INTERSEEDING AND PARAQUAT EFFECTS ON CENTRAL AND EASTERN OKLAHOMA RANGELAND VEGETATION

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CHAPTER I

Introduction

justification

In the Great Plains States forage on many thousands of acres of rangeland has been depleted by excessive grazing, erosion, drought, and the subsequent increase of unpalatable species. In Oklahoma, about two-thirds of the total range needs some degree of reestablishment, improvement and/or protection of the cover (O. C. N. I. 1970). These rangelands are producing at a relatively low level and the prospect for a rapid improvement based on natural succession is not favorable. Natural succession on previously cultivated land often requires many years to significantly improve range condition (Costello 1944).

Interseeding is considered as a unique opportunity for the Great Plains area, because it consists of establishment of plants seeded with minimum disturbance of soil and vegetation. This procedure minimizes the hazard of wind and water erosion, and introduces desirable species on poor condition rangelands. Interseeding costs less than complete seedbed preparation, and has been successful in the United States and in other countries.

The success of interseeding often depends on the kind of treatment executed before or during the seeding process to remove competition of the existing vegetation. The use of chemicals, fire or close grazing can increase the success of establishment of plants.

Fire is recognized as a useful tool in the management of rangeland. Controlled burning, followed by an application of fertilizer, may be beneficial in the establishment of seeded species and the removal of weedy vegetation.

Chemicals, such as contact herbicides, having a wide range of activity, can be used for the suppression of mixed stands of grasses and other vegetation with rapid inactivation in soils. Paraquat (1,1' dimethyl-4-4'-bipyridiniumion) has these properties, and its use in the interseeding procedure may help newly seeded species by reducing the effect of competing vegetation.

It is desirable to investigate the purity and viability of grass, legume and shrub seeds to provide information on the germination of these species and to determine the response, under different treatments, of tested species. This information can guide the choice of management and improvement programs on rangelands. A more accurate idea on the quality of the seeds is also developed.

The use of different chemical herbicides for the range renovation makes possible many alternatives for the control and management of undesirable vegetation. The willingness to change the methods of management is motivated by economic factors, coupled with a shortage of labor.

Millions of acres of rangelands in the western states must provide good quality forage to satisfy a growing demand for domestic livestock and wildlife. To meet these demands, rangemen must apply new ways to reduce unpalatable species and increase the capacity of land. Allen (1967) suggested the use of paraquat as an aid to rangeland improvement. This herbicide is distinguished from other chemicals for its properties, such as rapid absorption into foliage, effectiveness against grasses, and no residual soil toxicity.

objectives

Forage production often can be improved by interseeding palatable, productive species, while a contact herbicide is being sprayed for herbaceous weed control. The objectives of this study were to determine in central and eastern Oklahoma (1) the frequency of establishment of interseeded grasses, legumes and shrubs in combination with paraquat, burning and fertilization, (2) the germination quality of nine selected grasses, legumes and shrubs, (3) the effects of paraquat, burning and fertilization on the composition and quality of existing vegetation, and (4) the effects of rate and date of paraquat application on rangeland vegetation.

CHAPTER II

Review of Literature

Oklahoma, like other Great Plains States, undergoes an uncontrolled exploitation of its resources by grazing and fire, which often result in deterioration of rangeland forage production. This is aggravated by long periods of drought and/or intensive water and wind erosion. The 1967 Oklahoma Conservation Needs Inventory reported about 8,712,080 ha of native grazing land in Oklahoma. About 64% of this area needs either reestablishment, improvement or protection of cover (O. C. N. I. 1970).

interseeding

Perspectives.-The idea of range interseeding developed in 1899, when the first pasture furrowing was done in the Great Plains. The purpose of these furrows was to catch grass seeds blown by the wind and prevent their loss to the pasture (Schumacher 1964).

During past years, useful results have been obtained from interseeding in many areas of the world. During the past twenty years interseeding and topdressing with fertilizer gave good results in the unploughable hill country of New Zealand (Allen 1966). Different terms are employed such as oversowing, direct seeding, reseeding, and furrow seeding, but each of these terms refers to a technique whereby seeding is accomplished with only partial disturbance of the existing vegetation (Hervey 1960).

Wassen and Herby (1952) indicated the principal objective of interseeding was to increase animal production with the restoration of watershed value and soil stability, and the amelioration of food and cover for game.

Several workers conlcude that seeding is a means of reducing soil and water losses on depleted lands in eastern Oregon, Texas, and Oklahoma, and also a means of converting such lands to productive grazing areas (Nixon 1949, McCrillis 1965). Hervey (1960) underlined the fact that interseeding is a compromise between the very slow natural succession and the complete and relatively quick establishment of climax species, involving the plowing of land. Heinrichs (1952) indicated abandoned farmlands in Canada can be successfully reseeded by drilling seeds into the ground without any previous cultivation. In Idaho, range sites seeded to introduce grasses and legumes produced significantly more herbage than climax vegetation (Rumsey 1971). The addition of legumes to a nitrogen depleted grass sod offers real promise for amelioration of soil fertility (Wedin 1971).

Interseeding is a common method of range renovation and improvement (Wight and White 1974), and a means of improving soil and water conservation (Miller et al. 1953). Compared to the other methods of improvement, interseeding is becoming more and more popular in Nebraska (Schumacher 1964). Interseeding increased forage production on semiarid rangeland by improving species composition, the soil water regime and soil fertility in eastern Montana (Wight and White 1974).

Interseeding can reintroduce climax dominant species and hasten natural succession (Schumacher 1964). Others feel this method is needed to restore full production and good watershed condition within a reasonable period of time (Hurt 1950). Proper livestock management alone requires too much time to accomplish the desired change. Mechanical methods are practically impossible on thousands of acres of rocky and steep rangelands. In these circumstances range interseeding can reestablish native species in spaced rows on land where the erosion hazard is high and it is impractical to establish a cover crop (Schumacher 1964).

Soil.-Differences are major factors affecting productivity and establishment of seeded species. Sandy and sandy range soils are the most favorable sites for successful interseeding programs (Wight and White 1974). Satisfactory stands of sand lovegrass were produced in a dune sand soil and sandy soil. Several trials were successful on a silt loam soil, deficient in phosphorus and molybedenum where the pH was approximately 5.0. Interseeding has sometimes been successful on a silty site in New Zealand (Cullen 1966b).

In Idaho the increased production of seeded ranges compared with native range for a four year period averaged 224% for a loamy soil site 30 to 40 cms in depth (Rumsey 1971).

Except for Houston and Adams (Wight and White 1974), who reported that interseeding on clayey and panspot range sites increased herbage production, most of the other scientists found some difficulties in establishing seeded species on clay and clayey soils (Schumacher 1964). Generally the failure was due to the formation of a crust which inhibits the emergence of seedlings (Cullen 1966b). Other categories of soils, such as Mollisols, may show different reactions. These should support the best stands of perennial grasses and be the most productive in an effective depth of 45 to 61 cm (Evans et al. 1967). Interseeding has been more successful on coarse textured soils than on medium or fine textured soils (Springett 1967).

Seeding date.-The success of range seeding is highly dependent upon the date of seeding. Late fall and early spring are the planting periods which appear to be successful in Arizona, Utah, and western Colorado (Robertson 1947, Heaton 1956, McGinnies 1960). The seeding date is variable, from February through March for the warm season grasses, and from September 15 to October 15 for the cool season grasses in Texas and Oklahoma (Nixon 1949). Generally spring seeding is more successful than summer seeding. During spring more promising results are obtained because of soil moisture accumulated during the winter (Wedin 1971).

Weather conditions.-The success of establishing seeded species depends largely on the quantity and distribution of the rainfall and the level of the soil moisture. Inadequate soil moisture frequently limits germination and retards early growth, especially during critical periods (McGinnies 1959, Evans and Young 1970a). In the intermountain region where precipitation of 40 cm is considered necessary for successful seeding, a successful seeding was established in a year with only 20 cm precipitation, when soil, water and temperature conditions were favorable (Stewart 1950).

The success of range seeding depends on the climate conditions, regardless of chemical or mechanical treatments. If moisture is a limiting factor in plant growth, the amount and frequency of distribution of the precipitation may determine the degree of success of any seeded species. Other factors such as high and frequent winds, causing a high evaporation rate, great extremes of temperatures, and abundant sunshine can delay the germination of the drilled species (Johnston 1962). In the widely varying climate the primary aim of reseeding procedures should be to place the seed in a favorable environment for germination and establishment (Pearse 1952).

Species.-Rangelands are very hetergeneous. Each site has different limitations, and therefore no species can be successfully established on all sites. In several interseeding trials in Australia perennial grasses showed a real promise for establishment, because of their performance and soil stabilization value (Whittet 1952). They also have a longer green feed period and a more consistent level of forage production than annuals (Love and Burles 1952). Adapted perennial grasses are preferred in the semi-arid rangelands of the western states because of their high success of establishment (Evans et al. 1969). Perennial warm season grasses are very important as forage plants in the Great Plains, because they provide a good source of forage during the summer (Warnes and Newell 1969).

The use of grasses and forbs is continually increasing in the interseeding programs. Sand lovegrass (*Eragrostis trichodes*) has been established without any seedbed preparation in the western part of Oklahoma (Nixon 1949); a yellow sweetclover (*Melilotus officinalis*) increased production on dense clay range sites in eastern Montana (Wight and White 1974), and *Medicago* species were utilized in Canada in an effort to improve the nutritive quality of range forage (Johnston 1962). Crested wheatgrass (*Agropyron desertorum*) had the highest degree of success and the fewest failures in the intermountain west in Canada (Pearse 1952).

Seeding failures are often caused by severe competition for moisture and nutrients from the weedy vegetation, sometimes not totally controlled by chemical treatments (Evans et al. 1967). Bird damage to germinating seedlings, particularly subclover (Trifolium subterraneum) led to the abandonment of experiments in California (Kay and Owen 1970). In Canada, broadcasting the seed usually resulted in failure because surface soil conditions were too dry to allow grass seed to germinate (Heinrichs 1952).

Seeding depth.-Seed coverage is essential on rangeland where surface soil moisture is limited. Depending on the species being seeded, soil texture and climate, the optimum depth varies from 0.5 to 2.5 cm (Nixon 1949). A depth of 0.6 to 1.2 cm is required for small-seeded species and from 1.25 to 2.5 cm for the larger seeds (Pearse 1952). In sandy soil the depth of the furrow should be kept to a minimum to prevent coverage of the seed to excessive depth by drifting sand (Hervey 1960).

Seeding methods.-The decision to broadcast or drill seeds involves the question of no soil disturbance vs. minimal soil disturbance. Several studies involved a combination of these factors and conclusion drawn was to drill rather than broadcast (Miller et al. 1953). Broadcasting without covering the seed can be recommended only under exceptional climatic and agronomic circumstances (Pearse et al. 1948). In other cases an experimental drilling and broadcasting into disced cheatgrass (Bromus tectorum) resulted in almost no establishment of seeded grasses (Stewart 1950). Short (1943) reported, however, that thousands of acres of old fields in the Northern Great Plains have been successfully reseeded by drilling crested wheatgrass directly into the weedy cover.

In general successful broadcasting must be done at least in front of shallow discing (Hull and Stewart 1948); otherwise a failure of broadcast seeded species can result because surface soil conditions are often too dry to allow grass seed to germinate (Heinrichs 1952). Generally narrow row spacing is recommended, especially on steep slopes and wherever erosion is a problem (McGinnies 1960). Aerial seeding of depleted rangeland has been tried by ranchers since 1950 with some success, but disappointing results were also obtained (Wasser 1950).

Litter.-Plant litter creates a favorable microclimate for young seedlings establishment (Blackmore 1962, Whittet 1952). A heavy litter gave prolonged weed control when high rates of herbicide were applied, whereas marginal rates gave only temporary control (Kay and Owen 1970). The dead vegetation, resulting from weed control not only provides excellent erosion control, but creates a better environment for the new seedlings. Mulch helps retain moisture, controls temperature, and reduces the hazard of frost heaving (Kay 1966). By creating favorable microsites, plant litter may, however, favor the establishment of annual undesirable species in rangeland communities (Evans and Young 1970b).

Complementary treatments.-The application of fertilizer and lime may be necessary for the establishment of seeded species and maintenance of optimum soil pH. Under water stress, however, soil fertilization can seldom be recommended and the addition of fertilizer rarely justifies the cost (Pearse 1952). Cullen (1966a) found that lime aided germination and markedly improved the percent survival of grasses and clovers in New Zealand. Wedin (1971) feels that fertilizing is a must and it offers tremendous potential, when related to the amounts and time of application along with profitability.

Fire has been an important factor in shaping vegetation patterns for thousands of years (Sauer 1950, Cooper 1961). Burning conserves spring moisture for reseeding (Pechanec and Stewart 1944, Sampson 1952).

Gay and Dwyer (1965) revealed that burning and nitrogen fertilization in combination, increased forage production significantly over other treatment, including fertilization alone.

Paraquat gave satisfactory reduction of grass competition in Ohio where satisfactory stands of legumes were obtained by drilling into established grasses (Van Keuren and Triplett 1970). It is an effective means of eliminating green vegetation before the seeding process (Allen 1966, Douglas et al. 1965). The evaluation of paraquat as a contact herbicide in combination spray and reseeding programs in pasture and rangelands has been made both in the United States and abroad (Evans et al. 1960, Blackmore 1962, Elliott 1962, Jones 1962, Kay 1964).

In an interseeding program on a depleted rangeland where a mechanical treatment is quite difficult, several recommendations for successful establishment of seeded species include reduction of competition, correction of soil nutrient deficiencies, and selection of a adapted species. The use of paraquat or any other herbicide must be considered as a state in the technique of rangeland renewal (Allen 1967), since its role is to control unwanted vegetation which would compete with the newly sown seeds (Douglas 1965).

Generally where annuals dominate an area the establishment of perennial grasses is difficult, and the seeding success is usually directly proprotional to the degree of reduction of competing vegetation (Robertson and Pearse 1945, Whittet 1952). All scientists agree that competition was the main factor preventing establishment of the sown grasses (Stewart 1950, Robocker and Miller 1955, Evans et al. 1969, Cullen 1970).

Cheatgrass is considered as the most competitive vegetation (Hull 1963), and its removal led to successful natural and artificial reseedings on southern Idaho ranges (Hull and Stewart 1948). In addition an associated species, little barley (Hordeum pusillum), is found in many of the western and southern states of the United States (Albert 1956). The application of paraquat has been effective even where existing herbage is dense (Cullen 1970). Kay and Owen (1970) found it is safe to seed even the most sensitive plants after spraying paraquat at rates up to 16 times the amount required for weed control. One problem that may arise during paraquat application, is the hazard of killing perennial grass seeds not completely covered in the drilling process (Evans et al. 1967).

Problems.-Several problems, one of which is grazing before adequate establishment of seeded species, are encountered in the interseeding process (Frandsen 1949). Deferment of grazing must be practiced until the seeded plants have become established. The interseeding process may require more than one season to accomplish satisfactory establishment. Many grasses have delayed germination and good stands may be obtained the second year. Therefore it is advisable not to plow seeded areas until after the second growing season (Nixon 1949). Other agronomic problems are low soil fertility, high soil temperature and low seedling vigor of some of the adapted grasses (Thompson and Schaller 1960). Economic problems include the immediate cost, shortage of seed and adapted equipment for the interseeding process. These constitute major obstacles that cause slow adoption of interseeding realized in this area.

vegetation manipulation

In the Northern Great Plains, range fertilization has been tried with varying degrees of success for improving range condition and forage yield (Cosper et al. 1967). In Oklahoma range fertilization has not increased forage yield appreciably and the species composition changes to undesirable cool season species (Elder and Murphy 1958, Huffine and Elder 1960). Fertilization stimulated the growth of existing vegetation and accentuated the competitive effect of weedy grasses and forbs (Thompson and Schaller 1960, McCrillis 1965).

Graves and McMurphy (1969) found burned plots had more desirable decreaser species and fewer undesirable annuals. Fire also has been used to control cool season species (McMurphy and Anderson 1965). Wright (1974) said prescribed burning can increase herbage yields, increase utilization and availability of forage, and control undesirable shrubs. It stimulates forage production in stagnated grassland communities (Anderson et al. 1970).

Paraquat improves poor condition rangeland by reducing reinvasion of undesirable plants in seeded areas, and it appears to offer promise for improvement of ranges without reseeding (Whittet 1952). The bipyridinium herbicides contribute significantly to forage improvement on rangeland because of their rapid and complete toxicity towards any photosynthesizing tissue they contact (Allen 1966, Knight and Tomlinson 1967), especially the indigeneous vegetation (Douglas et al. 1965).

Since there is a variation in species composition and production from site to site the herbicide must have a broad weed control spectrum. The annual grasses germinating in the fall, such as cheatgrass, wild barley (Hordeum spp.), and broad leaved forbs, such as geraniums (Erodium spp.) are typical of the weed problems encountered on poor condition rangeland. These species are killed with low rates of paraquat, and it acts as a rangeland renovation herbicide whenever the complete removal of the equilibrium of the vegetation in favor of most desirable species (Blackmore 1965) because grass species exhibit a differential response to paraquat in their ability to recover after chemical defoliation (Douglas 1965).

germination

The use of dilute salt solutions in combination with prechill and light stimulates germination of several grass species. Colberg (1953) found that reed canarygrass (Phalaris arundinacea) germinates more readily if KNO_3 was used in combination with light. Mayer and Poljakoff-Mayber (1963) discovered that KNO_3 promotes germination of a number of species and this stimulation shows interaction with temperature. The advantages of using alternate temperatures in germinating numerous grass seeds have been suggested by Kearns and Toole (1939). The best treatments and environments for measuring germination potential of old world bluestem (Bothriochloa ischaemum) are a 2% salt solution of KNO_3, as a substrate moistening agent, alone or in combination with a 5-day prechill at 5-10 C and in either a 15-30 or 20-30 C alternating environment (Ahring and Harlen 1961). Harrington (1923) found the favorable effects of alternation of temperatures upon the germination of seed to be caused by the changes in temperatures and not by the mean or extreme temperatures reached. Several scientists showed that low germination of seed may have originated from improper storage conditions, unfavorable conditions in the germination of characteristics of seeds, such as seed coat thickness, prolonged dormancy or diseased seeds.

paraquat

Paraquat can exert a powerful influence over a treated area at any time of application (Allen 1965, Blackmore 1965). Several advantages exhibited by paraquat are (1) a high toxicity toward grasses, (2) complete inactivation on contact with soil, (3) no residual soil toxicity (Knight and Tomlinson 1967) because they are quickly and completely absorbed on clay minerals present in the soils (Weber et al. 1965, Coats et al. 1966), and (4) quick uptake by the plant and toxicity at low concentration of active ingredient especially on a cloudy day or in the evening (Warboys and Ledson 1965). Paraquat may be applied immediately before rain without its efficiency being impaired because it exerts a rapid action (Johnston 1962, Allen 1966).

Several scientists indicate the differential susceptibility of various species of grasses to given doses of paraquat and the influence of the date of application of paraquat on toxicity of the chemical to a particular grass (Jones 1962). This susceptibility increases as the growing season progresses, reaching an optimum in the fall/early winter (Allen 1966).

The practical significance of paraquat is its selectivity between annual and perennial grasses. Some herbicides are similar to paraquat in their mode of action, but at the same rates paraquat is very much more active (Hogue and Warren 1970). It exerts a more effective weed control initially and is longer lasting than cultivation. There is practically no erosion hazard, and a better seedbed results from dead vegetation (Kay 1966). Organic matter and minerals are not buried. They are left in the top few inches where they become more efficient (Beggs 1972). Furthermore, paraquat is effective against a wide range of annuals, tufted perennials and stoloniferous grasses (Allen 1966) in addition to its action against wild barley and downy brome (Hull and Stewart 1948). With certain rates, foliage of Johnsongrass (Sorghum halepense) was killed (Albert 1965).

Adding a surfactant to enhance the phytotixicity of paraquat is recommended (Evans 1965, Warboys and Ledson 1965). Generally X-77, a nonionic spreader-activator, is used (Kay and Owen 1970).

Different grass species exhibit different degrees of susceptibility to paraquat (Allen 1967). It is difficult to find an optimum rate that can be generalized for all species under all conditions. A rate of 2.25 kg/ha of paraquat eliminates all lowland grasses (Douglas and McIlvenny 1962, Douglas et al. 1965). At lower rates there can be selective responses of practical significance in the regrowth (Allen 1965). Complete control of cheatgrass was attained with a rate of 0.52 kg/ha of paraquat. At rates as low as 0.067 kg/ha, cheatgrass plants were partially desiccated and some measure of control was seen (Evans et al. 1967, Evans et al. 1969).

The best time of application is at flowering because paraquat arrests both seed development and the concomitant redistribution of nutrients within the plants (Agbakoba and Goodin 1971, Sneva 1967). Date of spraying is an important factor in the success of perennial grass establishment, thus it extends from the end of February to the beginning of April, with best control in the spring before seed formation of competing vegetation (Hull and Stewart 1948, Evans et al. 1969). In several experiments conducted in northeastern California and northern Nevada, Evans et al. (1967) reported that successful establishment of intermediate wheatgrass (Agropyron intermedium) by spring paraquat spraying in a big sagebrush

(*Artemisia tridentata*) community will be limited to years of average or above-average March through May precipitation. Thus the time of spraying is directly related to the conditions of cover and weather for any specific year.

The three major problems encountered when paraquat is applied as a grass killer are (1) the change of physical aspects of the seedbed permitting certain weeds to become dominant in a unique community (Evans et al. 1974), (2) periods of maximum susceptibility of co-dominant grasses may differ and (3) herbicide sprays may drift out of target areas (McKinlay et al. 1974).

CHAPTER III

Study Areas

The central Oklahoma study area is located on the Oklahoma Agricultural Experiment Station, 2.5 km north of Perkins, Oklahoma. The climate of the area is mild, but subject to sudden temperature changes in both winter and summer. The prevailing wind during the year is from the South. The most severe heat temperatures occur during the months of June, July and August, and are often accompanied by hot winds. The average monthly maximum temperatures are 30 C, 33 C and 32 C respectively for June, July and August. The 30-year average rainfall is 940 mm., as recorded by the U. S. Department of Commerce for Perkins (USDC 1972). The highest average amount of rainfall in one month is 129 mm., during May.

The soil is Konowa fine sandy loam, classified as a Ultic Haplustalfs, having a 1-3% slope and is moderately eroded. They are sandy, light-colored. They developed on convex slopes. They have brown to dark brown surface horizons with a lighter A2 horizon. The A horizon is about 50 cm thick. The subsurface horizons are yellowish-red to red sandy clay loam (Ford 1970). Konowa soils are well drained and are moderately permeable.

The grass vegetation consists of a closed community of bromes (*Bromus* spp.), little barley and abundant Johnsongrass. The main forb species are western yarrow (*Achillea lanulosa*), ragweed (*Ambrosia* spp.), and many flowered aster (Aster ericoides). Sumac (Rhus spp.) dominates the overall canopy. Other species such as sedges (Carex spp.) are present to a lesser degree.

The eastern Oklahoma study area is located on the Eastern Pasture Research Station, 23 km southwest of Muskogee, Oklahoma. The climate of this area is warm and humid with an 11-year average of 915 mm. of rainfall, recorded at the Research Station. The lowest temperatures recorded in January and February are respectively 16 and 8 C below zero. The highest temperatures recorded in July and August are respectively 40 and 42 C. The weather is rather variable with severe dry periods during the summer and very wet conditions during the fall , winter and spring.

The soil is Parsons silt loam, classified as a Mollic Albaqualfs, having a 0-1% slope. These are described as Planosol soils, occurring on nearly level plane surfaces, and are moderate to well-drained (Stiegler and Gray 1967). The soils present on the station are low in nitrogen and available phosphorus, and are acidic in reaction.

The primary vegetation consists of bromes, little barley and to lesser extent switchgrass (Panicum virgatum). Forb species include western yarrow, ragweed, many flowered aster, daisy fleabane (Erigeron strigosus), and goldenrod (Solidago spp.).

The scientific names of grasses are taken from Hitchcock (1950) and names of forbs and shrubs are from Waterfall (1969).

CHAPTER IV

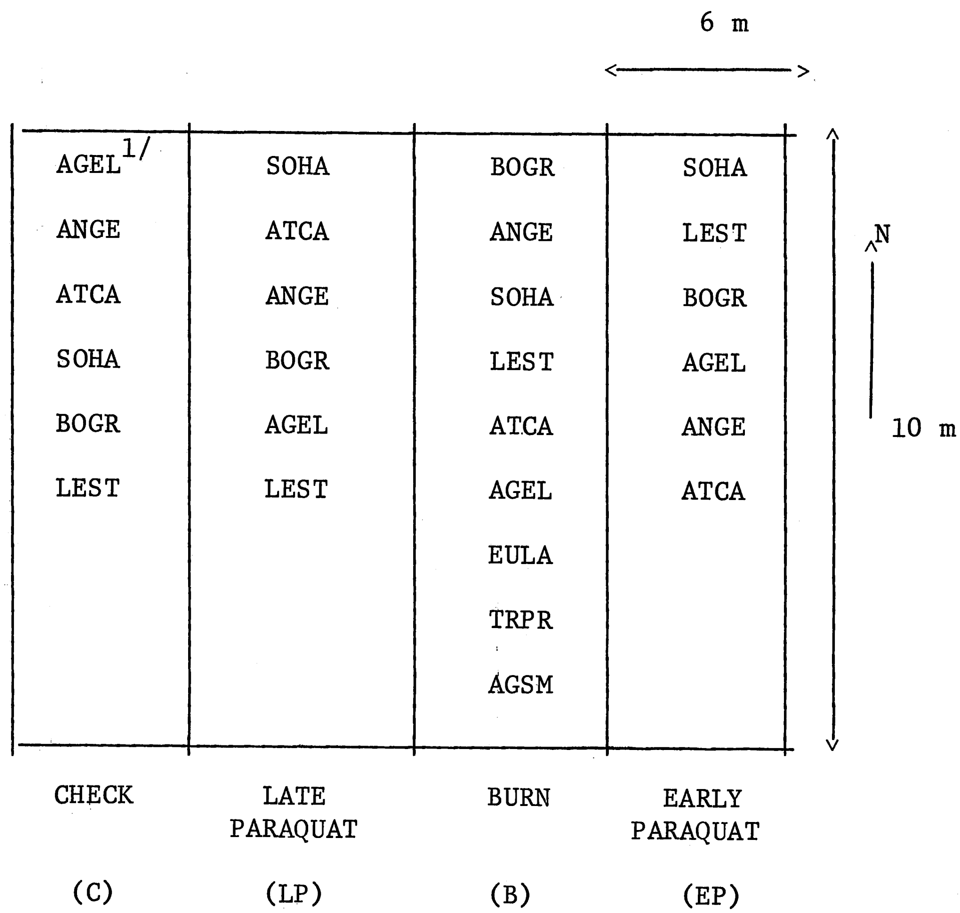
Procedures

interseeding

Experimental design.-A randomized split plot design was employed on the central Oklahoma study area using three replications (Fig. 1). Each plot measures 6 meters wide by 10 meters long. Two main plot treatments were two paraquat spraying dates. The first main plot received a rate of 0.56 kg of active ingredient per hectare on March 26, 1974. Paraquat spray, using the same rate, was applied on April 16, 1974 on the second main plot. The third main plot treatment was a controlled burn on March 12, 1974. One control plot was included in each replication. Sub-plot treatments of six seeded species were randomly located on each main plot.

A similar experimental design and plots were used on the eastern Oklahoma study area. The relatively low amount of fuel on these plots made burning impractical; therefore, rather than using burning as a treatment, one plot per replication received an additional 50 kg of phosphorus per hectare. In eastern Oklahoma the two paraquat spraying dates were April 1 and April 18, 1974.

Preseeding treatments.-The study area in central Oklahoma was shredded with a rotary mower in December, 1973 and fertilized on March 12, 1974 by broadcasting 40 kg of nitrogen per hectare on each



1/ Scientific names of seeded species

Fig. 1. Field layout of interseeding study.

plot including the check. On the same day 38 kg of phosphorus per hectare were drilled into the soil on each plot with a hoe drill. Fertilizers were applied after burning.

On March 26, 1974,0.56 kg of active paraquat per hectare was sprayed on appropriate plots with a carbon dioxide hand sprayer. The spray applied included 14.3 ml of active ingredient mixed in 1.9 liters of water plus 1.5 ml of X-77 surfactant. Paraquat was applied lengthwise in 91.5 cm bands within the plot, at a steady speed and height to insure adequate coverage. On April 16, the same rate of paraquat was applied by the same procedure on another plot within each replication.

Vegetation was mowed and removed from the eastern Oklahoma plots in October, 1973. On March 13, 1974, 50 kg of nitrogen, 123 kg of phosphorus and 86 kg of potassium per hectare were drilled into the soil on each plot with a hoe drill. The "fertilized" plot received the additional phosphorus fertilizer on March 13, 1974.

Seeding techniques.-Shallow furrows varying in depth from 2.5 to 6 cm were established using a hoe drill. About 40 furrows were established in the width of the plot with 25 cm between rows. Each three adjoining rows received the same species. Big bluestem (Andropogon gerardi), johnsongrass, fourwing saltbush (Atriplex canescens), Korean lespedeza (Lespedeza stipulacea), tall wheatgrass (Agropyron elogatum), winterfat (Eurotia lanata), western wheatgrass (Agropyron smithii) and hop clover (Trifolium procumbens) were seeded by hand into the furrows and then covered slightly in order to bring the seeds into contact with the soil. In addition to the first six species listed the last three species listed were seeded in burned areas. Furrow preparation and seeding were done on March 12, 1974.

The same six species seeded in central Oklahoma were also seeded in the study area of eastern Oklahoma. An additional grass species, alkali sacaton (Sporobolus airoides), with winterfat, western wheatgrass, and hop clover were seeded on the fertilized plot. Furrow preparation and seeding were done on March 13, 1974. All other seeding techniques were similar for the study areas in central and eastern Oklahoma.

Seedling Response.--Establishment of seeded species in both study areas was evaluated by seedling counts and height of plants seeded in various treatments. Percent frequency (Ecological Society of America 1952) of each species was determined by counting the total number of adjacent 30 cm segments of the middle seeded row which contained at least one seedling of the species seeded. This number was divided by 20, the total number of 30 cm segments sampled. Seedlings of certain rapidly established species were counted several times during growing season to study the effect of climate conditions on the vigor and mortality of seedlings. Observations were also taken concerning the effects of different treatments. Measurements were taken for all species in late October before the freezing period.

germination

Seeds used in this study were from seed samples of the following species: big bluestem, blue grama, johnsongrass, tall wheatgrass, western wheatgrass, alkali sacaton, korean lespedeza, hop clover, fourwing saltbush and winterfat. They were obtained from various commercial sources. Germination tests were conducted in the laboratory.

The experiment included one moist prechill period of two weeks followed by a final germination period of one week. Each step included one treatment with 2% potassium nitrate solution and one control with distilled water. Treatments were replicated four times. Each sample consisted of 50 pure seeds previously separated from empty seeds using a seed blower, an air-blowing procedure. These seeds were placed in covered petri dishes with two layers of paper toweling. Distilled water or 2% potassium nitrate solution was added.

Prechill treatments were started before the tests began and lasted two weeks at 5 to 10 C. At the end of this period samples for the second and final step of germination were prepared and placed with prechilled samples into the germinators for a period of one week of alternating 16 hours (dark) at 20 C and 8 hours (light) at 30 C. Each replication was placed on a separate tray using a completely random design.

Normal seedlings were counted and removed from the petri dish. Counts were made for 28 days at 7-day intervals.

vegetation manipulation

The effects of paraquat, applied on two different dates, fertilization and burning on rangeland vegetation in central and eastern Oklahoma were evaluated on June 14, 1974, and October 23, 1974. Three sample locations were systematically selected within each plot. Using a 0.5 m^2 circular quadrant, the species class composition and production of the vegetation were determined by the weight estimate (Pechanec and Pickford 1937) and double sampling (N. R. C. 1962) techniques. Species classes included cool season annual grasses, warm season grasses, forbs and shrubs. One of the three samples was randomly selected for clipping.

The vegetation was clipped at a 2 cm stubble height, weighed in the field and reweighed after drying to a constant weight at 45 C in a forced air oven. Dry matter production for each species class was determined after adjusting for percent dry matter.

All samples were ground to pass through a 1 mm screen and analyzed for in vitro dry matter digestibility (IVDMD) and crude protein. Crude protein percent was obtained by multiplying Kjeldahl nitrogen by the factor 6.25 (A. O. A. C. 1970). The method of Tilley and Terry (1963) was used to determine in vitro dry matter digestibility.

Two 2.5 cm by 30 cm soil core samples were taken using a soil tube at depths of 0-3 dm and 3-6 dm at each clipped plot in June and October, 1974. All soil samples were weighed before and after drying for soil water determination, and then ground to a fine powder. Each soil sample was analyzed for pH and organic matter, available phosphorus, and nitrate contents.

The pH was determined with a Beckman glass electrode pH meter on a 1:1 soil-water paste. The organic matter content was obtained by the method of Schollenberger (1931). Available phosphorus was determined by extraction with 0.1 N acetic acid and the development of the molybdate color complex and total nitrogen content was determined by the Kjeldahl method according to Harper (1948). Percent soil water was determined by the gravimetric method (N. R. C. 1962).

Soil temperature at a 4-cm depth was recorded at the same time soil temperature was determined.

paraquat

A randomized block design with three replications was employed

(Fig. 2). The individual plot size was three meters wide by five meters long. The experiment consisted of a comparison of seven rates of paraquat ranging from 0.00 to 1.12 kg/ha at 3 different rates. All treatments were randomly assigned to plots within each replication.

Paraquat rates of 0.00; 0.14; 0.28; 0.42; 0.56; 0.84; 1.12 kg/ha were sprayed on seven plots on March 26 and on seven different plots on April 16, 1974. Only 0.14 and 0.28 kg/ha were applied on May 2, 1974. Surfactant X-77 at 0.79 mg/liter was added to the spray solution. A carbon dioxide hand sprayer with "91.5" cm pattern was used for spraying paraquat. One band was applied lengthwise in each plot, at a steady speed with a constant height from the soil. Wind speed and direction, soil temperature, and relative humidity were determined at the time of spraying.

The effect of different rates and dates of paraquat application on the composition, quality and yield of native vegetation were evaluated in June and October, 1974. The determination of species class composition, production, forage quality and soil factors was made following the same procedures described in the vegetation manipulation study.

data analysis

All data collected were keypunched onto computer cards. The data were analyzed by using the Statistical Analysis System (Barr and Goodnight 1972) and the IBM 360/65 Computer of the Oklahoma State University Computer Center. Differences among treatments were determined by least significant differences, as given by Steel and Torrie (1960). Differences were stated as being "significant" at the probability level

5 m

N	2 Ap[1/]	5 Ap	3 My	6 Ap	3 m
	5 Mr	4 Mr	4 Ap	7 Ap	
Rep 1	3 Ap	7 Mr	1 Ap	2 My	
	3 Mr	2 Mr	1 Mr	6 Mr	

Treatments	Rates kg/ha	Dates
1. Mr	0.00	3/26
2. "	0.14	"
3. "	0.28	"
4. "	0.42	"
5. "	0.56	"
6. "	0.84	"
7. "	1.12	"
1. Ap	0.00	4/16
2. "	0.14	"
3. "	0.28	"
4. "	0.42	"
5. "	0.56	"
6. "	0.84	"
7. "	1.12	"
2. My	0.14	5/2
3. "	0.28	"

1/ Mr = March, Ap = April, My = May

Fig. 2. Field layout of paraquat study.

CHAPTER V

Results and Discussion

interseeding

Environmental conditions.-The precipitation during the early stage of development of seedlings in eastern Oklahoma was far below the long range average as recorded at the respective weather stations. Drought conditions were severe over both stations in June and July (Figs. 3 and 4).

The nature of the soils as well as the precipitation may have affected the development of the seeded grass species in both areas. The Konowa fine sandy loam at Perkins seemed to lend itself to the establishment of the seeded species, but the Parsons silt loam in eastern Oklahoma decreased the survival of seeded species. A compact clay horizon restricts the drainage of water during wet periods. Roots may die from a restriction of oxygen supply. Also Kay (1966) found that this soil does not crumble readily and generally leaves an open furrow with the seed exposed in the bottom. In sandy soil the seed can be covered by drifting sand. These situations emphasize the need for shallow furrows in sandy soil and the necessity of covering the seed in any compact soil. Competition from existing vegetation may limit germination and establishment of seeded species. Herbage production in June was 1960 kg/ha in central Oklahoma and 1800 kg/ha in eastern Oklahoma. Herbage production in October was approximately equal to that

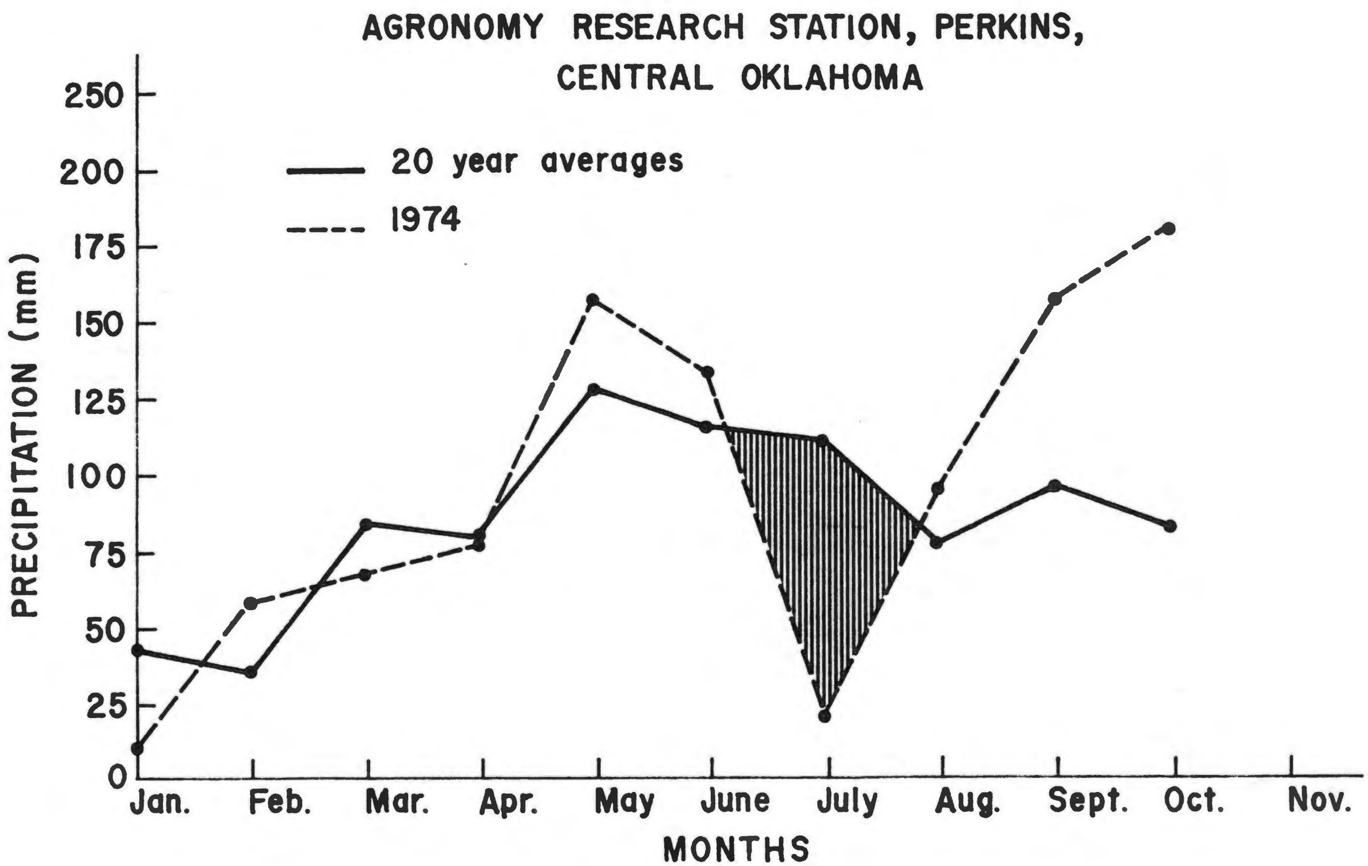


Fig. 3. Precipitation in central Oklahoma with 20-year average.

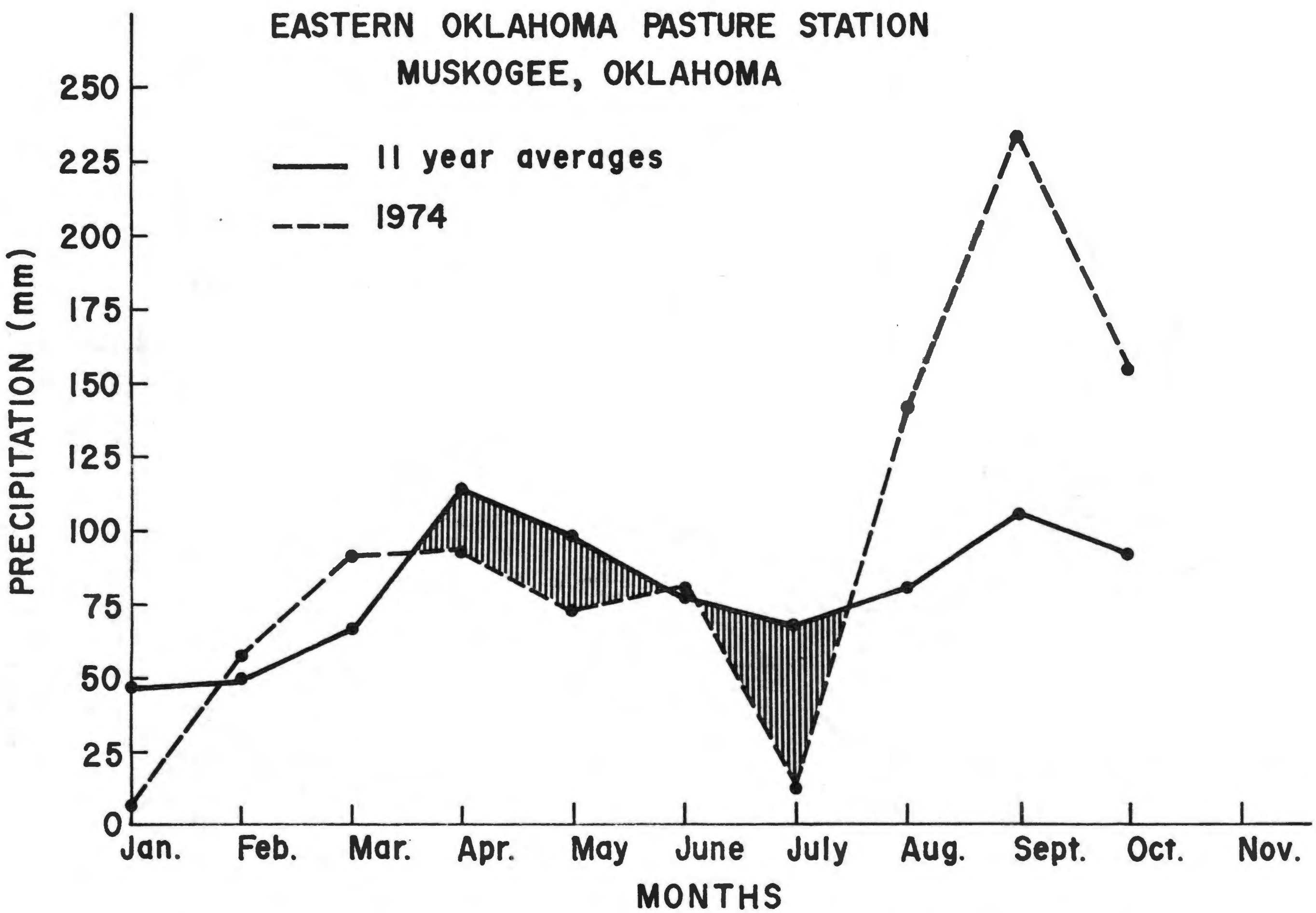


Fig. 4. Precipitation in eastern Oklahoma with 11-year average.

in June in both locations.

Surviving species.-It appears that Korean lespedeza is the species most capable of establishing itself in strong competing vegetation. Big bluestem and blue grama showed promising results in their adaptation to dry sites where minimum care was applied. Of the four species to be established, johnsongrass seedlings were the least competitive under minimum soil disturbance. In central and eastern Oklahoma, respectively, seedling frequency on control plots was 53% and 25% for Korean lespedeza, 17% and 2% for big bluestem, 15% and 0% for blue grama, and 17% and 0% for johnsongrass.

These four species were successfully established in the interseeding program. Five other seeded species either never germinated or germinated but failed to establish themselves under below normal conditions. The failure of some species to establish seedlings may be because they were cool season grasses (western wheatgrass, tall wheatgrass, and alkali sacaton). They were not in their proper environment with respect to optimum date of seeding. Heinrichs (1952) and McCrillis (1965) found that late fall seeding produced the best stand of cool season grasses. Even if these grasses are considered as successful competitors against existing vegetation, the spring seeding date was too late for these species to survive less than 25 mm rainfall during June and July and the strong competition of the existing vegetation. Winterfat and fourwing saltbush also failed to germinate when interseeded in March. The failure of these species to germinate and survive may be caused by low quality seeds. A laboratory germination study indicated very low germination rates of fourwing saltbush (11%)

and western wheatgrass (16%). Winterfat did not germinate.

Location X treatment X species.-Differences caused by location X treatment X species interaction are presented in Figure 5.

Controlled burning was the most effective treatment in central Oklahoma. It resulted in a high (55%) seedling frequency of big bluestem. Late paraquat treatment was more successful (23%) than other treatments in eastern Oklahoma, and better than early paraquat treatment in central and eastern Oklahoma. Early paraquat treatment had a small effect in seedling frequency in central Oklahoma (28%) and no effect in eastern Oklahoma (7%). The seedling frequency in the fertilized plot in eastern Oklahoma was very low (5%). Germinating big bluestem seeds benefited from reduced competition just prior to or during germination as a result of controlled burning or late paraquat application. Adverse establishment conditions apparently had a great detrimental effect on big bluestem particularly in eastern Oklahoma.

Controlled burning, early paraquat and late paraquat treatments were equally effective in increasing percent frequency of blue grama in central Oklahoma. Few grasses survived in eastern Oklahoma in early paraquat sprayed plots. The failure of blue grama in eastern Oklahoma may be caused by two months of drought occurring from May through July. This period may be considered critical because the root system of seedlings is not sufficiently developed to utilize the underground moisture.

Root development is important. Hyder (1974) discovered that blue grama initiates primary roots and adventitious roots but the latter roots develop at an average of only 2 mm below the soil surface. These adventitious roots usually die because of their location in a dry environment. The survival of a blue grama seedling depends upon the

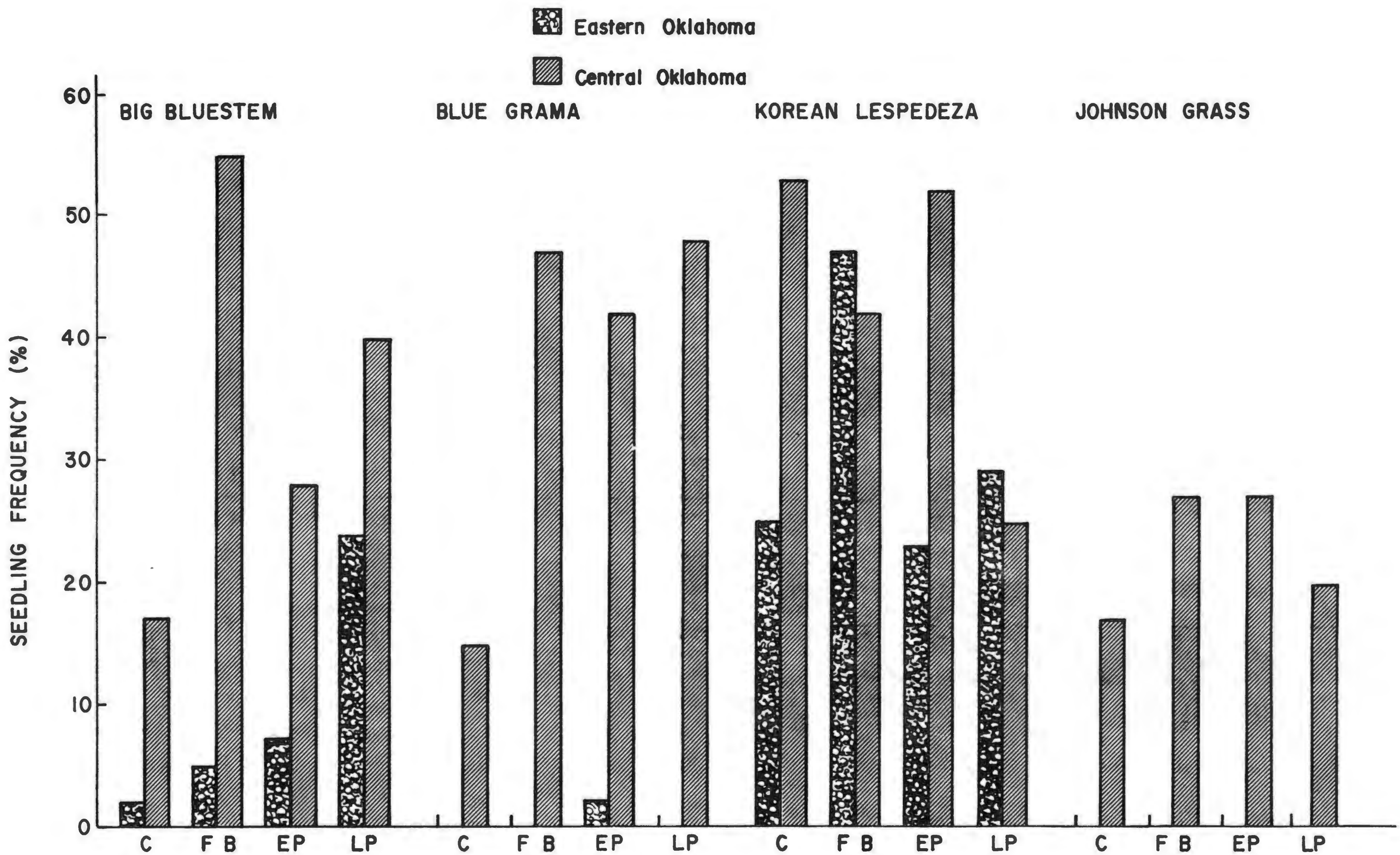


Fig. 5. Seedling frequency of seeded species in eastern and central Oklahoma on control (C), burned (B), fertilized (F), early paraquat (EP), and late paraquat (LP) plots. Least significant differences ($P<.05$) for treatment x species x location differences equals 15%.

seminal primary root which is generally sensitive to the severe environment. The best solution may be a mulch applied after seedling emergence or a cultivation creating favorable conditions for the extension of the adventitious roots from the crowns of new tillers.

Neither early nor late paraquat had any effect on seedling frequency of Korean lespedeza in eastern Oklahoma. Late paraquat treatment significantly decreased Korean lespedeza in central Oklahoma (25%). This result reflects the failure of Korean lespedeza to withstand the direct contact of paraquat when applied during the establishment of this species. Rapid germination and emergence of Korean lespedeza apparently occurred in less than four weeks and therefore lespedeza seedlings were killed by the paraquat.

The application of fertilizer in eastern Oklahoma did not affect any seeded species except Korean lespedeza. The seedling frequency of Korean lespedeza doubled on the fertilized plots. Although lespedeza is rapid growing and adaptable to a wide range of soil types and fertility levels, it does grow best on fertilized soil (Offut and Baldridge 1973). These characteristics enable lespedeza to survive and compete with existing vegetation, utilizing any available nutrients.

Laboratory germination study of Korean lespedeza indicated a high germination rate (84%) and total potential germination after 7 days of 20-30 C alternating temperatures. Rapid germination and emergence apparently allowed the lespedeza seedlings to develop adequate root systems before soil water became deficient.

The effect of location on the success of interseeded johnsongrass is evident. In eastern Oklahoma this species failed to survive. In central Oklahoma seedling frequencies were higher on burned plots and early paraquat treated plots, but seedling frequency differences were not significant. Johnsongrass seed germination in the laboratory was prolonged over a 28-day trial and was relatively low (47%).

Management implications.-The success of range interseeding is highly dependent upon the date of seeding. Each class of plants has an optimum date for seeding. Thus any attempt to seed warm season grasses and cool season grasses at the same time and even at the same season may result in the failure of one of them. In 1949 Nixon found that optimum dates for seeding warm season grasses in Oklahoma and Texas range from February through March for cool season grasses the best seedint dates were from September 15 to October 15.

Competing vegetation is the primary cause of failure of rangeland interseeding. Partial removal of existing vegetation through the use of paraquat now offers a feasible alternative for reducing the competitive effects of some cool season grasses and forbs without entirely destroying the protective cover of the soil.

Controlled burning before interseeding is as effective as paraquat in reducing competition from the existing vegetation and providing a relatively clean seedbed for the establishment of seeded forages (Wright 1974). The choice between controlled burning and paraquat will be determined by agronomic and economic considerations. Sometimes burning results in the complete destruction of cover and subsequently will expose the soil to wind and water erosion. The cost of paraquat application, including the labor, may limit its utilization in the interseeding program.

The interaction between treatments and seedling frequencies indicates that time of paraquat application is very important. If paraquat is to be used effectively, the development rate under existing environmental conditions for different species must be known before paraquat is applied. This could be determined without much difficulty by planting different species in different potted soils and varying environmental conditions in a growth chamber.

The application of fertilizer in eastern Oklahoma significantly increased the seedling frequency of Korean lespedeza. In accordance with the review of literature (Chapter II), fertilization did not contribute to the establishment of seeded grasses.

germination

Analysis of variance for species, treatments and periods is presented in Table 1. Germination percent of seeds subjected to different pregermination treatments and germination periods is presented in Table 2.

Untreated.-Tall wheatgrass, blue grama and Korean lespedeza produced more than 80% (Fig. 6) germination after seven days of germination period. Alkali sacaton, johnsongrass and big bluestem had an intermediary germination percent ranging from 38 to 51%. Winterfat, big hop clover, western wheatgrass and fourwing saltbush failed to perform and were markedly depressed by the untreated environment. Their germination ranged from 0 to 11%.

Under alternation of temperatures associated with light/dark periods, seed sensitivity of some species was not affected. The findings of Harrington (1923 and 1917) and Brown (1902) agree with the results of

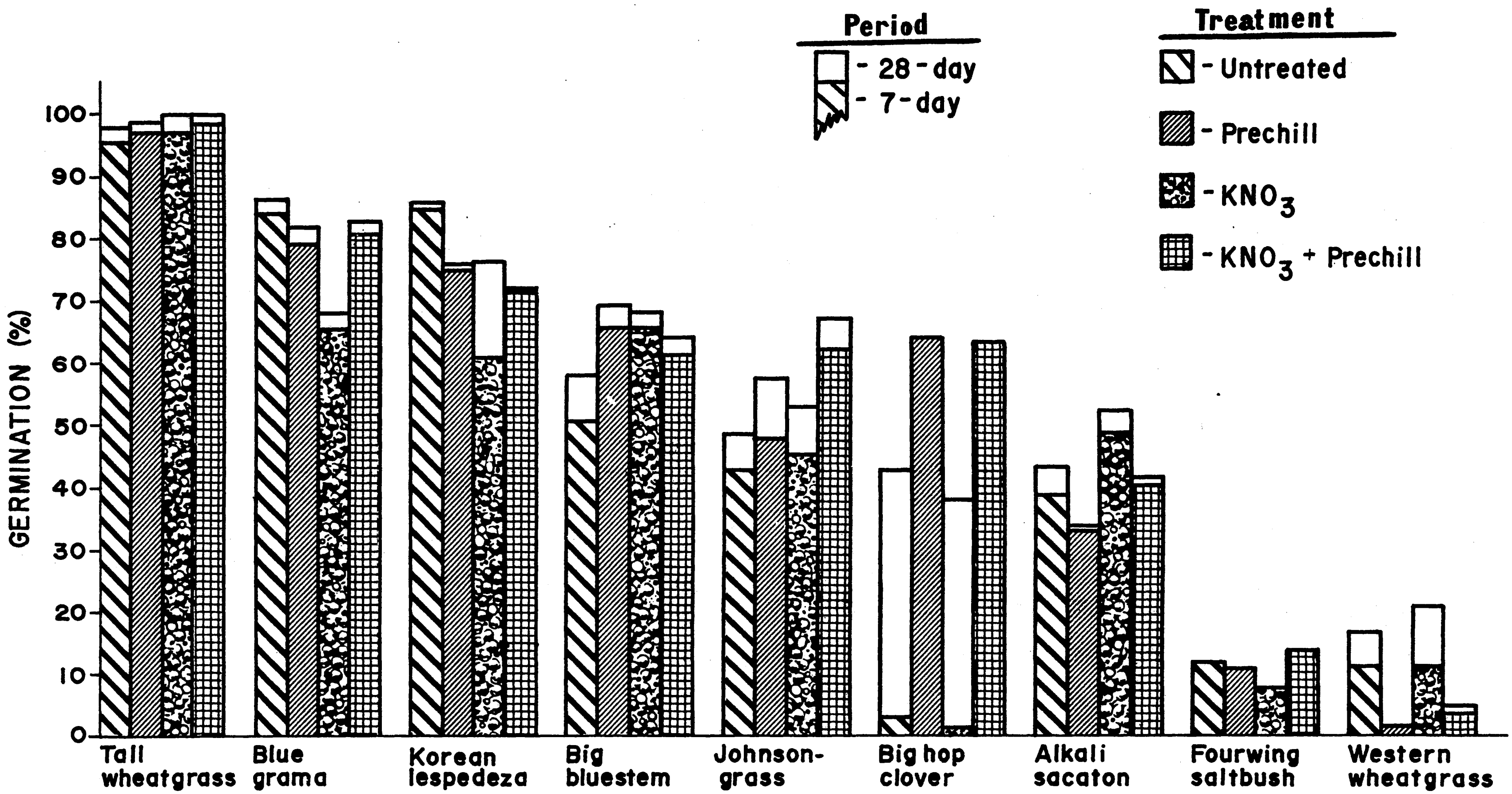


Fig. 6. Germination percent of species subjected to different pre-germination treatments and different germination periods. Least significant differences ($P<0.05$) for 7-day, treatment x species differences equals 13%. Least significant differences ($P<0.05$) for 28-day, treatment x species differences equals 15%.

this study that an alternation of temperatures has a favorable effect upon the germination of many kinds of seeds. Some seeds may require a appropriate environment such as a moist prechill and/or potassium nitrate treatment in addition to the alternation of temperatures and light and period of incubation. The origin of these seeds is not known. This factor must be taken into consideration if further research is to be undertaken.

Prechill.-Only three species were significantly affected by the prechill treatment. Prechilling increased the 7-day germination of big bluestem from 51 to 65% and big hop clover from 3 to 65%. It reduced western wheatgrass germination from 11 to 1%, but this may have been caused by a heavy mold infestation. The prechill period had induced the germination of certain species by breaking dormancy of seeds and stimulating the rapid growth of embryos. For the remaining species, it is possible that environmental requirements for a maximum germination may not be entirely satisfied by the moist prechill alone.

KNO_3.- The use of KNO_3 as a moistening agent without a moist prechill seemed to have little effect on the germination of most species. It was significantly effective in increasing the germination percentage of big bluestem after 7 days of incubation. Blue grama and Korean lespedeza germination was significantly depressed after 7 days of incubation. Continuing the incubation to 28 days, the lespedeza recovered.

There was a close similarity of action among treatments with the exception of a few species. Most of the tested species exhibited a similar behavior when saturated with water (untreated) or 2% KNO_3

solution, or prechilled. Williams and Harper (1965) studied *Chenopodium album* and found prechilling or treatment with either KNO_3 or certain other nitrogenous radicals increased the germination of black seeds of this species. The germination of *Lepidium virginicum* was increased to 88% or more by a temperature change from 15 to 25 C or by soaking in 0.2% KNO_3 solution (Toole and Toole 1955). The importance of light, temperature and nitrate interaction has been explained by Henson (1970) who found that light to some extent substitutes for nitrate and vice versa.

A 2% solution of KNO_3 increased germination percent of some species did not affect others, but was detrimental to blue grama and Korean lespedeza. Ahring, et al. (1963) found that NO_3^- was responsible for increasing germination percent of *Eragrostis trichodes*, while the radical K^+ had no effect. They also suggested the existence of a threshold antagonism of 0.2% KNO_3 towards some seeds. Roots of sand lovegrass did not penetrate KNO_3 solutions.

KNO_3 + prechill.-Germination of johnsongrass was improved by the combination of 2% KNO_3 solution and 2 weeks moist prechill. Separately they did not increase the germination of johnsongrass. Thus the KNO_3 prechill interaction was beneficial, complimenting the action between KNO_3 and prechill. According to Ahring and Harlan (1961) a salt solution of 0.2% KNO_3 in combination with a 5-day prechill was among the best treatments and environments for measuring the germination capacity of king ranch bluestem (*Bothriochloa ischaemum*).

The germination of big hop clover was significantly greater when seeds were subjected to treatment combination, but were markedly depressed by KNO_3 alone. The increased germination resulted from a moist prechill. Young et al. (1970) found 4 of the 19 legumes--subterranean clover, cup clover, wooly prodvetch and sainfoin--produced considerable germination when incubated at 0.5 C for 7 through 28 days, and in this case big hop clover appeared to be well adapted to germinate in a cold environment.

Germination periods.-Prolonging the period of incubation beyond 7 days slightly increased the germination percent of Korean lespedeza. The most favorable environment for lespedeza regardless of seed treatments was the 20-30 C alternating temperatures. Continued germination of Korean lespedeza may have been caused by a gradual adaptation of seeds to 2% KNO_3 solution. Seeds became sensitive to the action of KNO_3 after 7 days and the capacity of seeds to germinate became greater.

A 28-day incubation period of germination increased the johnsongrass germination over the 7-day period for all treatments; therefore there was no interaction between a longer period of incubation and treatments.

The longer the period of incubation the higher the germination percent of big hop clover in the check and the 2% KNO_3 solution. The sensitivity of big hop clover increased and an additional germination occurred when the incubation period was extended from 7 to 28 days. This trend was evident in the field when big hop clover was interseeded. Its germination was delayed seven months to satisfy its temperature requirement for breaking the dormancy of seeds. Thus big hop clover can be well adapted to an arid range site. It can germinate readily in the cold seedbeds of this site in late fall and early spring. Since the combination of moist prechill and 2% KNO_3 solution or moist prechill alone increased the capacity of hop clover to germinate after one week.

Management implications.-Results of this study indicate that a moist prechill alone or in combination with a dilute solution of KNO_3 (2%) under an alternating period of 16 hours (darkness) at 20 C and 8 hours (light) at 30 C improve the germination of big bluestem, johnsongrass, and big hop clover (Fig. 6). The environment of alternating temperature and light was as effective as any treatment for almost half of the tested species.

Considering these results, a question arises as to why some seeds failed to germinate or did not perform well under a variety of treatments. One reason is that seeds of all tested species went through similar treatments under a unique environment. Pre-germination treatment and germination periods were equal for different species. Other factors such as genotype, age, degree of seed maturity and storage condition may possibly influence germination behavior of some seeds.

Laboratory tests showed that most of the potential germination under conditions of this study were 7 days of incubation for all species except big hop clover. Young et al. (1970) indicated that environmental conditions which permit germination are often of short duration on rangelands. These conditions may not allow the seeds to survive rapid changes of weather such as long periods of drought. In this case, only the most resistant plants may survive. Consequently, Ellern and Tadmor (1966) defined an ideal plant for establishment or arid rangelands as, "one having the ability to germinate and develop rapidly at low temperatures so as to withstand an early change to a hot dry climate".

vegetation manipulation

Data for production and composition of the four vegetation classes, cool season grasses, warm season grasses, forbs and shrubs, are presented in Table 3. Cool season grasses included primarily cheatgrass and little barley in central Oklahoma and cheatgrass, little barley and canada wildrye (Elymus canadensis) in eastern Oklahoma. Warm season grasses included primarily johnsongrass, indiangrass and splitbeard in central Oklahoma and johnsongrass, switchgrass and indiangrass in eastern Oklahoma. The major forbs present in both areas were western yarrow, ragweed and goldenrod species, heath aster, canada thistle (Cirsium arvense), texas croton (Croton texensis) and daisy fleabane. Other forbs such as ironweed (Vernonia baldwini) and sunflower were present only in eastern Oklahoma. The major shrub species in central Oklahoma was sumac species. No shrub species occurred on plots in eastern Oklahoma, although buckbrush was in the area.

June central Oklahoma vegetation.-Production of cool season grasses (500 kg/ha), warm season grasses (610 kg/ha), forbs (850 kg/ha) and shrubs (230 kg/ha) on untreated, control plots in central Oklahoma is shown in Figure 7. Cool season grasses, nearing full maturity, were completely developed. Sumac was abundant and dominated most plots. Warm season grasses and forbs were in their advanced stages of growth.

Controlled burning reduced all classes of vegetation, but reduced cool season grasses and shrubs more than warm season grasses and forbs. The removal of previous year's vegetation in September and the extraction of roots of perennial vegetation by the hoe drill after burning and during drilling may have affected shrub production on burned plots.

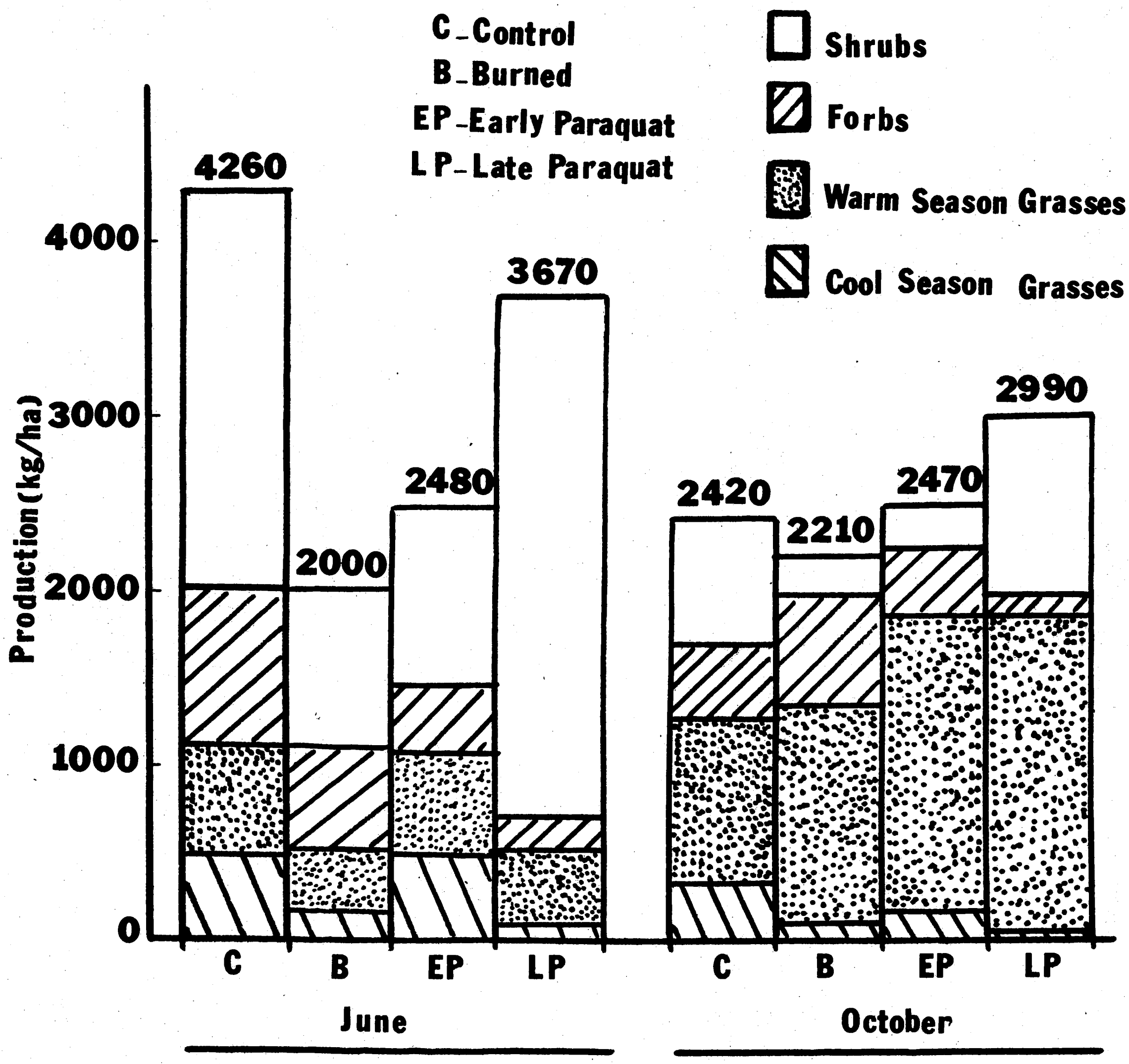


Fig. 7. Vegetation production (kg/ha) on experimental plots in central Oklahoma.

McMurphy and Anderson (1965) reported smooth sumac (Rhus glabra) increased after fire. Johnsongrass was the major warm season grass dominant on burned plots.

Early paraquat application had little or no effect on cool season and warm season grasses. The lack of response to paraquat may be related to the low rate applied or the incapacity of paraquat to reach these species when they were in their early stage of development. An adjustment of the application date and perhaps the rate of paraquat may be necessary to obtain greater reduction.

Forb and shrub production were reduced by half by early paraquat application. At the time of early application of paraquat most forbs were in the seedling stage of sensitive to the action of contact herbicide. Some of them did not recover. The reduction of shrubs may have been caused by a temporary retardation of sumac growth. There was a partial burn of the upper leaves of sumac immediately after paraquat application. These symptoms disappeared within two weeks and sumac rapidly recovered.

Late application of paraquat had a greater effect on cool season grasses and forbs than on warm season grasses and shrubs. The large decrease of cool season grass and forb production was indirectly beneficial to shrub growth because of the reduced competition.

Shrubs produced 76% of the total herbage production on late paraquat treated plots. The addition of brush control herbicides, such as 2,4,5-T is recommended, if further research is to be undertaken in this area.

October central Oklahoma vegetation.-Maturity of all species resulted in dehydration and pronounced defoliation of many species, especially sumac. On check plots maturity and weathering reduced production of sool season grasses (500 kg/ha in June and 260 kg/ha in October), forbs (850 kg/ha in June and 400 kg/ha in October) and shrubs (2300 kg/ha in June and 760 kg/ha in October). Warm season grasses increased about 400 kg/ha between June and October. Species in the latter class of vegetation reached full maturity in October with the development of large seed heads and fully extended foliage.

Cool season grass and shrub production declined on burned plots in October but forb production was as great as in June and greater than on control plots in October. The distribution of forb species was very heterogeneous especially western ragweed and some aster species. Fire caused a change in botanical composition of forb species and a constant level of production from June to October.

Warm season grass production was four times greater in October than in June on the burned plots. Buried seeds of warm season grasses may profit from the bare seedbed and became rapidly established. Thus fire depressed cool season grasses and shrubs and enhanced warm season grass production in an environment relatively free from competition.

Total vegetation production on plots treated with early paraquat was equal to that on control plots in October. Production of cool season grasses and shrubs decreased while production of warm season grasses was three times greater than in June and 660 kg more than on control plots in October. The reduction in forbs and shrubs resulted in reduced competition for later maturing, warm season grasses.

All classes of vegetation responded similarly to the controlled burn and the early application of paraquat. Therefore either of these treatments could be used to obtain comparable results.

Cool season grass and forb production on plots treated with the late application of paraquat was very low, and similar to that on the same plots in June. There was no regrowth of cool season grasses or forbs after the April application of paraquat. Shrubs were reduced in the same proportion on plots sprayed with a later application of paraquat as on control. Warm season grass production increased by about 1400 kg/ha on plots sprayed with paraquat in April but only 400 kg/ha on untreated plots.

There was an interrelation among different dominant vegetation classes and early and late paraquat application and controlled burning. As shrub production declined on burned and early paraquat treated plots, warm season grasses increased appreciably. Warm season grass production also increased greatly on plots sprayed in April, even though shrub production on these plots was as great as on untreated plots. Apparently the large reduction in cool season grasses and forbs produced the same or greater reduction in competition as did the reduction of shrubs on burned plots and plots sprayed in March.

<u>June eastern Oklahoma vegetation.</u>-Production of cool season grasses, warm season grasses and forbs on plots in eastern Oklahoma is shown in Figure 8. Forb production (330 kg/ha) was slightly lower than cool season grass production (510 kg/ha) and much lower than warm season grasses production (960 kg/ha) on untreated plots. Shrubs were not present in the area. Total vegetation in eastern Oklahoma (1800 kg/ha) was half that in central Oklahoma (4260 kg/ha), although herbage production was similar.

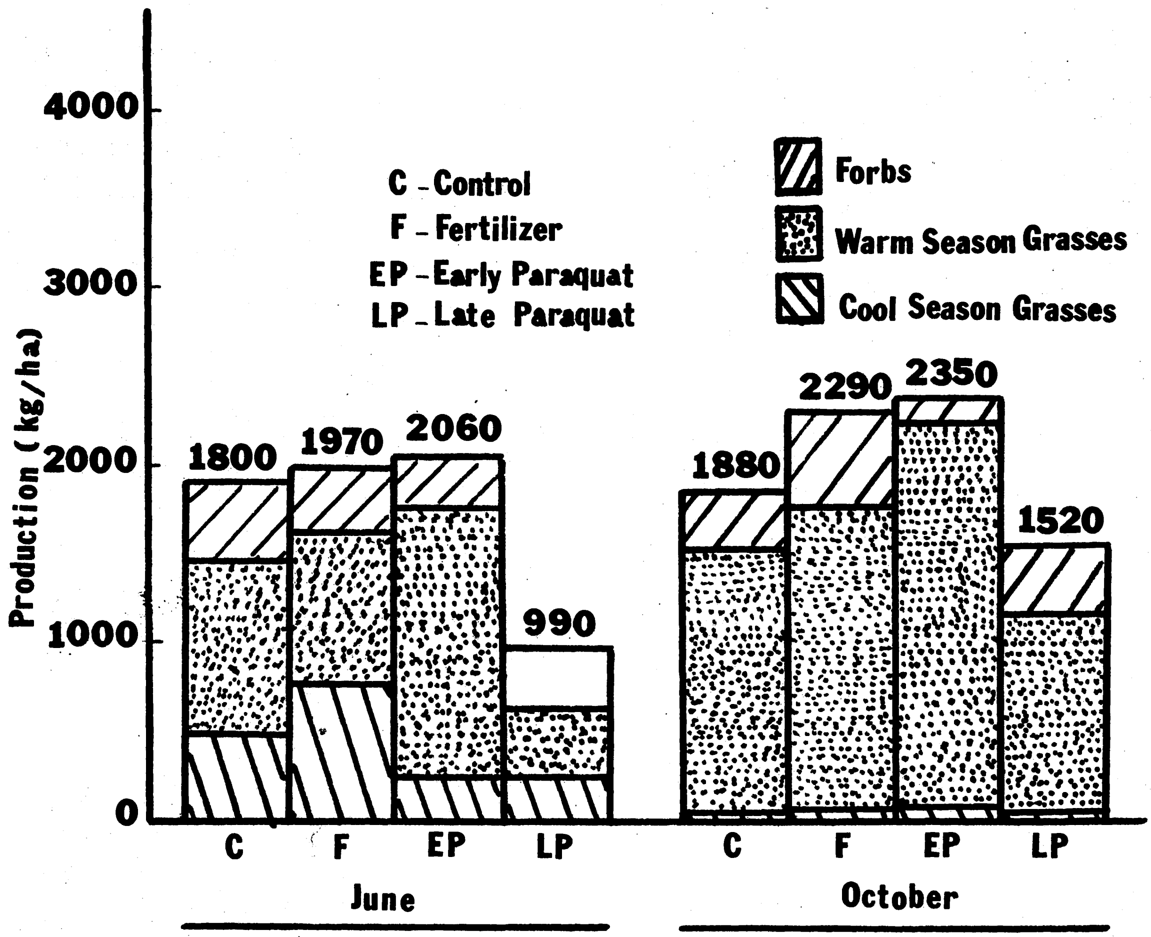


Fig. 8. Vegetation production (kg/ha) on experimental plots in eastern Oklahoma.

Fertilizer increased cool season grasses but had little or no effect on warm season grasses and forbs. The rapid growth of cool season grasses may have deprived warm season grasses and forbs of nutrients available in the soil.

The March application of paraquat greatly reduced cool season grasses and increased warm season grasses by June. Most warm season grasses started their growing season later after paraquat application. In June there was more warm season grass production in eastern Oklahoma (1510 kg/ha) than in central Oklahoma (530 kg/ha).

Late application of paraquat reduced by more than half production of both cool season grasses and warm season grasses. In eastern Oklahoma johnsongrass did not dominate warm season grass species as it did in central Oklahoma. Indiangrass and switchgrass and to a lesser extent other perennial grasses were present in the area at the time of late paraquat application. Dry weather, prevailing in eastern Oklahoma, speeded the maturity of most warm season grasses and increased herbicidal action of paraquat on green plant tissue. Springett (1967) also found the desiccant effect of paraquat increased rapidly in bright light and at high temperatures.

<u>October eastern Oklahoma vegetation.</u>-Weathering in eastern Oklahoma was more harsh than in central Oklahoma. Cool season grasses were negligible on all plots in eastern Oklahoma in October. Warm season grass production increased by 500 kg/ha. In central and eastern Oklahoma the October warm season grass production was directly proportional to the quantity of warm season grasses produced in June (Coefficient of Proportionality was 1.6). Forb production was the same in October as in June. Early maturing forbs had been eliminated by the drought which

started in April and lasted approximately four months. Only the most drought resistant forbs survived during this period. The major forbs present in October were the summer perennial, western ragweed, aster species and ironweed.

Warm season grass production on fertilized plots in October was twice as much as that in June. Forbs responded favorably to the addition of fertilizer.

Warm season grass production in plots treated with early application of paraquat was 40% greater than the June production of the same plots and 40% greater than the October control. Warm season grasses represented 68% of the total vegetation growing in plots treated with early application of paraquat in June and increased to 91% in October in the same plots. Production of warm season grasses depended upon their early growth which occurred in May and June following the early application of paraquat and the period of drought. Apparently early growth of grasses greatly affects their total annual production.

In June warm season grass production was half that on untreated plots indicating a direct effect from paraquat applied after that the growth of warm season grasses began. Warm season grass production on plots sprayed in April with paraquat was still less than on untreated plots by October. Late application of paraquat was more detrimental to warm season grasses in eastern Oklahoma than in central Oklahoma. This differential detrimental effect may have been the result of both drought and spraying at a more advanced phenological stage in eastern Oklahoma. Cool season grasses and forbs did not differ from their respective October production in the untreated plots.

Conclusion.-The addition of 2,4-D to paraquat was necessary for control of some broadleaf weeds associated with downy brome in preparation for immediate seeding (Evans et al. 1967). Shrubs, particularly sumac, dominated the central Oklahoma area study and were highly competitive with most existing range species. Shrubs influenced the botanical composition of the growing vegetation and their removal by a foliage spray of 2,4,5-T or other herbicide is necessary in further research in this area. Burning and late application of paraquat were equally effective in controlling cool season grasses. Forb production was slightly lower on plots treated with late application of paraquat than that on burned plots. Fertilizer increased cool season grasses.

Vegetation dry matter content.-The dry matter content of total vegetation in central and eastern Oklahoma are presented in Figure 9. Vegetation dry matter percent on the untreated plots (52%) in June was slightly higher than that on the burned plots (41%) and plots treated with paraquat (40%) in central Oklahoma. The difference being significant at the 9% level. There was no difference between June and October dry matter percent because composition and stage of maturity of most species changed through the summer. In June, cool season grasses and shrubs reached their full maturity and contribute to the increase of dry matter content better than warm season grasses which were in the early stage of development. While cool season grass and shrub production declined in October, the warm season grass production was twice as much as in June, and yielded a maximum dry matter percent as it matured.

In eastern Oklahoma, June dry matter content on fertilized plots and plots treated with late application of paraquat was significantly

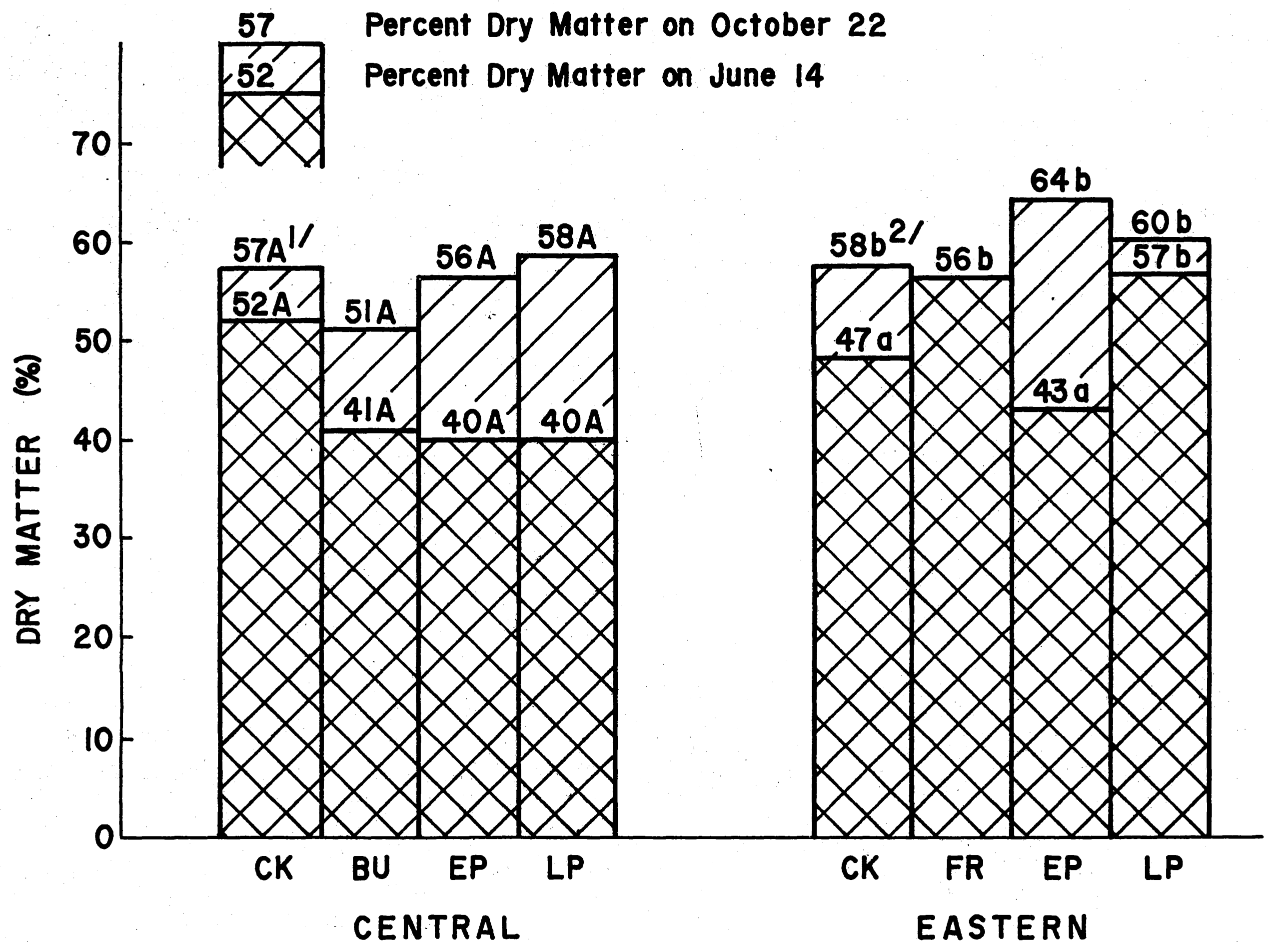


Fig. 9. Dry matter content (%) in herbage in response to treatment x sampling day interaction. Treatments are check (CK), burn (BU), fertilizer (FR), early paraquat (EP) and late paraquat (LP).
1/ Means followed by the same uppercase letter are not significantly ($P>0.05$) different
2/ Means followed by the same lowercase letter are not significantly ($P>0.05$) different

greater than that on the June control and plots treated early with paraquat. Dry matter content of all treated plots increased in October and was significantly greater than in June in eastern Oklahoma.

Dry matter content generally increased throughout the growing season as stems matured and became more fibrous. This seasonal fluctuation is caused by a variation in chemical composition. The latter is probably influenced by the stage of maturity of vegetation when harvested (Hopper and Nesbitt 1930). The dry matter content of vegetation depends, in addition to the stage of maturity, upon the treatment. The October vegetation dry matter content on plots treated with early application of paraquat was significantly greater than the June dry matter content of the same plots.

Vegetation digestibility.-The *in vitro* dry matter digestibility of total vegetation was determined only in June. It was the same in central and eastern Oklahoma under all treatments. It ranged from 51 to 60% with an average of 56%.

Vegetation crude protein content.-Crude protein content of total vegetation was determined from clipped samples collected in June. They are presented in (Fig. 10). In central Oklahoma crude protein percent from treated plots was significantly higher (8.9 to 9.9%) than that from check plots (6.6%). The low crude protein content of total vegetation from check plots corresponds to a higher dry matter content determined from the same vegetation.

The comparatively low crude protein (6.6%) on check plots in central Oklahoma were due largely to the abundance of maturing cool season grasses (500 kg/ha), forbs (850 kg/ha) and/or shrubs (2300 kg).

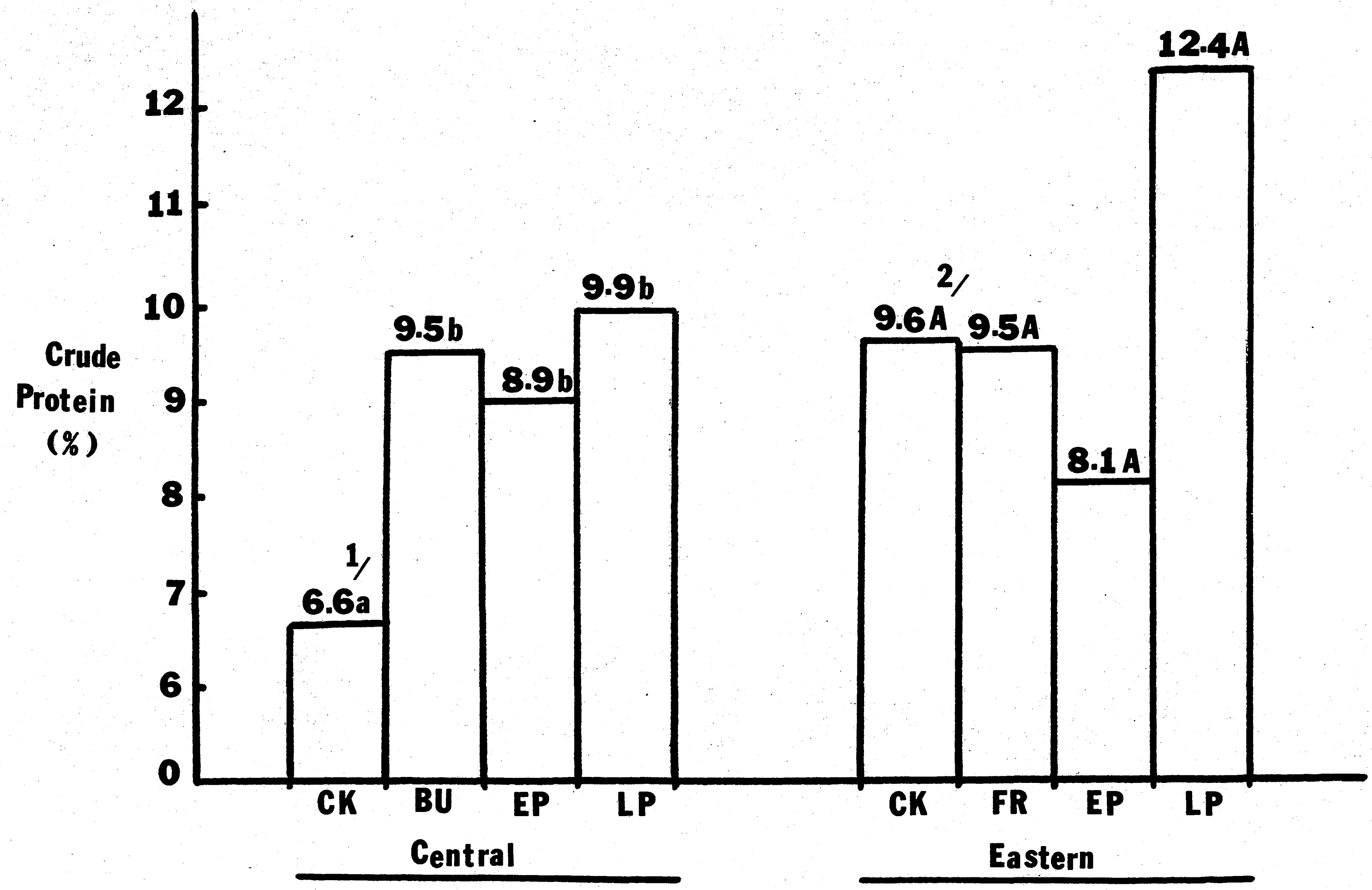


Fig 10. Crude protein content (%) on June 14 in herbage from check (CK), burn (BU), fertilizer (FR), early paraquat (EP), and late paraquat (LP) plots.

1/ Means followed by the same lower case letter are not significantly (P>0.05) different.

2/ Means followed by the same upper case letter are not significantly (P>0.05) different.

Vegetation on treated plots was immature, because most stands developed after regrowth of treated vegetation, having less dry cool season grasses, less forbs and woody stems (Watkins 1943). The controlled burn effect on crude protein content of total vegetation was equal to the paraquat treatment effect whether applied earlier or later.

In eastern Oklahoma, the herbage on plots treated with paraquat was higher (12.4%) in crude protein than that on all other treated and check plots (8.1 to 9.6%). The relatively low crude protein content of vegetation on the check and fertilized plots may have been caused by the greater amounts of cool season grasses, respectively 510 kg/ha for the check and 750 kg/ha for the fertilized plots. It seems that the high warm season grass production (1510 kg/ha) resulted in a very low protein content on plots treated with early application of paraquat.

In general there was less seasonal variation in plant composition due to the existence of different classes of vegetation maturing in different seasons. Grasses and forbs usually have a high level of protein in their early growth stage to rather poor roughages at maturity, while shrubs have a much smaller seasonal fluctuation (Blasidell et al. 1952).

Vegetation crude protein yield.-Yield of crude protein was determined for the June sampling. Crude protein yield is the total amount of protein in the vegetation. It is determined by multiplying percentage of crude protein by total herbage production. Crude protein yield is expressed as kg crude protein/hectare and presented in Figure 11.

In central Oklahoma crude protein yield of vegetation sampled from plots treated with late application of paraquat was significantly higher

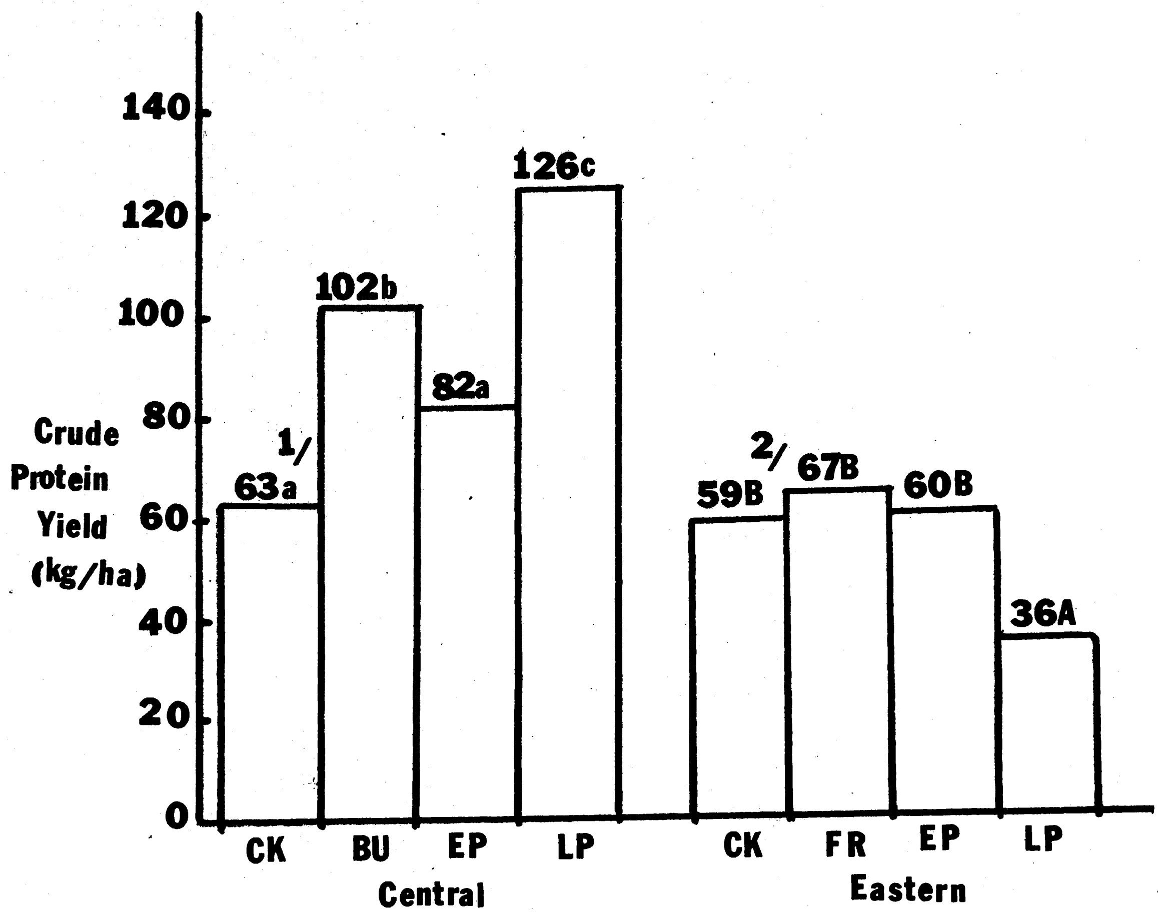


Fig. 11. Crude protein yield (kg/ha) on June 14 from vegetation on check (CK), burn (BU), fertilizer (FR), early paraquat (EP), and late paraquat (LP) plots.
1/ Means followed by the same lower letter are not significantly (P>0.05) different.
2/ Means followed by the same upper letter are not significantly (P>0.05) different.

(126 kg/ha) than that from the burned plot (102 kg/ha). The latter was significantly greater than that from either plots treated with early application of paraquat (82 kg/ha) or the check (63 kg/ha).

The high value of crude protein yield in plots treated with late application of paraquat is due to the fact that crude protein content of total vegetation on plots treated late with paraquat was significantly higher than that on the check plots and slightly greater than that on other treated plots. Vegetation production from plots treated with late application of paraquat was greater (3.670 kg/ha) that those from either burned plots (2000 kg/ha) or plots treated early with paraquat (2480 kg/ha). The crude protein content on the checks was low (6.6%), hence, crude protein yield was also low even if total vegetation production on check was very high (4260 kg/ha).

In eastern Oklahoma check (59 kg/ha), burned plots (67 kg/ha) and plots treated early with paraquat (60 kg/ha) had the same crude protein yield. They had significantly more crude protein yield than plots treated with late application of paraquat (36 kg/ha). Although crude protein content of vegetation on plots treated with late application of paraquat was slightly higher than that on other plots, its total vegetation production was low (990 kg/ha).

Soil chemical analysis.-Soil samples taken in June and October were analyzed for various soil constituents.

The maximum soil moisture in central Oklahoma (15%) and eastern Oklahoma (29%) was recorded in October. The 30 cm and 60 cm layers contained more water in October than in June. There was more rainfall during and preceeding the October sampling date. Also, more vegetation reaching the end of maturity, did not rapidly exhaust the soil water.

The highest soil temperature was recorded in June in central Oklahoma (24 C) and eastern Oklahoma (28 C). The most severe heat generally occurs during June, July and August in central and eastern Oklahoma.

Organic matter content averaged an overall mean of 0.9% at the 30 cm depth and 0.6% at the 60 cm depth in central Oklahoma. In eastern Oklahoma the average was 1.9% at the 30 cm depth and 0.8% at the 60 cm depth in eastern Oklahoma.

A small increase in the organic matter content resulted from paraquat application in central Oklahoma. Dead vegetation contributed to the increase in organic matter. The accumulation of litter was more pronounced when paraquat was applied at an advanced stage of development of vegetation.

No other components exhibited any clear changes as a result of paraquat application, fertilizer, and controlled burning. Phosphorus level was higher in central Oklahoma (12.3 kg/ha at 30 cm depth and 3.5 kg/ha at 60 cm depth) than in eastern Oklahoma (4.5 kg/ha at 30 cm depth and 3.4 kg/ha at 60 cm depth). Soil pH was less than 6.5 in central Oklahoma and equal to 5.3 in eastern Oklahoma.

paraquat

Seven rates (0.00 to 1.12 kg/ha) of paraquat were applied on March 26 to seven different plots. On April 16, seven more rates were sprayed on seven different plots. On May 2, 1974 only two rates (0.14 and 0.28 kg/ha) of paraquat were applied on two different plots. The selection of these two low rates for the May application was to test the effects of time and possible weed resistance. After a preliminary analysis of the data, I decided to regroup each two successive rates together and to come up with only eight rates in order to localize the effect of shrubs and have a more accurate and consistent idea of the effect of paraquat on the existing vegetation. Data for production and composition of four vegetation classes as affected by different paraquat treatments are presented in Table 4 for the June sampling and Table 5 for the October sampling.

June vegetation production.-Production of vegetation on the untreated plot was 540 kg/ha, warm season grasses 1070 kg/ha, forbs 650 kg/ha and shrubs 1260 kg/ha. Stage of maturity and composition of classes of vegetation were previously discussed in the vegetation manipulation section.

The application of heavy rate (0.98 kg/ha) of paraquat in March, or medium to heavy rates (0.49 to 0.98 kg/ha) in April, or a low rate (0.21 kg/ha) of paraquat in May was shown to be equally and significantly effective in controlling cool season grasses. The success of low rates of paraquat when applied in May was positively related to the maturity level of cool season grasses and subsequently the increasing degree of grass susceptibility (Allen 1967). Cool season grass production was positively correlated to forb production ($r=.45$) ($P<.001$).

Production of warm season grasses significantly increased (1780 kg/ha) at the higher rate (.98 kg/ha) of paraquat when applied in March. As the date of paraquat application is retarded to April or May, the low rate (.21 kg/ha) significantly increased warm season grasses more than any other paraquat treatments. Warm season grass production was negatively correlated to shrub production (r=¯.55) (P<.001)

Paraquat reduced forb production by more than half to two-thirds when medium to heavy rates (0.49 to 0.98 kg/ha) were applied in April (320 kg/ha and 240 kg/ha respectively). The lowest rate (.21 kg/ha) was very effective against forbs (230 kg/ha) in May. Thus as the growing season progressed forbs became more susceptible to a lower paraquat rate (.21 kg/ha).

It seems that not only annual forbs were killed but also perennial forbs. Bowes and Friesen (1967) found that perennial forbs were reduced by 12 and 16% when rates of 0.28 kg/ha and 1.12 kg/ha were applied respectively. Forb production was negatively correlated to shrub production (r=-.44) (P<.01).

Shrub production was effectively controlled by the highest rate (.98 kg/ha) when applied in March (470 kg/ha) and also the lowest rate (.21 kg/ha) when applied in May (670 kg/ha). Shrub production was negatively correlated to the percent of cool season grasses (r=¯.39) (P<.05) and forbs (r=¯.62).

It is difficult to speculate on the effect of paraquat on shrubs because of the unequal distribution of shrubs in the field. Shrub production in the first replication (340 kg/ha) was significantly different from that in the second (1160 kg/ha) or third (1320 kg/ha) replication.

Brush control must be done before heavy canopies develop because penetration of herbicide sprays is sometimes difficult. Thus plants having thick leaves (most woody plants), not only require a higher dosage but also a much longer exposure to paraquat than more succulent species (Bovey and Davis 1967).

October vegetation production.-The clean initial control of cool season grasses remained throughout the summer. Most paraquat rates (except the .21 kg/ha and .49 kg/ha when applied in March) significantly reduced cool season grasses. In general later application of paraquat at a low rate (.21 kg/ha) was better than early application of low or medium rate (.21 to .49 kg/ha).

Although many field studies have shown paraquat to be inactivated as phytotoxic compounds on contact with soil, it is possible that complete inactivation does not always occur. Paraquat residues persisted on the soil (Watkin and Sagar 1971). The greater control of cool season grasses with a later paraquat application may result from adsorption of the active ingredient by soil particles and the increasing amount of litter.

Warm season grass production increased directly with the rate of paraquat (0.12 to 0.98 kg/ha) and with the later date of application (March to May). The difference in warm season grass production was significant at the 7% level of probability. The May application of paraquat (.21 kg/ha) produced the greatest amount of vegetation (2370 kg/ha). The highest rate (.98 kg/ha) in April (2080 kg/ha) and March (2080 kg/ha) closely followed the May application of a low paraquat rate. Warm season grass production was negatively correlated to forb production (r=-.23) at the 11% level of probability.

Maturity and weathering reduced production of forbs (650 kg/ha in June and 330 kg/ha in October), shrubs (1260 kg/ha in June and 160 kg/ha in October) and cool season grasses (540 kg/ha in June and 140 kg/ha in October) while warm season grasses increased about 500 kg/ha between June and October.

The control of forbs was slightly greater at the high rate in April (.98 kg/ha) and the low rate (.21 kg/ha) in May. Forb production decreased by about 280 kg/ha on plots sprayed with a low rate (.21 kg/ha) of paraquat in May. Forb production was negatively correlated to shrub production ($r=^{-}.28$) ($P<.05$). Differences among replications were highly significant.

Shrubs were fairly well controlled by the low rate (.21 kg/ha) in May (80 kg/ha), medium rate (.49 kg/ha) in April (40 kg/ha) and the high rate (.98 kg/ha) in March (14 kg/ha). Difference in shrub production was significant at the 7% level of probability. Generally, paraquat succeeded in limiting shrub production.

<u>Vegetation chemical analysis.</u>-Vegetation dry matter content, crude protein content, dry matter digestibility and crude protein yield are presented in Table 6 for the June sampling date and Table 7 for the October sampling date.

Vegetation dry matter content averaged 34% in June when most stands of dominant species were in an early stage of growth. Dry matter content increased throughout summer to a level of 61% in October. Vegetation dry matter content was highly correlated to cool season grass production ($r=.45$) ($P<.01$) but negatively correlated to shrub percent ($r=^{-}.24$) at the 9% level of probability. Crude protein content averaged 12% in June and was negatively correlated to dry matter content ($r=^{-}.29$) ($P<.05$). Crude protein content and yield and dry matter digestibility were determined from clipped samples collected in June.

Dry matter digestibility slightly declined in Juen (59 to 67%) as the rate of paraquat exceeded .21 kg/ha. Dry matter digestion content was highly correlated to cool season grass production ($r=.42$) ($P<.01$), forb production ($r=.47$) ($P<.01$) and warm season grass production ($r=.36$) ($P<.01$) but negatively correlated to shrub production ($r={}^{-}.48$) ($P<.00$). Apparently the increasing amount of forbs and cool season grasses increased dry matter digestibility. Crude protein yield slightly decreased as the date of paraquat application was delayed from March to May. These different levels of crude protein yield resulted from a variation of total vegetation (2400 to 3500 kg/ha) among plots since the crude protein content was approximately constant (11 to 12%).

Soil chemical analysis.-Soil samples taken in June and October were chemically analyzed. Results of various soil constituents are presented in Table 6 for the June sampling and Table 7 for the October sampling dates.

In June moisture percent in the 0-30 cm soil profile was negatively correlated with growing warm season grasses ($r={}^{-}.29$) ($P<.05$) which totally depended upon the soil water because of the drought period (May-June). The average soil moisture from the upper (0-30 cm) profile to a deeper (30-60 cm) profile remained approximately at the same level (13 to 15%) regardless of treatments. Apparently shrubs limited the depletion of soil water of the upper profile by providing more shade and eliminating most understory vegetation. Shrub production was highly correlated to soil moisture of the upper profile ($r=.47$) ($P<.01$). Shrubs may develop a deeper root system as they grow and utilize soil moisture from a deeper profile. There was more soil water in the lower profile (15%) in October. Surface soil moisture was removed by evaporation.

Soil potassium content was greater at the 30-60 cm depth (224 kg/ha) than that at the 0-30 cm depth (181 kg/ha). Potassium level of the upper profile was negatively correlated to the production of shrubs (r=-.26) (P<.07). Soil pH at the 30-60 cm depth ranged from 5.7 to 6.2. The change in soil pH to different treatments cannot be explained.

The success of paraquat in the rangeland improvement program depends on (1) the time of application of paraquat in relation to susceptibility of existing vegetation, (2) the optimum rate of paraquat for a control of most indesirable species and (3) the amount of surface litter remaining (Allen 1967) in relation to the possibility of residual effect after paraquat application in the soil (Watkin and Sagar 1971). Paraquat increased production of warm season grasses. The lowest rates applied in April or May significantly increased warm season grasses. Cool season grasses were very susceptible to paraquat treatment and forbs were reduced by more than half when higher rates were applied. Shrub production was limited by the high rates of paraquat.

CHAPTER VI

Summary and Conclusions

A randomized split plot design was employed using three replications in central and eastern Oklahoma. Two main plot treatments were two paraquat (rates =0.56 kg/ha) spraying dates. The first application was on March 26, the second application was on April 16, 1974. The third main plot treatment was a controlled burn on March 12, 1974 in central Oklahoma and addition of 50 kg of phosphorus/ha in eastern Oklahoma. One control plot was included in each replication. Sub-plot treatments were the seeding of six selected species, including perennial grasses, legumes and forbs in March. Establishment of seeded species in both areas was evaluated by seedling counts in October.

Germination tests were conducted in the laboratory to determine the quality of seeds used in the interseeding study. Experiment comprised two steps: one moist prechill period of two weeks followed by a final germination period of one week. Treatments included a 2% potassium nitrate solution and a control with distilled water.

The effect of paraquat, applied on two different dates, fertilization, and burning on the existing vegetation in the interseeded areas in central and eastern Oklahoma were evaluated in June and October.

A randomized block design with three replications was employed. The experiment consisted of a comparison of seven rates of paraquat ranging from 0.00 to 1.12 kg/ha sprayed at 3 different dates.

The objectives of these studies were: (1) to determine the seedling frequency of interseeded, (2) to determine the effects of paraquat, burning and fertilization on the composition and quality of existing vegetation,(3) to deterimine in the laboratory the ability of nine selected grasses, legumes and forbs to produce normal plants under favorable conditions and, (4) to determine the optimum rate and date of paraquat application to improve poor condition rangeland.

The beneficial effect of weed control with paraquat and burning can be seen in the overall means of seedling frequency (23%) early in the fall of 1974 in both central and eastern Oklahoma.

Four species (Korean lespedeza, big bluestem, blue grama and johnsongrass) were successfully established, but five other seeded species failed to establish themselves under below normal conditions. Korean lespedeza had the highest seedling frequency (43%) in central Oklahoma, and only slightly lower (30%) in eastern Oklahoma.

The interaction between treatments and seedling frequencies indicates that time of paraquat application is very important. If paraquat is to be used effectively, the development rate under existing environmental conditions for different species must be known before paraquat is applied. This could be determined without much difficulty by planting different species in different potted soils and varying environmental conditions in a growth chamber.

Results of the germination study indicate that a moist prechill alone or in combination with a dilute solution of KNO_3 (2%) under an alternating period of 16 hours (darkness) at 20 C and 8 hours (light) at 30 C improve the percent of germination of big bluestem, johnsongrass, and big hop clover. The environment of alternation of temperature and light was as effective as any treatment for almost half of the tested species.

In central Oklahoma controlled burn reduced all classes of vegetation but reduced cool season grasses and shrubs more than warm season grasses and forbs in June. Johnsongrass was the major warm season grass dominant on burned plots. Early application of paraquat had little or no effect on cool season and warm season grasses while forb and shrub production were reduced by half. Late application of paraquat had a greater effect on cool season grasses and forbs than on warm season grasses and shrubs. Shrubs produced 76% of the total production on plots treated with late application of paraquat.

In October the central Oklahoma vegetation matured as a result of dehydration and weathering. Controlled burn depressed cool season grasses and shrubs and enhanced warm season grass production. All classes of vegetation responded similarly to the controlled burn and the early application of paraquat. Warm season grass production increased by about 1400 kg/ha on plots sprayed with paraquat in April but only 400 kg/ha on check plots.

In eastern Oklahoma fertilizer increased cool season grasses. March application of paraquat reduced cool season grasses and increased warm season grasses. Late application of paraquat reduced by more than half production of both cool season and warm season grasses when sampling was done in June.

In October warm season grass production on fertilized plots was twice as much as that in June in eastern Oklahoma. Warm season grasses was 40% greater than the June production when treated with early application of paraquat. Late application of paraquat was detrimental to warm season grasses in eastern Oklahoma. Cool season grasses and forbs did not differ from their respective October production in the untreated plots as a result of late application of paraquat.

Controlled burn effect on crude protein content of total vegetation was equal to the paraquat treatment effect whether applied earlier or later in central Oklahoma. In general there was less seasonal variation in plant composition due to the existence of different classes of vegetation in different seasons.

Production of warm season grasses significantly increased (1780 kg/ha) at the high rate (.98 kg/ha) of paraquat when applied in March. As the growing season progressed forbs became more susceptible to a lower paraquat rate (.21 kg/ha). Low paraquat is positively related to the maturity of cool season grasses. The low rate (.21 kg/ha) when applied in May was very effective in controlling cool season grasses. Shrub production in June was limited by the high rate of paraquat (.98 kg/ha).

In October warm season grass production increased directly with higher rate (0.12 to 0.98 kg/ha) and later date of paraquat application (March to May). Production of cool season grasses was negligible throughout summer. Forb production decreased when highest rate was applied in April and lowest rate in May. Shrub production was fairly well controlled by the low rate in May.

Vegetation dry matter content was highly correlated to cool season grass production. Dry matter digestibility slightly declined in June as the rate of paraquat exceeded .21 kg/ha. Crude protein content was negatively correlated to dry matter content and averaged 12%. Crude protein yield slightly decreased as the date of application of paraquat was delayed from March to May. Apparently shrubs limited the depletion of soil water of the upper profile. Soil potassium was negatively correlated to the production of shrubs.

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APPENDIX

Table 1. Analysis of variance of germination percent after 7 and 20 days of incubation.

Source of Variation	DF	Germination period: 7 Days Mean Square	7 Days Probability Level	28 Days Mean Square	28 Days Probability Level
Replication	3	0.0049	0.72	0.0038	0.6
Replication X Tmt	9	0.0104		0.0056	
Treatment	3	0.0826	0.01	0.0051	0.5
Species	8	1.4770	0.01	1.4308	0.1
Treatment X Species	24	0.0729	0.01	0.0263	0.1
Rep X Tmt X Spp	72	0.0080		0.0111	
Residual	24	0.0074		0.0104	
Coefficient of Variation		17		19	

Table 2. Germination percent of seeds subjected to different pre pregermination treatments and germination periods.

Treatment	Species	Germination period (days)			
		7	14	21	28
Untreated	Tall wheatgrass	95	97	97	97
	Blue grama	84	85	86	86
	Korean lespedeza	84	84	84	84
	Big bluestem	51	57	57	58
	Johnsongrass	43	45	46	48
	Big hop clover	3	15	39	42
	Alkali sacaton	38	43	43	44
	Fourwing saltbush	11	11	11	11
	Western wheatgrass	11	15	16	16
Prechill	Tall wheatgrass	97	99	99	99
	Blue grama	79	82	82	82
	Korean lespedeza	74	75	75	75
	Big bluestem	65	69	69	69
	Johnsongrass	47	55	57	57
	Big hop clover	65	65	65	65
	Alkali sacaton	32	33	33	33
	Fourwing saltbush	11	11	11	11
	Western wheatgrass	1	1	1	1
KNO_3	Tall wheatgrass	97	99	99	99
	Blue grama	65	67	67	67
	Korean lespedeza	60	75	76	76
	Big bluestem	65	67	67	68
	Johnsongrass	45	50	51	53
	Big hop clover	1	21	37	38
	Alkali sacaton	48	52	52	52
	Fourwing saltbush	7	7	7	7
	Western wheatgrass	11	19	19	20
KNO_3 + Prechill	Tall wheatgrass	98	99	99	99
	Blue grama	81	82	83	83
	Korean lespedeza	71	71	71	71
	Big bluestem	61	64	64	64
	Johnsongrass	62	64	66	66
	Big hop clover	63	63	63	63
	Alkali sacaton	40	41	41	41
	Fourwing saltbush	14	14	14	14
	Western wheatgrass	3	3	4	4

Table 3. Vegetation production (kg/ha) and composition in June and October in central and eastern Oklahoma.

Location	Month	Treatment	Vegetation classes: Cool Season Grasses (kg/ha)	(%)	Warm Season Grasses (kg/ha)	(%)	Total Grasses (kg/ha)	(%)	Forbs (kg/ha)	(%)	Herbs (kg/ha)	(%)	Shrubs (kg/ha)	(%)	Total Vegetation
Central	June	Control	500	14	610	17	1110	31	850	22	1960	53	2300	47	4260
		Burn	180	12	310	20	490	32	560	31	1050	63	950	34	2000
		Early paraquat	500	24	530	23	1030	47	400	17	1430	64	1050	36	2480
		Late paraquat	90	4	440	14	530	18	150	6	680	24	2990	76	3670
	Oct.	Control	260	11	1000	43	1260	54	400	16	1660	70	760	30	2420
		Burn	70	3	1260	57	1330	60	650	29	1980	89	230	11	2210
		Early paraquat	180	8	1660	66	1840	73	410	18	2240	91	230	8	2470
		Late paraquat	30	1	1800	62	1830	63	90	3	1920	66	1070	34	2990
Eastern	June	Control	510	28	960	52	1470	80	330	20	1800		0		1800
		Fertilizer	750	38	860	45	1610	83	360	17	1970		0		1970
		Early paraquat	200	11	1510	68	1710	80	350	20	2060		0		2060
		Late paraquat	200	21	430	43	630	63	360	37	990		0		990
	Oct.	Control	40	2	1480	78	1520	80	360	20	1880		0		1880
		Fertilizer	50	3	1710	70	1760	73	530	27	2290		0		2290
		Early paraquat	50	2	2150	91	2200	93	150	7	2350		0		2350
		Late paraquat	30	2	1080	71	1110	73	410	27	1520		0		1520

Table 4. Vegetation production (kg/ha) and composition (%) in June in response to rate (kg/ha) and date of paraquat application.

Paraquat Treatment		Vegetation classes							
		Cool Season Grasses		Warm Season Grasses		Forbs		Shrubs	
Rates	Dates	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)
0.00	3/26	540	17	1070	32	650	19	126	32
0.21	3/26	500	19	730	26	780	29	920	26
0.49	3/26	350	14	1040	44	460	19	770	24
0.98	4/16	80	3	1780	66	490	18	470	14
0.21	4/16	320	11	1500	45	560	19	900	26
0.49	4/16	40	2	1170	54	320	15	940	28
0.98	4/16	3	1	1130	47	240	11	1570	42
0.21	5/2	120	5	1550	64	230	10	670	21
Probability Level		P<.01	P<.01	P<.05	P<.05	P<.05	P<.17	P<.59	P<.68
LSD .05		160	6	600	22	300	13	1150	30

Table 5. Vegetation production (kg/ha) and composition (%) in October in response to rate (kg/ha) and date of paraquat application.

Paraquat Treatment		Vegetation Classes							
		Cool Season Grasses		Warm Season Grasses		Forbs		Shrubs	
Rates	Dates	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)	(kg/ha)	(%)
0.00	Check	140	8	1560	67	330	18	160	7
0.21	3/26	120	5	1770	63	430	18	350	14
0.49	3/26	90	5	1920	70	400	18	230	7
0.98	3/26	30	1	2080	87	300	11	14	1
0.21	4/16	40	2	1730	68	270	14	390	16
0.49	4/16	20	1	1850	81	250	17	40	1
0.98	4/16	3	1	2080	84	190	9	210	6
0.21	5/2	40	2	2370	89	50	2	80	7
Probability Level		P<.01	P<.01	P<.07	P<.01	P<.27	P<.17	P<.07	P<.15
LSD	.05	44	2	480	13	310	13	260	12

Table 6. Chemical analysis of vegetation sampled in June and soil water content (%) in response to rate (kg/ha) and date of paraquat application.

Paraquat Treatment Rates	Dates	Soil Water 0-30 cm (%)	Soil Water 30-60 cm (%)	Vegetation chemical analysis: Dry Matter (%)	Crude Protein (%)	Dry Matter Digestion (%)	Crude Protein Yield (kg/ha)	Soil Temperature (C)
0.00	Check	17	15	37	12	67	450	23
0.21	3/26	9	21	37	12	66	390	23
0.49	3/26	10	14	35	11	62	300	23
0.98	3/26	13	14	32	11	63	300	23
0.21	4/16	10	12	38	11	64	400	23
0.49	4/16	14	19	20	12	63	320	23
0.98	4/16	16	14	34	13	59	390	23
0.21	5/2	12	14	32	12	63	340	23
Average		13	15	34	12	63	360	23
Probability Level		P<.90	P<.56	P<.21	P<.42	P<.28	P<.44	P<.96

Table 7. Chemical analysis of soil sampled in October and dry matter content of vegetation in response to rate (kg/ha) and date of paraquat application.

Paraquat Treatment		Soil Water		Potassium		Soil Temperature	PH	Dry Matter
Rates	Dates	0-30 cm (%)	30-60 cm (%)	0-30 cm (kg/ha)	30-60 cm (kg/ha)	(C)	30-60 cm	(%)
0.00	Check	14	37	185	216	18	5.8	61
0.21	3/26	15	16	185	244	18	6.2	64
0.49	3/26	16	14	183	213	18	6.1	62
0.98	3/26	13	39	199	218	18	5.7	58
0.21	4/16	14	13	168	211	18	6.1	61
0.49	4/16	16	14	163	208	18	5.9	61
0.98	4/16	16	14	180	227	18	5.7	62
0.21	5/2	16	13	192	259	17	6.2	59
Average		15	20	181	224	18	6.0	61
Probability Level		P<.59	P<.40	P<.26	P<.23	P<.17	P<.05	P<.95

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