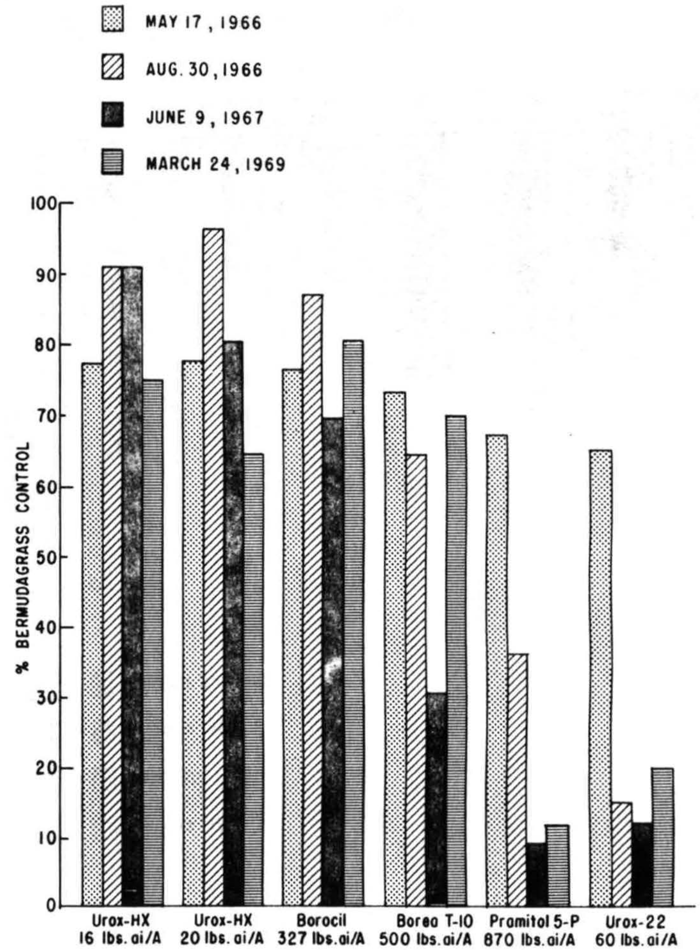
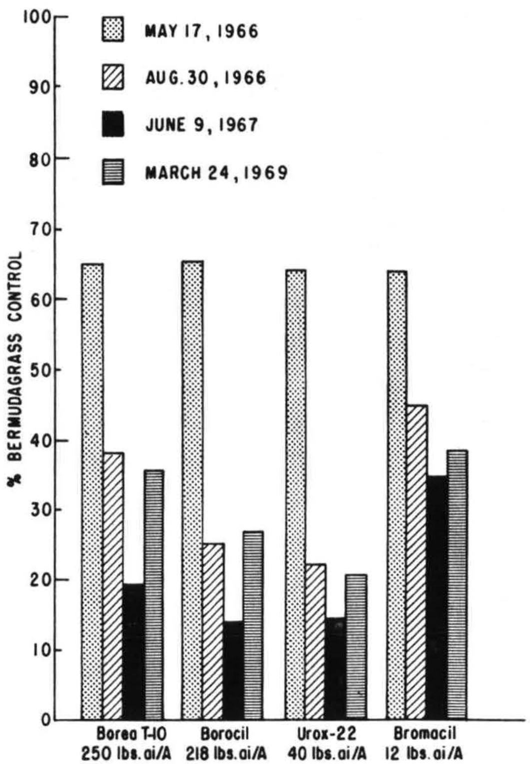


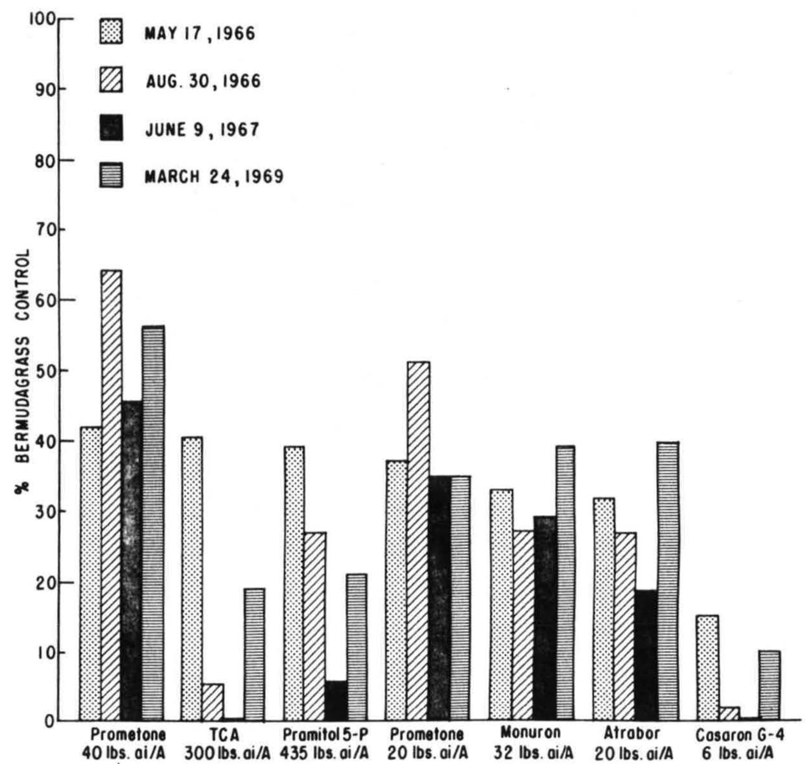
Figure 3-66. The effect of various chemicals applied November 30, 1965, on the control of bermudagrass on US-177 shoulders 4.8 miles south of US-66 junction in central Oklahoma as evaluated on the above dates.





Figures 3-67 and 3-68. The effect of various chemicals applied November 30, 1965, on the control of bermudagrass on US-177 shoulders 4.8 miles south of US-66 junction in central Oklahoma as evaluated on the above dates.





Figures 3-69 and 3-70. The effect of various chemicals applied November 30, 1965, on the control of bermudagrass on US-177 shoulders 4.8 miles south of US-66 junction in central Oklahoma as evaluated on the above dates.

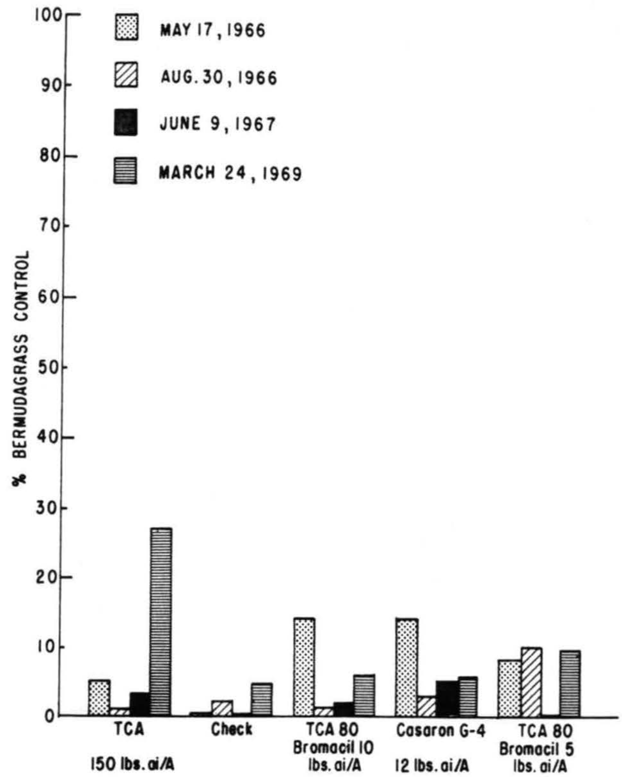


Figure 3-71. The effect of various chemicals applied November 30, 1965, on the control of bermudagrass on US-177 shoulders 4.8 miles south of US-66 junction in central Oklahoma as evaluated on the above dates.