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Control of pinegrass by herbicide as a site preparation technique in two western Montana clearcuts

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CONTROL OF PINEGRASS BY HERBICIDE AS A SITE PREPARATION

TECHNIQUE IN TWO WESTERN MONTANA CLEARCUTS

By

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Control of Pinegrass by Herbicide as a Site Preparation Technique in Two Western Montana Clearcuts (77 pp.)

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Pinegrass (Calamagrostis rubescens Buckl.) is a rhizomatous forest grass which responds prolifically to surface scarification and burning. Herbicides were applied to two western Montana clearcuts to study their effectiveness as an alternative site preparation technique for controlling pinegrass. The treatments applied at Blue Mountain were: glyphosate at 1.0 and 3.0 pounds (lbs.) AI (Active Ingredient)/acre, glyphosate at 2.0 lbs. + hexazinone at 2.0 lbs. AI/acre, glyphosate at 2.0 lbs. + atrazine at 4.0 lbs. AI/acre, hexazinone at 2.0 lbs. AI/acre, atrazine at 4.0 lbs. AI/acre, dalapon at 8.45 lbs. AI/acre, and dalapon at 8.45 lbs. + atrazine at 4.0 lbs. AI/acre. At White Stallion three more treatments were added to this list; these were: glyphosate at 2.0 lbs. AI/acre, glyphosate at 1.0 lb. + hexazinone at 1.0 lb. AI/acre and a scalp.

Applications were made in June, 1979, September, 1979, and May, 1980 at Blue Mountain. Douglas-fir (Pseudotsuga menziesii (Mirbel) Franco.) and ponderosa pine (Pinus ponderosa Dougl.) seedlings were planted prior to application and on plots previously treated. At White Stallion treatments were applied in June, 1980 with before and after application planting of Douglas-fir and lodgepole pine (Pinus contorta Dougl.). Pre-dawn plant moisture stress of seedlings was determined by pressure bomb in August, 1980.

Glyphosate alone successfully controlled pinegrass if applied in June, hexazinone was most successful in the fall or spring, dalapon was most successful in the fall, but atrazine alone did not successfully control pinegrass at any application time. Dalapon + atrazine was most successful when applied in the fall or spring; however, other chemical combinations were generally no more successful than one of the chemicals applied alone. Generally, seedling survival improved and moisture stress was less if seedlings were planted after or one year before herbicide applications. Seedlings at White Stallion which were sheltered from glyphosate applied alone or in combination had better survival and lower moisture stress than if exposed to the spray. Seedling survival on scalped plots was high; however, competing vegetation quickly re-occupied the plots and plant moisture stress was generally high relative to control seedlings.

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CHAPTER 1

INTRODUCTION

The passage of the National Forest Management Act in 1976 provided National Forest land managers with a mandate to eliminate the reforestation backlog on National Forest lands by 1984.[1] The reforestation backlog is comprised of areas that have been cut over or otherwise denuded or deforested and are in need of reforestation.

The failure of attempts to reforest these areas immediately after disturbance has resulted in site dominance by weed species which are additional obstacles to successful forest regeneration. Often the use of site preparation techniques conventional to western Montana, such as scarification and burning, can eliminate problem vegetation if applied correctly. However, pinegrass (*Calamagrostis rubescens* Buckl.) is a rhizomatous forest grass which increases following disturbance, and in some cases has been observed to proliferate following application of these techniques (Lewis, 1967; Marcum, 1971; Steele and Beaufait, 1969; Weaver, 1951; Young et al., 1967). Observations by Stewart and Beebe (1974) and Dimock (1977) indicate herbicides have potential as a tool for the control of pinegrass.

Objectives

The objectives of this study were:

[1]PL 94-588

1. To study the effects of atrazine, dalapon, glyphosate and hexazinone on pinegrass growth and/or elimination.

2. To study the effects and interaction between herbicides, planting dates, application dates and rates of application.

Two sites were chosen as replicates for the study. The first was initiated in 1979 and will be referred to as the Blue Mountain site. The second site will be referred to as White Stallion and was initiated in 1980. Treatments and herbicide rates of application expressed as AI (Active Ingredient) in lbs./acre (kg/ha) are presented in Table 1.

Table 1. Treatments and Rates of Application Expressed as AI (Active Ingredients).

Treatments	lbs./acre	kg/ha
glyphosate	1.0	1.12
*glyphosate	2.0	2.25
glyphosate	3.0	3.37
*glyphosate +	1.0	1.12
hexazinone	1.0	1.12
glyphosate +	2.0	2.25
hexazinone	2.0	2.25
glyphosate +	2.0	2.25
atrazine	4.0	4.49
hexazinone	2.0	2.25
dalapon	8.45	9.49
dalapon +	8.45	9.49
atrazine	4.0	4.49
atrazine	4.0	4.49
*scalp		
control		

*delineates treatments added at White Stallion

CHAPTER 2

LITERATURE REVIEW

Numerous factors influence the ability of herbicides to control target plants. This chapter presents physiological responses, effects on conifers and soil relationships of the chemicals used in this study.

Atrazine

Physiological Responses

The primary mode of atrazine uptake is passive absorption by the roots where it proceeds across the cortical tissue and enters the xylem. From here it is translocated upward in plants to the photosynthetic tissues (Ciba-Geigy, 1978). Minshall (1975) found the quantity of atrazine in the petiole to be as high as that in the xylem suggesting lateral movement of atrazine from the xylem to the adjacent tissues. Possible reactions of various plant species to the effects of atrazine include blockage of carbohydrate production by photosynthesis, inhibition of the Hill reaction of photosynthesis, and reduction in CO_2 fixation and oxygen evolution (Ciba-Geigy, 1978). Brewer et al. (1979) found evidence supporting the conclusion that atrazine, cyanazine, and procyazine are photosynthetic electron transport inhibitors. They went on to identify the site of herbicidal action as being on the reducing side of photosystem II, somewhere between the primary flourescence quencher and plastoquinone.

Effects on Conifers

In a greenhouse study Kozlowski and Kuntz (1963) found germination and survival of white pine (Pinus strobus L.) to be greater than red pine (Pinus resinosa Ait.) for pre- and post-emergance applications of atrazine in composted greenhouse soil and Plainfield sand. Jeffrey pine (Pinus jefferii Grev. and Bal.) and ponderosa pine (Pinus ponderosa Laws.) survival were much more successful on plots treated with varying rates of atrazine than untreated plots in western Nevada (Eckert, 1979). Crouch and Hafenstein (1977) found survival of planted ponderosa pine seedlings on plots treated in the fall with atrazine at 4 lbs. per acre to be significantly better than unsprayed - planted plots.

Douglas-fir (Psuedotsuga menziesii (Mirb.) Franco.) survival was more than doubled on drier sites east of the crest of the Coast Range in Oregon following grass control by a broadcast treatment of atrazine at 4 lbs. AI/acre over the tops of recently planted seedlings (Gratkowski et al., 1979). Newton (1980) ranked Douglas-fir and Pinus spp. as resistant to the highest rates of atrazine allowed by the label. Abies spp. and Tsuga spp. were ranked as variable to resistant to similar rates.

Soil Relationships

The primary mode of atrazine uptake is passive absorption by roots. Therefore, it may be considered a soil treatment with success dependent upon transport of the herbicide from the soil surface to the root zone of the target plant. The probability of residual phtotoxicity is enhanced if higher levels of the herbicide remain in the soil solution. Factors contributing to this include high soil moisture content, low electrolyte concentration and low soil temperature (Dao and Lavy, 1978). Greater leaching can also be expected on light soils, where as heavy soils and increasing bulk density inhibit percolation. Kozlowski and Kuntz (1963) found atrazine relatively more leachable than other triazines possibly due to its greater solubility.

Atrazine transport and residual phytotoxic activity can be limited by adsorption to soil polysaccharide components with irreversible adsorption on humic acids. Adsorption to activated charcoal is irreversible if atrazine is not present in the soil solution (Sanborn et al., 1977; Fusi et al., 1977). High soil temperatures and low surface pH values enhance adsorption and have resulted in greater degradation. Release of atrazine to plants appears to occur when pH rises above 7 (McGlammery and Slife, 1966; Dao et al., 1980; Kells et al., 1980).

Detoxification generally occurs by chemical hydrolysis which converts atrazine to hydroxyatrazine. Microorganisms are then able to attack the hydroxyatrazine ring increasing the rate of degradation. A second mode of detoxification is deamination which can result from degradation of atrazine by *Nocardia* spp. (Skipper et al., 1977; Giardina et al., 1980). The effects of atrazine on soil microorganisms has ranged from increasing populations to no effect to temporary declines in soil microbial numbers (Cole, 1976; Sanborn et al., 1977; Percich and Lockwood, 1978).

Dalapon

Physiological Responses

Dalapon is a systemic herbicide which is uptaken primarily through the foliage. Transport of the herbicide is associated with and apparently dependent upon movement of the photosynthates downward through the phloem. Other areas of transport include transpiration streams from the roots or lower stems, and lateral movement in the phloem-xylem interchange (Foy, 1961a; Leasure, 1964). Foy (1961a) found that acute toxicity to foliage resulting from high concentrations of dalapon reduced or prevented its movement from the infected area. However, in the absence of acute toxicity dalapon was still being transported out of the infected area after 2 weeks. Also, in both tolerant and susceptible plant species retranslocation and accumulation of dalapon shifted in response to loci of high metabolic activity. Activity was found to be greater on green, active, well expanded leaves than on either fully matured senescent leaves or very young immature leaves.

Dalapon is usually not metabolized by plants. Foy (1961b) observed the intact molecule or dissociable salts to be present in dormant or quiscent tissues for long periods following treatment. Foy (1961a) reported that dalapon has been excreted from the roots of foliar treated plants as dalapon.

Leasure (1964) stated that both competitive and non-competitive enzyme reactions have been attributed to dalapon. Competition is thought to occur between dalapon and pyruvic acid for attachment to pyruvate attacking enzymes and by inhibition of pantothenic acid synthesis. Non-competitively it was hypothesized to act as a protein participant generally inactivating the enzyme complex.

Effects on Conifers

Reports of the effects of dalapon on conifers have been inconsistent. In the southwest Heidman (1967) indicated dalapon applications of 10 lbs. AI/acre caused no noticeable damage to ponderosa pine seedlings. This is contrary to a report by Newton and Overton (1973) who made observations of damage to conifers when dalapon was applied over the tops -- even during the dormant season. Their study revealed a mixture of dalapon and atrazine could be used safely on Douglas-fir and grand fir (Abies grandis (Doug.) Lindl.) seedlings. Gratkowski (1975) reported that at one location in southwestern Oregon a combination of atrazine and dalapon completely defoliated well established ponderosa pines 8 - 15 feet tall. On the Wenatchee National Forest Stewart and Beebe (1974) found ponderosa pine seedlings were not damaged when planted immediately after spraying 5 lbs. dalapon per acre. Newton (1980) ranked Pinus spp., Douglas-fir, Abies spp. and Tsuga spp. as variable to resistant to the highest rates of dalapon allowed by the label.

Soil Relationships

Although dalapon decomposition takes place most rapidly as a result of microbiological activity, microsite conditions indirectly affect the rate of decomposition. The persistance of dalapon was tested by Day et al. (1962) in 43 California soils under laboratory conditions with results showing the rates of decomposition ranging from less than 2 weeks to retention of 2/3 of the applied dalapon 8 weeks after application. The ability of soil microorganisms to alter the pH of the medium in which they grow supports the contention that OM, pH, and CEC all affect the microbial decomposition of dalapon (Kaufman, 1964). Dalapon degradation takes place more rapidly under warm (80^{o}F) moist soil conditions than in cool (40^{o}F) dry soils (Theigs, 1955; Wingfield et al., 1977). Davies and Marsh (1977) found dalapon applications did not effect CO_2 evolution or mineralization of N, but inhibited nitrification for at least 3 weeks in one of the soils tested.

Numerous authors have reported the decomposition of dalapon to occur readily in soils containing certain strains of *Arthrobacter*, *Pseudomonas*, *Rhizobium*, *Flavobacterium*, *Clonostachys*, *Agrobacterium*, *Nocardia* and *Trichoderma viride* (Jensen, 1957; Magee and Comer, 1959; Hirsch and Alexander, 1960; MacGregor, 1963; Kaufman, 1964; Leasure, 1964; Senior et al., 1976; Berry et al., 1979).

Glyphosate

Physiological Responses

Sprankle et al., (1975a) found glyphosate to be rapidly absorbed by foliage and readily translocated in quackgrass and many other annual and perennial plant species. Evidence shows glyphosate to cause accumulation of shikimic acid in plant tissues due to an inhibition of enzymatic conversion of shikimic acid to chorismic acid. This blocks biosynthetic formation of anthraquinoid pigments and the three aromatic amino acids: phenylalanine, tyrosine and tryptophan (Jaworski, 1972; Hollander and Amrhein, 1980; Amrhein et al., 1980; Steinrucken and Amrhein, 1980). Secondary effects include induction of phenylalanine amonia-lyase activity accompanied by an increase in growth inhibiting phenolics (Duke and Hoagland, 1978; Hoagland et al., 1978; Hoagland et al., 1979).

Effects on Conifers

Sutton (1978) reported evidence that glyphosate applications during shoot elongation caused some mortality among white spruce (Picea glauca (Moench) Voss) as a direct result of treatment and indirectly, possibly from canopy drip. Other effects included tip burn on western red cedar (Thuja plicata Donn) and western firs (Abies spp.) when glyphosate was applied at 2.24 kg/ha. Hardening off of current years growth prior to treatment was strongly recommended. Seedlings stressed by budworm infestation and browsing had significant positive responses when released from competing vegetation by glyphosate treatment. Radosevich et al. (1980) found severe herbicide injury to western conifer seedlings if applications were made when photosynthesis was high, pre-dawn xylem sap tension was low and active shoot growth was in progress.

Soil Relationships

Glyphosate is inactivated in the soil at rates 25 times the proposed use rates. Data interpretation indicated more glyphosate was bound to the soil at the lower pH levels of 4.6 to 5.1. Also, initial glyphosate binding was reversible when phosphate anions were competing with glyphosate for binding sites. It was postulated that inactivation is by reversible adsorption to clay and organic matter through the phosphoric acid moiety. Further investigation revealed glyphosate mobility in the soil is very limited and is influenced by soil pH, phosphate level and soil type. Glyphosate was easily bound to clay and organic matter, and an observed degradation pattern suggested cometabolism by the constitutive mocrobial populations following the initial inactivation of glyphosate (Sprankle et al., 1975b; Torstensson and Aamise, 1977). Glyphosate is stable in sunlight, has low propensity to runoff and has minimal effects on microflora.

Microbial degradation is the predominant mechanism in soil degradation; however, rates vary by soil type (Rueppel et al., 1977; Moshier and Penner, 1978).

Hexazinone

Physiological Responses

Hexazinone is believed to act as a photosynthetic inhibitor. As stated by I. E. DuPont's technical data sheet (1978) best results would be obtained by spraying while the target plant is actively growing. The product gives contact and residual control; however, precipitation is necessary for soil activation. If root absorption does not occur resistant plants may recover from foliar injury and continue to grow (Rohrbough, 1979). Newton (1980) stated that annual and perennial grasses are killed by medium or lower rates of hexazinone while broadleaf herbs may require higher rates for adequate kill.

Effects on Conifers

Newton (1980) ranked *Pinus* spp., *Abies* spp. and Douglas-fir as resistant to the highest rate of hexazinone applied. South and Sung (1980) conducted assay tests for photosynthesis inhibiting triazine herbicides and found hexazinone to be more toxic to loblolly pine (*Pinus taeda* L.) than either atrazine or prometryn. Further results indicated different tolerances among pine seedlings to herbicides. Longleaf pine (*Pinus palustris* Mill.) was found to be more tolerant to hexazinone than loblolly pine which was more tolerant than either short leaf (*Pinus echinata* Mill.) or eastern white pine (*Pinus strobus* L.). Fitzgerald and Fortson (1979) found decreased herbaceous competition within the first growing season after application and increased loblolly pine growth in the first and second growing seasons. Phytotoxic effects on seedlings resulted from both foliar and root assimilation.

Soil Relationships

Additions of 5 and 20 ppm hexazinone to two soils had no effect on the soil nitrifying process during a 5 week test period. Soil population counts of fungi and bacteria were not reduced in 3 agricultural soils after being treated with 10 ppm hexazinone. The composition of fungal groups relative to each other were unchanged (Rhodes et al., 1980). The major routes of degradation by microbial decomposition, photodegradation in water or metabolism in rats involves demethylation and hydroxylation. The half-life of hexazinone in soils varies from one to 12 months depending on soil and climatic conditions (Rohrbough, 1979; Rhodes and Jewell, 1980; Rhodes, 1980a; Rhodes, 1980b).

Chapter 3

PROCEDURES

Several components of the study required different procedures for their implementation. This chapter is devoted to describing the sites, experimental designs, application methods, sampling schemes, and analyses involving in the study.

Site Descriptions

The primary criterion for site selection was a clearcut with a stand of pinegrass covering enough area to accommodate a large number of study plots. Secondary criteria included a steep slope which could not be dozer scarified and a soil void of significant clay content which could influence the effectiveness of root active herbicides such as atrazine.

Blue Mountain

The Blue Mountain study site is located on the Missoula District of the Lolo National Forest: approximately 18 miles southwest of Missoula, Mt. The legal description is W½, SE¼, Sec. 1. T12N, R21W (Appendix A, Plate I). The plots are situated just below the Blue Mountain road between the 5560 and 5740 foot elevations on a westerly aspect of 40% to 45% slope. A similar site adjacent to the study site was keyed to a habitat type of *Pseudotsuga menziesii*/*Calamagrostis* *rubescens*, *Calamagrostis rubescens* phase.

Two soil series occur on the study site. The Mitten series contains 27 plots and is a loamy-skeletal, mixed, frigid Andic Dystric Eutrochrept. The Tevis series contains 217 plots and is a loamy-skeletal, mixed, frigid Dystric Eutrochrept. The primary difference between the two soils is a volcanic ash layer present in the Mitten series (Soil Conservation Service). The parent material is belt pre-cambrian with Mt. Shields red argillite and green argillite being most abundant.

Stand records indicate the forest type was western larch (*Larix occidentalis* Nutt.) with a site index of 36-45. The study area had been clearcut in 1965 followed by a prescribed burn the following fall. The site was also machine scarified in 1971. Although conversations with district personnel suggest three planting attempts using ponderosa pine and Douglas-fir, records show only the last attempt in spring, 1965, with no species specified.

White Stallion Study Site

The White Stallion study site lies along the White Stallion road in the North Fork Rye Creek drainage of the Darby District, Bitterroot National Forest. The district management reference is stand no. 62-4-03 with the legal description being SW¼, Sec. 29, T4N, R19W (Appendix B, Plate II). On a southwest aspect of 6200 feet elevation, the habitat type as described by district records is *Abies lasiocarpa*/*Xerophyllum tenax*, *Vaccinium scoparium* phase. The topography is undulating on an upper slope ranging from 11-21% from the horizontal. Soils in the area are coarse loamy, micaceous, frigid Typic Cryocrepts with a gneiss parent material. The soil series for this type of soil in the area has not been established (Soil Conservation Service).

The stand history begins with a 1968 clearcut followed by a broadcast burn in 1970 for site preparation. Natural seeding was relied on for reforestation resulting in poor, scattered stocking of lodgepole pine (*Pinus contorta* Dougl.), Englemann spruce (*Picea englemanii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.).

Experimental Designs

Blue Mountain

The original split-split plot design used for plot lay out at Blue Mountain is presented in Table 2. Herbicide applications were conducted June 24, 1979, September 16, 1979 and May 12, 1980. Three application times, 9 treatments, and 3 planting times were replicated 3 times on 243 plots. Plots were 3m x 3m in size and were systematically located with 2m spacing to prevent contamination from adjacent treatments. A treatment was then randomly assigned to each plot location. Table 14 (Appendix A) presents the plot numbering system and the herbicide formulations, rates and mixtures. Figures 8 and 9 (Appendix A) are plot relocation maps of the study site. Douglas-fir and ponderosa pine 2.0 bareroot nursery stock were used for planting 14 days prior to herbicide application in June, 1979 and 5 days prior to the May, 1980 application. Two seedlings of each species were planted by mattocks (hoedag) on the corners of the center m^2 of selected plots. Seedlings were not planted in September, 1979 because of nursery stock problems encountered with the June planting.

Table 2. Split-split Plot Design Used at the Blue Mountain Study Site

Treatments	Application Times								
	June, 1979			September, 1979			May, 1980		
	Plantings in			Plantings in			Plantings in		
	June 1979	Sept. 1979	May 1980	June 1979	Sept. 1979	May 1980	June 1979	Sept. 1979	May 1980
glyphosate 1.0 glyphosate 3.0 glyphosate + hexazinone hexazinone glyphosate + atrazine dalapon dalapon + atrazine atrazine control									

Table 3. Split Plot Design Used at the White Stallion Study Site

Treatments	June, 1980 Application	
	Planted before application	Planted after application
*glyphosate 1.0 *glyphosate 2.0 *glyphosate 3.0 *glyphosate + atrazine *glyphosate 1.0 + hexazinone 1.0 *glyphosate 2.0 + hexazinone 2.0 hexazinone dalapon dalapon + atrazine atrazine **scalp control		

*half of the seedlings planted before application were covered during application

**half of the seedlings planted before application were shaded

White Stallion

The design employed at White Stallion is presented in Table 3. The study consists of 3 experimental blocks each divided into 2 major plots representing the planting times. Each major plot is divided into 12 treatments with each treatment containing 3 plots. The plot numbering system, treatments, and herbicide formulations, rates and mixtures are presented in Table 15 (Appendix B). Figure 10, 11 and 12 (Appendix B) are plot relocation maps. The scalped treatment was introduced after the other treatments had been randomized, and were therefore randomly scattered around the perimeter of the blocks.

Plots were 3m x 3m and were systematically located with 2m spacing. Treatments were then randomly assigned to each plot. Two 2,0 bareroot lodgepole pine and Douglas-fir seedlings were planted by matox on the corners of the center m^2 of each plot. Half of the seedlings were planted on one major plot prior to herbicide application. Scalped plots were planted when the vegetation was removed. Half of the seedlings planted before application on plots treated with glyphosate, alone or mixed, were protected from the spray and the other half exposed; respective seedlings on scalped plots were shaded after planting.

Herbicide Mixing and Application

All herbicides were applied in a solution of 20 gallons of water per acre using a knapsack sprayer with cone type nozzle. Rinsing of the sprayer between treatments was accomplished with water only if the herbicide for the following treatment was to remain the same. The triple rinse method was utilized if other herbicides were to be applied (Shaw, 1974).

A problem with herbicide application was not recognized until after all treatments were applied. Apparently, suffecient water remained in the boom and pump from between treatment rinses to dilute the herbicide applied to the first few plots in each treatment. Consquently, these plots produced unreliable data and were excluded from the analyses. Plots included in the analyses are presented in Figures 8 and 9 (Appendix A) and Figures 10, 11 and 12 (Appendix B).

Sampling

Soil moisture content can affect the mobility of soil active herbicides such as atrazine, dalapon and hexazinone thus influencing how rapidly they can enter the rhizosphere of the target plant. To estimate this parameter soil samples were collected from 12 randomly selected plots from each block within 24 hours of herbicide application at White Stallion. At Blue Mountain samples were collected from each treated plot within 24 hours after the May, 1980 application. All samples were collected from the top 20 cm of the soil and percent moisture content was determined by the gravimetric method. Field capacity and wilting coefficient of the soil were determined using the pressure plate.

Vegetative response was assessed by placing an elevated m^2 grid containing 100 points over the center m^2 of each plot. A plumb line was dropped from each grid point and frequency of vegetation was recorded by species as the live plant material intersected the plumb line. One pre-application assessment was made and post-application assessments were made after 7 days, 14 days, 25 days, 50 days, and thereafter at 50 day intervals for the duration of the experiment.

All plots were assessed for vegetative response before and after applications at Blue Mountain. At White Stallion a sample of 3 plots, based on the Blue Mountain sample size, were randomly selected from each treatment within each block for a pre-application assessment. The assessment data was used to calculate the sample size for each treatment via the Neyman allocation (Cochran, 1963). The result was an overall reduction in the number of plots which needed to be read. Post-application assessments at White Stallion for 7, 14, 25, 50 and 100 days were made on these plots only (Figures 10, 11 and 12, Appendix B). Seedlings at both sites were counted before the application and at 50 day intervals after the application.

A pressure bomb was available for derermining seedling moisture stress in late August, 1980. Pre-dawn samples were taken from all surviving seedlings on reliable plots at Blue Mountain. At White Stallion at least 3 seedlings of each species were selected from all treatments within blocks 2 and 3. Samples were usually taken from twigs of Douglas-fir and needle fasicles from the pines. Occasionally, when little green vegetation was left on the seedlings, the main stem was used for sampling and the seedling was sacrificed.

Analysis

Plant moisture stress data were ranked and compared to the control treatment using a Mann-Whitney U-test (Sokal and Rohlf, 1969; Rohlf and Sokal, 1969). Heterogenous variance associated with pinegrass response data required the following transformation prior to analysis:

$$\log(R + 1)$$

where R is the actual pinegrass response per plot, and 1 is added to eliminate zero values. Standard analysis of variance (Table 4), followed by Duncan's multiple range tests were then used to evaluate treatment effects on pinegrass. White Stallion treatment means within an assessment time were not statistically comparable because of differences in sample size.

Table 4. Standard One-way Analysis of Variance Table Used to Evaluate treatment Effects on Pinegrass (from Ott, 1977)

Source	Sum of Squares	Degrees of freedom	Mean square	F test
between	SSB	t-1	$S_B^2 = SSB/_{t-1}$	S_B^2/S_W^2
within	SSW	n-t	$S_W^2 = SSW/_{n-t}$	
Totals	TSS	n-1		

where: SSB = sum of squares between assessments (treatments)

SSW = sum of squares within assessments (treatments)

TSS = total sum of squares

t = number of assessments (treatments)

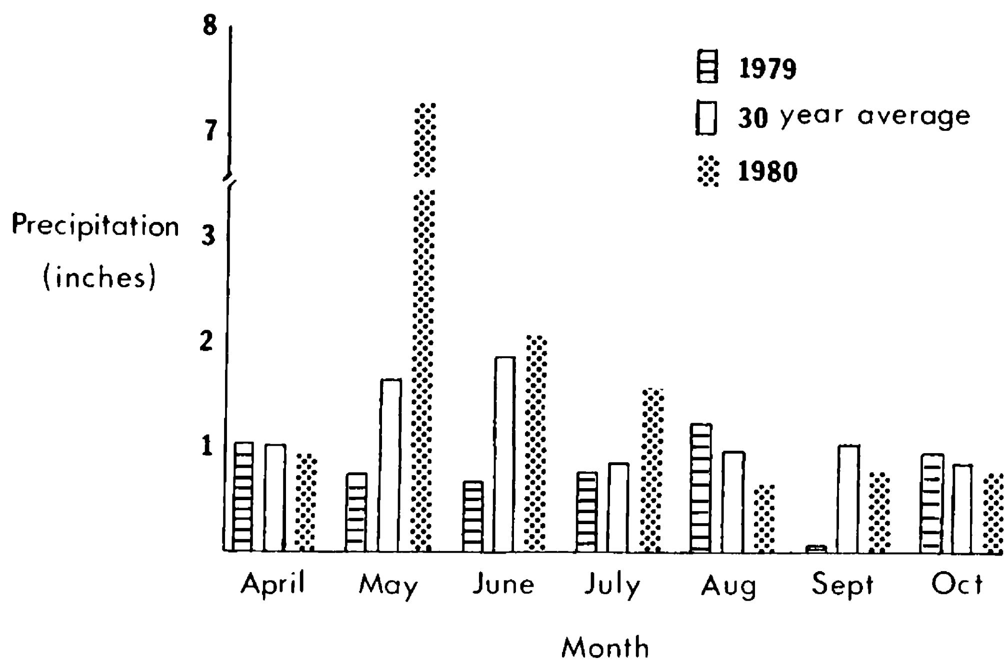
n = number of samples

CHAPTER 4

RESULTS

Precipitation data collected at the permanent gauging station in Missoula, Montana for April through October during 1979, 1980 and for a 30 year average are presented in Figure 1.[1,2] Although precipitation amounts were probably higher at the study site, similar trends were reported at the Hamilton and Stevensville, Montana and Powell, Idaho gauging stations suggesting a similar trend on Blue Mountain.

Figure 1. Precipitation Which Fell in Missoula, MT During the 1979 and 1980 Growing Seasons and the 30 Year Average



[1]National Oceanic and Atmospheric Administration, Climatological Data: Montana. Environ. Data and Info. Service, 1980, 82, No. 13.

[2]National Oceanic and Atmospheric Administration, 1980, 83, No. 13.

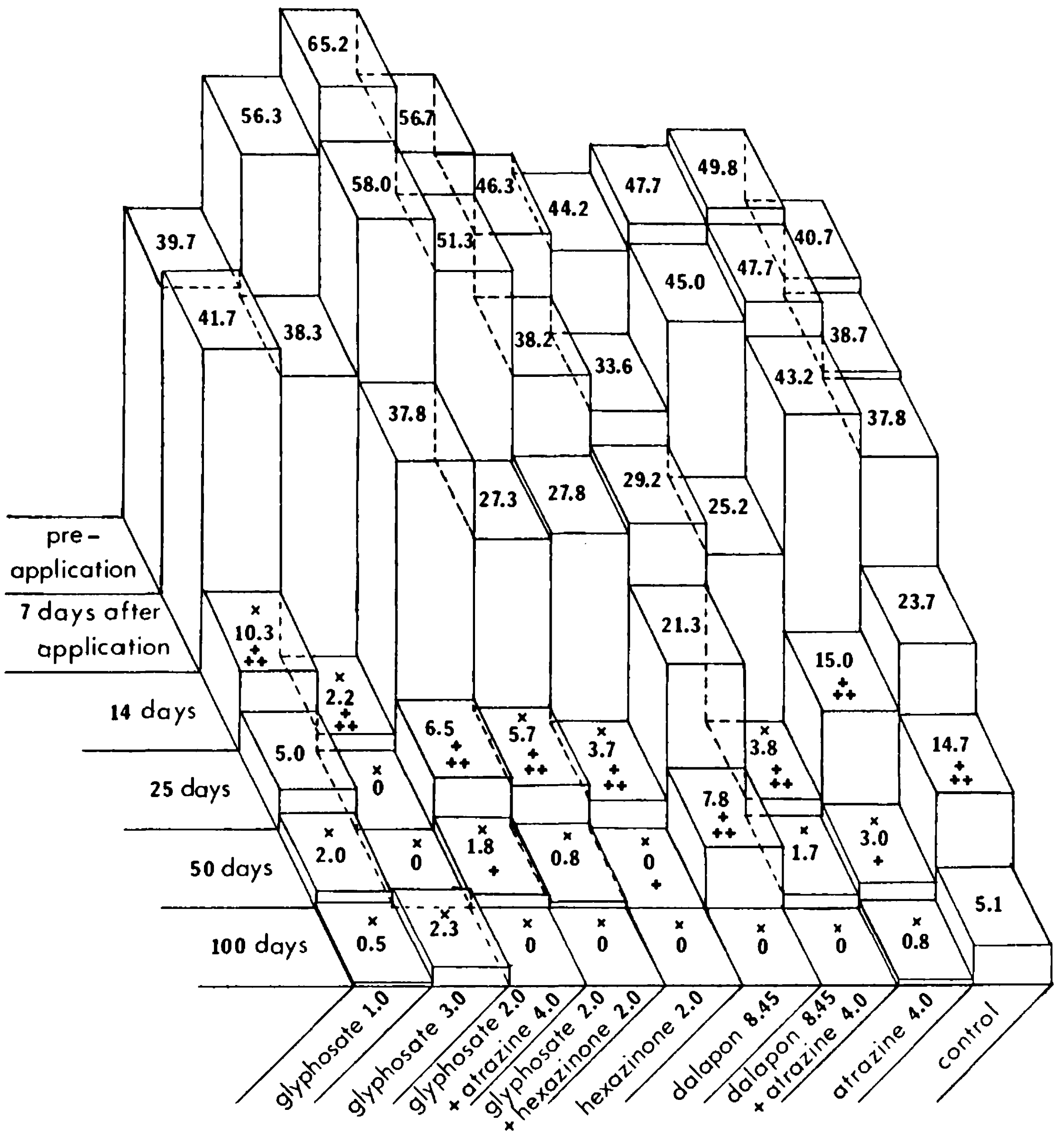
Vegetation Responses

June, 1979 Application

Pinegrass responses to the June, 1979 application at Blue Mountain are presented in Figures 2 and 3. At the time of application pinegrass foliage was well developed, but not mature as seed stalk formation had not begun. Pinegrass frequencies gradually decreased through out the growing season on control plots starting at a mean of 40.7 at pre-application and being 5.1 by 100 days after application. This was probably due to the relatively dry 1979 growing season (Figure 1). By 14 days after application pinegrass frequencies on plots treated with glyphosate were significantly less than control or pre-application frequencies. By 25 days after application all treatments except dalapon and the control had significantly reduced pinegrass below pre-application levels. Pinegrass frequencies on plots treated with glyphosate at 3.0 lbs./acre, glyphosate + hexazinone, hexazinone and dalapon + atrazine were significantly less than the 23.7 control mean frequency. At 50 days glyphosate + atrazine, hexazinone, and atrazine continued to significantly reduce pinegrass, and significant reductions were recorded on plots treated with dalapon and control plots. Also, pinegrass frequencies on all treatments except dalapon were significantly less than the 14.7 control mean frequency. Generally, the gradual reduction of pinegrass on plots treated with dalapon or atrazine was similar to that on control plots.

Pinegrass frequencies for the same plots during the 1980 field season are presented in Figure 3. At some time during the growing season all plots except those treated with glyphosate at 1.0 and 3.0

Figure 2. Mean Frequencies of Pinegrass on Blue Mountain Before and for 100 Days After the June, 1979 Application. Herbicide Rates are Expressed in Lbs. AI/Acre

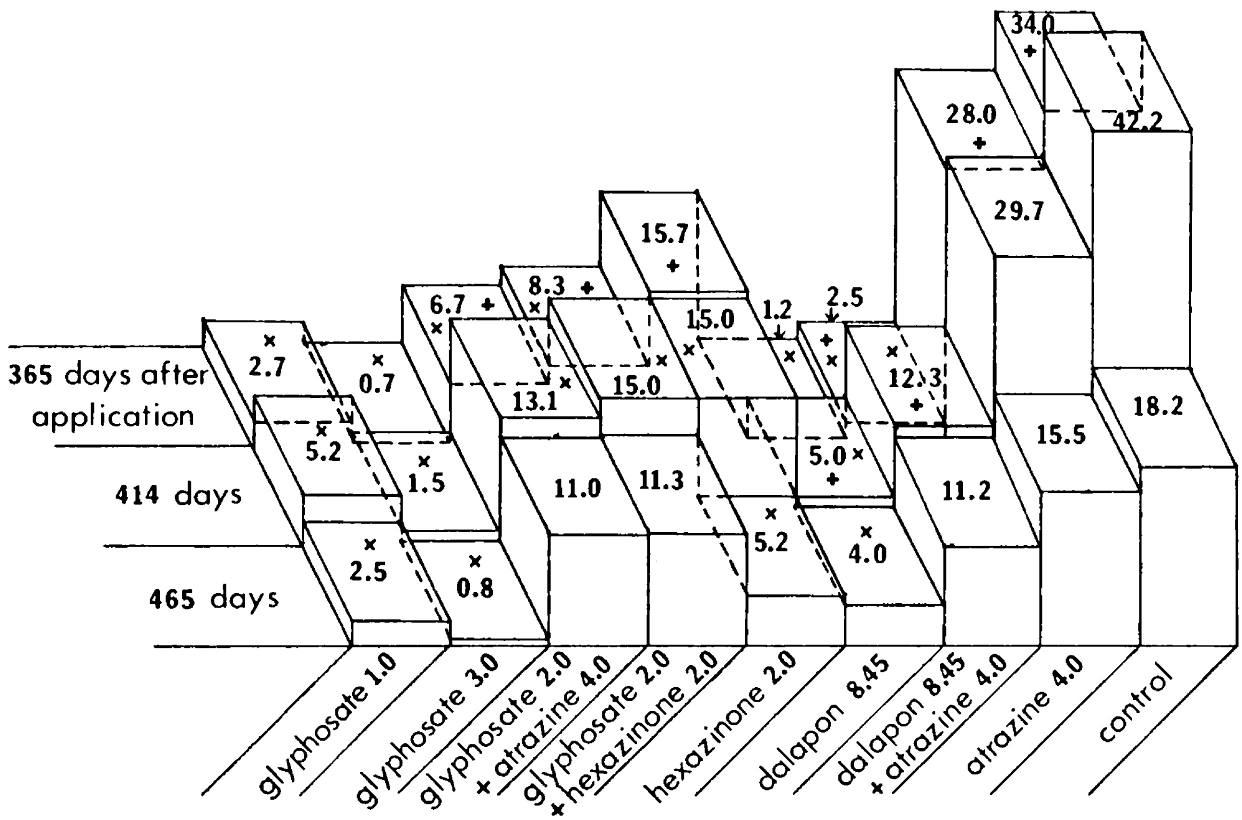


× indicates a significant difference from the control at a specified assessment time, $\alpha = .05$.

+ indicates a significant difference from the immediately preceding assessment, $\alpha = .05$.

++ indicates earliest significant difference from the pre-application assessment, $\alpha = .05$.

Figure 3. Mean Frequencies of Pinegrass on Blue Mountain During the 1980 Growing Season on Plots Treated in June, 1979. Herbicide Rates are Expressed in Lbs. AI/Acre



* indicates a significant difference from the control at a specified assessment time, $\alpha = .05$.

\+ indicates a significant difference from the immediately preceding assessment, $\alpha = .05$.

Table 5. Comparison of 1979 - 1980 Pinegrass Frequencies Before the June, 1979 Application and 365 Days After Application at Blue Mountain

Day	glyphosate 1.0		glyphosate 3.0		glyphosate+ hexazinone		hexazinone		glyphosate + atrazine		dalapon		dalapon + atrazine		atrazine		control	
	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980	1979	1980
June 20	39.7	2.7[a]	56.3	0.7[a]	56.7	8.3[a]	46.3	15.7[a]	65.2	6.7[a]	44.2	1.2[a]	47.7	0.2[a]	49.8	28.0	40.7	34.0
Aug. 14	2.0	5.2	0.2	1.5	0.8	15.0[a]	0.2	15.2[a]	1.8	13.2[a]	7.8	5.0	1.7	12.3[a]	3.0	29.7[a]	14.7	42.2[a]
Oct. 3	0.5	2.5	2.3	0.8	0.3	11.3[a]	0.2	5.2[a]	0.2	11.0[a]	0.2	4.0[a]	0.7	11.2[a]	0.8	15.5[a]	5.2	18.2[a]

[a]indicates a significant difference from the previous year at $\alpha = .05$

Table 6. Herbaceous Vegetation Totals Before and After Each Application on Blue Mountain

Treatment	June Application				September Application				May Application			
	Annual		Perennial		Annual		Perennial		Annual		Perennial	
	June 1979	June 1980	June 1979	June 1980	Sept. 1979	Oct. 1980	Sept. 1979	Oct. 1980	May 1980	July 1980	May 1980	July 1980
glyphosate 1.0	8	12	98	56	0	0	22	4	0	4	4	36
glyphosate 3.0	0	52	133	9	9	2	22	3	0	0	14	31
glyphosate + hexazinone	5	2	60	35	1	0	27	1	0	0	17	20
hexazinone	12	4	58	23	5	0	15	13	0	1	4	3
glyphosate + atrazine	2	13	85	44	14	20	18	9	0	0	24	8
dalapon + atrazine	7	16	74	57	2	1	2	11	0	5	9	24
atrazine	3	7	73	58	5	0	15	34	0	0	7	73
dalapon	2	14	121	64	4	2	9	27	2	17	8	75
control	1	0	126	142	0	0	19	48	0	0	7	64

lbs. per acre experienced a significant increase in pinegrass freuqncies. Pinegrass frequencies on plots treated with glyphosate or dalapon were significantly less than control freuqncies through out the field season. The frequency of pinegrass on control plots reflect growing conditions as influenced by unusually high precipitation during the spring and early summer months of 1980 (Figure 1). Table 5 presents the mean frequencies of pinegrass for three dates during both 1979 and 1980 growing seasons. The June 20, 1979 number is the pre-application pinegrass frequency. Atrazine was the only herbicide treatment which did not maintain pinegrass at levels signifieantly lower than pre-application levels. By August 14, 1980 a significant increase over pinegrass levels exactly one year earlier had occurred on plots treated with glyphosate + hexazinone, glyphosate + atrazine, dalapon + atrazine, atrazine and control plots. By October 3 dalapon was included in this group. The increase of pinegrass during the later months of the 1980 growing season was attributed to the increased precipitation in 1980 and to the relative effectiveness of the individual treatments.

Herbaceous vegetation responded consistently over all the treatments (Table 6). All treatments reduced the perennial herbs with the greatest decreases occurring on plots treated with glyphosate at 3.0 lbs. per acre. Annual herbaceous plants increased by 1980 on all plots but those treated with hexazinone alone or in combination. The most dramatic increase in annual vegetation occurred on plots treated with glyphosate at 3.0 lbs./acre.

September, 1979 Application

The September application took place after pinegrass seed dissemination. Figure 4 illustrates pinegrass response to treatments applied at this time. The natural curing of pinegrass as it became dormant precluded observations of acute response to herbicides. Therefore, observations during the 1980 field season presented as shaded bars are a more reliable indicator of the response of pinegrass to the various treatments.

Glyphosate treatments alone and with atrazine were relatively ineffective when compared to dalapon and hexazinone treatments. The peak 1980 pinegrass frequency on plots treated with glyphosate at 1 lb./acre and glyphosate + atrazine were very close to frequencies on control plots and to 1979 frequencies before application. Also, at 380 days plots which received these two treatments had frequencies significantly higher than control plots. At 3 lbs./acre glyphosate maintained pinegrass at frequencies significantly lower than the 1979 peak; however, there was a continual increase in pinegrass as the 1980 season progressed. Throughout 1980 pinegrass frequencies on plots treated with hexazinone, glyphosate + hexazinone, dalapon and dalapon + atrazine were significantly less than 1980 control or 1979 pre-application frequencies. Atrazine alone was unsuccessful in controlling pinegrass.

An October, 1980 assessment of the response of herbaceous vegetation to the September, 1979 application is presented in Table 6. A time lag of approximately 3 weeks between annual assessments reduces the comparability of these data because annual plants are rapidly dying and perennials are entering dormancy. Consequently, these data are not reliable indicators of a treatment's ability to control these types of vegetation.

Figure 4. Mean Frequencies of Pinegrass by Treatment Before and After the September, 1979 Application on Blue Mountain. Herbicide Rates are Expressed in Lbs. AI/Acre

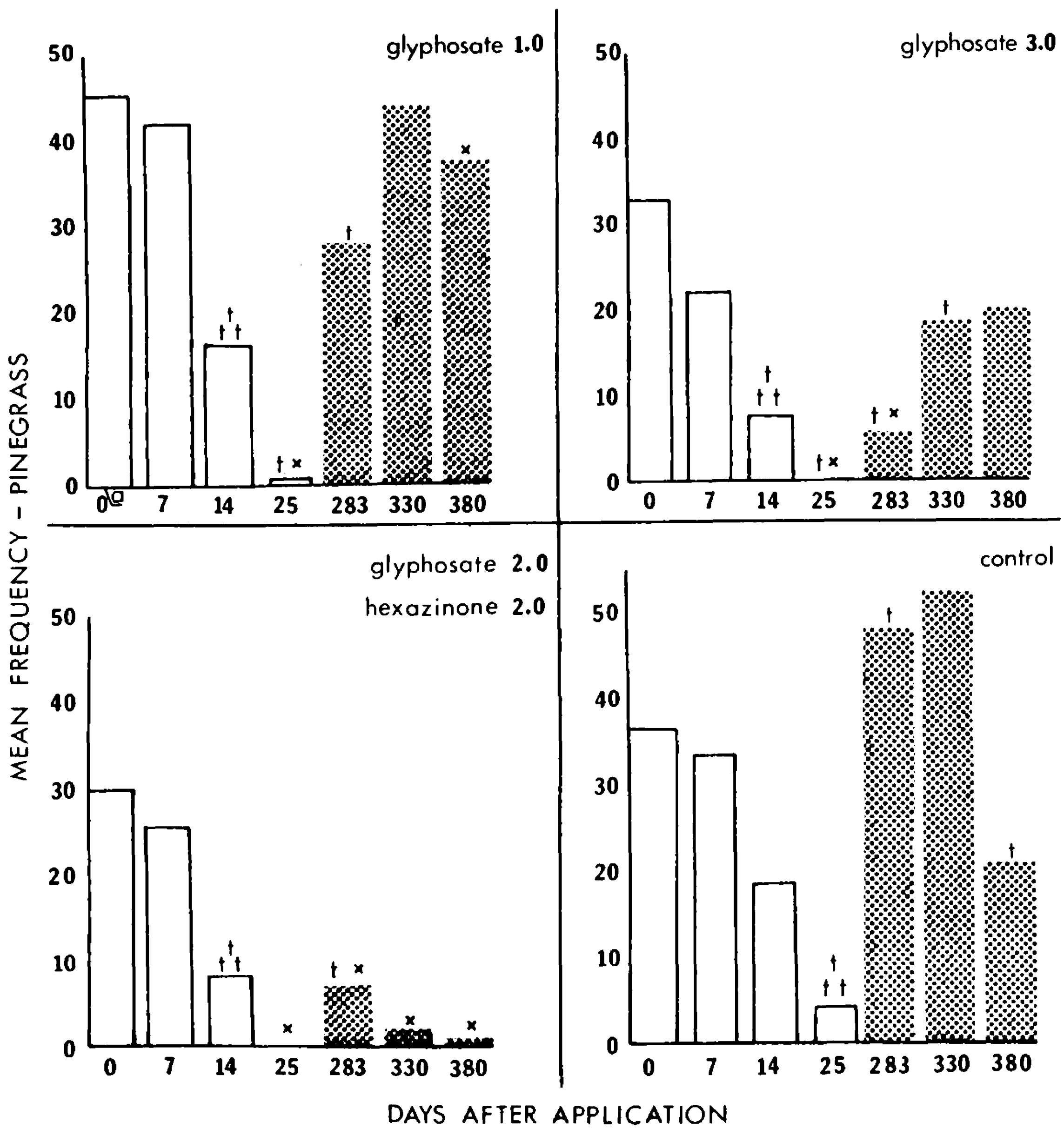
*indicates a significant difference from the control at a specified application time, $\alpha = .05$.

†† indicates earliest significant difference from the pre-application assessment, $\alpha = .05$.

† incicates a significant difference from the immediately preceding assessment, $\alpha = .05$.

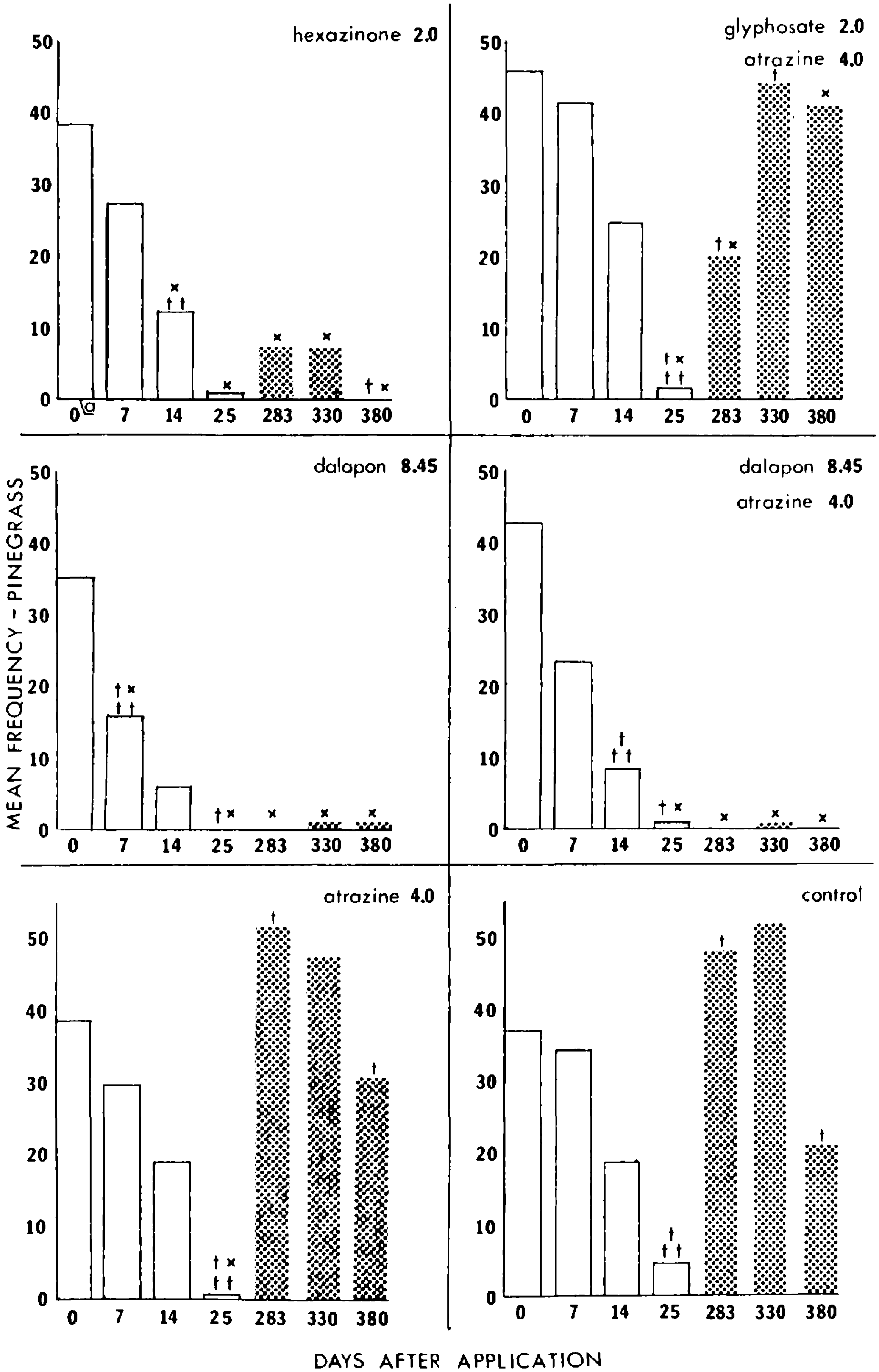
▯ 1979 field season assessments

▩ 1980 field season assessments



[a]day zero is the pre-application assessment.

Figure 4. (continued)



\a day zero is the pre-application assessment.

May, 1980 Application

Pinegrass was in its earliest stages of development at the time of application. Visible above ground growth consisted of scattered blades 1 to 3 inches long. Precipitation in May, 1980 approached record levels (Figure 1, page 20) and the soil moisture levels at the time of herbicide application were near field capacity (Table 7). The pinegrass frequency assessment 7 days after application was precluded by snow, and the assessment on day 14 was only partially completed because of Mt. Saint Helens ash fallout.

Pinegrass response to treatments applied in May, 1980 are presented in Figure 5. Plots treated with glyphosate alone achieved and maintained pinegrass frequencies at levels similar to control frequencies and significantly higher than pre-application levels. Glyphosate + atrazine had relatively better results as pinegrass frequencies never increased significantly above the pre-application level. This is in sharp contrast to plots treated with atrazine alone where pinegrass frequencies were similar to those found on control plots.

Hexazinone alone, glyphosate + hexazinone and dalapon + atrazine

Table 7. Percent Soil Moisture at Field Capacity, at the Wilting Coefficient and at the Time of the May, 1980 Application on Blue Mountain

	Percent Soil Moisture		
	1/3 bar*	15 bar*	May, 1980**
Mean	45.98	24.49	44.5
Standard deviation	2.32	2.22	6.45

*n = 6

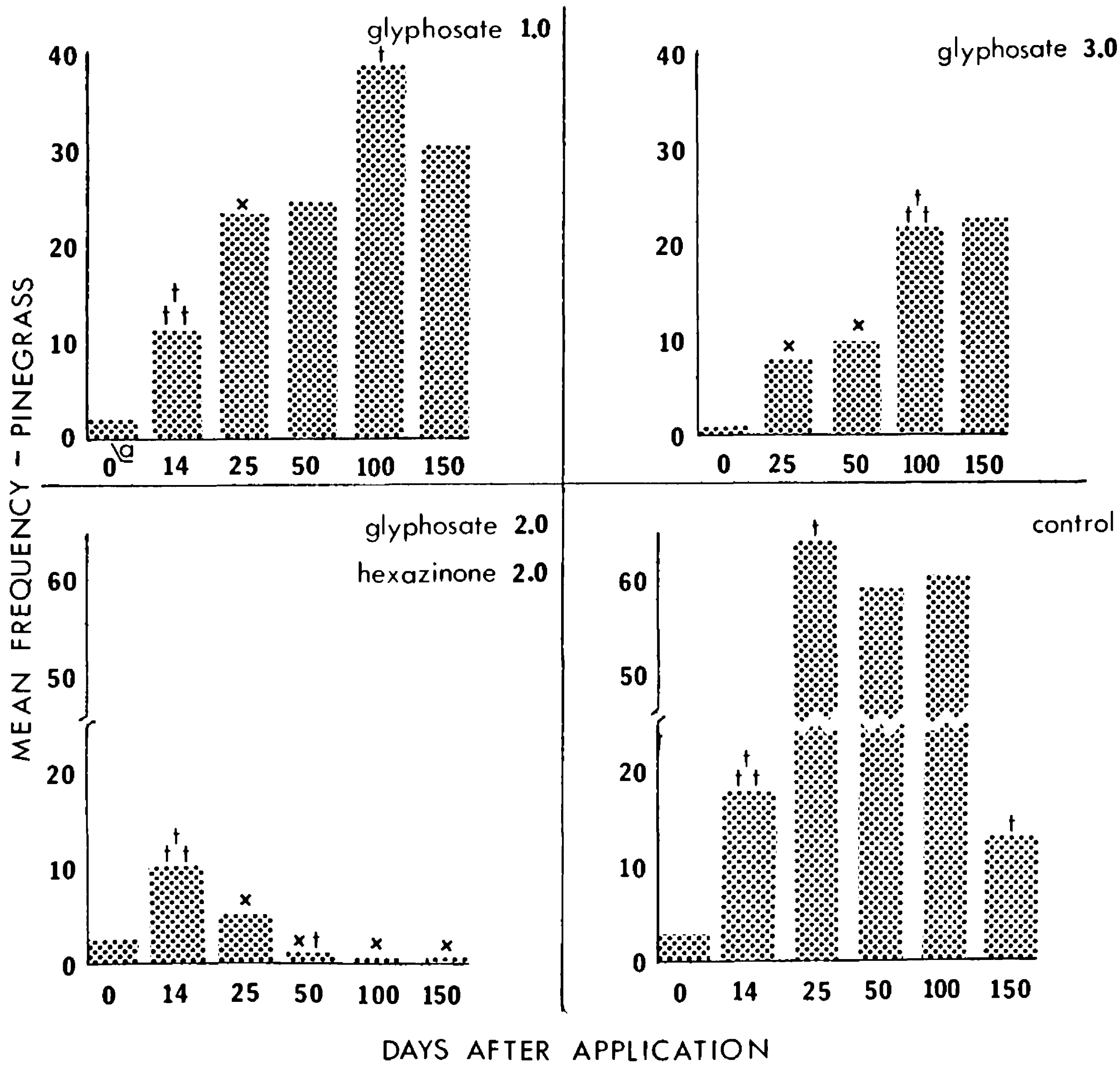
*n = 9

Figure 5. Mean Frequencies of Pinegrass by Treatment Before and After the May, 1980 Application on Blue Mountain. Herbicide rates are expressed in lbs. AI/acre.

× indicates a significant difference from the control at specified assessment time, $\alpha = .05$.

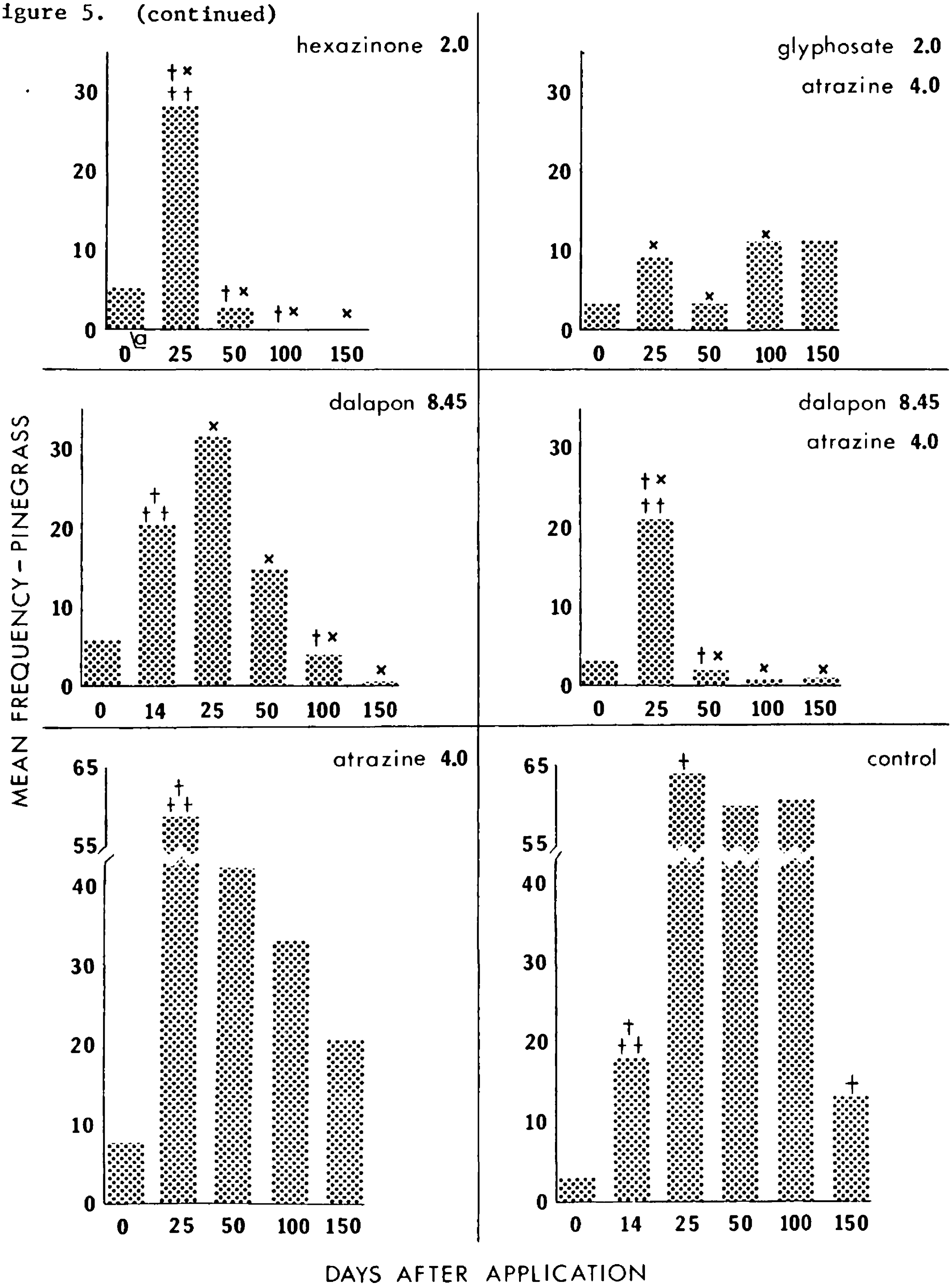
†† indicates earliest significant difference from the pre-application assessment, $\alpha = .05$.

† indicates a significant difference from the immediately preceding assessment, $\alpha = .05$.



\a day zero is the pre-application assessment.

Figure 5. (continued)



[a]day zero is the pre-application assessment.

had similar effects on pinegrass. The reaction was characterized by a short term significant increase in pinegrass frequency followed by a significant decrease by 50 days after application. Frequencies were then maintained at the lower level for the remainder of the growing season. Pinegrass treated with dalapon alone followed a bell shaped trend with the highest frequency occurring 25 days after application followed by a decrease which became significant after 100 days. Pinegrass frequencies on all these treatments were significantly less than those on control plots by 25 days after treatment.

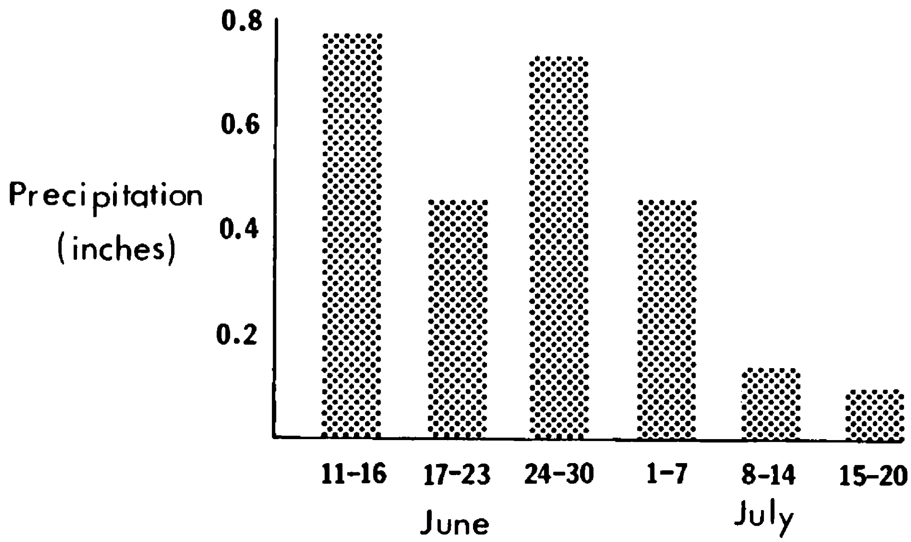
Frequency of herbaceous vegetation before the May, 1980 application and in July, 1980 are presented in Table 6, page 25. A large increase in annual vegetation was observed only on plots treated with dalapon alone. The substantial increase in perennial vegetation on control plots was also observed on plots treated with dalapon, atrazine, dalapon + atrazine and glyphosate at 1.0 or 3.0 lbs./acre. A decrease was noted only on plots treated with glyphosate + atrazine.

June, 1980 Application

At the time of the June, 1980 application at White Stallion pinegrass leaf blades were well expanded and actively photosynthyzing, but flowering had not begun. Precipitation data for one week before herbicide application through four weeks after application suggest ample rain fell to move the soil active herbicides into the soil solution (Figure 6). The soil moisture content at the time of application exceeded field capacity and provided adequate soil solution for atrazine, hexazinone and dalapon mobility (Table 8).

Pinegrass responses to the treatments established at the White

Figure 6. Precipitation Which Fell at White Stallion from One Week Before to Four Weeks After Herbicide Application.



Stallion site were similar to the Blue Mountain results (Figure 7). Glyphosate alone or with atrazine or hexazinone at the higher rates reduced pinegrass significantly by 14 days after application. Dalapon, dalapon + atrazine, and glyphosate at 1.0 lb. + hexazinone at 1.0 lb./ acre reduced pinegrass significantly by 25 days while hexazinone alone required 50 days to produce a significant reduction. Little variation

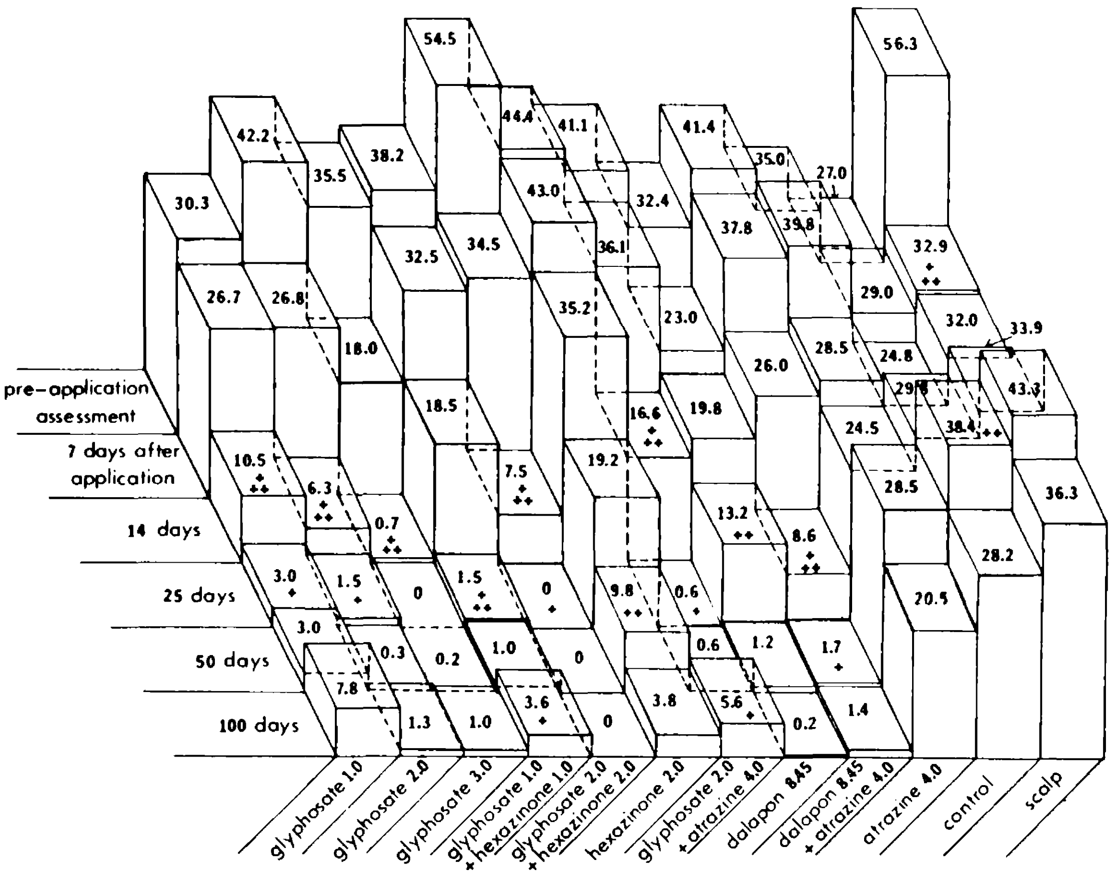
Table 8. Percent Soil Moisture at Field Capacity, at the Wilting Coefficient and at the Time of the June, 1980 Application at White Stallion.

	Percent Soil Moisture		
	1/3 bar*	15 bar*	June, 1980**
mean	25.52	7.42	36.64
standard deviation	2.52	.82	9.29

*n = 6

**n = 36

Figure 7. Mean Frequencies of Pinegrass at White Stallion Before the June, 1980 Application and for 100 Days After Application. Herbicide Rates are Expressed in Lbs. AI/acre



+indicates significant difference from the immediately preceeding assessment, $\alpha = .05$

++indicates earliest significant difference from the pre-application assessment, $\alpha = .05$

Table 9. Vegetation Totals Prior to Application and Near the End of the Growing Season for Shrubs, *Xerophyllum tenax*, *Carex geyeri* and Herbaceous Plants at White Stallion.

Treatment (lbs./acre)	Shrubs		*Xerophyllum tenax*		*Carex geyeri*		Herbaceous plants	
	June	Sept.	June	Sept.	June	Sept.	June	Sept.
glyphosate 1.0	6	3	71	74	18	0	12	24
glyphosate 2.0	0	1	26	20	60	0	17	37
glyphosate 3.0	23	0	57	33	26	6	0	6
glyphosate 1.0 + hexazinone 1.0	36	4	68	38	76	0	5	18
glyphosate 2.0 + hexazinone 2.0	4	2	50	37	15	0	1	9
hexazinone 2.0	2	6	68	43	14	0	6	4
glyphosate 2.0 + atrazine 2.0	22	2	61	48	31	0	0	10
dalapon 8.45	16	18	25	21	95	46	12	18
dalapon 8.45 + atrazine 4.0	10	8	40	42	31	8	27	24
atrazine 4.0	4	7	12	32	34	27	0	3
scalp	21	26	94	70	45	44	4	8
control	21	23	78	62	27	17	10	6

in pinegrass freuqncies occurred on plots treated with atrazine or the control as the growing season progressed. The reduction of pingrass on scalped plots immediately after treatment was followed by a gradual increase until a new peak was reached after 50 days.

Other vegetation which covered substantial portions of the site and their responses to treatments are presented in Table 9. Glyphosate alone or with atrazine or hexazinone provided the most visible decrease in shrubs or treated plots. Xerophyllum texax (Pursh) Nutt. was never completely killed by any treatment, but glyphosate at 3.0 lbs./acre, glyphosate + hexazinone at 1.0 or 2.0 lbs./acre and hexazinone alone caused noticeable damage to the plants. Damage was characterized by severe chlorosis at leaf blade extremities with only the leaf bases remaining green. Glyphosate alone or in combination, and hexazinone alone or in combination provided the most successful control of Carex geyeri (Booth). Herbaceous vegetation generally increased or maintained relatively stable frequencies on all treatments through out the growing season.

Seedling Responses

Seedling Survival

Seedlings planted in June, 1979 on Blue Mountain were adversely affected by many complicating factors. Because of the exclusion of one block from the analysis due to the application problem, reliable data was collected from only four seedlings of each species exposed to a particular treatment at a specified application time. Also, a hail storm occurred on the site between planting and application. Many seedlings were de-foliated and/or broken during this storm which limited their exposure to

Table 10. Summary of Planted Ponerosa Pine Seedling Survival on the Blue Mountain Study Site as of October, 1980.[3]

Treatments	Application Times					
	June, 1979		September, 1979		May, 1980	
	planted June, 1979	planted May, 1980	planted June, 1979	planted May, 1980	planted June, 1979	planted May 1980
glyphosate 1 lb.	1	4	0	4	0	2
glyphosate 3 lbs.	0	4	0	4	1	2
glyphosate + hexazinone	1	4	0	4	0	3
hexazinone	0	4	0	4	0	4
glyphosate + atrazine	0	4	1	3	1	4
atrazine	0	4	0	4	0	4
dalapon + atrazine	1	3	0	4	0	4
dalapon	2	4	0	4	0	3
control	0	4	0	4	0	4

[3] N = 4

Table 11. Summary of Planted Douglas-fir Seedling Survival on the Blue Mountain Study Site as of October, 1980.[4]

Treatments	Application Times					
	June, 1979		September, 1979		May, 1980	
	planted June, 1979	planted May, 1980	planted June, 1979	planted May, 1980	planted June, 1979	planted May, 1980
glyphosate 1 lb.	1	4	3	4	3	3
glyphosate 3 lbs.	2	4	0	3	0	1
glyphosate + hexazinone	3	4	1	4	2	4
hexazinone	4	3	2	4	3	4
glyphosate + atrazine	3	4	3	4	3	4
atrazine	3	4	3	4	4	4
dalapon + atrazine	4	4	3	4	4	4
dalapon	1	4	1	4	2	4
control	1	3	4	4	2	4

[4] N = 4

herbicide sprays and placed them under additional stress. Ponderosa pine seedlings were of poor quality nursery stock having lammas growth. Consequently, mortality from planting shock was very high on all treatments (Table 10). Douglas-fir seedlings had better survival than ponderosa pine; however, the previously mentioned problems coupled with rodent damage and a dry field season resulted in erratic mortality within treatments (Table 11). Consequently, treatment effects were not distinguishable for Douglas-fir.

Douglas-fir and ponderosa pine seedlings planted in May, 1980 on Blue Mountain survived well on all plots including the control. The planting success can be attributed to unusually high precipitation during May, 1980 and above average precipitation during June and July (Figure 1, page 20). Consequently, there was little variation in seedling survival between treatments for either species. Future observations of these seedlings may reveal survival trends among treatments.

One block was excluded from the analyses of White Stallion seedling survival data because of the application problem mentioned earlier. On remaining plots 12 seedlings of each species had been planted prior to application. Half of the seedlings were exposed and half were sheltered from application of glyphosate alone or in combination. Twelve seedlings of each species were planted on each treatment after herbicide application. Although statistical analyses of these data were not possible because of the small sample size, some survival trends developed which are worth mentioning.

Table 12 presents the percent survival of lodgepole pine by treatment. Seedlings sheltered from applications of glyphosate alone or with hexazinone or atrazine had much better survival than exposed seedlings.

Table 12. Percent Survival of Lodgepole Pine at White Stallion by Planting Time and Treatment

Planting Time \ Treatment	glyphosate 1.0	glyphosate 2.0	glyphosate 3.0	glyphosate 1.0 + hexazinone 1.0	glyphosate 2.0 + hexazinone 2.0	hexazinone 2.0	glyphosate 2.0 + atrazine 4.0	dalapon 8.45	dalapon 8.45 + atrazine 4.0	atrazine 4.0	scalp	control
lodgepole pine planted before application exposed*	33	0	0	0	0	67	17	33	33	83	83[n]	67
lodgepole pine planted before application sheltered*	33	50	67	50	67	-	67	-	-	-	67[s]	67
lodgepole pine planted after application**	58	83	42	67	33	58	42	58	42	42	92[n]	58

[s]indicates seedlings were shaded

[n]indicates seedlings were not shaded

*N = 6

**N = 12

Table 13. Percent Survival of Douglas-fir at White Stallion by Planting Time and Treatment

Planting time \ Treatment	glyphosate 1.0	glyphosate 2.0	glyphosate 3.0	glyphosate 1.0 + hexazinone 1.0	glyphosate 2.0 + hexazinone 2.0	hexazinone 2.0	glyphosate 2.0 + atrazine 4.0	dalapon 8.45	dalapon 8.45 + atrazine 4.0	atrazine 4.0	scalp	control
Douglas-fir planted before application exposed*	67	83	67	50	50	50	100	33	50	67	50^{n}	83
Douglas-fir planted before application sheltered*	83	83	83	50	67	-	83	-	-	-	83^{s}	67
Douglas-fir planted after application**	83	75	50	83	58	83	67	92	25	50	75^{n}	92

^{s}indicates seedlings were shaded

^{n}indicates seedlings were not shaded

*N = 6

**N = 12

Survival generally improved or remained relatively stable for all treatments when seedlings were planted after application as opposed to being planted before application. On scalped plots seedlings which were not shaded had slightly better survival than shaded seedlings or control seedlings. Control seedling survival generally exceeded survival on herbicide treated plots when seedlings were planted before application and exposed to the sprays; similar survival was achieved if seedlings were sheltered or planted after application.

Douglas-fir survival between planting treatments was less dramatic than in lodgepole pine at White Stallion (Table 13). Survival was slightly better if seedlings were sheltered from the glyphosate spray alone or with hexazinone than if exposed. Seedlings on scalped plots had better survival when shaded, and survival increased substantially if seedlings were planted after application of dalapon. Survival was relatively consistant between treated and control plots for each planting time except when seedlings were planted after the application of dalapon + atrazine when survival decreased considerably.

Seedling Moisture Stress

Moisture stress data for Douglas-fir seedlings planted in June, 1979 and May, 1980 on Blue Mountain are presented in Table 16 (Appendix C). Seedlings planted in 1979 on plots treated with dalapon + atrazine, and atrazine alone were ranked significantly less than control seedlings for the September, 1979 and May, 1980 applications. Seedlings on plots treated in May, 1980 with glyphosate at 1.0 lbs./acre, glyphosate + hexazinone, hexazinone and glyphosate + atrazine had significantly less moisture stress than control seedlings.

Moisture stress of Douglas-fir seedlings planted in May, 1980 on plots treated in June, 1979 with dalapon, atrazine, dalapon + atrazine, hexazinone, glyphosate + hexazinone, and glyphosate + atrazine were all ranked significantly less than control seedlings. Of the September, 1979 application, only seedlings on plots treated with dalapon + atrazine and glyphosate + hexazinone had moisture stresses significantly less than control seedlings. Plots treated with dalapon + atrazine, hexazinone, and atrazine applied in May, 1980 over the tops of recently planted Douglas-fir had seedlings with significantly less moisture stress than control seedlings.

Ponderosa pine seedling moisture stress differences were undetectable for plots planted in June, 1979 on Blue Mountain primarily due to high mortality (Table 17, Appendix C). However, pine seedlings planted in May, 1980 had significant differences within all three application times. Seedlings planted on plots treated with glyphosate + hexazinone in June, 1979 had significantly less moisture stress than control seedlings. For the September, 1979 and May, 1980 applications moisture stress of seedlings planted on plots treated with dalapon + atrazine, atrazine, and hexazinone were ranked significantly less than control seedlings.

Predawn moisture stresses for lodgepole pine seedlings planted at White Stallion in June, 1980 are presented in Table 18 (Appendix C). Lodgepole pine seedlings exposed to hexazinone, dalapon + atrazine or atrazine alone had moisture stresses significantly less than control seedlings. When seedlings were sheltered from glyphosate applied alone or in mixture only those plots treated with glyphosate + atrazine had moisture stresses significantly less than control seedlings. Seedlings planted after herbicide application generally had less moisture stress than seedlings planted before application. Glyphosate at 3.0 lbs./acre, glyphosate + hexazinone, dalapon and dalapon + atrazine had moisture stresses significantly less than control seedlings when planted after application.

High moisture stress among Douglas-fir control seedlings for both planting times resulted in many significant differences from treated seedlings at White Stallion (Table 19, Appendix C). Exposed seedlings on plots treated with glyphosate alone, glyphosate + hexazinone at 2.0 lbs./acre, glyphosate + atrazine, dalapon, and hexazinone had significantly less moisture stress than control seedlings. Seedlings sheltered from glyphosate sprays had less moisture stress than exposed seedlings except on plots treated with glyphosate + atrazine; this same trend was true for significant differences between sheltered and control seedlings. Seedlings planted after application on plots treated with glyphosate at 1.0 and 3.0 lbs./acre, glyphosate at 2.0 + hexazinone at 2.0 lbs./acre, hexazinone alone and dalapon alone had significantly less moisture stress than control seedlings. Seedlings on scalped plots had significantly less moisture stress than control seedlings only if shaded after planting.

CHAPTER 5

DISCUSSION

The phenology of pinegrass at White Stallion and Blue Mountain was similar for the June applications making their results relatively comparable. At both sites pinegrass responded slower to soil active herbicides than to the strictly foliar active glyphosate. The most acute responses were to glyphosate applied at the higher rates of 2.0 and 3.0 lbs./acre. The small differences between responses to the two rates indicates 2.0 lbs./acre was as effective as 3.0 lbs./acre. The June application appears to be the most effective time for glyphosate application since the May and September applications at Blue Mountain were relatively ineffective.

Douglas-fir and lodgepole pine seedling survival increased when planted after application of glyphosate. Therefore, glyphosate may be toxic to conifers when applied over the tops of newly planted seedlings. An Englemann spruce sapling which occurred on a White Stallion plot treated with glyphosate at 3.0 lbs./acre had completed bud burst and was flushing new growth at the time of application. All of the new growth on the side of the tree exposed to the spray was killed; however, visual observation suggested needles which were one year old or older were unaffected by the spray. This agrees with observations by Radosivich et al. (1980) who found reduced conifer tolerance to glyphosate when applications were made before or during active growth. Consequently, the use of glyphosate as a release spray applied in early summer in western Montana should be avoided because of the potential for damage to crop trees.

Many species such as pinegrass respond to late season precipitation by initiating regrowth in early fall months. Glyphosate application for conifer release is considered a sound treatment during this stage of development if winter buds have formed on conifers. However, because of the dry conditions at Blue Mountain at the time of the September application (Figure 1, page 20) little regrowth had occurred in pinegrass. Results of glyphosate application in the fall may improve under better conditions for fall regrowth.

The failure of the May application of glyphosate to control pinegrass was attributed to the small amount of leaf surface area exposed to the spray. Most of the spray fell on the dead stems and blades of the previous growing season.

The purpose of applying glyphosate in combination with atrazine or hexazinone was to achieve the rapid effects of foliar active glyphosate and the residual effects of soil active atrazine or hexazinone. The slow reduction of pinegrass after the June application on plots treated with glyphosate + atrazine relative to glyphosate alone may suggest a possible antagonism between chemicals. This would agree with observation by Appleby and Somabhi (1978) who found a reduction in glyphosate phytotoxicity when mixed with either atrazine or simazine wettable powders. The antagonism was attributed to a physical binding between chemicals in the spray solution. Possibly because of this antagonism glyphosate alone generally out performed glyphosate + atrazine in its ability to control pinegrass.

In all applications except the June, 1980 application at White Stallion the glyphosate + hexazinone combination caused a reaction from pinegrass similar to hexazinone alone. Glyphosate killed pinegrass more rapidly in the June applications and provided better control the second season after application than did glyphosate + hexazinone or hexazinone. The September and May applications had opposite results with hexazinone controlling pinegrass as well as glyphosate + hexazinone and better than glyphosate. Apparently, glyphosate or hexazinone applied separately can provide similar or better control than the chemicals applied in combination.

The success of atrazine primarily depends on its availability to the root system of target plants. Winter precipitation following the fall application of atrazine and the heavy rainfall following the May application were expected to move the herbicide into the pinegrass root zone. The toxic potential should have been maintained because of its long residual activity. However, atrazine was unsuccessful in controlling pinegrass at any application time. These results are similar to those of Stewart and Beebe (1974) who found atrazine at 4.0 lbs./acre to be ineffective on pinegrass on residual soils, but found some success on pumice soils. Newton (1980) stated that perennial grasses have a wide range of sensitivity to atrazine from mortality at medium or lower rates to resistant to the highest rates applied. Gratkowski (1975) considered atrazine the most effective herbicide for grass control in the Pacific Northwest. These observations exemplify a problem in generalizing species responses to specific herbicides. Although two species may be within the same family one may be resistant and the other highly susceptible to an herbicide. The variation in species susceptibility to atrazine and the effects reported here suggest pinegrass is resistant to atrazine at 4.0 lbs. AI/acre.

An irony exists in that although pinegrass was not killed by applications of atrazine, seedling survival was high and moisture stress was low on these plots relative to control seedlings. These results are partially consistent with those of Boyd (1981) who observed poor vegetative control but good seedling survival on plots treated with atrazine. In many rhizomatous perennial grasses the rhizomes and about 20% of the root system are the only vegetative parts of the plants to over winter in a dormant state. Consequently, spring emergence requires utilization of stored carbohydrates for initiation of both root and shoot growth. Emergence and development of above ground vegetation was not stopped by atrazine treatments; however, it became chlorotic during the growing season following the September and May applications on Blue Mountain. Chlorosis is an indicator of reduced chlorophyll synthesis which would inhibit photosynthesis and slow carbohydrate production. Fewer carbohydrates would inhibit pinegrass root growth thus precluding its ability to find hydrologically available soil moisture. Consequently, there would be more soil moisture available to the planted conifer seedlings. The preceding could account for the low seedling moisture stress and good survival on plots treated with atrazine.

Newton (1980) suggested combinations of chemicals such as dalapon + atrazine are sometimes more effective than either herbicide alone. In this study dalapon alone or in combination with atrazine successfully controlled pinegrass after all applications. Considering the results of atrazine applied alone, the success of dalapon + atrazine was attributed to the effects of dalapon. Good seedling survival and low plant moisture stresses on plots treated with dalapon + atrazine suggest a synergism between chemicals which agrees with observations by Newton and Overton (1973).

Lodgepole pine survival was better on scalped plots than on control plots if seedlings were not shaded after planting, and Douglas-fir survival was better if seedlings were shaded. Only shaded Douglas-fir seedlings had lower moisture stress than control seedlings. The gradual re-occupation of scalped plots by competing vegetation, and the failure to eliminate live root systems in the vicinity of planted seedlings probably contribute to the higher moisture stress. Quite possibly the real test for seedling survival on scalped plots will be in the second or third growing season after planting.

The plant moisture stress data suggest that successful reduction of competing vegetation by certain treatments provides the important effect of increased available moisture for the planted seedlings. Particularly, dalapon + atrazine and hexazinone seem to have the greatest versatility in time of application for providing this combination of effects.

Douglas-fir seedling moisture stress on plots treated with glyphosate + hexazinone were less when seedlings were planted after application, when seedlings were sheltered from the spray, or when seedlings were planted almost one year prior to application. Ponderosa pine and lodgepole pine seedlings reacted similarly when treatments were applied prior to planting. Douglas-fir and lodgepole pine seedling moisture stress was reduced if sheltered from or planted after application of glyphosate.

Wide variation in seedling moisture stress data often occurred within a species on particular treatments. An example would be the range of moisture stress from 7.0 to 31.0 bars tension in ponderosa pine planted in May, 1980 on plots treated with dalapon in September, 1979 at Blue Mountain (Table 17, Appendix C). Possible explanations for this include planting shock, individual seedling morphology and physiology at the time of planting, and how well the seedling was planted.

Research Recommendations

The use of herbicides for site preparation is a relatively new technique in western Montana. Realistically, political and economic considerations will ultimately decide the future of forest use of herbicides in this area. Therefore, arguments promoting the use of these chemicals must be based on sound research which confirm the real benefits derived from their use.

The least expensive research would be to continue to monitor the studies which have been started. Reliable seedling establishment requires 4 to 5 years in western Montana; therefore, benefits from treatments applied last year are not fully realized.

Treatments which are still questionable include fall applications of glyphosate at 2.0 lbs. AI/acre, hexazinone at 2.0 lbs. /acre for site preparation, dalapon and atrazine. Glyphosate applications in the fall may have potential if environmental conditions are amenable to fall regrowth of target plants. Of the rates applied here, 2.0 lbs. AI/acre appears to offer optimum pinegrass control.

Currently, the reforestation label for hexazinone does not include site preparation as a recommended use. Conventional use of hexazinone for this purpose will require additional data indicating crop species are not susceptible to damage or mortality from these applications.

Application of dalapon is still questionable because of conflicting observations made by Boyd (1981). Apparently, control of pinegrass in his study was not as complete as that achieved on Blue Mountain.

Although atrazine provided little reduction in pinegrass competition, good seedling survival and low seedling moisture stress on these plots warrant further evaluation of this chemical's usefulness for site preparation.

Finally, the pressure bomb can provide valuable insight into the effects of reduced competition on the moisture status of conifer seedlings. Consequently, its role in evaluation of the effectiveness of site preparation techniques should be included in further research; particularly in western Montana where long term seedling establishment periods are the rule.

Summary and Conclusions

1. Glyphosate at 1.0, 2.0, or 3.0 lbs. AI/acre can successfully control pinegrass if applied in the early summer when leaf blades are elongated and actively photosynthizing. The medium rate gave optimum control of pinegrass. Lodgepole pine seedling survival improved if seedlings were sheltered from the herbicide spray or if they were planted after application.

2. Hexazinone at 2.0 lbs. AI/acre was most successful when applied in the fall or spring. Douglas-fir, lodgepole pine, and ponderosa pine seedlings on plots treated with hexazinone generally had less moisture stress than control seedlings.

3. Dalapon at 8.45 lbs. AI/acre was most successful when applied in the fall. Treatments applied in the spring and early summer provided gradual control of pinegrass with some recovery occurring in the second growing season following the early summer application. Survival of Douglas-fir and lodgepole pine improved if planted after herbicide application.

4. Atrazine at 4.0 lbs. AI/acre did not successfully kill pinegrass following any application. However, moisture stress in Douglas-fir and ponderosa pine seedlings on plots treated with atrazine was generally less than that of seedlings on control plots.

5. The dalapon + atrazine combination was most successful when applied in the fall and spring. The early summer application had gradual success and maintained some control of pinegrass during the second season after application. Moisture stresses in lodgepole pine, ponderosa pine and Douglas-fir were less on treated plots than on control plots for most planting and application times.

6. Glyphosate + hexazinone induced a more rapid response from pinegrass following the spring application than did hexazinone alone. Reduced seedling moisture stresses occurred on plots treated with the higher rates of 2.0 lbs./acre. Other chemical combinations were essentially no more successful, and in some cases less successful, than one of the two chemicals used alone.

7. Lodgepole pine seedlings planted on scalped plots had

similar or better survival than control seedlings. Shaded Douglas-fir seedlings on these plots had better survival and lower moisture stresses than control seedlings.

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APPENDIX A

Blue Mountain Study Site

Plate I. Blue Mountain Study Area Location, Missoula Ranger District, Lolo National Forest[1]

<u>Legend</u>

study area location	☐
scale	1:24,000
Contour interval	40 feet (12.2 meters)

[1]U.S. Geological Survey. 1978. Blue Mountain Quadrangle.

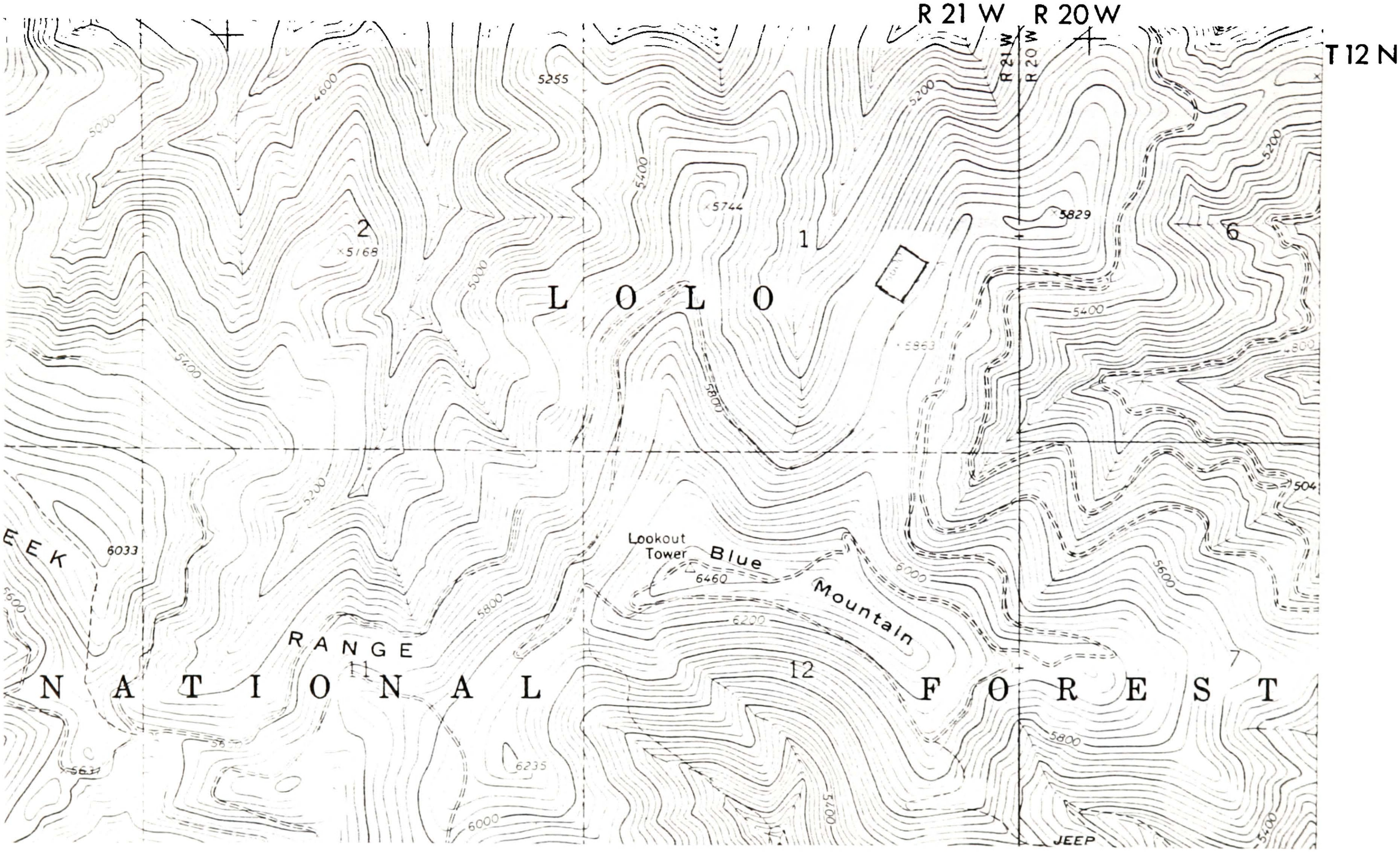

R 21 W
R 20 W
T 12 N
LOLO
NATIONAL FOREST
RANGE
Lookout Tower
Blue Mountain
6460
5744
5829
5168
5255
6033
6235
5863
JEEP
1
2
6
7
11
12

Table 14. Design, Treatments, Herbicide Forumulations and Plot Numbering System for the Blue Mountain Study

Treatments Number	Planting Time	Treatments*
01	1	1 lb. G
01	2	1 lb. G
01	3	1 lb. G
02	1	2 lbs. G + 2 lbs. H
02	2	2 lbs. G + 2 lbs. H
02	3	2 lbs. G + 2 lbs. H
03	1	3 lbs. G
03	2	3 lbs. G
03	3	3 lbs. G
04	1	2 lbs. H
04	2	2 lbs. H
04	3	2 lbs. H
05	1	2 lbs. G + 4 lbs. A
05	2	2 lbs. G + 4 lbs. A
05	3	2 lbs. G + 4 lbs. A
06	1	8.45 lbs. D
06	2	8.45 lbs. D
06	3	8.45 lbs. D
07	1	8.45 lbs. D + 4 lbs. A
07	2	8.45 lbs. D + 4 lbs. A
07	3	8.45 lbs. D + 4 lbs. A
08	1	4 lbs. A
08	2	4 lbs. A
08	3	4 lbs. A
09	1	Control
09	2	Control
09	3	Control

Remarks

The study area consists of 3 experimental blocks. Each block is divided into 3 major plots which represent the June, 1979, Sept., 1979, and May, 1980 application times. Each major plot is composed of the 9 treatments listed here. Treatments were replicated 3 times within each major plot so that one plot would be available for each planting time.

Plots are numbered by a three digit code. The first digit indicates the application time, the second digit indicates a treatment and the last digit indicates the planting time.

Example: plot no. 213
- 2 - indicates the second application in Sept., 1979.
- 1 - indicates plot was treated with 1 lb. glyphosate
- 3 - indicates plot was planted in May, 1980.

Application times:
- 1 - June, 1979
- 2 - September, 1979 (aborted)
- 3 - May, 1980

Explanation

G - glyphosate (liquid)
H - hexazinone (soluble powder)
A - atrazine (liquid)
D - dalapon (soluble powder)
* - herbicide rates expressed as ai per acre

Figure 8. Plot Relocation Map of the Blue Mountain Study Site, Block 1

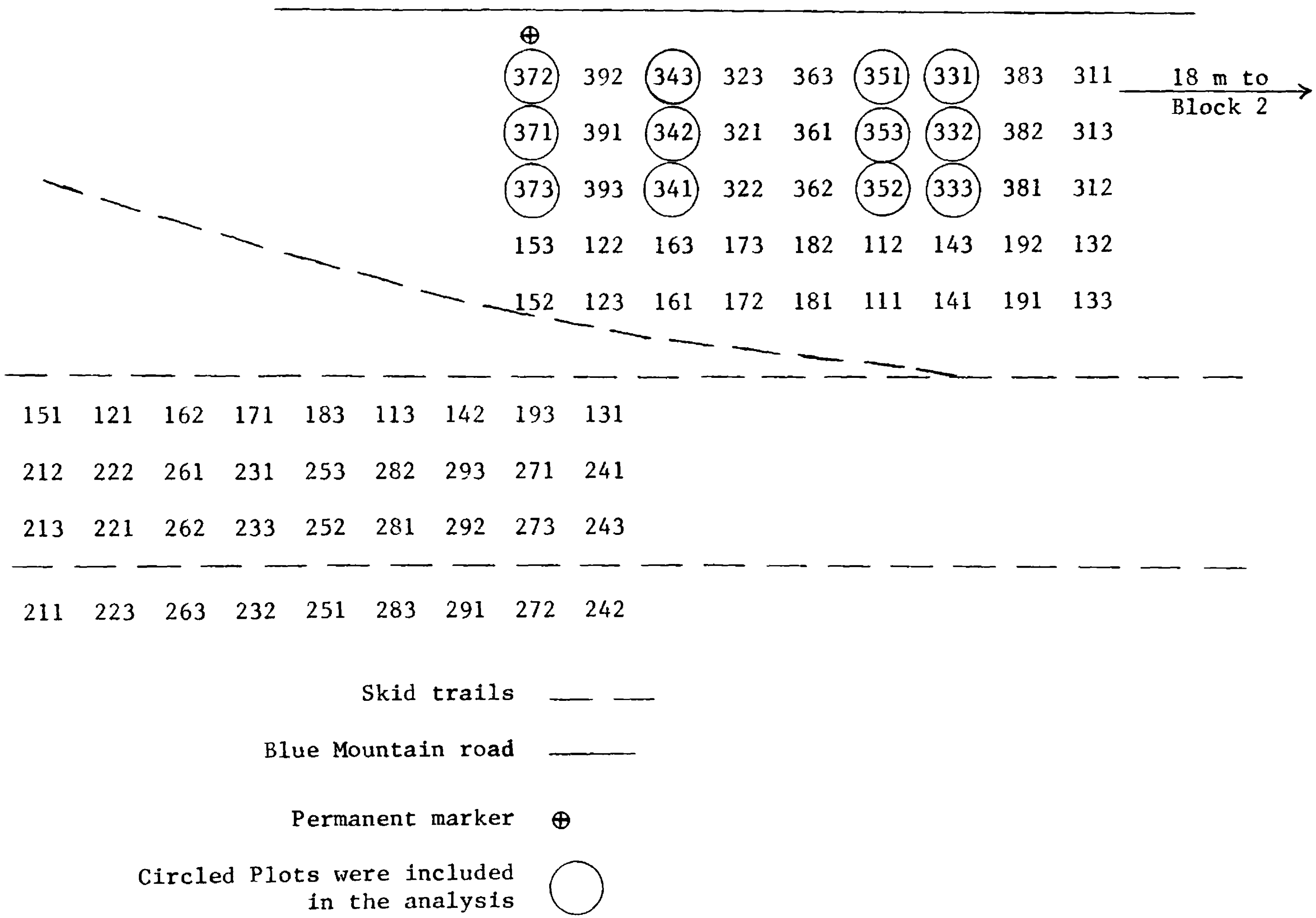
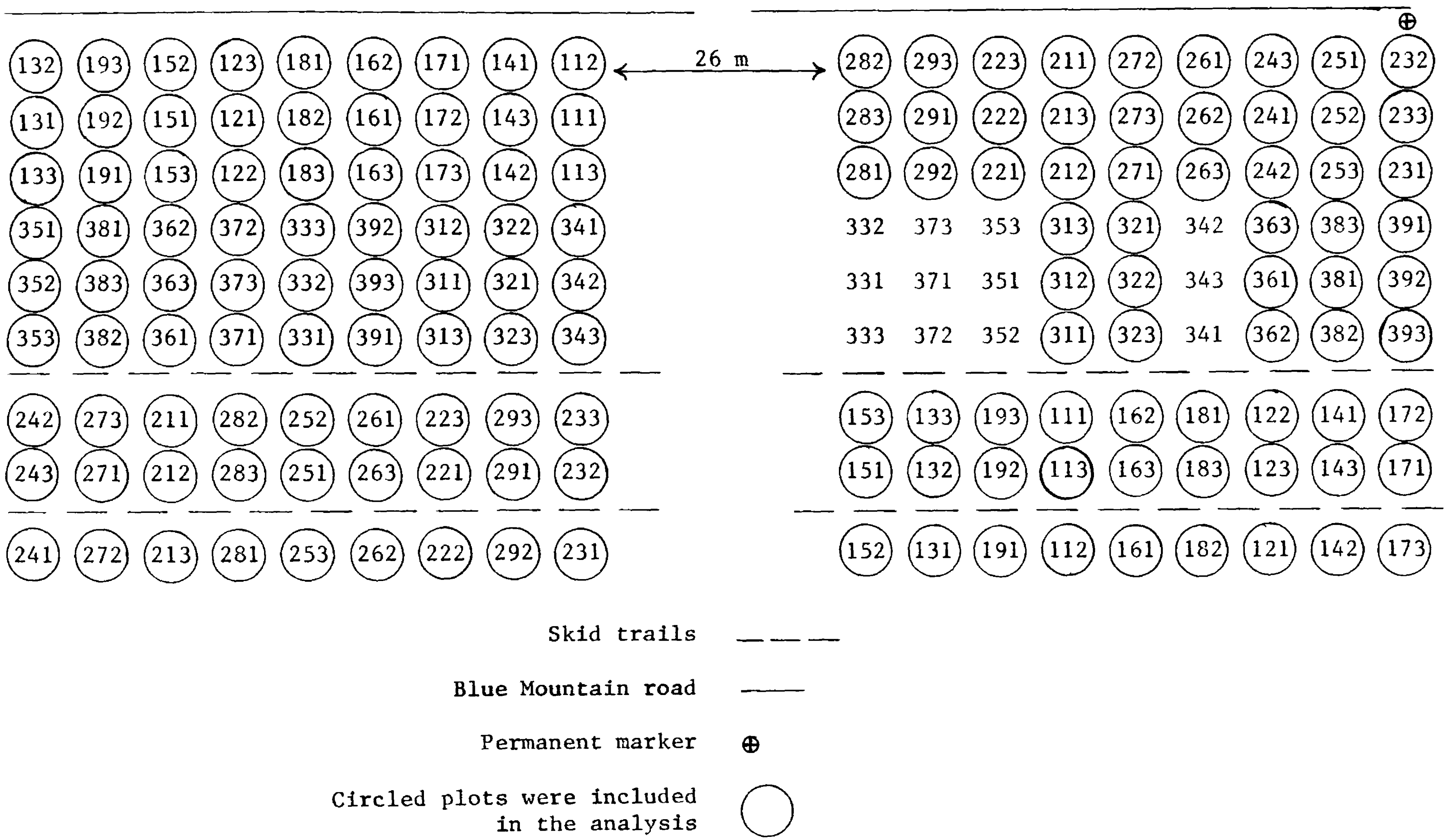


Figure 9. Plot Relocation Map of the Blue Mountain Study Site, Blocks 2 and 3



APPENDIX B

White Stallion Study Site

Plate II. White Stallion Study Area, Darby Ranger District, Bitterroot National Forest.[2]

Legend

study area locations	
scale	1:24,000
contour interval	40 feet (12.2 meters)

[2]U.S. Geological Survey. 1978. Bald Top Mountain Quadrangle.

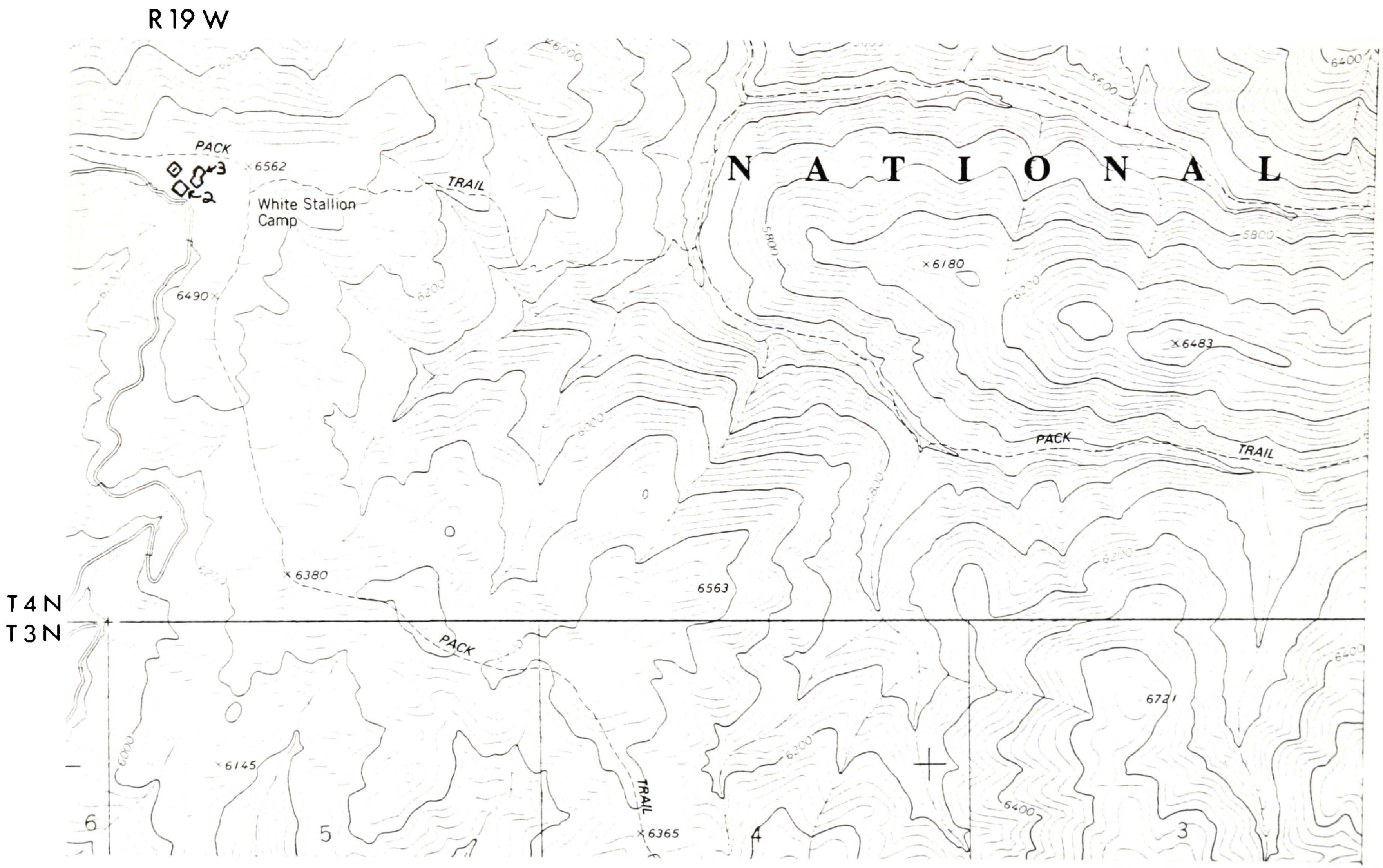

R 19 W
T 4 N
T 3 N
PACK
TRAIL
White Stallion Camp
NATIONAL
PACK
TRAIL
PACK
TRAIL
6562
6490
6380
6180
6483
6563
6721
6145
6365
6
5
4
3

Table 15. Design, Treatment, Herbicide Forumulations and Plot Numbering System for the White Stallion Study

Treatment Number	Planting Time	Treatment*
01	1	1 lb. G
01	2	1 lb. G
02	1	2 lb. G & 2 lb. H
02	2	2 lb. G & 2 lb. H
03	1	3 lb. G
03	2	3 lb. G
04	1	2 lb. H
04	2	2 lb. H
05	1	2 lb. G & 4 lb. A
05	2	2 lb. G & 4 lb. A
06	1	8.45 lb. D
06	2	8.45 lb. D
07	1	8.45 lb. D & 4 lb. A
07	2	8.45 lb. D & 4 lb. A
08	1	4 lb. A
08	2	4 lb. A
09	1	Control
09	2	Control
10	1	1 lb. G & 1 lb. H
10	2	1 lb. G & 1 lb. H
11	1	2 lb. G
11	2	2 lb. G
12	1	Scalp
12	2	Scalp

Remarks

The study area consists of 3 experimental blocks. Each treatment is replicated 6 times within each block. Each block was split into two major plots such that 3 replicates of each treatment were planted before and 3 planted after herbicide application. Plot locations were randomly selected.

Plots are numbered by a four digit code. The first digit indicates planting time, the next 2 digits indicate treatment number and the 4th digit indicates the plot number.

Example: plot No. 2043
- 2 - indicates plot was planted after herbicide application
- 04 - indicates plot was treated with 2 lbs. hexazinone
- 3 indicates 3rd replicate for the specified planting time within a block

Treatment number 101, 102, 103, 105, 110 & 111 only:
Plots were split in half with one seedling of each species protected from herbicide spray by covering during application.

All scalps were made immediately before planting. As above, plots of the first planting time were split in half with one seedling of each species shaded after planting.

Explanation

Planting time: 1 - Before herbicide application
2 - After herbicide application

G - glyphosate (liquid)
H - hexazinone (liquid)
A - atrazine (liquid)
D - dalapon (soluble powder)
* - herbicide rates expressed as AI per acre

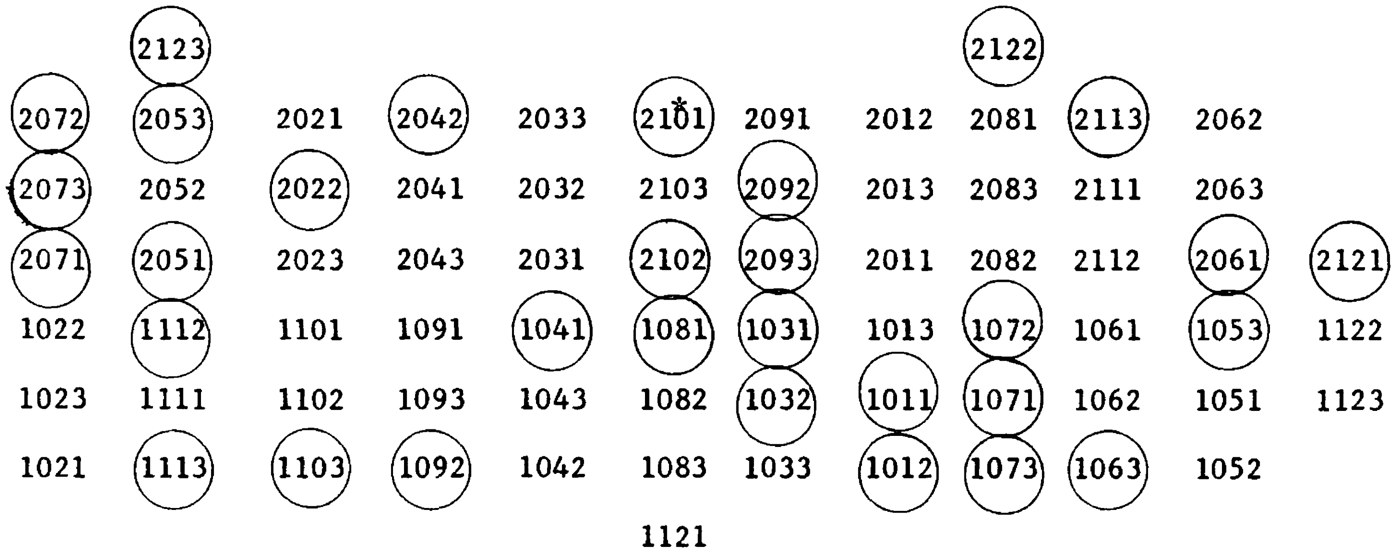
Fire 10. Plot Relocation Map of the White Stallion Study, Block 1.[3]

				1121		1123					
1122	1101	1073	1081	1062	1043	1093	1113	1053	1033	1011	1021
	1103	1072	1083	1061	1041	1092	1111	1052	1032	1012	1023
	1102	1071	1082	1063	1042	1091	1112	1051	1031	1013	1022
	2081	2041	2053	2111	2091	2071	2061	2103	2031	2013	2023
2123	2082	2042	2051	2113	2093	2072	2063	2102	2032	2012	2022
2122	2083	2043	2052	2112	2092	2073	2062	2101	2033	2011	*2021
						2121					

[3] Circled plots were included in the analysis

*indicates position of T-post permanent relocation marker.

Figure 11. Plot Relocation Map of the White Stallion Study Site, Block 2.[4]



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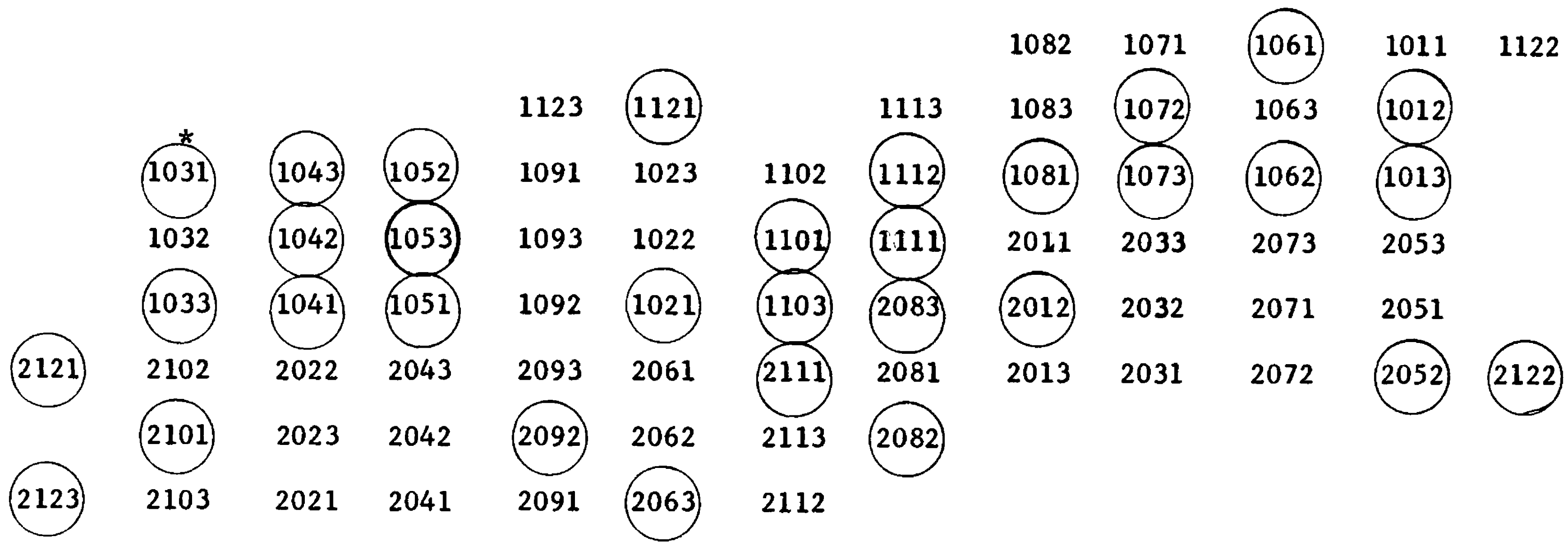
[4]Circled plots were included in the analysis

*Indicates position of t-post permanent relocation marker.

Figure 12. Plot Relocation Map of the White Stallion Study Site, Block 3.[5]



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[5]Circled plots were included in the analysis.

* Indicates position of t-post permanent relocation marker.

APPENDIX C

Seedling Moisture Stress Data

Table 16. Douglas-fir Seedling Moisture Stress Data Expressed in Negative Bars for the June, 1979 and May, 1980 Planting Times and June, 1979, September, 1979 and May, 1980 Herbicide Applications at Blue Mountain

Planting and Application time \ Treatment	glyphosate 1.0	glyphosate 3.0	hexazinone	glyphosate + hexazinone	glyphosate + atrazine	dalapon	dalapon + atrazine	atrazine	control
Herbicides	21.5	15.0	9.0	10.0	18.0	13.5	8.5	18.0	12.0
applied June, 1979	-	18.0	7.0	32.5	7.0	-	13.5	16.0	-
Seedlings	-	9.0	7.0	8.0	14.0	-	8.5	26.0	-
planted June, 1979	-	-	5.0	-	-	-	7.5	-	-
Herbicides applied	14.0	-	9.0	12.5	6.0	7.0	*10.0	10.5	12.0
September, 1979	19.0	-	-	-	8.0	-	7.0	8.0	14.0
Seedlings planted	20.0	-	-	-	13.0	-	6.5	-	24.0
June,1979	-	-	-	-	-	-	-	-	14.0
Herbicides applied	*7.0	-	*9.5	*10.5	*6.5	20.5	*8.0	*7.0	17.0
May, 1980	7.5	-	8.5	9.0	10.5	14.5	9.0	9.0	24.5
Seedlings planted	-	-	8.0	-	8.0	-	6.5	15.5	20.5
June, 1979	-	-	-	-	-	-	11.0	-	-
Herbicides	14.5	19.0	*10.5	*6.0	*20.0	*23.0	*11.0	*23.0	23.0
applied June, 1979	10.5	28.5	8.5	9.5	11.0	19.5	22.5	13.0	31.0
Seedlings planted	25.5	9.0	-	-	17.0	13.0	14.5	10.5	44.5
May, 1980	17.5	13.5	-	-	18.5	16.0	10.5	18.5	25.0
Herbicides applied	16.5	8.5	9.0	*7.5	10.5	16.5	*9.0	10.0	15.0
September, 1979	17.5	20.5	11.0	7.0	16.5	10.5	9.5	9.0	13.0
Seedlings planted	24.0	14.5	20.5	10.0	17.0	14.0	10.0	9.0	20.0
May, 1980	15.0	26.5	17.5	8.0	8.5	15.0	8.0	25.5	13.5
Herbicides applied	9.5	16.0	*7.5	19.5	10.0	14.5	*7.0	*15.0	22.0
May, 1980	15.5	-	14.0	19.5	21.0	9.5	5.0	9.5	16.0
Seedlings planted	45.0	-	6.5	10.0	20.0	15.0	13.0	14.5	14.0
May, 1980	-	-	8.0	25.0	10.5	20.5	7.5	13.5	15.5

*indicates seedlings for the specified treatment, application time ant planting time are significantly less than control seelings, = .10.

Table 17. Ponderosa Pine Seedling Moisture Stress Data Expressed in Negative Bars for the June, 1979 and May, 1980 Planting Times and June, 1979, September, 1979 and May, 1980 Herbicide Application Times at Blue Mountain

Planting and Application time \ Treatment	glyphosate 1.0	glyphosate 3.0	hexazinone	glyphosate + hexazinone	glyphosate + atrazine	dalapon	dalapon + atrazine	atrazine	control
Herbicides applied	9.0	-	-	10.0	-	11.5	11.0	-	-
June, 1979	-	-	-	-	-	12.5	-	-	-
Seedlings planted	-	-	-	-	-	-	-	-	-
June, 1979	-	-	-	-	-	-	-	-	-
Herbicides applied	-	-	-	-	10.5	-	-	-	-
September, 1979	-	-	-	-	-	-	-	-	-
Seedlings planted	-	-	-	-	-	-	-	-	-
June, 1979	-	-	-	-	-	-	-	-	-
Herbicides applied	-	9.0	15.0	-	7.0	-	-	-	-
May, 1980	-	-	-	-	8.0	-	-	-	-
Seedlings planted	-	-	-	-	-	-	-	-	-
June, 1979	-	-	-	-	-	-	-	-	-
Herbicides applied	12.0	9.0	9.0	6.5*	18.5	10.0	15.0	6.5	12.5
June, 1979	16.5	9.0	6.5	6.0	37.5	11.5	15.0	9.5	20.5
Seedlings planted	15.5	16.5	5.0	6.0	17.0	12.0	8.0	20.0	13.0
May, 1980	19.5	-	-	6.0	16.0	15.5	-	15.0	6.0
Herbicides applied	23.0	23.0	7.5*	18.5	12.5	7.5	8.0*	7.0*	13.5
September, 1979	16.0	16.0	6.0	8.5	17.5	7.0	9.0	9.0	13.5
Seedlings planted	22.5	28.5	11.5	20.5	14.5	10.5	6.5	15.0	13.5
May, 1980	15.5	14.0	6.5	5.5	9.0	31.0	6.0	7.5	23.5
Herbicides applied	43.5	30.0	7.0*	28.5	16.0	9.5	10.5*	8.0*	18.0
May, 1980	51.5	63.5	8.0	18.5	23.5	9.0	7.5	12.0	19.5
Seedlings planted	-	-	7.0	18.0	35.0	45.0	6.5	7.0	18.0
May, 1980	-	-	9.0	-	25.5	-	9.5	11.0	24.0

*indicates seedlings for the specified treatment, application time and planting time are significantly less than control seedlings, = .10.

Table 18. Lodgepole Pine Seedling Moisture Stress Data Expressed in Negative Bars for the June, 1980 Planting Time at White Stallion

Planting time \ Treatment	glyphosate 1.0	glyphosate 2.0	glyphosate 3.0	glyphosate 1.0+ hexazinone 1.0	glyphosate 2.0+ hexazinone 2.0	hexazinone	glyphosate + atrazine	dalapon	dalapon + atrazine	atrazine	scalp	control
Planted before application exposed	37.0	—	—	—	5.5	5.0*	15.0	5.5	5.0*	5.0*	15.0^{n}	8.0
	14.0	—	—	—	—	7.5	—	11.0	7.5	3.5	8.0^{n}	17.5
	—	—	—	—	—	7.0	—	10.0	5.5	—	10.0^{n}	24.0
	—	—	—	—	—	5.5	—	—	—	—	—	—
Planted before application sheltered	8.0	18.0	22.5	11.0	18.0		9.0*				15.0^{s}	8.0
	—	16.5	16.5	5.5	7.5		4.0				7.0^{s}	17.5
	—	27.0	8.0	—	—		5.5				12.0^{s}	24.0
	—	5.5	—	—	—		—				—	—
Planted after application	9.5	3.0	5.0	27.0	5.0*	5.0	6.0	6.0*	5.0*	7.0	6.5^{n}	8.5
	5.5	7.0	6.0	12.0	7.0	6.0	5.0	6.0	5.0	14.0	8.0^{n}	6.5
	7.0	7.0	—	8.5	4.0	11.0	9.5	5.0	5.0	—	13.0^{n}	16.0
	—	21.0	—	—	5.5	—	—	—	—	—	7.5^{n}	—
											7.5^{n}	
											19.0^{n}	

*indicates the treated seedling group is ranked significantly less than control seedlings at = .10.

^{s}seedlings were shaded

^{n}seedlings were not shaded

Table 19. Douglas-fir Seedling Moisture Stress Data Expressed in Negative Bars for the June, 1980 Planting Time at White Stallion

Planting time \ Treatment	glyphosate 1.0	glyphosate 2.0	glyphosate 3.0	glyphosate 1.0 + hexazinone 1.0	glyphosate 2.0 + hexazinone 2.0	hexazinone	glyphosate + atrazine	dalapon	dalapon + atrazine	atrazine	scalp	control
Planted before application exposed	16.0*	24.0*	11.0*	7.0	16.0*	8.0*	10.5*	8.0*	7.5	12.5	10.5^{n}	16.5
	11.0	11.5	16.0	19.0	9.5	12.0	9.0	12.5	22.5	10.0	14.5^{n}	32.0
	15.0	15.0	15.0	29.0	19.0	5.5	7.0	16.5	—	25.0	14.5^{n}	24.0
	—	13.0	—	—	—	—	9.0	—	—	—	—	23.0
							18.0					
Planted before application sheltered	10.5*	10.0*	20.0*	7.0*	7.0*		20.5				9.0*^{s}	16.5
	9.0	7.0	12.5	7.0	6.0		11.0				10.0^{s}	32.0
	4.5	16.0	12.5	—	—		10.0				15.5^{s}	24.0
	—	—	5.5	—	—		—				—	23.0
Planted after application	10.0*	10.5	10.0*	37.5	10.0*	9.0*	18.5	9.0*	11.0	19.0	13.5^{n}	19.5
	17.0	10.5	7.5	12.5	8.0	6.0	14.5	10.0	16.0	36.0	25.5^{n}	10.5
	8.5	20.0	11.0	14.0	13.5	7.5	8.0	14.0	—	—	9.0^{n}	17.5
	—	—	—	—	—	—	—	—	—	—	8.0^{n}	—
											12.5^{n}	

*indicates the treated seedling group is ranked significantly less than control seedlings, = .10.

^{s}seedlings were shaded

^{n}seedlings were not shaded