Changes in an infested plant community after an application of picloram, the effect of glyphosate on bud dormancy, the effect of pulling and the fuel potential of leafy spurge (Euphorbia esula L.)
by Bruce Dale Maxwell

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University

Abstract:

Leafy spurge (Euphorbia esula L.) is a successful invader weed on rangeland that is difficult to control. Research was initiated to determine the effect of a herbicide used on range plant communities to control leafy spurge, to find specific weaknesses in the plant that would lead to improved control methods and to determine a possible use for the plant.

Picloram (4-amino-3,5,6-trichloropicolinic acid) was applied by airplane to a range-land plant community to control leafy spurge. Biomass, canopy cover, composition, frequency and number of species were recorded on grazed and ungrazed areas which were subdivided into sprayed and unsprayed treatments. The application of picloram has caused a decrease in species diversity which ultimately could cause a decrease in forage production.

The effect of glyphosate [N-(phosphonomethyl)glycine] on the regulation of bud dormancy in leafy spurge was studied. Radioactive glyphosate was applied to leafy spurge plants in the pre-bloom, late bloom and senescent growth stages. The highest concentration of labelled glyphosate other than the treated leaf was found in the root crown buds of plants that were senescing at the time of application. Increased concentration of 14C-glyphosate in the root crown buds of senescing plants may be directly related to the number of buds released from dormancy the following summer.

The effect of pulling on the control of leafy spurge wag studied. The most effective long term control was produced when plants were hand pulled in the bloom stage of growth. None of the machine pulling, mowing, herbicide, or herbicide applied to regrowth after pulling treatments significantly decreased the density of leafy spurge one year after treatment.

The economic and productive potential of leafy spurge when grown under optimum agronomic conditions was studied. Oil, hydrocarbon, total protein, and dry weight production were measured on three harvest dates. Calorimetric analysis was performed to determine the potential of leafy spurge as a fuel crop. Leafy spurge hay can produce four times more energy per year than wheat straw. The immediate potential of leafy spurge may be to use the whole plant biomass as a locally grown fuel crop for home heating. •

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A thesis submitted in partial fulfillment
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of

Master of Science

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Agronomy

MONTANA STATE UNIVERSITY
Bozeman, Montana

August 1984

APPROVAL

of a thesis submitted by

Bruce Dale Maxwell

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citation, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ACKNOWLEDGMENTS

I would like to express my deep appreciation to my advisor, Pete Fay, for his ideas and friendship; and for the challenges he gave me.

Sincere thanks are extended to the members of my committee, Michael Foley and Tad Weaver for helpful advice and direction.

I would also like to thank members of the weed crew, Dan Burkhart, Tim Chicoine, Lee Coble, Bill Dyer, Celestine Lacey, Scott Nissen and many others who gave their time and support to complete this project.

I am especially grateful to my wife, Anne, for her continued support, understanding and encouragement.

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ABSTRACT

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CHAPTER 1

LITERATURE REVIEW

Introduction

Leafy spurge (*Euphorbia esula* L.) is a deep rooted perennial plant that has become a noxious weed by infesting millions of acres of pasture and rangeland in the north central United States and Canada.

Leafy spurge is found worldwide with the exception of Australia. It is believed to have originated in Asia in the Caucasus region of Russia (Croizat, 1945). In Canada it is found in every province except Newfoundland (Harris and Alex, 1971). Leafy spurge was first collected in the United States in Massachusetts in 1827 (Britton, 1921) and was found as far west as Michigan in 1881 (Dunn, 1979).

There were approximately 0.9 million hectares (2.3 million acres) of infested land in the United States in 1979 (Noble et al., 1979). Montana and North Dakota have the most infested acres, and the infestation is increasing in the Great Plains and Intermountain states to the south and west (Dunn, 1979).

Leafy spurge is a dicotyledonous herbaceous plant with a dense habit of growth and a greenish-yellow inflorescence. It has one to several shoots originating from the crown, a thickened region of stem and transition tissue immediately below the soil surface (Raju et al., 1964). The shoots can grow to one meter at maturity (Selleck et al., 1962). Latex is present throughout the entire plant at all growth stages and is exuded upon injury (Bakke, 1936). The linear leaves are alternate, and generally without petioles (Moore, 1958). The umbel inflorescence consists of yellow flowers subtended by large, round, greenish-yellow bracts. The stems become woody as the plant matures, and both leaves and stems turn orange-red in the fall. Sometimes the dead stems persist into the following summer (Selleck et al., 1962).

Leafy spurge can inhabit a broad range of habitats including xeric to subhumid climates, fine to coarse soils, open grasslands, and under forest canopies (Selleck et al,, 1962). Leafy spurge will not tolerate continual cultivation, therefore it has not become established on cultivated land to any degree (Coupland and Alex, 1954).

The spread of leafy spurge is attributed to efficient reproduction by seed and vegetative buds (Bakke, 1936). The seeds are formed in three-lobed capsules which explode when dry, projecting the seeds as far as 4.5 m (Bakke, 1936; Selleck et al., 1962). The seeds can be further dispersed by animals or flotation (Selleck et al., 1962).

The extensive root system of leafy spurge is well adapted to crowd out neighboring species and to store large amounts of food reserve. The density of roots is greatest in the top 15 cm of soil and decreases with depth (Selleck et al., 1962). Leafy spurge roots have been reported at depths exceeding 4.5 m (Bakke, 1936). Vegetative reproduction originates from buds on the crown, main roots and lateral roots (Coupland and Alex, 1954). The greatest number of buds are found near the soil surface, and preformed buds have been found on roots to depths of 3 m (Coupland and Alex, 1955). Vegetative shoots appear early in the spring, often before other species have begun to grow. The shoots develop from buds formed the previous fall on the crown.

Selleck et al. (1962) determined that the annual increase in the radius of a leafy spurge patch ranged from 8 cm to 1.3 m. Average annual spread was less on patches located on ungrazed native grassland. Further studies by the same authors indicated that an increasing density of leafy spurge was unimpeded by introduced brome grass (*Bromus* spp.), and only slightly impeded by crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) when the original stand of leafy spurge was sparse. It was also suggested that the density of the weed may be more easily restricted by an established stand of grass than by an introduced stand. In the same study the number of annual and perennial forb species as well as shrub species decreased over a seven year period as a result of competition from leafy spurge and grasses. Leafy spurge may also have an effect on the range plant community by directly retarding the growth and development of competitors through allelopathy (LeTourneau et al., 1957).

Leafy spurge reduces forage production through direct weed competition (Lym and Messersmith, 1983). Forage utilization by livestock is decreased because the weed contains a digestive irritant which affects cattle and horses thereby discouraging them from grazing in infested areas (Selleck et al., 1962).

Changes in a Plant Community After an Application of Picloram

Picloram (4-amino-3,5,6-trichloropicolinic acid) has been widely used on pastures and rangeland to control leafy spurge. An application rate of 1.1 kg/ha of picloram can provide 90 to 100% control of leafy spurge for up to 2 years (Alley et al., 1983; Lym and Messersmith, 1983). None of the herbicides tested have successfully eradicated leafy spurge.

Herbicide persistence, broad spectrum phytotoxicity, and movement with water are important properties of picloram that must be considered when it is used on rangeland. Picloram is more toxic to many broadleaf plants than 2,4-D (2,4-dichlorophenoxy acetic acid) and 2,4,5-T (2,4,5-trichlorphenoxy acetic acid) but only moderately toxic to grasses (Hamaker et al., 1963). It has been classified as an auxin-type herbicide and appears to function as a growth regulator (Eisinger et al., 1966; Chang and Foy, 1971; Eisinger and Moore, 1971).

Picloram is very soluble in water (430 ppm) (Anon., 1983), therefore the danger of crop injury through contamination of irrigation water, surface runoff, lateral movement in soil, or spray drift exists (Anon., 1972). There are sometimes sufficient amounts of picloram in runoff water to kill or seriously injure sensitive plants within a few days after treatment (Trichell et al., 1968). Picloram residues of 10 μg/l or more in irrigation water severely affects the growth of some crop seedlings (Bovey and Scifres, 1971).

Herbicides that are persistent in the soil have been the most effective in controlling leafy spurge. In range and pasture plant communities picloram decomposes in soil at rates similar to the urea and triazine herbicide (Corbin, 1971; Dowler et al., 1968). With an initial application rate of 2.2 kg active ingredient (ai)/ha, the time required for the herbicide to decompose to a negligible level (0.7 g/ha) varies from 4.5 months to 4.6 years (Goring and Hamaker, 1971). Picloram applied to leafy spurge at 1.1 kg ai/ha in a granular formulation at three sites in Wyoming showed differential persistence in the top 24 inches of soil. The highest level of residual picloram was 0.476 ppm in the top 24 inches one year after application (Alley, 1983). Application rate, season of application, and soil texture influenced the rate of dissipation of picloram from pasture soils in Nebraska (Scifres et al., 1969).

Scifres et al. (1971) monitored picloram residues in rangeland vegetation and found about 25 ppm picloram in buffalograss (*Buchloe dactyloides* (Nutt.) Engelin.) and blue grama (*Bouteloua gracilis* Willd. ex HBK Lag ex Duffiths) immediately after application of 0.28 kg ai/ha picloram. Less than 1.0 ppm of picloram was detected in grass tissue 30 to 60 days after treatment. They also found that detectable picloram was reduced by 93% in herbaceous, broadleaf species 30 days after application. Scifres and Halifax (1972) found that picloram had no influence on germination or growth of range grass seedlings.

The use of picloram to control leafy spurge on native or seeded grassland can increase forage production. In North Dakota forage production in a leafy spurge infestation increased over an untreated control one year after application of picloram at 1.1 and 2.2 kg ai/ha (Lym and Messersmith, 1981). Forage yields were less when picloram was applied at 2.2 kg ai/ha than when lower rates were applied.

In Wyoming leafy spurge infestations were treated with picloram at 0.56, 1.1, and 2.2 kg ai/ha and forage production was measured for four years (Whitson and Alley, 1983). Areas treated with 2.2 kg ai/ha of picloram produced the most air-dried forage while the untreated check produced the least. High rates of picloram caused prostrate growth and suppressed production of grasses for two years, but they recovered after 4 years.

Arnold and Santelmann (1966) studied the effects of picloram on native grass and forb species in Oklahoma. After one year they concluded that an application of picloram (at a range of rates from 1.1 kg ai/ha to 4.4 kg ai/ha) to established native range did not reduce forage production or desirable plant frequency. However, forb production was reduced by picloram at all the tested rates.

McDaniel at al. (1982) evaluated vegetation response, and changes in grazing use and capacity following brush control with picloram plus 2,4,5-T in north-central Texas. One year after application, grass cover increased significantly, but after the second year there was no difference in ground cover between sprayed and unsprayed rangeland. Increased grass yield (dry biomass) may occur within 120 days to 3 years after application but the increase may not occur over consecutive years. An especially favorable response of high producing forage species provided a 7 to 16% increase in grazing capacity over the four year study period.

A study measuring changes in forage yield in Saskatchewan, Canada following the use of 1.1 kg ai/ha of picloram to control aspen poplar (*Populus tremuloides* Michx) indicated that four years after treatment grasses had not increased and forbs had decreased dramatically compared to an untreated check (Bowes, 1982).

Scifres and Polk (1974) evaluated vegetation changes for four years following aerial application of 2,4,5-T plus picloram (1:1) at 0.56 kg ai/ha to control honey mesquite (*Prosopis gandulosa* Torr. var. *glandulosa*). They concluded that forage production increased on areas with brush control and protection from grazing, but only in years of average or above average rainfall. Areas sprayed and protected from grazing supported more grasses of fair to good grazing value than did unsprayed areas. In another study investigating the changes in vegetation following honey mesquite control, annual fluctuation in rainfall was the most important factor influencing vegetative growth (McDaniel et al., 1982). When rainfall was above the annual average, broadleaf forbs were very productive but perennial grass production was not increased. Grass production with below annual average rainfall was equal to or greater than production in wet years. They concluded that competition from annual broadleaf plants was largely responsible for the suppressed perennial grass production during wet years.

A study of competition between native forbs and grasses indicated that rhizomatous forbs decreased the production of big bluestem (*Andropogon gerardii* Vitman), a rhizomatous grass, and forbs with a taproot system had no competition effect on the grass yield (Dwyer, 1958).

Scifres et al. (1977) reported an increase in consumption of native grass by livestock as a direct function of increased grass availability in response to brush control. They also reported increased moisture use efficiency of forage plants by the use of herbicides based on kg/ha of native grass produced per cm precipitation. In the same study, forb diversity and production was reduced for two years by the herbicide which they believed could have negative effects on wildlife.

Picloram provides broad spectrum control of trees, shrubs, and herbaceous plants and is typically used on rangeland to produce a pure grass cover. Often, the target plant is a single species but many shrubs and herbaceous species are removed, some of which might be important to the stability or nutrient base of the community (Anon., 1972). The primary management concern on rangeland is for long-term yield, therefore a stable productive ecosystem is sought. The stability of a complex mixture of plant species may influence the average yield of grasslands over a longer period than would a less complex system (Spedding, 1971). McNaughton (1971) suggested that species diversity is principally a mechanism which generates community stability. Whittaker (1970) concluded that diversity generally increases with plant succession and is paralleled by an increase in biomass.

Killing a broad spectrum of herbaceous species could result in loss of legumes, an important nitrogen source to the ecosystem (Anon., 1972). Spedding (1971) used the example of grass/clover mixture to point out that a mixture of two plant species (grass plus a nitrogen fixer) can be more productive than either species grown alone.

A diverse rangeland flora may be less susceptible to serious losses in production from adverse climatic conditions or insect damage (Vallentine, 1971). Diversity may provide buffering against drought (Anon., 1971). A plant community which consists of species with varying degrees of drought resistance may be more productive in a long term sense than a community with a single, slightly less drought resistant species (Spedding, 1971). On western Canada rangelands plant communities must have the ability to withstand frequent droughts which reduce the abundance and cover of the higher yielding grasses (Anon., 1972). Since root growth of grass species can be differentially affected by picloram (Scifres and Halifax, 1972a), the resistance of treated rangeland ecosystems to grazing and drought could be seriously impaired (Anon., 1972).

Cornell and Orias (1964) predicted that greater species diversity will accompany greater rates of production of organic matter and/or greater environmental stability, but only under the restrictions of an ecosystem not in successional stages. Goodman (1975) concluded that there was no single relationship between diversity and stability in ecological systems, and that there has been few confirmations of the diversity-stability hypothesis. He further suggested that when a severe disturbance occurs in a community which will nullify the evolutionary adjustment of its species-species interactions, then some measures of instability, such as the fraction of species subsequently lost, may well increase with diversity. There is a general agreement that the diversity-stability hypothesis must be further tested under long term requirements for specific situations (Connell and Orias, 1964; Goodman, 1975; Spedding, 1971).

Rate of change curves for successional plant communities are usually convex, with changes occurring most rapidly in the early stages (Odum, 1969). The approach to managing rangeland vegetation should be to maintain the community at a state where the rate of successional change is slow. This can be accomplished by using picloram strictly for spot treatment so that adequate competition remains from forbes and shrubs (Anon., 1972).

Leafy Spurge Bud Growth Regulation

The physiology and anatomy of leafy spurge bud release has been studied by several authors (McIntyre, 1979; McIntyre, 1971; McIntyre and Raju, 1967; Raju, 1975; Raju and Marchuck, 1977). Bud growth will occur upon killing or removing the top growth of leafy spurge (Sellect et al., 1962), a result of the removal of apical dominance.

There is some evidence that nutrition can be important in the regulation of apical dominance (McIntyre, 1971). McIntyre (1971) suggested that under experimental conditions the degree of leafy spurge root bud inhibition is determined by the ability of the buds to compete with the dominant shoots for a limited nitrogen supply. In a later study McIntyre (1979) hypothesized that internal competition between buds for water could play an important role in the mechanism controlling root bud growth inhibition. He also reported that an increase in humidity from 50 to 90% released leafy spurge root buds from apical dominance exerted by shoots.

Raju (1975) reported that decapitation of seedlings stimulated completion of the vascular connections between the hypocotylary axis and buds of leafy spurge, and that the process may be mediated by auxin (IAA). In the same study vascular induction was found to coincide with an increase in soluble carbohydrates and a simultaneous decrease in IAA at the junction of the adventitious buds.

The root system and associated buds are the most important structures limiting control of leafy spurge (Coupland and Alex, 1955; Messersmith, 1983; Raju et al., 1963). Herbicides must kill the root system to at least a depth of one meter to prevent emergence of new shoots from existing plants, or treatments must be repeated to deplete the carbohydrate reserves in the root (Messersmith, 1983).

The Action of Glyphosate on Leafy Spurge

None of the herbicides tested to date have provided complete root kill of leafy spurge below a few centimeters. Glyphosate [N-(phosphonomethyl)glycine] has provided effective control of many perennial weeds (Gottrup et al., 1976; Sandberg and Meggitt, 1977; Shultz and Burnside, 1980; Wyrill and Burnside, 1976). Glyphosate is a nonselective, post emergence herbicide which translocates readily throughout rhizomes and root systems of perennial plants to tissue of high metabolic activity (Gougler and Geiger, 1981; McIntyre and Hsiao, 1982; Shultz and Burnside, 1980). Glyphosate does not provide long term control of regrowth from leafy spurge roots or crowns (Bybee et al., 1979).

The time of year when glyphosate is applied to leafy spurge can affect control. Messersmith (1973) reported 44 and 51% control of leafy spurge one year after glyphosate was applied at 1.13 and 2.24 kg ai/ha in the spring. In the same study, glyphosate applied in the fall at 1.12, 1.68, and 2.24 kg ai/ha provided 85% control of leafy spurge when evaluated the spring following treatment. This response is consistent with results from studies where glyphosate was applied to quackgrass [*Agropyron repens* (L.) Beauv.] in the spring and fall (Behrens and Elakkad, 1972; Sprankle and Meggitt, 1972). Banks et al. (1977) reported that glyphosate provided the best control of horsenettle (*Solanum carolinense* L.) when applied to fully mature and fruiting plants.

The absorption of glyphosate through plant tissue is dependent upon species. Gottrup et al. (1976) compared the sensitivity of Canadian thistle [*Cirsium arvense* (L.) Scop.] and leafy spurge to glyphosate and concluded that Canadian thistle was more susceptible because its leaf characteristics were more conducive to absorption of glyphosate. Wyrill and Burnside (1976) reported that uptake of glyphosate by common milkweed (*Asclepias syriaca* L.) and hemp dogbane (*Apocynum cannabinum* L.) was slow because of differences in polarity between the leaf surface and the glyphosate molecule. Sprankle et al. (1975) reported rapid absorption of glyphosate by several weeds including quackgrass (*Agropyron repens* (L.) Beauv.), yellow nutsedge (*Cuperus esculentus* L.), field bindweed (*Convolvulus arvensis* L.) and Canada thistle (*Cirsium arvense* (L.) Scop.).

Glyphosate is translocated readily in plants to meristematic areas of high metabolic activity (Gottrup et al., 1976; Sprankle et al., 1975; Whitwell et al., 1980; Wyrill and Burnside, 1976). Glyphosate is translocated in both the apoplast, and symplast of leafy spurge (Gottrup et al., 1976). Bybee et al. (1979) reported that glyphosate was evenly distributed throughout the leafy spurge plant except during seed production when a greater proportion was translocated to the roots. Schultz and Burnside (1980) using autoradiographs found that foliarly applied glyphosate accumulated in the roots and new leaves of hemp dogbane.

Metabolism of glyphosate has not been detected in leafy spurge (Gottrup et al., 1976) or other perennial species (Wyrill and Burnside, 1976; Zandstra and Nishimoto, 1977).

The mechanism of action of glyphosate has been intensely studied (Amrhein et al., 1980; Baur, 1979a; Baur, 1979b; Duke et al., 1980; Foley et al., 1983; Jaworski, 1972; Steinrucken and Amrhein, 1980). Jaworski (1972) reported that glyphosate induced growth inhibition in nutrient solution culture could be reversed by the addition of aromatic amino acids to the medium indicating the growth disturbance was related to inhibition of protein synthesis. Amrhein et al. (1980) found that glyphosate inhibits production of chorismate a precursor of aromatic amino acids in the shikimic acid pathway (Figure 1). It was soon found that glyphosate was a potent inhibitor of the enzyme 5-enolpyruvyl-shikimic acid-3-phosphate synthase which catalyzes the formation of chorismate (Steinrucken and Amrhein, 1980). Tryptophan, a product of the shikimic acid pathway is a precursor of indoleacetic acid (IAA), which is an important growth regulating phytohormone. Regulation of IAA synthesis could explain many of the growth regulating properties of glyphosate.

Baur (1979a) simultaneously added IAA and glyphosate to sorghum seedlings in an attempt to relate glyphosate to inhibition of IAA synthesis. The addition of the IAA did not overcome the growth stimulating effect of glyphosate, therefore he concluded that glyphosate, rather than blocking IAA synthesis, either blocks the supply of auxin to the basal buds or blocks the action of IAA once it enters the basal stem. In studies examining the effect of glyphosate on auxin transport in corn and cotton tissue, Baur (1979a) concluded that glyphosate inhibits the transport of IAA and consequently releases lateral buds from apical dominance.

The effectiveness of foliar-applied herbicides for leafy spurge control is dependent on the translocation of the herbicides into the basal stem and root system, and accumulation

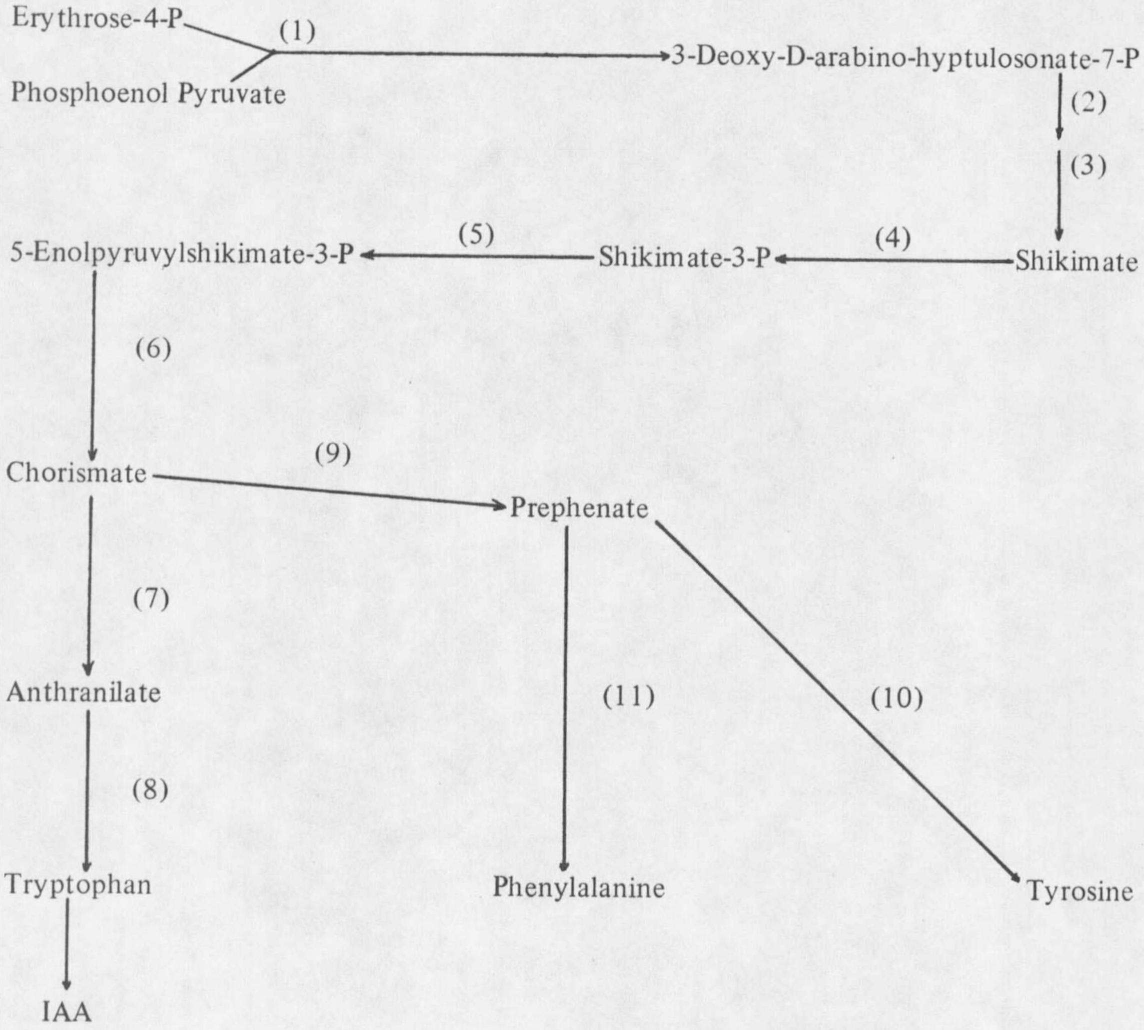

Figure 1. The shikimic acid pathway including the enzymes: (1) 3-deoxy-2-oxo-D-arabino-heptulosate-7-phosphate synthetase, (2) 5-dehydroquinate synthetase, (3) shikimate dehydrogenase, (4) shikimate kinase, (5) 5-enolpyruvylshikimate-3-phosphate synthase, (6) chorismate synthetase, (7) anthranilate synthetase, (8) tryptophan synthetase, (9) chorismate mutase, (10) prephenate dehydrogenase, (11) prephenate dehydratase (Steinrucken and Amrhein, 1980).

of the herbicides in the lateral buds. When the leafy spurge plants are growing undisturbed most of the buds are dormant (McIntyre, 1972), their growth having been arrested by the inhibiting influence of the parent shoot (apical dominance maintained by the presence of IAA). The most effective herbicides for perennial plant control are translocated preferentially to active meristems in association with natural assimilates, therefore treatments that release lateral bud inhibition will increase uptake of the herbicides and result in more effective control (McIntyre and Hsiao, 1982).

The growth regulating properties of glyphosate have been described. Baur et al. (1977) describing swelling of the lower stem followed by release of basal buds by sublethal levels of glyphosate on a variety of grain sorghum [*Sorghum bicolor* (L.) Moench 'Tophand'] that does not normally produce basal shoots. Histochemical studies indicated that the apical bud of plants treated with glyphosate at sublethal rates were viable so bud release was not due to death of the apical meristem (Baur et al., 1977). Glyphosate at sublethal rates has been reported to cause main stem malformation, tillering, and increased branching on several species (Caseley, 1972; Coupland and Caseley, 1975; Swanson and Shuman, 1982).

Pulling as a Method of Weed Control

Hand pulling is the oldest method of weed control. It is a practical and efficient method of eliminating weeds from home gardens, and within rows and hills of certain cultivated crops when certain weed species are difficult to control with other methods (Anderson, 1983; Robbins et al., 1942). Some weeds of grainfields occur in low enough densities that hand pulling is a viable alternative to chemical control (Robbins, 1942).

At least one mechanical weed puller[1] has been developed specifically to pull tall weeds from seeded rows of cultivated row crops. It appears that there are no published reports concerning the effectiveness of that machine.

Pulling weeds is most effective on annual and biennial species which do not regrow from roots left in the soil (Robbins, 1942). In order to eradicate perennial weeds by pulling or cultivation, the operation must remove top growth often enough to starve the plant (Helgeson, 1975). Pool and Cairns (1939) reported that a single pulling provided 55 to 65 percent control of ragwort (*Senecio jacobaea* L.), a perennial pasture weed in New Zealand. In the same study it was determined that the best control of regrowth was obtained when plants were pulled at the flowering stage which was attributed to low levels of stored carbohydrate leaving deficient reserves in the remaining roots for growth of new shoots.

In order to control a perennial weed all means of reproduction must be effectively removed (Selleck et al., 1962). Pulling can eliminate seed production by removing the plant before the seeds are developed (Robbins, 1942). While pulling does not necessarily eliminate vegetative reproduction, it can have an effect on regrowth density, survival, or ability to reproduce (Pool and Cairns, 1939).

Leafy spurge is a troublesome perennial weed because of its capacity to thrive under many environmental conditions and its ability to reproduce both by seed and from buds below the soil surface (Raju et al., 1963; Selleck et al., 1962). The depth from which vegetative regrowth can occur is important in relation to control by pulling. The buds on the root system of leafy spurge that develop into leafy shoots have an underground portion which is persistent after aerial portions have senesced (Raju et al., 1963). Buds are developed on these underground stems and a number of them develop into shoots the following year. After several years this region of the underground stem thickens from continued bud

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[1] Bourquin Weed Puller, Bourquin Design and Mfg., Inc., Colby, Kansas 67701.

tissue development into a crown region (Messersmith, 1983). Coupland et al. (1955) reported that the majority of leafy spurge shoots originate from the crown near the soil surface, although shoots are capable of emerging from one meter deep. Leafy spurge buds which give rise to shoots decrease in abundance with increasing depth (Coupland and Alex, 1955), therefore, pulling could be effective in decreasing regrowth if the crown is removed.

The persistence of leafy spurge is usually attributed to the characteristics of the root system. The roots store a large food reserve for use in regeneration and survival when environmental conditions are poor (Selleck et al., 1962). The amount of regrowth after pulling depends on the age of the root, the carbohydrate reserves stored in the root, and the ability of the plant to recover from injury caused by pulling (Pool and Cairns, 1939).

Seasonal fluctuations in root carbohydrate levels may be an important factor to consider in determining the optimum time for pulling. Bybee (1979) reported that herbicides were more effective on leafy spurge when application coincided with low root carbohydrate content. Perennial plant root systems are reported to be lowest in stored carbohydrates at the bud or early bloom stage (Arny, 1932; McWhorter, 1961; Popova and Bozova, 1975). The early bloom stage was the most effective time for pulling ragwort (Pool and Cairns, 1939). It is difficult to measure the variation in carbohydrate levels of leafy spurge because the carbohydrates in the latex may not be utilized (Biesboer and Mahlberg, 1978).

Pulling a plant can be very destructive to the root system and may make it more susceptible to pathogen attack. Agronomic techniques that have been developed to reduce wounding and constrain development of disease can be manipulated to encourage pathogens for biological control of weeds (Holcomb, 1982). Wounding plants provides an avenue for many plant pathogens to penetrate their hosts (Cowling, 1978).

Plant Protection of Hydrocarbons

Early research investigating hydrocarbon producing plants was prompted by naval blockades which prevented exportation of natural rubber being exported from Malaysia to Europe and America. Natural rubber is a familiar form of hydrocarbon extracted from the rubber tree (*Hevea brasiliensis*), a member of the Euphorbiaceae family.

Thomas Edison examined thousands of plants that could be grown in the United States as a source of rubber, and determined that the genus *Euphorbia* contained high amounts of latex (Polhamus, 1967). Buehrer and Benson (1945) reported the results of numerous studies that examined rubber content of native American plants, but restricted their investigation to plants indigenous to the southwest United States. Minshall (1957) used a similar procedure to study the rubber content of plants found in Canada.

Recent interest in replacing petroleum based fuels led to an increase in biofuel research including investigations of potential plant sources of hydrocarbons. Hydrocarbons can collectively refer to extracts from green plants including tall oil and its derivatives (fatty acids, rosin acids), naval stores (solvents, terpene resins, rosin), vegetable oils, waxes, tannins (phenolic compounds) and natural rubber (Buchanan et al., 1978a). Over 2,000 plant species produce hydrocarbons (Calvin, 1976). Plants in the Euphorbiaceae and Asclepiadaceae families are potential sources of hydrocarbons similar to those found in crude oil (Coffey and Halloran, 1979; Buchanan et al., 1978a).

Latex from plants in the genus *Euphorbia* has received increasing attention because it contains a mixture of low molecular weight hydrocarbons (C_{15}, C_{20}, C_{30} compounds) (Nielson et al., 1979; Wang and Huffman, 1981). When water is removed from the latex the resulting material is a liquid oil which yields various products after catalytic cracking, which are similar to those obtained by cracking naphtha (Maugh, 1979), a high quality petroleum fraction that is one of the principal raw materials used in the chemical industry (Wang and Huffman, 1981).

Approximately ten percent of the fossil hydrocarbon supply annually is cracked down to ethylene and used for production of synthetic fibers and plastics (Nishimura et al., 1977). Calvin (1979) suggested that short-chained plant hydrocarbons could be substituted for fossil fuel for fiber and plastic production.

Vegetable oils are an important class of plant extracted hydrocarbons from the standpoint of both volume and value. Wang and Huffman (1981) reported that the average heat value of common triglyceride oils extracted from plant sources is equivalent to that normally obtained from fuel oil and some of these plant derived oils are suitable for combustion in diesel engines.

Wiatr (1984) reported that oils extracted from leaves of *Euphorbia esula* constituted an energy-rich fraction of biomass with calorific values comparable to values reported for hydrocarbons (i.e., oils) from *E. lathyris*. These calorific values are much greater than lignite or anthracite coal and are only slightly less than the caloric value of petroleum.

In order to minimize dependence on fossil energy, plant material can be utilized as a supplemental source of liquid and solid fuels as well as chemical feed stocks (Wang and Huffman, 1981). Several authors (Buchanan et al., 1978a, 1978b; Buchanan, 1978; Calvin, 1977; Gartside, 1975) suggest that agricultural production of hydrocarbons may be compatible with a need for increased food and fiber production if the entire plant could be harvested for hydrocarbons, fiber, protein and carbohydrates. It is at present economically feasible to extract plant-derived hydrocarbons if they constitute two percent or more of the plant's dry weight (Buchanan et al., 1978a; Polhamus, 1967; Buehrer and Benson, 1945; Minshall, 1957).

Coffey and Halloran (1979) stated that *Euphorbia tirucalli, E. lactea* and *E. lathyris* may have potential for hydrocarbon production. Hydrocarbon production was determined for several species of *Euphorbia* by growing them under agronomic conditions in southern California (Calvin, 1979). A Japanese firm planted *E. tirucalli* and estimated that five to ten barrels of oil could be produced per acre per year. Calvin (1979) estimated that *E. lathyris* could produce eight to twelve percent of the plant dry weight in oil which would yield ten to twenty barrels of oil per acre per year. Since qualitative differences in hydrocarbons were found among Euphorbia species (Coffey and Halloran, 1979), selection and genetic improvement could improve the yield of hydrocarbons (Buchanan et al., 1978a; Calvin, 1979; Coffey and Halloran, 1979).

Agronomic and environmental factors as well as economic pressures can influence hydrocarbon production. In response to the discovery of synthetic rubber, natural rubber yields were increased from an average of 200 kg/ha in 1945 to over 2000 kg/ha by 1965 by using specialized agronomic techniques (Calvin, 1977). Factors such as annual precipitation, growing degree days and time of harvest regulated hydrocarbon levels in *Parthenium argentatum* (Coffey and Halloran, 1979). Buchanan et al. (1978) found that variations in whole plant oils were caused by such factors as growing conditions, soil fertility, disease and insect infestations. Blamey and Chapmen (1981) reported that oil energy yield and overall production of sunflower (*Helianthus annuus*) could be increased by fertilization with phosphorus and nitrogen. All of these studies indicate that agronomic factors play a crucial role in the productivity of hydrocarbon producing plants and large increases in production can be expected if promising plant material is identified.

Euphorbia lathyris has been reported to have promise for hydrocarbon production (Coffey and Halloran, 1979; Calvin, 1979). Irrigation and fertilization of *E. lathyris* had little effect on hydrocarbon production (Sachs et al., 1981), therefore it was suggested that it may be well suited for growth in arid regions not suitable for food crops (Calvin, 1979). Kingsolver (1982) reported that genetic, agronomic and chemical data from studies conducted in Arizona indicated that *E. lathyris* is unsuitable for culture in arid lands and that the overall potential of the plant may be limited. Sachs et al. (1981) reported problems with establishing *E. lathyris* as a crop.

The woody biomass potential of the Chinese tallow tree (*Sapium sebiferum*) has been studied (Scheld and Cowles, 1981). This rapidly growing tree is a member of the Euphorbiaceae family that has been introduced to the southeast United States. The authors concluded that the Chinese tallow tree could be established over large acreages by conventional agricultural planting methods to provide woody biomass for direct burning or as feed stock for commercial production of ethanol, methanol or charcoal due to its high heat value (4200 cal/g).

Greene and Crane (1980) have investigated whole plant biomass fuel potential of several crop residues as a replacement for fossil fuels in rural areas. They concluded that localized use of crop residue such as wheat straw was practical and economically feasible for heating farm homes and buildings at this time.

Plant species that have the most potential as petrochemical substitutes are those that can be most easily adapted to cropping practices and be productive on marginal agriculture land (Buchanan et al., 1978a; Calvin, 1979). Many of the potential hydrocarbon-producing species grow in soils not suited to food crops and are of a weedy nature (Calvin, 1979).

Summary

Leafy spurge is a well adapted, tenacious weed that has invaded thousands of hectares of pasture and rangeland in the northern Great Plains. It was introduced from Eurasia and has few natural enemies. There has been no success with eradication of leafy spurge with herbicides. Picloram is the most effective herbicide for long term control of leafy spurge. The literature generally indicates that grass production and carrying capacity for cattle can be immediately increased by the use of picloram to control weeds on rangeland. However, spraying large continuous acres of picloram could decrease the long term productivity of the range by decreasing the plant species diversity.

Leafy spurge has an efficient means of vegetative reproduction. The knowledge of physiological mechanisms which control vegetative growth from buds on perennial plants is limited. The literature indicates that glyphosate has growth regulating properties which may influence apical dominance and bud growth.

In order to control perennial weeds all means of reproduction must be effectively removed. Pulling can eliminate seed production by removing the plants before seed is produced. Pulling can be effective in decreasing the vigor of vegetative regrowth if time of pulling coincides with low carbohydrate levels in the roots. Fluctuation in carbohydrate levels in leafy spurge are not fully understood. Pulling can cause significant injury to the roots which may increase the potential for pathogen attack.

Plants can produce hydrocarbons that now are obtained from fossil fuel sources. A system for determining the plants with the highest potential for producing hydrocarbons has been developed. Emphasis has been placed on those species which are well adapted to marginal agriculture land. Several species in the genus *Euphorbia* show potential for producing hydrocarbons.

CHAPTER 2

CHANGES IN A LEAFY SPURGE INFESTED PLANT COMMUNITY AFTER AN APPLICATION OF PICLORAM

Abstract

Picloram (4 amino-3,5,6-trichloropicolinic acid) was applied aerially at 1.1 kg active ingredient (ai)/ha to rangeland in central Montana for control of leafy spurge (*Euphorbia esula* L.). The response of grass and shrub communities to herbicide application were measured. A two by two design was used with four treatments including grazed and ungrazed areas which were subdivided into sprayed and unsprayed treatments. Measurement of biomass, canopy cover, composition, frequency, and number of plant species were taken 1 and 13 months after aerial application of picloram.

By all measures leafy spurge decreased from unsprayed to sprayed treatments at 1 and 13 months after application. Other perennial and biennial forbs decreased in 1982 and decreased further in 1983. Under grazed and ungrazed conditions perennial grass production increased 30% and 36% respectively in response to the herbicide one month after application.

The application of picloram caused a decrease in species diversity by removing most of the forbs. A significant decrease in the species richness occurred in the two year period after picloram was applied; all the species lost were forbs. The percent of total plant cover contributed by perennial grasses increased during the second year after spraying. It is expected that the decrease in species diversity may encourage weed reinfestation, decrease nitrogen availability in the soil by removal of nitrogen fixers, and/or make the community more susceptible to production losses from drought, disease, or insect attack.

Introduction

Picloram is a broad spectrum herbicide that can severely alter the diversity of a plant community by removing forbs (Anon., 1972; Bowes, 1982; Arnold and Santelmann, 1966). Because sudden changes in the composition of a rangeland plant community may have long term disbenefits we describe here the changes observed in the first two years after picloram application and speculate on their implications.

Leafy spurge (*Euphorbia esula* L.) is a threat to much valuable grazing land in Montana. It is a deep rooted perennial weed which not only reduces forage production by competition but also reduces forage utilization by livestock (Lym and Messersmith, 1983). This reduction is presumably due to a digestive irritant which affects cattle and horses and thereby discourages them from grazing in infested areas (Selleck et al., 1962).

Picloram is the most effective tool for controlling leafy spurge (Lym and Messersmith, 1983). It has therefore been widely used on pasture and rangeland to control leafy spurge in the northern Great Plains. An application rate of 1.1 kg active ingredient (ai)/ha of picloram can provide 90-100% control of leafy spurge for up to 2 years (Alley et al., 1983; Lym and Messersmith, 1983). This relatively high concentration of picloram is required for long term control because leafy spurge is less sensitive to picloram than most broadleaf species.

Picloram application removes most of the forbs from a range plant community and decreases the vegetative diversity. A decrease in number of species presumably leads to an increase in unfilled ecological niches. The ecological niche being defined as a physical space as well as an interactive, competitive position within the plant community. The plant community response to those open niches can have broad management implications. Some authors believe that such a decrease in species diversity will decrease the stability of a plant community (McNaughton, 1971; Spedding, 1971). Potential implications of an unstable plant community are: decrease in total biomass production (Whittaker, 1970), increased susceptibility to loss from adverse climatic conditions or insect attack (Vallentine, 1971), and increased susceptibility to invasion by the same or different weeds.

To determine evolution of a pasture or rangeland plant community after herbicide application, periodic measurements over several years are required. The succession observed will be dependent on the community initially present as well as environmental factors (e.g., annual precipitation, distribution of precipitation throughout the year, the range condition or seral stage of the community at the time of application, the adjacent seed banks that are capable of causing new or reinfestation, and the nature of the herbicide with regard to species spectrum and length of residual).

The objective of this study was to determine what changes do occur in a widespread non-native *Agropyron cristatum-Poa pratensis* community after an application of picloram. More specifically, we wanted to measure changes in yield and competition due to the loss of and reinvasion of species. Although these parameters must be observed for several years after application of the herbicide, only one year after picloram was applied some trends important to the land manager can be discussed.

Materials and Methods

On June 23, 1982 picloram was applied at 1.1 kg ai/ha with an airplane to an extensive infestation of leafy spurge on the N-Bar ranch near Grass Range, Montana. Two geographically different but vegetatively similar sites within the sprayed areas were selected for study.

Site one is on an alluvial fan with a grassland community type dominated by two introduced perennial grass species, *Poa pratensis* L. and *Agropyron cristatum* (L.) Gaertn. Leafy spurge was the dominant forb throughout the site. Examination of similar sites in the area indicate that before invasion this site was occupied by an *Agropyron smithii*

Rydg./*Stipa viridula* Trin. community type. Site one was cultivated and apparently planted to *Agropyron cristatum* in the early 1900s.

Records supplied by the ranch foreman indicate that cattle grazing on site one has been relatively light (60 AUM/year) for the past 8 years. Site one is located in a 1000 acre pasture. In 1982 there were 17 black angus steers in the pasture for 30 days, and in 1983 there were 23 yearling heifers placed in the pasture for 25 days.

Site two is located on a stream terrace in the bottom of a draw. The vegetation consists of a relatively undisturbed *Artemesia cana* Pursh/*Agropyron smithii* community type with *Poa pratensis* and *E. esula* as abundant invader species. Site two was grazed in 1982 and 1983 but no information was available on the level of grazing.

Three treatment blocks were established on each site. Plastic tarps (40 m by 12 m) were placed over half of each block during spraying to provide an unsprayed treatment. Barbed wire fences were then erected to provide an exclosure around half of each block creating four treatments per block; unsprayed-ungrazed, unsprayed-grazed, sprayed-grazed, and sprayed-ungrazed (Figure 2). No exclosures were used on site two.

Ten personal transects were established on each treatment plot. Each transect is 10 m long and they are 1.5 m apart. A 20 cm by 50 cm frame (0.1 m^2) was placed every 1.5 meters along two transects giving 10 subsamples within each plot. In each frame the percent canopy cover (Daubenmire, 1970) was estimated for perennial grasses as a group, for each forb and shrub species and for bare ground, rock, litter, lichens, and moss (Appendix, Tables 32-44). From the canopy cover data, percent composition relative to the other vegetation, percent frequency of species, and number of species could be determined. Perennial grasses were extremely intermixed, therefore canopy cover was estimated as a group, and presence and dominance were recorded for each species separately. The frames were placed at the same locations each year. A complete list of the species and the elements measured is included in the Appendix (Table 31).

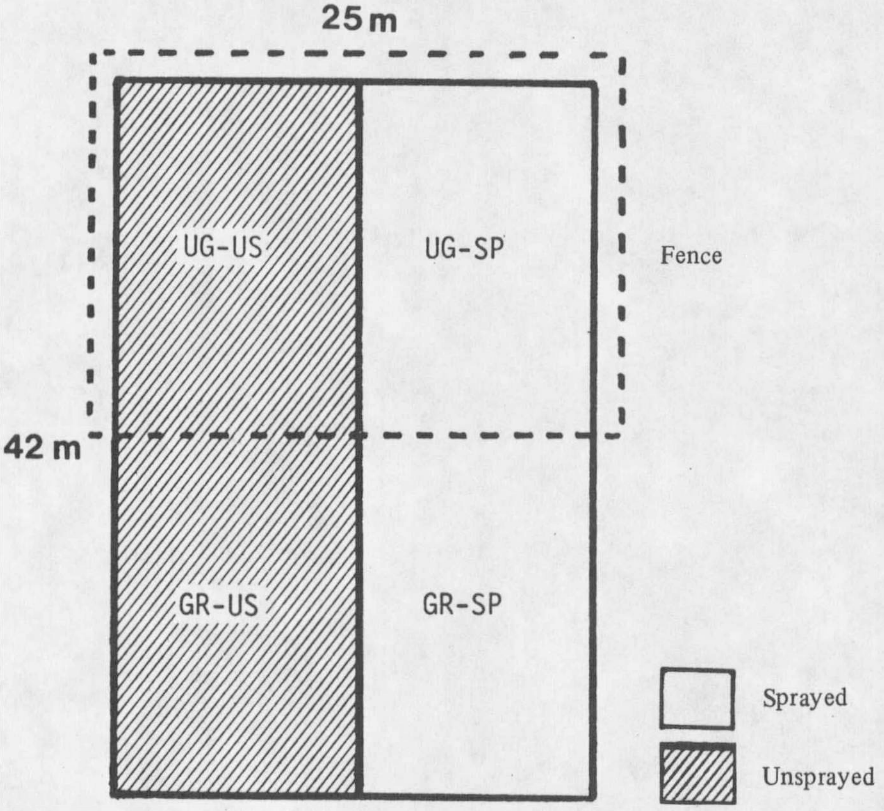

Figure 2. Treatment diagram showing unsprayed area (US), sprayed (SP), grazed (GR) and ungrazed area (UG) of a block on site one at the N-Bar Ranch.

For biomass determinations five half square meter frames were placed at a different point each year along fixed transects within each plot and in a predetermined pattern. Plant material was clipped 3 cm above ground and current year growth was separated and saved. Plants were divided into species groups (perennial grass, perennial and biennial forbs, leafy spurge, annual forbs, and shrubs) and oven dried at 50 C for 48 hours to obtain dry weight biomass. Percent canopy cover and dry weight biomass was measured in 1982 one month after herbicide application, and, in 1983, thirteen months after application at maximum standing crop. Maximum standing crop was assumed, in both years, to coincide with the late bloom growth stage of leafy spurge.

There are limitations to the methods employed in this study. Composition, frequency, and number of species data are all derived from canopy cover estimations. While these data are subjective they are useful for comparing results from year to year because the frames were placed at the same location within a treatment in successive years. In contrast, the biomass measurements were taken from frames placed in different locations each year, so the data reflect variation in biomass both from year to year and from new frame locations each year. Statistical analysis assumed a randomized complete block design and significance was determined at the 5% level using the LSD test.

Results and Discussion

The vegetation on both sites was similar and responded similarly to picloram, therefore a general discussion for both sites is appropriate. In this regard three points should be noted. (1) Site one had a greater variety of perennial forbs while site two had a larger shrub component. (2) Initial (1982) effects were only measured at site one. Data was first collected one month after application to describe the immediate impact of picloram and to compare the sensitivity of species in the plant community. (3) The grazing factor was only measured at site one and was highly variable because of heavy use by cattle in the area immediately surrounding the exclosures.

Variation in annual precipitation caused fluctuations in the vigor of the vegetation which confounded comparisons between years. Monthly precipitation data (Appendix, Table 45) was obtained from Grass Range, Montana which is approximately 19 km from site one and 11 km from site two on the N-Bar ranch. There was 49 cm, 54 cm, and 26 cm of precipitation in 1981, 1982 and 1983, respectively. However, in 1981 and 1982 in the months of May and June a high level of precipitation occurred which increased forb vigor and encouraged the growth of certain annuals.

Cover and biomass data showed that leafy spurge decreased 13 months after application of picloram at both sites (Tables 1 and 2). Differences between treatments one month after application were not consistent because the effect of picloram on leafy spurge occurs slowly. The decrease in leafy spurge 13 months after application was consistent with decreases measured in other studies where picloram was used to control leafy spurge (Lym and Messersmith, 1981; Whitson and Alley, 1983).

Table 1. The Biomass and Canopy Cover of Leafy Spurge 1 Month and 13 Months After Application of Picloram in 1982.

	Leafy Spurge Biomass (kg/ha)[1]			Leafy Spurge Canopy Cover (%)[1]		
	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983
Ungrazed:						
Unsprayed	335 a	420 b	—	17 b	16 b	—
Sprayed	218 a	16 a	—	8 a	3 a	—
Grazed:						
Unsprayed	611 b	583 b	569 b	27 c	39 c	48 b
Sprayed	243 a	34 a	14 a	10 a	2 a	0.4 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 2. The Percent Composition and Frequency of Leafy Spurge 1 Month and 13 Months After Application of Picloram in 1982.

	Leafy Spurge Composition (%)[1]			Leafy Spurge Frequency (%)[1]		
	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983
Ungrazed:						
Unsprayed	10 a	13 a	–	100 a	93 b	–
Sprayed	22 b	3 a	–	80 a	57 a	–
Grazed:						
Unsprayed	26 b	29 a	69 b	100 a	100 b	96 b
Sprayed	13 ab	31 a	0.9 a	90 a	53 a	33 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

By most measures the other perennial and biennial forbs decreased in response to picloram in both 1982 and 1983. Exceptions were the number of species and the percent frequency at site one in 1982 (Tables 3 and 4). Most of the species originally present were still present one month after spraying, although most displayed herbicide injury symptoms (epinasty and wilting).

Table 3. The Biomass, Canopy Cover and Number of Perennial and Biennial Forb Species 1 Month and 13 Months After Application of Picloram in 1982.

	Biomass (kg/ha)[1]			Canopy Cover (%)[1]			Number of Species[1]		
	Site 1		Site 2	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983	1982	1983	1983
Ungrazed:									
Unsprayed	828 c	95 b	–	30 b	16 c	–	13 a	13 b	–
Sprayed	57 a	0 a	–	12 a	0 a	–	9 a	0 a	–
Grazed:									
Unsprayed	426 b	78 b	2 b	25 b	9 b	2 b	10 a	12 b	4 b
Sprayed	54 a	0 a	0 a	13 a	0.2 a	0 a	10 a	1 a	0 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 4. The Percent Composition and Frequency of Perennial and Biennial Forbs 1 Month and 13 Months After Application of Picloram in 1982.

	Composition (%)[1]			Frequency (%)[1]		
	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983
Ungrazed:						
Unsprayed	34 c	13 b	–	100 a	97 c	–
Sprayed	16 a	0 a	–	100 a	0 a	–
Grazed:						
Unsprayed	25 b	7 ab	2 b	100 a	97 c	53 b
Sprayed	17 ab	2 a	0 a	100 a	20 b	0 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

In comparing grazed and ungrazed treatments on unsprayed plots there was an increase of leafy spurge on grazed areas and a decrease of other perennial and biennial forbs as measured by some of the parameters. Comparison of grazed with ungrazed plots that were sprayed indicated that the grazing factor had no effect on perennial and biennial forbs (including leafy spurge). Statistically significant differences were not consistent enough between parameters measured or between years to determine a trend of perennial and biennial forb response to grazing.

The drastic decrease in perennial and biennial forb biomass and percent composition from 1982 to 1983 on unsprayed areas was attributed primarily to the behavior of the biennial, yellow sweet clover [*Melilotus officinalis* (L.) Lam.]. The relatively wet spring in 1981 encouraged the growth of the sweet clover, a large forb that requires moisture for establishment. After establishment the plant will complete its life cycle under dry conditions (Turkington et al., 1978). The relatively moist spring of 1982 increased the vigor and ultimately the biomass of the sweet clover. Very little precipitation occurred in the spring of 1983 so sweet clover was not present (Appendix, Table 45). Other forbs that may have been encouraged to grow by the wet spring in 1982 were *Medicago lupulina* L., *Solanum triflorum* Nutt., and *Bahia oppositifolia* (Nutt.) Gray.

The response of black medic (*Medicago lupulina*), the only significant annual forb species, is seen in most of the annual forb parameters measured in 1982 (Tables 5 and 6). There was very little black medic present in 1983 because of the dry spring.

Table 5. The Biomass, Canopy Cover and Number of Annual Forb Species 1 Month and 13 Months After Application of Picloram in 1982.

	Biomass (kg/ha)[1]			Canopy Cover (%)[1]			Number of Species[1]		
	Site 1		Site 2	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983	1982	1983	1983
Ungrazed:									
Unsprayed	–	0.7 a	–	9 b	0.4 a	–	2 a	2 a	–
Sprayed	–	1.5 a	–	4 a	0.4 a	–	2 a	1 a	–
Grazed:									
Unsprayed	–	1.5 a	–	11 b	1.0 b	0.12 a	2 a	2 a	1 a
Sprayed	–	0 a	–	3 a	0.1 a	0.02 a	2 a	1 a	0 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 6. The Percent Composition and Frequency of Annual Forbs 1 Month and 13 Months After Application of Picloram in 1982.

	Composition (%)[1]			Frequency (%)[1]		
	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983
Ungrazed:						
Unsprayed	10 ab	0.3 a	–	83 ab	40 ab	–
Sprayed	5 ab	0.4 a	–	93 ab	27 ab	–
Grazed:						
Unsprayed	11 b	0.8 a	0.2 b	97 b	50 b	20 a
Sprayed	4 a	2.4 a	.04 a	70 a	17 a	3 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Artemesia cana, the only shrub species present on site two, was well represented and became increasingly visible as the leafy spurge died. Picloram caused a reduction in canopy cover and biomass (current year growth) of this species, however the decrease in biomass was not statistically significant (Table 7). On site one there were three shrub species (*Rosa* *arkansana* Porter, *Gutierrezia sarothrae* (Pursh) Britt. & Rusby., and *Chrysothamnus nauseous* (Pall.) Britt.), but all were widely scattered and contributed little to the parameters studied.

Table 7. The Biomass, Canopy Cover and Number of Shrub Species 1 Month and 13 Months After Application of Picloram in 1982.

	Biomass (kg/ha)[1]			Canopy Cover (%)[1]			Number of Species[1]		
	Site 1		Site 2	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983	1982	1983	1983
Ungrazed:									
Unsprayed	0 a	0 a	–	0.5 a	0.3 ab	–	3 a	3 a	–
Sprayed	0 a	0 a	–	0 a	0 a	–	0 a	0 a	–
Grazed:									
Unsprayed	25 a	19 b	17 a	1.2 b	0.6 b	3.0 b	3 a	3 a	1 a
Sprayed	0 a	0 a	15 a	0.3 a	0 a	0.4 a	1 a	0 a	1 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Perennial grasses, the important forage species for cattle, were examined in detail. After one year there were no differences in the number of perennial grass species between treatments. One month after spraying under both grazed and ungrazed conditions there was an increase in perennial grass biomass in response to picloram (Table 8).

Table 8. The Biomass, Canopy Cover and Number of Perennial Grass Species 1 Month and 13 Months After Application of Picloram in 1982.

	Biomass (kg/ha)[1]			Canopy Cover (%)[1]			Number of Species[1]		
	Site 1		Site 2	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983	1982	1983	1983
Ungrazed:									
Unsprayed	1125 a	1337 ab	–	40 a	90 b	–	–	4 a	–
Sprayed	1535 b	1545 b	–	45 a	96 c	–	–	5 a	–
Grazed:									
Unsprayed	1027 a	1262 a	1203 a	40 a	83 a	77 a	–	5 a	5 a
Sprayed	1462 b	1395 ab	1178 a	54 b	92 b	88 b	–	6 a	5 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

It appears that the perennial grasses occupied the open niches created by the disappearance of forbs sensitive to picloram since an increase in perennial grass canopy cover and composition was measured both years on sprayed plots (Tables 8 and 9). The release of competition with forbs for moisture and nutrients allowed an increase in grass biomass within one month. One year after application of picloram the increase in grass biomass on sprayed treatments was not significant, although the canopy cover did remain significantly greater. There may be an initial growth response of the grasses to reduced competition followed by picloram-induced inhibition of production one year after application. The possibility that grasses in the sprayed areas were under stress from picloram one year after application is supported by the observation of Scifres and Halifax (1972a) that picloram reduced root production of some perennial grass species. This might have occurred if much of the picloram initially intercepted and absorbed by the vegetation moved, the following year, into the root zone where it could effect perennial grass root growth. It is also possible that the grasses in sprayed areas were under greater moisture stress in 1983. Moisture stress would have been less severe on unsprayed areas in 1983 if persistent leafy spurge stems from unsprayed plants caught snow and increased moisture recharge.

Table 9. The Percent Composition and Frequency of Perennial Grasses 1 Month and 13 Months After Application of Picloram in 1982.

	Composition (%)[1]			Frequency (%)[1]		
	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983
Ungrazed:						
Unsprayed	45 ab	74 a	–	100 a	100 a	–
Sprayed	58 bc	97 b	–	100 a	100 a	–
Grazed:						
Unsprayed	38 a	63 a	77 a	100 a	100 a	100 a
Sprayed	66 c	98 b	88 b	100 a	100 a	100 a

[1] Means within each column followed by the same letter are note statistically different at the 5% level as determined by the LSD test of significance.

Competition from the forbs on the unsprayed plots, and some utilization of the grass on the grazed-unsprayed treatment could account for the biomass and canopy cover difference between the ungrazed-sprayed and grazed-sprayed treatments in 1983.

Perennial grass presence was measured for each species as percent occurrence (frequency) and percent dominance within the perennial grass group one year after application of picloram (Table 10). *Poa pratensis* decreased 10% in dominance from unsprayed to sprayed and *Agropyron cristatum* increased 10% in both occurrence and dominance after spraying. *Agropyron smithii* was never dominant and decreased in occurrence 26% on sprayed areas. None of these changes from unsprayed to sprayed treatments were significant at the 5% level which may be due to variability between frames caused by the typically aggregated growth habit of some of the species. Despite the variability the trend in response to picloram appears to be toward a grass monoculture where *A. cristatum* and *P. pratensis* will be the major components. When grazing is also imposed upon the community the species response may differ slightly but the general trend toward a few grass species is the same.

Table 10. The Percent Frequency of Perennial Grass Species 13 Months After Application of Picloram on Ungrazed Areas.[1]

	Unsprayed		Sprayed	
Species	% Occurrence	% Dominance	% Occurrence	% Dominance
Poa pratensis	100	67	100	57
Agropyron cristatum	67	33	77	43
Agropyron smithii	83	0	57	0
Koeleria cristata	53	0	47	0

[1] There was no differences between unsprayed and sprayed treatments for any of the species in occurrence or dominance at the 5% level of significance as determined by the LSD test of significance.

Total biomass decreased from unsprayed to sprayed treatments both years but the decrease was only significant on grazed areas of site one in 1983 (Table 11). Increased grass production as a result of decreased forb competition and niche filling in the plant community apparently does not make up for the loss in forb biomass from the herbicide.

Table 11. The Biomass, Canopy Cover and Number of Total Species 1 Month and 13 Months After Application of Picloram in 1982.

	Biomass (kg/ha)[1]			Canopy Cover (%)[1]			Number of Species[1]		
	Site 1		Site 2	Site 1		Site 2	Site 1		Site 2
Treatments	1982	1983	1983	1982	1983	1983	1982	1983	1983
Ungrazed:									
Unsprayed	2319 a	1853 b	–		106 b	–	–	21 b	–
Sprayed	1809 a	1561 ab	–		93 a	–	–	7 a	–
Grazed:									
Unsprayed	2092 a	1944 b	1789 a		97 a	82 a	–	21 b	12 b
Sprayed	1794 a	1429 a	1208 a		92 a	88 b	–	9 a	7 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

A trend in vegetative diversity is best determined by the number of plant species in each treatment. There has been a significant decrease in the number of species since picloram was applied. All of the species lost were forbs.

In order to simplify interpretation of the biomass response to picloram and eliminate the variation caused by fluctuation in annual precipitation, the sprayed treatments on grazed and ungrazed areas from site one were compared to the control (ungrazed-unsprayed treatment). This method of analysis indicates that grazing was a significant factor only on perennial grasses in 1983 (Table 12).

In order to avoid the complexity of interacting factors (herbicide, precipitation, and grazing) when trying to identify trends it was important to look at only gross changes in the plant community. Two trends that potentially are the most important with regard to management implications will be discussed.

Table 12. The Change in Biomass for Each Year Measured as a Percent Increase or Decrease from the Control Which Was Ungrazed and Unsprayed.

	Leafy Spurge (%)		Perennial and Biennial Forbs (%)	
Treatments	1982	1983	1982	1983
Ungrazed-sprayed	-35	-96*	-92*	-100*
Grazed-sprayed	-27	-92*	-93*	-100*
	Perennial Grasses (%)		Total Vegetation (%)	
Ungrazed-sprayed	+36*	+16	-23	-16
Grazed-sprayed	+30*	+4	-23	-23*

*Differences from the control are significant at the 5% level as determined by the LSD test of significance.

The trend of decreasing number of forbs on sprayed areas represents a decrease in species diversity in the community. A decrease in diversity is theoretically associated with both decreased ecosystem stability and decreased yield on grasslands (McNaughton, 1971; Spedding, 1971; Whittaker, 1970).

If the decrease in herbaceous species includes legumes, an important nitrogen source in the rangeland ecosystem may be lost (Anon., 1972). Four legume species (*Melilotus officinalis, Medicago lupulina, Trifolium* sp., and *Vicia americana* Muhl.) were lost from the community as a result of spraying picloram.

A diverse rangeland flora may be less susceptible to loss from climatic extremes or insect attack (Vallentine, 1971). Severe and extreme drought occurred in 51 of the 432 months between March 1931 and June 1966 in central Montana (Magnuson, 1967). The two grass species which responded with increased production after picloram application are differentially sensitive to drought. *Agropyron cristatum* is quite drought resistant while *Poa pratensis,* the most common species is relatively drought sensitive. Therefore, after an application of picloram a prolonged drought could eliminate the *P. pratensis* and select for an *A. cristatum* monoculture in the community.

The second trend, reinfestation and invasion of new species as a result of herbicide application should be monitored to determine which species will fill the empty niches. No new species have become established in the first year after application. The perennial grasses responded quickly and thoroughly to refill the empty niches before forbs could invade. The residual characteristic of picloram may retard forb invasion.

Leafy spurge is not erradicated by picloram at the 1.1 kg ai/ha rate (Vore and Alley, 1980). Regrowth from the root system is expected to begin the second season after application when the residual level of picloram in soil falls below an inhibitory level. In the present study leafy spurge regrowth was observed one year after spraying. Since leafy spurge is one of the least sensitive forbs to picloram it will probably reinfest a treated site sooner than most of the other forb species. The rate and extent of leafy spurge reinfestation will depend in part on the competitive ability of the grass species that were little affected by the picloram (Selleck et al., 1962).

Summary

Considering these trends there is mounting evidence that application of picloram to large leafy spurge infestations will not provide stable, long-term productive range plant communities. The dilemma remains that picloram is still the most effective tool available for controlling leafy spurge. We conclude that the application of picloram for leafy spurge control should be restricted to small pioneer patches where entire plant communities will not be subjected to the detrimental effects of the herbicide. Further analysis of the present sites as well as other treated plant communities will help quantify the long-term effects of picloram on rangeland.

CHAPTER 3

THE EFFECT OF GLYPHOSATE ON THE REGULATION OF BUD DORMANCY IN LEAFY SPURGE

Abstract

Glyphosate [N-(phosphonomethyl)glycine] was applied to leafy spurge (*Euphorbia esula* L.) in the field at sublethal and lethal rates. A proliferation of growth ("witches' broom") was observed on stems of leafy spurge plants that were treated with glyphosate the previous spring. Fall applications of glyphosate stimulated witches' broom growth and an increase in the number of stems/m^2 as a result of bud growth on the crown region of the root system. Approximately 83% of the total ^{14}C-glyphosate applied to the leaves of senescing plants was absorbed. There was a decrease in the amount of labelled glyphosate translocated out of the treated leaf as applications were made later in the season. The accumulation of ^{14}C-glyphosate in the treated stem, root crown, and primary root remained constant throughout the growing season. Secondary roots accumulated 25% of the absorbed ^{14}C-glyphosate when applications were made to plants in the pre-bloom stage, but the percentage declined when applications were made at more advanced growth stages. The highest concentration of labelled glyphosate other than the treated leaf was in the root crown buds of plants that were senescing at the time of application. Increased concentration of ^{14}C-glyphosate in the root crown buds of senescing plants may be directly related to the number of buds released from dormancy the following summer.

Introduction

Leafy spurge is difficult to control because effective concentrations of herbicides are not translocating throughout the root system, or are bypassing the dormant root and crown buds from which regrowth occurs (Galitz and Davis, 1983). In order to provide long term control of leafy spurge with herbicides, the chemicals must control growth of all the dormant buds on the root system.

In field studies we observed prolific growth from lateral buds on the stem and upper root of leafy spurge plants that were sprayed with glyphosate. Glyphosate at sublethal rates causes tillering, and witches' broom growth on other plants (Baur et al., 1977; Coupland and Caseley, 1975; Swanson and Shuman, 1982). This indicates that glyphosate can temporarily overcome apical dominance either directly or indirectly which results in uncharacteristic bud growth. The ability to manipulate bud growth would be a significant step toward control of many perennial weed species.

The objectives of this study were to measure the field response of leafy spurge to glyphosate applied at several stages of plant growth, and to monitor the movement of ^{14}C-glyphosate in the root system of mature plants grown under field conditions. This information can be used to determine if a relationship between the pattern of glyphosate movement in leafy spurge, and lateral bud release from dormancy exists.

Materials and Methods

Field Studies

The isopropylamine salt of glyphosate was applied to leafy spurge at 0.14, 0.28, 0.56, 1.12, and 4.48 kg ai/ha on September 11, 1982 to plants in the senescent growth stage, and on June 2, 1983 to plants in the pre-bloom stage of growth. Applications were made with a CO_2 pressurized backpack sprayer delivering 91.6 liters/ha of water at 275.8 kPa pressure with a flat fan nozzle. The experimental design was a randomized complete block with 3 replications. The experiment was conducted at two locations in south central Montana. The number of leafy spurge stems/m^2 at the soil surface were counted on May 23, 1983 and August 8, 1983 on plots that were sprayed on September 11, 1982 at location one. At the same location on September 2, 1983, stem counts/m^2 were taken on plots that were sprayed on June 1, 1983.

Translocation Experiments

The leafy spurge plants used in this experiment were established in 1965 at the Post Research Farm, Bozeman, Montana in metal canisters (17.8 cm in diameter by 90 cm deep) that were placed inside 20 cm diameter by 90 cm deep concrete cylinders sunk into the ground on 1.2 meter centers. The entire volume of the canister was filled with mature root material. Herbicide treatments were applied at the pre-bloom (June 2, 1983), full bloom (July 25, 1983), and senescent (September 5, 1983) growth stages. The treatments were replicated 4 times.

Commercially formulated glyphosate applied as in the field was sprayed on randomly selected plants at 1.1 kg ai/ha. Immediately after application radioactive glyphosate (440,000 dpm's) was applied in 10 one μl drops to the adaxial surface of one leaf. The leaf to be treated was located by measuring the height of the plant then choosing the leaf that was closest to 2/3 the height. A paper tag was used to mark the treated leaf.

Radioactive glyphosate[2] was received as glyphosate-methyl-^{14}C (34 uCi) with a specific activity of 1.97 mCi mM^{-1}. All the ^{14}C-glyphosate (2.96 mg) was dissolved in 70% ethylamine (1.64 μl) and brought to a 500 μl (.5 ml) total volume with distilled water

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[2] Radioactive ^{14}C-glyphosate was donated by Monsanto Agric. Products Co., St. Louis, MO 63166.

and 0.25% v/v MON 0818[3] non-ionic surfactant added. From this stock solution a 155 μl aliquot was added to 196 μl of non-labelled, commercially formulated glyphosate (1.1 kg ai/ha) taken from the spray tank used to make the broadcast application on the first treatment date. This provided a 351 μl total volume with 7.02 uCi of activity that was used for all the treatments over the 1983 growing season. Ten μl of ^{14}C-glyphosate was applied directly into a scintillation vial containing 15 ml of Hydrocount[4] at each growth stage application to determine the exact amount of radioactivity applied to each plant.

A stiff support wire was inserted into the ground to hold the treated leaf in a horizontal position. White plastic tents sheltered the plants to prevent loss of ^{14}C-glyphosate by rain or wind.

Plant material was collected 48 and 120 hours after application at each growth stage. Each treatment was replicated four times. The metal canisters were removed from the field, and cut longitudinally with tin shears. Before the soil and plant material were removed from the canister, the treated leaf was washed with a stream (40 ml) of distilled water into a 60 ml vial. The treated leaf was then removed from the plant, placed in the same 60 ml vial, and agitated for 20 seconds to ensure removal of the ^{14}C-glyphosate from the surface of the leaf. The vial was brought to a 60 ml volume with distilled water and a 1 ml aliquot was removed and placed in a scintillation vial with 15 ml of Hydrocount.

The soil plus plant material was rolled out of the metal canister onto a 1 m by 1.1 m sheet of galvanized metal that was placed on an incline with a screen at the base to catch all the plant material that might break off during washing. Before washing, all loose root material was collected as a separate sample. Soil was gently washed from the root system,

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[3] MON 0818 is a non-ionic surfactant, manufactured by Monsanto Agric. Products Co. and included in the commercial formulation.

[4] Hydrocount is manufactured by J. T. Baker Chemicals B. V., Deventer, Holland.

and the treated plant was carefully separated from other plants growing in the same canister. The additional plants not attached to the treated plant were grouped into a single sample for each canister (replication). The treated plant was divided into zones 1 through 6 for further sampling (Figure 1).

Zone one, the above ground portion of the plant, consisted of the treated leaf, the stem and other leaves, additional stems originating from the treated plant, and a leaf wash collection from the treated leaf. Zones two through six consisted of dormant pink buds, the main root of the treated stem (primary root), and all remaining root material (secondary roots). Each treated plant was cut into zones by first removing the shoots then determining the base of the root crown as the point where the upper main root narrows or the point where the first major secondary root originates. The rest of the root system was measured and divided into four equal length zones (15-18 cm). The primary root was cut free of all other root material in each zone, the dormant (pink) buds were counted, and a percentage of the buds were removed for a sample. After all the samples were collected from a treated plant (Table 45), the plant material that remained on the screen was collected as a sample, and an estimated percentage of the soil that came from the canister was also collected as a sample.

The samples were placed in paper bags, labelled, and taken to the lab to be oven dried at 55 C for 48 hours. Each sample was then weighed, and homogenized with mortar and pestle. Aliquots (5-300 mg) of ground material were weighed and then oxidized in a biological material oxidizer[5] for three minutes. The ^{14}C was trapped in Carbon 14 Cocktail[6] as $^{14}C\text{-}CO_2$. The ^{14}C content was measured for 10 minutes in a liquid scintillation spectrometer.[7] These data were analyzed using a completely randomized design.

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[5] Harvey Oxidizer, Ox 300, Harvey Instrument Co., 123 Patterson St., Hillsdale, NJ.

[6] Carbon 14 Cocktail is manufactured by R. J. Harvey Instrument Corp.

[7] Tri-Carb model 2002, Packard Instrument Co., Downers Grove, IL.

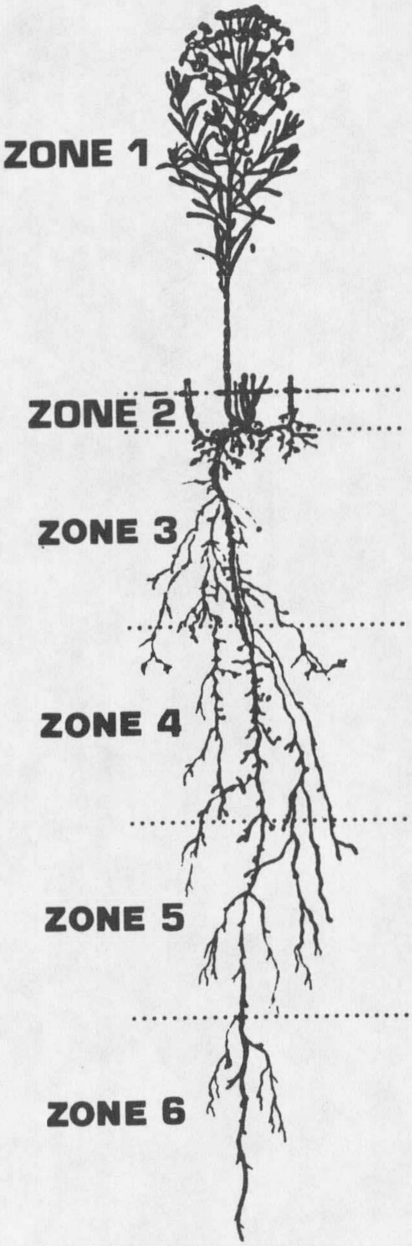

Figure 3. The zones of the leafy spurge plant from which samples were collected to determine regions of ^{14}C-glyphosate accumulation.

Results and Discussion

Field Experiments

Glyphosate applied in the spring to plants in the pre-bloom growth stage caused a proliferation of axillary branching (witches' broom) on stems two months after application. There was no effect on the number of stems m^{-2} at the soil surface (Table 13). Fall applications of glyphosate stimulated bud growth initiation on the root crown and upper portions of the root system which resulted in almost a three-fold increase in the number of stems at the soil surface, an effect that was not observed until the middle of the following growing season (Table 13). Earlier in the season, the number of stems m^{-2} was significantly decreased and no witches' broom growth was observed. The delayed effect observed may be the result of prolonged glyphosate activity within the plant since glyphosate is resistant to degradation in leafy spurge and other higher plants (Gottrup et al., 1976).

Table 13. The Effect of Glyphosate, Applied Under Field Conditions in the Spring at the Pre-Bloom Growth Stage and Fall at the Senescent Stage, on Leafy Spurge Stem Production.[1]

	Stems per Square Meter at the Soil Surface		
	Growth Stage at Application		
	Pre-bloom	Senescent	
	Date of Measurement[2]		
Glyphosate (kg/ha)	(9-2-83)	(5-23-83)	(8-8-83)
.14	1151 b	151 c	506 a
.28	915 ab	129 bc	829 a
.56	1033 b	54 a	829 a
1.12	732 a	75 ab	1345 b
4.48	—	43 a	1474 b
Untreated	753 a	226 d	560 a

[1] Data are averages of 16 replications for each treatment.

[2] Means within the column followed by the same letter are not significantly different at the 5% level using LSD test.

The differential bud growth response to glyphosate applied at different growth stages prompted an investigation into the nature of glyphosate translocation when the herbicide was applied at different growth stages.

Translocation Experiments

This study was designed to closely simulate field conditions in order to provide a detailed analysis of the translocation pattern of glyphosate in mature roots of leafy spurge. Previous studies (Bybee, 1979) of glyphosate movement in leafy spurge were conducted with immature plants (Gottrup et al., 1976).

The ^{14}C-glyphosate was readily absorbed by leafy spurge plants at all growth stages (Table 14). The maximum absorption occurred when plants were in the senescent growth stage when 83% of the total ^{14}C applied was absorbed by 120 hours after application. At this growth stage the treated leaf retained the largest percentage of the absorbed ^{14}C-glyphosate (Table 15).

Table 14. The Percent of ^{14}C-Glyphosate That was Absorbed by Leafy Spurge Plants 48 and 120 Hours After Application.[1]

Treatment Date	Plant Stage at Application	Percent ^{14}C-Glyphosate Absorbed Time After Application[2] 48 Hours	 120 Hours
6- 2-83	Pre-bloom	58 a	63 a
7-25-83	Full bloom	56 a	76 a
9- 5-83	Senescent	55 a	83 a

[1] Data are averages of four replications.

[2] Means within the column followed by the same letter are not significantly different at the 5% level using the LSD test.

Glyphosate moved readily throughout the plants at all growth stages. In general, more label accumulated in the root system than in the root crown and stem. Translocation out of the treated leaf was greatest when glyphosate was applied to leafy spurge plants in the prebloom growth stage. This pattern of movement may be due to early season growth in

Table 15. The Percent of Absorbed ^{14}C-Glyphosate in the Treated Leaf, Treated Stem, and Additional Stems Emanating From a Common Root Crown Area of Leafy Spurge.[1]

Herbicide Application Date	Growth Stage at Application	Percent of Absorbed ^{14}C-Glyphosate[2]		
		Treated Leaf	Treated Stem	Untreated Stems
6- 2-83	Pre-bloom	48 a	8 a	3.0 b
7-25-83	Full bloom	57 ab	7 a	0.3 a
9- 5-83	Senescent	61 b	10 a	0.8 a

[1] Data are averages from four replications.

[2] Means within a column followed by the same letter are not significantly different at the 5% level using the LSD test.

shoots and secondary roots. Sprankle et al. (1975) found glyphosate moved to areas of high metabolic activity in both perennial and annual plant species.

Non-treated stems originating from root buds on the treated plant accumulated significantly more glyphosate early in the growing season (Table 15). The percent of absorbed ^{14}C-glyphosate in the treated stem was unaffected by the growth stage.

Growth stage did not effect the distribution of radioactivity in the root crown and primary root, but did significantly effect the distribution of label in secondary roots (Table 16). The secondary roots accumulated 25% of the absorbed ^{14}C-glyphosate applied to plants in the pre-bloom stage. Plants in the senescent stage at application time accumulated only 6% of the absorbed ^{14}C-glyphosate in the secondary roots. This pattern of accumulation may be due to sink attraction as a result of increased secondary root growth early in the growing season. Glyphosate is probably moving in the symplast with the assimilates (Gougler and Geiger, 1981).

Leafy spurge plants have a large secondary root system (Coupland and Alex, 1955). While a high percentage of the absorbed glyphosate accumulated in the secondary root system, the effect was not lethal because the herbicide is spread throughout a large volume

Table 16. The Percent of Absorbed ^{14}C-Glyphosate Found in the Root Crown, Primary and Secondary Roots, and Root Buds of Leafy Spurge 120 Hours After Application at Three Growth Stages.[1]

Treatment Date	Growth Stage at Application	Percent of Absorbed ^{14}C-Glyphosate[2] Root Crown	Primary Root	Secondary Roots	Root Buds
6- 2-83	Pre-bloom	3 a	11 a	25 b	0.5 a
7-25-83	Full bloom	5 a	14 a	13 ab	0.2 b
9- 5-83	Senescent	4 a	13 a	6 a	0.9 c

[1] Data are averages of four replications.

[2] Means within a column followed by the same letter are not significantly different at the 5% level using the LSD test.

of tissue. The actual concentration of radiolabel expressed on a dry weight basis of secondary root material indicated a lower concentration per gram of tissue than in other portions of the root system (Table 17).

The amount of ^{14}C-glyphosate in the dormant buds on the root crown (Table 18) and primary root (Table 16) varied significantly with the growth stage at application. The lowest level of glyphosate found in the root and crown buds was observed when glyphosate was applied to plants in the full bloom growth stage (Table 16). There was more translocation of ^{14}C-glyphosate into root and crown buds when plants were in the pre-bloom stage, and the highest accumulation in these buds was measured when glyphosate was applied to plants that were senescing (Table 18).

Glyphosate and Bud Response

A relationship between glyphosate and the root bud growth response in leafy spurge is suggested by integrating the field observations with the translocation data. In early fall when leafy spurge plants are senescing, the crown and root buds are actively elongating. The active buds become sinks for glyphosate accumulation. Root bud elongation occurs over a relatively short period of time (2 to 4 weeks) but ceases before the new shoots

Table 17. The Concentration of ^{14}C-Glyphosate (expressed as DPMs per gram of oven dried tissue) in Different Parts of Leafy Spurge 48 and 120 Hours After Application.[1]

Plant Part	DPMs per Gram of Oven Dried Tissue Time After Application[2] 48 Hours	 120 Hours
Secondary roots	2,439 a	3,727 a
Primary root	6,027 ab	8,909 ab
Root crown	10,320 bc	15,090 ab
Root buds	9,321 ab	15,750 ab
Treated stem	10,880 bc	19,520 b
Crown buds	17,140 c	40,403 c

[1] Data were averaged over three application dates and four replications on each application date.

[2] Means within a column followed by the same letter are not significantly different at the 5% level using the LSD test.

Table 18. The Concentration of ^{14}C-Glyphosate (expressed as DPMs per gram of oven dried tissue) in Root Crown Buds of Leafy Spurge 48 and 120 Hours After Application at Three Stages of Growth.[1]

Herbicide Treatment Date	Growth Stage of Leafy Spurge at Application	DPMs per Gram of Oven Dried Tissue Time After Application[2] 48 Hours	 120 Hours
6- 2-83	Pre-bloom	22,060 a	18,800 a
7-25-83	Full bloom	12,280 a	22,660 a
9- 5-83	Senescent	17,080 a	79,750 b

[1] Data are averages of four replications.

[2] Means within a column followed by the same letter are not significantly different at the 5% level using the LSD test.

emerge from the soil (McIntyre, 1979). These buds then remain dormant over the winter until conditions suitable for growth occur the following spring.

The period of active bud growth in the fall is short, therefore the accumulation of glyphosate only reaches sublethal levels. When bud growth resumes in the spring, growth of the elongated buds is inhibited by glyphosate so that buds do not emerge until the middle of July. Growth inhibition was measured by stem counts (Table 13). When new shoots did appear midway through the growing season, witches' broom growth was observed, a characteristic of sublethal rates of glyphosate observed on other species (Baur et al., 1977; Coupland and Caseley, 1975; Swanson and Shuman, 1982). Further observations of plants sprayed in the fall indicated an increase in the number of elongating buds on the root crown the spring following application (Table 19). These observations indicate that glyphosate has the ability to remove apical dominance and increase crown bud elongation on leafy spurge plants. The loss of apical dominance may be the result of blockage of apical activity or a direct, overriding effect of glyphosate on the basal buds (Baur, 1979a).

Table 19. The Number of Elongating Buds on the Root Crown of Leafy Spurge Plants Which Were Sprayed With Glyphosate on September 11, 1982 at Two Locations in Montana.[1]

Glyphosate Application Rate	Number of Elongating Buds per Plant	
	Date of Counting[2]	
	5-23-83	8-8-83
(kg/ha)		
1.12	5.3 b	0.0 a
2.24	1.5 a	0.4 a
Untreated	0.3 a	0.2 a

[1] Data are averaged over two locations.
[2] Means within a column followed by the same letter are not significantly different at the 5% level using the LSD test.

Amrhein et al. (1980) and Jaworski (1972) reported that glyphosate may have the potential to release lateral buds from dormancy by inhibiting the synthesis of aromatic amino acids which are precursors to indoleacetic acid (IAA). In studies measuring the effect of glyphosate on auxin transport, Baur (1979b) concluded that glyphosate inhibited IAA transport, and consequently released lateral buds from apical dominance. The data and observations from the present studies support both mode of action theories. Further evidence for the inhibitory activity of glyphosate in relation to apical dominance is the witches' broom phenomena observed on leafy spurge. The witches' broom growth may be the result of an initial accumulation of glyphosate in apical meristems. When inhibitory levels are reached IAA synthesis or transport inhibition occurs and branches arise from buds immediately below the shoot apex. The branching continues because glyphosate is still intact and mobile therefore it moves to the new active apical meristem where it again slowly accumulates to inhibitory levels and the process of branching reoccurs. Plants displaying witches' broom growth eventually overcome the effect of glyphosate by dilution during branch production.

Summary

The release of bud dormancy on the root crown and lateral roots when the herbicide was applied at the senescent growth stage is the most important effect of glyphosate on leafy spurge. In terms of leafy spurge control, root buds are critical structures since they are under the control of an efficient growth regulation system that permits dormancy release of only one or two buds at a time following a major disturbance to the shoot (Raju, 1975; Raju and Marchuk, 1977). Effective alteration of the bud dormancy regulation system is the key to providing long term control of leafy spurge.

Future research should be conducted to determine how long glyphosate remains active and intact in leafy spurge plants, and how it is involved in release of dormancy in the buds when applied the previous growing season.

CHAPTER 4

THE EFFECT OF PULLING ON THE REGROWTH OF LEAFY SPURGE

Abstract

Leafy spurge (*Euphorbia esula* L.) pulls easily from the ground and a significant amount of root damage is incurred. Measurements were taken on stem diameter, length of root material pulled, and Joules required to pull leafy spurge plants from the soil. With a pulling force of 5.4 to 8.1 Joules, 2.4 to 4.8 cm of root material was removed from the ground. A timing experiment was established to determine the optimum time of year to pull leafy spurge. The most effective long term control occurred when plants were pulled on June 17, 1982, and July 8, 1983 when plants were in the early bloom and late bloom growth stages respectively. In a third experiment the effect of machine pulling of leafy spurge was compared to mowing, an application of 0.56 kg ai/ha of picloram (4-amino-3,5,6-trichloropicolinic acid), an application of 2.24 kg ai/ha of 2,4-D amine (2,4-dichlorophenoxy acetic acid), and application of 2,4-D amine (1.12 kg ai/ha) to regrowth after pulling and mowing. Two, 4-D applied alone in June provided the best control. None of the treatments (machine pulling, mowing, herbicide application, or herbicide applied to regrowth after pulling) significantly decreased the density of leafy spurge one year after application. Pulling may be used in the future to enhance infection of soil borne pathogens on leafy spurge.

Introduction

Leafy spurge is a deep rooted perennial weed of range and pasture lands (Messersmith and Lym, 1983). The plant reproduces by seed or vegetatively from underground root stocks. Herbicides are the most effective means of control but only when used repeatedly. New methods for controlling leafy spurge need to be developed which will permit consistent long term control.

Leafy spurge pulls easily by hand from the ground. When the stem is pulled the plant generally breaks off at the base of the thickened root crown and significant damage is incurred which could increase susceptibility to soil borne diseases. A large percentage of the buds from which regrowth occurs originate from the root crown, the transition zone between root and stem located just beneath the soil surface (Coupland and Alex, 1955; Coupland et al., 1955). Therefore, regrowth could be significantly decreased by pulling leafy spurge.

The objective of this study was to determine the feasibility of pulling to control leafy spurge. Three separate experiments were conducted to measure the energy required to pull leafy spurge, to determine the optimum time of the growing season to pull leafy spurge and to test the effectiveness of two pulling machine designs on controlling leafy spurge.

Methods and Materials

Torque Experiment

Measurements were taken on the stem diameter, length of root material pulled, and foot-pounds required to pull each plant from the ground to quantify root damage, and energy requirements to pull leafy spurge plants from soil. Fifteen plants were pulled at three sites. Site one had a moist silt loam soil. Site two was a dry silt loam soil. Site three is best described as rocks with very little soil in a dry condition.

A torque wrench was mounted on a stand with a lever arm from which a clamp was hung by a wire. The clamp was fixed to the base of a randomly selected leafy spurge stem and pulled. Foot pounds required to pull the plant were read directly from the torque meter on the wrench and converted to Joules. Prior to pulling, the stem diameter was measured 2 cm from the soil surface. The length of root material pulled from the soil was measured after pulling.

Time of Pulling Experiment

Experiments were established at two sites in south central Montana to determine the optimum time to pull leafy spurge. Site one is located in a low rainfall area (25 cm/year) eight miles south of Whitehall, Montana on a river terrace with a silt loam soil. Site two is a moist site (48 cm/year) located one mile northeast of Bozeman, Montana in a stream bottom with a clay loam soil. Plants were hand pulled every two weeks throughout the growing season from plots 2.1 m by 5.3 m.

Plants were hand pulled every two weeks beginning on May 11, 1982 and continued until August 17, 1982 on site one. On site two plants were pulled every two weeks starting on June 24, 1983 and ended on August 19, 1983. The experimental design was a randomized complete block with three replications of each pulling date treatment.

Two rating methods were used to compare leafy spurge control. Stem density counts were made in four random 0.09 m^2 locations in each plot at site one on September 1, 1982, June 12, 1983, and September 1, 1983. Visual ratings were taken on site one on May 24, 1984. On site two, stem counts were taken as described above prior to pulling, and regrowth stem counts as well as visual ratings were taken on June 5, 1984.

Machine Pulling Experiment

An experiment was initiated in June, 1983 to compare the effect of machine pulling of leafy spurge with mowing, herbicide applications, and applications of herbicide to regrowth after pulling and mowing. This experiment was established eight miles south of Whitehall, Montana on a dry sandy loam soil.

Two different pulling machines were tested (Figure 4). The first machine was designed by the authors and utilized two conditioner cylinders from a hay swather. The cylinders were mounted together and oriented perpendicular to the direction of travel. Leafy spurge stems feed into the conditioners which are spinning in opposite directions. The plant is pulled from the ground by the spinning and pinching action of the hay conditioner.

The other pulling machine design tested (Figure 5) is commercially available from Bourquin Design and Mfg. (Colby, Kansas) and was originally tested to pull weeds in row crops. It has dual wheels which are mounted parallel to the direction of travel which operate on the same pulling concept of pinching the stem between two spinning wheels which pulls the weed from the soil.

Two herbicides that are commonly used to control leafy spurge were compared to the cultural control treatments. The amine formulation of 2,4-D was applied at 2.24 kg ai/ha, and picloram was applied at .56 kg ai/ha. Mowing was done with a Jari Mower (Jari Division, Year Around Cab Corp., Mankato, Minnesota) with a one meter wide sickle bar.

Machine pulling, herbicide applications, and mowing treatments were established on June 29, 1983 when the leafy spurge plants were in the early bloom stage of growth. The leafy spurge regrowth on the pulled and mowed plots was treated with 2,4-D amine at 1.12 kg ai/ha on July 21, 1983 when regrowth had reached approximately 15 cm. One half of the plots where leafy spurge was pulled or mowed were not retreated. The regrowth on these plots was sprayed on September 1, 1983 with 1.12 kg ai/ha of 2,4-D amine when the leafy spurge plants had regrown to an average height of 20 cm.

The machine pulling experiment utilized a randomized complete block design with three replications. Each plot was 2.7 m by 9.1 m. The number of stems per 0.09 m^2 were counted prior to application on all the plots. On August 11, 1983, biomass of leafy spurge

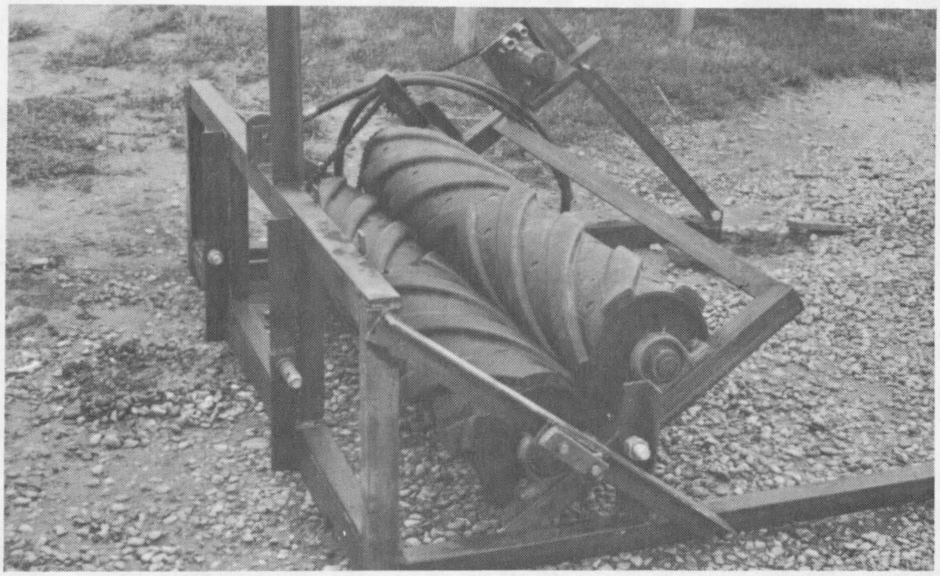

Figure 4. A tractor mounted, hydraulically driven machine developed by Montana State University weed researchers to pull leafy spurge plants from the ground.

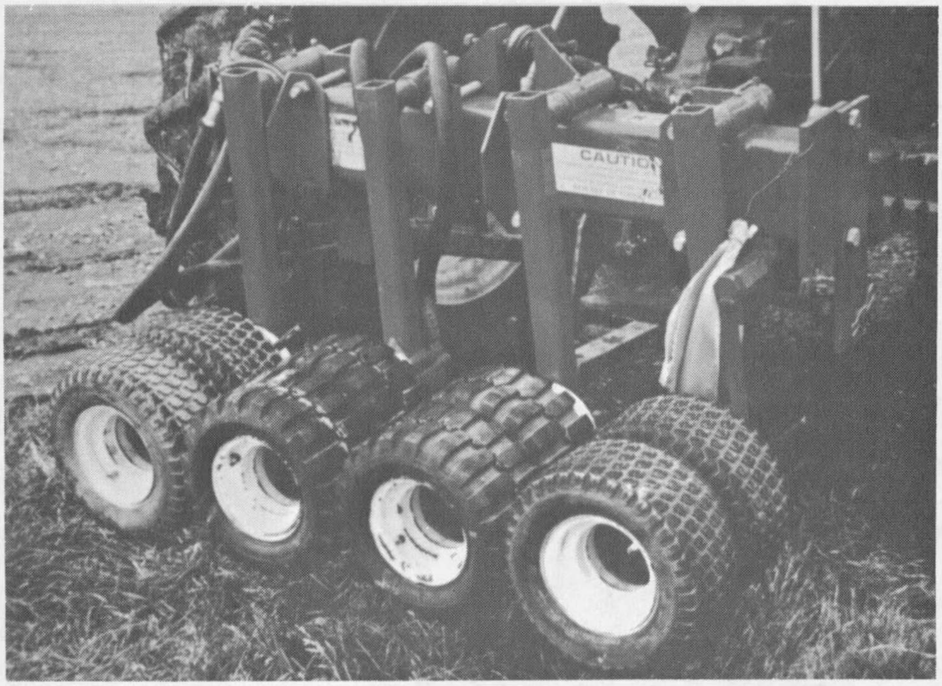

Figure 5. The tractor mounted, hydraulically driven Bourquin Weed Puller (Bourquin Design and Mfg., Colby, Kansas) design for pulling weeds from row crops.

and perennial grass was measured by clipping plant material 3 cm above the soil surface in a 0.09 m^2 area. The leafy spurge and perennial grasses were separated, and dryed in an oven at 50 C for 24 hours and weighed. On June 6, 1984, leafy spurge stems per 0.09 m^2 were counted, and visual ratings of percent leafy spurge control were conducted.

Results and Discussion

Torque Experiment

After it was observed that leafy spurge pulls easily from the soil, an experiment was conducted to quantify the energy required for pulling, and the root damage incurred as a result of pulling. Ortman et al. (1968) studied the vertical-pull technique for evaluating tolerance of corn root systems to root worms and found that pounds of vertical pull needed to pull a plant from the soil is an efficient and useful method of obtaining quantitative data on root system characteristics. In the same study it was determined that variation in the energy requirements for pulling corn plants was caused by different soil textures and soil moisture levels.

Approximately 2.4 to 4.8 cm of leafy spurge root material was removed from rangeland with a pull of 5.4 to 8.1 Joules (Table 20). The amount of energy required to pull leafy spurge did not vary with soil texture or soil moisture levels, however, root material was removed from a moist silt loam easier than from a dry silt loam soil. The average leafy spurge stem diameter was greater on moist silt loam than on dry silt loam soil, which may have been a factor influencing the amount of root material removed. There were no significant linear correlations between plant characteristics and plant damage.

Table 20. The Effect of Site Characteristics Including Soil Texture and Moisture, and Plant Characteristics (stem diameter and energy required to pull) on Root Damage Inflicted by Pulling Leafy Spurge.

Site Characteristics		Plant Characteristics[1]		Plant Damage[1]
Soil Texture	Soil Moisture	Stem Diameter (mm)	Energy Required To Pull (Joules)	Root Length Pulled (cm)
Silt loam	Moist	5.8 b	5.8 a	4.8 b
Silt loam	Dry	3.9 a	5.4 a	2.4 a
Rocky	Dry	4.3 ab	8.1 a	3.3 ab

[1] Means within a column followed by the same letter are not significantly different at the 0.05 level using the LSD test.

Time of Pulling Experiment

Visual evaluations of control were consistently higher than stand density counts because of the stunted nature of leafy spurge regrowth after hand pulling. Stunting of regrowth was still evident 15 months after pulling on site one. The most effective long term control of leafy spurge from hand pulling on site one was found on plots that were pulled on June 17, 1982 when the plants were in the early bloom growth stage (Table 21). One year after pulling there was a maximum of 35 percent leafy spurge control as determined by density. Visual ratings indicated 36 percent control on the same treatment at site one, two years after hand pulling. In a similar study pulling produced the best control of ragwort when the plants were in the flowering stage (Pool and Cairns, 1939).

Table 21. The Efficacy of Hand Pulling Leafy Spurge at Different Growth Stages on Site One.

Growth Stage at the Time of Pulling	Pulling Date	Percent Control Based on Stem Density[1]			Percent Control Based on Visual Rating[1]
		9-1-82	6-12-83	9-1-83	5-24-84
Pre-bloom	6-1-82	36 a	9 a	5 a	3 a
Early bloom	6-17-82	71 b	35 b	25 b	36 b
Mid bloom	7-19-82	94 c	27 ab	12 ab	17 ab
Mid bloom	8-3-82	95 c	22 ab	5 a	12 ab
Early seed	8-17-82	96 c	17 ab	2 a	5 a

[1] Means within a column followed by the same letter are not significantly different at the 0.05 level using the LSD test.

On site two visual ratings taken in June, 1984 indicated that maximum leafy spurge control occurred on plots pulled in late July and August of 1983 when the plants were in the early and late seed production stages (Table 22), however there was considerable variation so no statistically significant differences occurred between pulling dates. Density measurements confirmed the lack of significant differences, however, best control occurred when plants were in the late bloom stage of growth early in July which is consistent with the results at site one. The stunted appearance of regrowth again influenced the visual ratings for percent control.

Table 22. The Efficacy of Hand Pulling Leafy Spurge at Different Growth Stages on Site Two.

Growth Stage at the Time of Pulling	Pulling Date	Percent Control Based on Stand Density[1]	Percent Control Based on Visual Rating[1]
		6-5-84	6-5-84
Mid bloom	6-24-83	11 a	38 a
Late bloom	7-8-83	25 a	49 a
Early seed	7-22-83	20 a	56 a
Mid seed	8-5-83	21 a	51 a
Late seed	8-19-83	0 a	58 a

[1] Means within a column followed by the same letter are not significantly different at the 0.05 level using the LSD test.

Regrowth from plants that were pulled in the bloom stage or later did not produce seed the season of treatment at either site. On site one the optimum time for pulling leafy spurge for maximum long term control was June 17 when the plants were in the early bloom stage. On site two, the best time to pull in decrease density was July 8 when the plants were in the late bloom growth stage. Site one was a dry site with few competing plant species. Site two was relatively moist and had a dense grass stand which provided significant competition for regrowth. This may explain the greater degree of stunting of leafy spurge regrowth at site two as reflected in the visual ratings for percent control.

Machine Pulling Experiment

The pulling machine designed and fabricated at Montana State University could pull leafy spurge from sparse infestations but was not structurally capable of pulling a large number of plants at once, therefore data from treatments using the MSU puller were not included in the statistical analysis. The Bourquin Weed Puller could be adapted for use in pulling leafy spurge from pastures which are accessible to tractors.

Measurements taken during the season of application showed that 2,4-D applied at 2.24 kg ai/ha was the most effective treatment for control of leafy spurge (Table 23). Leafy spurge biomass was significantly reduced when 2,4-D was applied alone, and when pulling and mowing were followed by an application of 2,4-D to regrowth. Perennial grass biomass decreased following all mowing treatments, and after application of picloram. There was no regrowth of perennial grasses during the six week interval between treatment and biomass measurement for mowed treatments probably because of grazing by cattle. There was significant leafy spurge regrowth with these treatments which increased competition with the grasses. The decrease in perennial grass biomass following an application of picloram was probably due to grass injury from the herbicide and not from grazing since leafy spurge density was not reduced following herbicide use.

Cattle were released onto the machine pulling experiment location a few days after the treatments were made. Six weeks after treatment, increased cattle use was measured by counting cowpies per plot (Table 24). Color, thickness of crust, and flavor were used as criteria to age the cowpies to ensure they were plopped after treatment. It was reasonable to assume cattle use as indicated by cowpie density since plot borders were vigorously infested by a dense stand of leafy spurge which cattle avoid due to an irritant contained in the plant (Selleck et al., 1962). Cattle use increased but not significantly on plots where 2,4-D was applied alone or to regrowth after pulling or mowing. Cattle preferred those plots which had the most grass and least leafy spurge.

Table 23. The Effect of Machine Pulling, Mowing, Herbicide Treatments, and Combination Treatments on Leafy Spurge and Perennial Grass Production, and Cattle Use the Season of Application.

	Application		Dry Weight Biomass (8-11-83)[1]		
Leafy Spurge Treatment	Rate (kg ai/ha)	Date	Leafy Spurge (kg ai/ha)	Perennial Grass (kg ai/ha)	Cowpies per Plot[1]
Pulled with Bourquin Puller	–	6-29-83	656 abc	731 ab	1.7 ab
Mowed	–	6-29-83	1140 bcd	333 a	2.7 ab
Pulled with Bourquin	–	6-29-83			
Puller + 2,4-D amine	1.12	7-21-83	183 a	828 ab	3.7 b
Mowed +	–	6-29-83			
2,4-D amine	1.12	7-21-83	333 ab	366 a	4.3 b
2,4-D amine	2.24	6-29-83	161 a	1140 b	5.0 b
Picloram	0.56	6-29-83	1624 d	871 a	0.7 a
Control	–	–	1527 cd	1226 b	2.0 ab

[1] Means within a column followed by the same letter are not significantly different at the 0.05 level using the LSD test.

Table 24. The Effect of Machine Pulling, Mowing, Herbicide Treatments and Combination Treatments on Leafy Spurge Density Using Stem Counts and Percent Control and Using a Visual Rating Method Taken on 6-6-84, Approximately 12 Months After the Initial Treatments Were Made.

	Application		Leafy Spurge Density[2]		Leafy Spurge Control[2]
Leafy Spurge Treatment	Rate (kg ai/ha)	Date	Stem Density (stems/ft^2)	Change in Density (%)	Visual Method (%)
Pulled with Bourquin Puller	–	6-29-83	22.4 a	-7	2.3 ab
Mowed	–	6-29-83	41.1 b	+71	4.0 ab
Pulled with Bourquin	–	6-29-83			
Puller + 2,4-D amine[1]	1.12	7-21-83	21.8 a	-10	10.0 ab
Mowed	–	6-29-83			
+ 2,4-D amine[1]	1.12	7-21-83	31.0 a	+29	10.7 b
2,4-D amine	2.24	6-29-83	19.8 a	-18	6.0 ab
Picloram	0.56	6-29-83	27.9 a	+16	2.3 ab
Control	–	–	24.1 a	0	0 a

[1] 2,4-D amine was applied after pulling and mowing when the leafy spurge regrowth was approximately 15 cm tall.

[2] Means within a column followed by the same letter are not significantly different at the 0.05 level using the LSD test.

None of the machine pulled, mowed, herbicide, or combination treatments significantly decreased the density of leafy spurge one year after application (Table 24). The Bourquin puller, 2,4,-D applied alone, and the Bourquin puller treatment supplemented by an application of 2,4-D to regrowth tended to decrease leafy spurge density, although the differences were not significant. Mowing increased leafy spurge stem density 71% one year after treatment. A low rate of picloram, and mowing followed by 2,4-D to regrowth tended to increase leafy spurge density, however, the increase was not statistically significant. Visual ratings indicated control was minimal one year after treatment. Stunted leafy spurge plants were observed when plants were mowed and machine pulled, however, the stunting was not as severe as the stunting observed in the experiment where leafy spurge was hand pulled (Tables 21 and 24).

Summary

Mechanized pulling was less effective than an application of 2,4-D for leafy spurge control in pastures. Hand pulling was more thorough than machine pulling and produced detrimental effects to the leafy spurge population for a longer period of time. If soil-borne pathogens which attack leafy spurge are discovered in the future pulling may be an effective means of enhancing infection because of root injury which occurs as a result of pulling.

The most significant finding of this research was the fact that pulling decreased the density and mowing increased the density of leafy spurge 11 months after treatment. This indicates the reproductive importance of the first few centimeters of stem and transition tissue below the soil surface. When apical dominance was released by mowing, new shoots were initiated from the leafy spurge crown. When the plants were pulled and the crown was removed, regrowth was forced to occur from root tissue.

The crown of a leafy spurge plant contains a maize of vascular tissue which may block efficient translocation of herbicides to root tissue below the crown. It is possible that application of herbicides to young plants, or pulled plants which have little or no crown tissue might enhance herbicide translocation throughout the root system. Perhaps the application of a translocated herbicide when regrowth first appears after pulling would provide more effective long term control.

Hand pulling would be an effective way to control small leafy spurge infestations. Seed production can be eliminated and regrowth is severely stunted which will slow the advancing infestation. Pulling would be the best means of controlling small patches along waterways where herbicide use is restricted and where leafy spurge seed must be removed to prevent dispersal by water. Future research should include timing of herbicide application to regrowth at different development stages after pulling.

CHAPTER 5

THE ECONOMIC POTENTIAL OF LEAFY SPURGE

Abstract

Leafy spurge (*Euphorbia esula* L.) is a noxious perennial weed that infests pastures, rangeland and waste areas in the Northern Great Plains. The objective of this study was to determine the productive potential of the plant when grown under optimum agronomic conditions. Plants were fertilized and irrigated. Oil, hydrocarbon, total protein, and dry weight production were measured on three harvest dates. Calorimetric analyses were performed to determine the potential of leafy spurge as a fuel crop. The hydrocarbon content of 12 strains of leafy spurge was determined to measure genetic variability for this trait. The addition of fertilizer doubled dry weight production but did not affect percent oil or hydrocarbon content. Oil and hydrocarbon production averaged 6.8 and 0.6% on a plant dry weight basis. Maximum production of plant biomass, protein, and hydrocarbon was obtained from a mid-July harvest. Oil content increased later in the growing season. The total protein content of leafy spurge averaged 12%. Whole plant biomass had a caloric value of 4407 calories per gram while the oils contained 10,019 calories per gram. Leafy spurge hay can produce four times more energy per ha per year than wheat straw; therefore, the immediate potential of leafy spurge whole plant biomass as a locally grown fuel crop for home heating purposes is suggested.

Introduction

Leafy spurge (*Euphorbia esula* L.) is a noxious perennial weed found in the north-central United States and Canada (Dunn, 1979). The latex of this species contains potentially useful oils and hydrocarbons. Interest in utilizing leafy spurge has increased because it is uneconomical to control, thrives on marginal land, and has no significant insect or disease pests. The technology and equipment for fertilization, irrigation, and harvesting the plant is in place so obstacles to production do not exist.

The latex of plants in the Euphorbiaceae contains low molecular weight hydrocarbons (Calvin, 1979) which yield chemicals similar to products obtained after catalytic cracking of naphtha (Maugh, 1979). These products represent a high value petroleum fraction used as principal raw materials in the chemical industry (Wang and Huffman, 1981). Coffey and Halloran (1979) analyzed *Euphorbia tirucalli* L., *E. lactea* Haw, and *E. lathyris* L. and concluded that those plants have potential for hydrocarbon production. The agronomic and hydrocarbon potential of gopher plant (*E. lathyris*) has been studied intensely (Calvin, 1979; Kinglover, 1982; Ognibene, 1981; Sachs et al., 1981). Kingslover (1982) reported that the agronomic, genetic, and energetic potential of *E. lathyris* limits it as an energy crop. One of the primary limitations of *E. lathyris* is it is not agronomically adapted to marginal areas.

The objective of this study was to determine the yield of oils, hydrocarbons, total protein, biomass, and caloric production of cultivated leafy spurge.

Materials and Methods

Experimental plots were established in a split plot design near Whitehall, Montana on a river terrace pasture heavily infested with leafy spurge. The two main plot treatments were fertilized and non-fertilized plots (4.6 m by 9.1 m) which were further divided into three subplots (3.0 m by 4.6 m) receiving different harvest date treatments. All treatments were replicated three times. The experiment was conducted in 1981 and 1982.

The experiment was sprinkler irrigated with 5 cm of water per week for the entire growing season starting the last week of June. Fertilized plots received phosphorus (80 kg P_2O per ha) by banding 4 cm deep in rows 18 cm apart during the last week of October, the year prior to production. Ammonium nitrate (80 kg of N per ha) was applied to individual plots in the beginning of April, and the third week of July. The first harvest was on July 15, when the plants were in the full bloom stage of growth. Plants were harvested in the late bloom and mid-seed stages of growth on August 3 and August 17, respectively.

Plots were harvested by mowing with a one-meter wide sickle bar mower. Fresh weight production was determined at harvest. Harvested plant material was oven-dried (30 C) for 48 hours and weighed to determine dry weight production. Total protein content was determined using the Kjeldahl method (AOAC, 1980).

Dry plant material was ground in a Wiley mill to pass through a 1 mm mesh screen and extracted for a minimum of 24 hours in a Soxhlet apparatus following the method of extraction of Buchanan et al. (1978) to determine oil and hydrocarbon content. Calorimetric determinations were made on whole plant tissue and all extractives with a Parr Adiabatic O_2 Bomb calorimeter interfaced to a Parr Model 1680 Master control unit. Samples from individual plots were subsampled six times and analyzed. All results have been reported as percent of total dry weight biomass.

Twelve biotypes of leafy spurge were harvested during the 1980 growing season and analyzed for hydrocarbon content using the method described above. The 12 biotypes were originally collected by Professor Emeritus Laurence O. Baker of Montana State University in 1964. The plants have been maintained at the Post Research Farm, Bozeman in individual cement cisterns.

Results and Discussion

Biomass Production

Dry weight yield of leafy spurge was 7.5 MT/ha/yr on fertilized plots harvested in mid-July (Table 25). There was over a two-fold response to fertilizer on plots harvested in July. The earliest harvest date yielded 2.5 to 2.6 tons more biomass per ha than August harvest dates on fertilized plots possibly as a result of a greater leaf to stem ratio.

Table 25. Leafy Spurge Dry Weight Production in Response to Fertilizer and Three Dates of Harvest in 1982 at Whitehall, Montana.

	Leafy Spurge Production (MT/ha)[1]	
Harvest Date	Non-fertilized	Fertilized
7-15-82	3.1 a	7.5 b
8- 3-82	2.4 a	4.9 a
8-17-82	3.0 a	5.0 ab

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Oil and Hydrocarbon

Oil and hydrocarbon content in fertilized biomass averaged 6.8 and 0.6%, respectively (Table 26). Fertilization did not increase the percentage of oil or hydrocarbons in leafy spurge biomass. A significant increase in oil content to a seasonal high of 9.7% was observed in the early August harvest. This was followed by a 40% decline in oil content two weeks later to a level of 5.8%. The hydrocarbon content of leafy spurge biomass was consistently low and never exceeded 0.7% on a dry weight basis. These observations suggest that maximum oil production would be obtained from biomass harvested in early August.

Table 26. The Oil, Hydrocarbon, and Protein Content of Fertilized and Unfertilized Leafy Spurge Averaged Over Three Harvest Dates in 1982.

	Percentage of Total Biomass[1]		
Treatment	Oils	Hydrocarbons	Protein
Fertilized	6.8 a	0.6 a	13.2 a
Non-fertilized	6.7 a	0.3 a	12.7 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Protein

The mean protein content of leafy spurge biomass for all harvests was 11.5%. A mid-July high of 14.2% was subsequently followed by a mid-August low of 8.2% (Table 27). This significant reduction in protein level could be attributed to the presence of reproductive biomass in the July harvest and the loss of seed protein through seed dispersal by mid-August.

Table 27. The Effect of Harvest Date on Oil, Hydrocarbon, and Protein Content of Leafy Spurge on Fertilized Plots in 1982.

	Percent of Total Biomass[1]		
Harvest Date	Oils	Hydrocarbons	Protein
7-15-82	3.9 a	0.7 a	14.2 b
8-03-82	9.7 c	0.5 a	12.2 b
8-17-82	5.8 b	0.5 a	8.2 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Calorific Values and Energy Production

The calorific value of whole plant biomass was 4407 calories per gram, a value consistent with other biomaterials such as wood or straw (Table 28). The high calorific value of leafy spurge oil was in excess of 10,000 calories per gram, and therefore is comparable to crude oil and superior to anthracite coal. Fertilization and harvest date did not affect the calorific values of whole plant biomass or oils from leafy spurge (unpublished results).

Table 28. Comparisons of Energy Content of Leafy Spurge, Crude Oil, Wheat Straw, Anthracite Coal, and Lodgepole Pine.

Material	Calories per gram	Calorie Production per ha per year (in billions)
Leafy spurge constituents		
Dry plant material	4,407	33.1
Oils	10,019	–
Crude oil	10,500[1]	–
Anthracite coal	7,156[2]	–
Wheat straw (*Triticum aestivum* L.)	4,200[3]	8.0
Lodgepole pine (*Pinus contorta* Dougl.)	2,600[4]	5.5[5]

[1] Johnson and Auth, 1951.

[2] Johnson and Auth, 1951.

[3] Green and Crane, 1980.

[4] Lodgepole pine at 12% moisture (Anon., 1955) and 8930 BTUs/lb (Corder, 1973).

[5] Using 1,119 kg of lodgepole pine firewood material (85 cu ft of solid wood/cord) per hectare (Anon., 1955).

Ecotypic Variability

Twelve biotypes of leafy spurge were tested for hydrocarbon content (Table 29). The hydrocarbon content ranged from 0.12 to 2.27% on a dry weight basis which indicates that potential for improvement through selection exists.

Table 29. The Hydrocarbon Content of 12 Biotypes of Leafy Spurge.

Ecotype No.	Collection Location	Hydrocarbon Content (%)
1	Alberta, Canada	0.40
2	Saskatchewan, Canada	0.60
3	Colorado	1.12
4	Wyoming	2.27
5	Idaho	1.56
6	South Dakota	0.73
7	North Dakota I	0.38
8	North Dakota II	0.88
9	Missoula, Montana	2.18
10	Moccasin, Montana	0.73
11	Bozeman, Montana	1.96
12	Antelope, Montana	1.24
	LSD (.05)	1.58

Buchanan et al. (1978a) described a numerical rating system based on botanical chemical composition and fiber structure for evaluating the potential of hydrocarbon-bearing plants (Table 30). A score of 5 indicated extremely high potential for development into a hydrocarbon and oil producing crop, while a score of 17 would indicate a candidate plant species had little potential for exploitation. A rating of 8 would indicate that a species was ideally suited either for hydrocarbon or oil production and borderline species received a rating of 11 which suggested some potential as an energy crop.

Table 30. Evaluation of the Potential of Leafy Spurge as a Hydrocarbon-Producing Crop According to the Buchanan et al. (1978a) Rating System.

Characteristic Description	Leafy Spurge Rating
BOTANICAL EVALUATION (Scale: 1 to 5) Plant species were classified into five groups according to their adaptability as a crop and probable yield of biomass. Rating 1 is assigned to the species with the highest potential adaptability.	2
FIBER UTILITY (Scale: 1 to 2) Rating 1 is applied to fibrous or woody species potentially useful for fiber, papermaking, or board products; rating 2 is for succulent, pulpy, non-woody, non-fibrous species.	2
PROTEIN PRODUCTION (Scale: 1 to 2) Rating 1 is assigned to species with greater than 14% crude protein.	2
OIL PRODUCTION (Scale: 1 to 4) Rating 1 is assigned to species with greater than 8% oil; rating 2 is 5% to 8% oil; rating 3 is 2% to 5% oil; and rating 4 is assigned to species with less than 2% oil.	1
HYDROCARBON PRODUCTION (Scale: 1 to 4) Rating 1 is assigned to species with greater than 2% hydrocarbon; rating 2 is 1.2% to 2.0% hydrocarbon; rating 3 is 0.4% to 1.2 hydrocarbon; and rating 4 is plants with less than 0.4% hydrocarbon.	3
TOTAL	10

Biomass samples from wild populations of *Euphorbia cyparissias* L., *E. supina* Raf., *E. heterophylla* L., *E. lathyris* L., and *E. dentata* Michx. were collected and analyzed. These species received scores of 12, 13, 11, 10, and 10, respectively (Buchanan et al., 1978a, 1978b). Scores for these species would doubtless improve if the plants were cultivated intensively in the manner of our study.

Using the Buchanan et al. (1978a) rating system *E. esula* would conservatively receive a score of 10 based on data from our study (Table 30). Cultivated leafy spurge could be planted and routinely harvested, therefore it would receive a favorable botanical rating. Under the category of chemical composition leafy spurge would be rated highly because of the high percentage of oil (10%) which counters the relatively low hydrocarbon content. It is conceivable that with agronomic selection and genetic manipulation, leafy spurge could receive a rating of 8 or 9 under the system of Buchanan et al. (1978a).

Sachs et al. (1981) reported that *E. lathyris* would yield 19.8 to 24.7 barrels of petroleum-like products per hectare which contain 8.9 million calories per kilogram. The production potential of oils from leafy spurge is approximately 5.5 barrels per hectare with an energy content of 9.5 million calories per kilogram. *E. lathyris* has a 7-month growing season in California, whereas *E. esula* is grown over a 4-month season in Montana.

In contrast to the limited genetic variability reported for *E. lathyris* (Kingslover, 1982), leafy spurge may have potential for genetic improvement by conventional plant breeding methods. This potential is based on the wide variation in hydrocarbon content in existing biotypes (Table 29), and the occurrence of interspecific crosses by leafy spurge (Ebke and McCarty, 1983). The possibility of producing improved vigor through plant breeding techniques should be explored before negative conclusions concerning the potential of this plant are made.

Some of the major economic factors which limit the production of biofuels include (1) the cost of extraction of the oil and hydrocarbon fractions, (2) transportation, and (3) storage problems that accompany a centralized facility. These factors can, in part, be overcome by considering the use of the total biomass of the plant for producing energy.

Considering the high calorific value of leafy spurge biomass, there is potential for direct utilization as fuel.

Biofuel Potential of Leafy Spurge

Increased interest has been shown in wood and other renewable resource heating systems for farms, small localized industries, and homes (Greene and Crane, 1980). Yield of wheat straw, a crop residue from wheat production, averages 4 MT/ha/yr and contains 4.2 million calories of energy per kilogram (Green and Crane, 1980). A well managed stand of lodgepole pine (*Pinus contorta* Dougl.) produces 84.5 MT of wood per hectare with a calorific value of 2.6 million calories per kilogram on no less than a 50-year rotation (Anon., 1955). By comparison, leafy spurge, when fertilized and irrigated, produced an average of 5.8 MT/ha/yr with a calorific value of 9.5 million calories per kilogram per year. Unlike wheat, leafy spurge does not have to be replanted each year. Further comparisons show that wheat straw has an energy output of 8.1 billion cal/ha/yr, lodgepole pine has 4.4 billion cal/ha/yr, while leafy spurge produces 33.1 billion cal/ha/yr (Table 28).

The major potential of leafy spurge lies in the high net energy yield of the foliage biomass. The technology for utilizing crop residues directly as fuel is available since several furnaces[9] are currently being marketed which are capable of burning baled leafy spurge. The average farm house and shop in Montana occupy 3,000 and 5,000 ft^2, respectively, and utilize approximately 71 billion calories of energy per year (Shelton, 1976). Therefore, it would require approximately 2.1 hectares of leafy spurge-infested land to produce enough hay to heat buildings on the average farm in Montana for one year.[10] The mechanization for harvest and storage of leafy spurge hay is in place on the farms and ranches in the infested areas, and the plant is thriving on marginal, low-value lands.

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[9] Mid-State Manufacturing Co., Columbus, Nebraska, and A. F. Petersens Maskinfabrik, Nordhavnsvej 4, 6100 Hadesley, Denmark.

[10] Allowances must be made for less than 100% efficient burning of biomaterials.

Summary

Despite its classification as a noxious weed, leafy spurge has the potential to provide a renewable source of fuel for local use in rural areas. It is not presently feasible to grow leafy spurge as a substitute for petrochemicals. However, with the decreasing supply of fossil fuels, the future is certain to see the utilization of plants as renewable sources of energy. Plants that will be most attractive will be perennials like *E. esula* that grow on marginal agricultural land and have few endemic enemies.

CHAPTER 6

SUMMARY

Leafy spurge is a major weed problem on pasture and rangeland in the north central United States and southern provinces of Canada. Four distinct research projects relative to the leafy spurge problem were initiated. They included: an analysis of changes in a leafy spurge infested plant community after an application of picloram, the effect of glyphosate on the regulation of bud dormancy in leafy spurge, the effect of pulling for control of leafy spurge, and the economic potential of leafy spurge.

The application of picloram to a rangeland plant community caused a decrease in species diversity by removing most of the forbs. The decrease in species diversity may encourage weed reinfestation, decrease the nitrogen in the soil by removal of nitrogen fixing forbs, or make the community more susceptible to production losses from drought, disease, or insect attack. Future measurements on this study will determine what the long term response of the plant community is to broad scale application of picloram.

Leafy spurge has an efficient means of vegetative reproduction. Glyphosate when applied at the senescent growth stage can cause release of root bud dormancy which leads to abnormal growth in new shoots. The growth regulating quality of glyphosate can be used as a tool to increase understanding of the mechanisms which regulate growth from buds on leafy spurge plants. Understanding what controls regrowth is critical in gaining effective methods to control leafy spurge. Future research should be conducted to determine the specific physiological processes involved in bud dormancy.

In an attempt to develop a cultural control technique, the concept of pulling leafy spurge plants was examined. Machine pulling is not a realistic alternative to chemical control. If a soil borne pathogen can be developed as a biological control agent on leafy spurge then pulling may be an effective way to increase infection.

Leafy spurge has the potential to provide a renewable source of fuel for local use in rural areas. It is not economically feasible to grow leafy spurge as a petrochemical substitute at the present, however, the future is certain to see plants utilized as renewable sources of energy. The concept of finding uses for our well adapted weeds deserves more attention from the scientific community.

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APPENDIX TABLES

Table 31. A List of All the Species, Species Groups and Elements Observed on Site One and Two at the N-Bar Ranch.[2]

Species Code	Latin Binomial[3]	Author[3]	L[4]	O[5]	S[6]	GR[7]
PGRS	Perennial Grasses					
	Agropyron cristatum	(L.) Gaertn.	P	I	C	I
	Agropyron smithii	Rydb.	P	N	C	I
	Calamagrostis montanensis	(Scribn.) Scribn.	P	N	C	I
	Carex spp.					
	Carex brevior	(Dewey) Mack.	P	N	C	–
	Carex stenophylla	Wahl.	P	N	C	I
	Dactylis glomerata	L.	P	I	C	V
	Koeleria cristata	Pers.	P	N	C	I
	Phleum pratense	L.	P	I	C	V
	Poa ampla		P	N	C	D
	Poa compressa	L.	P	I	C	V
	Poa juncifolia	Scribn.	P	N	C	D
	Poa pratensis	L.	P	I	C	V
	Poa sandbergii	Vasey	P	N	C	I
	Stipa viridula	Trin.	P	N	C	D
ANFB	Annual Forbs					
ANSP	*Androsace* spp.					
	Androsace occidentalis	Pursh	A	N	C	V
	Androsace septentrionalis	L.	A	N	C	V
DRNE	*Draba nemorosa*	L.	A	–	–	V
MELU	*Medicago lupulina*	L.	A	I	C	V
SOTR	*Solanum triflorum*	Nutt.	A	N	W	V
BIFB	Biennial Forbs					
CIUN	*Cirsium undulatum*	(Nutt.) Spreng.	B	N	W	V
MEOF	*Melilotus officinalis*	Lam.	B	I	C	V
TRDU	*Tragopogon dubius*	Scop.	B	I	C	V
PFRB	Perennial Forbs					
ACMI	*Achillea millefolium*	L.	P	N	W	I
	Anemone multifida	Poir.	P	–	C	–
ANPA	*Antennaria parviflora*	Nutt.	P	N	C	I
ANRA	*Antennaria racemosa*	Hook.	P	N	C	I
ARFR	*Artemesia frigida*	Willd.	P	N	W	I
ARLU	*Artemesia ludoviciana*	Nutt.	P	N	W	I
ASFA	*Aster falcatus*	Lindl.	P	N	W	I
	Astragalus adsurgens	Hook.	P	–	–	–
	Astragalus drummondii	Hook.	P	N	C	I
BAOP	*Bahia oppositifolia*	Nutt.	P	N	C	I
EUES	*Euphorbia esula*	L.	P	I	C	V
GACO	*Gaura coccinea*	(Nutt.) Pursh	P	N	W	I
LIPU	*Liatris punctata*	Hook.	P	N	W	D
PEAL	*Penstemon albidus*	Nutt.	P	N	C	I

Table 31 (continued).

Species Code	Latin Binomial[3]	Author[3]	L[4]	O[5]	S[6]	GR[7]
	Perennial Forbs (continued)					
POPE	*Potentilla pensylvanica*	L.	P	N	–	I
RACO	*Ratibida columnifera*	(Nutt.) Woot & Standl.	P	N	W	I
RAGL	*Ranunculus glaberrimus*	Hook.	P	N	C	I
SOMI	*Solidago missouriensis*	Nutt.	P	N	C	I
SOMO	*Solidago mollis*	Bartl.	P	N	W	I
SPCO	*Sphaeralcea coccinea*	(Pursh) Rydb.	P	N	C	I
TAOF	*Taraxacum officinale*	Weber	P	I	C	V
TRSP	*Trifolium* spp.					
VIAM	*Vicia americana*	Muhl.	P	N	C	D
SHRB	Shrubs					
ARCA	*Artemesia cana*	Pursh	P	N	W	I
CHNA	*Chrysothemnus nauseosus*	(Pall.) Britt.	P	N	W	I
GUSA	*Gutierrezia sarothrae*	(Pursh) Britt. & Rusby.	P	N	W	I
ROAR	*Rosa arkansana*	Porter	P	N	C	I
	Trees					
	Pinus ponderosa	Dougl.				
	Elements measured in the ecosystem					
BAGR	Bare Ground					
ROCK	Rock					
LITR	Litter					
LICH	Lichen					
MOSS	Moss (Includes all spp.)					

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[1] Species codes were made by using the first two letters of the genus and the first two letters of the species and were used on the field forms.

[2] Percent canopy cover was estimated for only those species, species group, or element with a code.

[3] Latin binomials and authors are according to Hitchcock and Cronquist (1973).

[4] Longevity (L) of the species: P = Perennial, B = Biennial, A = Annual (Wambolt, 1981).

[5] Origin (O) of the species: N = Native to North America, I = Introduced to North America (Wambolt, 1981).

[6] Season of growth (S): C = Cool Season, W = Warm Season (Wambolt, 1981).

[7] Grazing response (GR) to cattle use: D = Decreaser, I = Increaser, V = Invader (Wambolt, 1981).

Table 32. Percent Canopy Cover of Pertinent Elements and Perennial Grasses on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

Treatment	Bare Ground[1]	Rock[1]	Litter[1]	Lichens[1]	Moss[1]	Perennial Grasses[1]
1982						
Ungrazed:						
Unsprayed	3.90 e	0.13 a	93.33 ab	1.67 ab	2.03 bc	40.27 a
Sprayed	3.20 de	0.43 a	91.40 a	3.40 d	1.88 bc	44.50 a
Grazed:						
Unsprayed	2.70 cde	0.57 a	94.33 bc	0.93 a	1.92 bc	40.30 a
Sprayed	2.30 bcd	0.18 a	93.57 abc	1.83 abc	2.28 c	54.30 b
1983						
Ungrazed:						
Unsprayed	1.10 ab	0.07 a	96.23 cd	1.38 a	1.10 ab	89.70 cd
Sprayed	0.30 a	0.18 a	99.03 e	3.03 cd	0.67 a	96.40 d
Grazed:						
Unsprayed	0.80 a	0.37 a	97.17 de	0.87 a	0.68 a	82.70 c
Sprayed	1.61 abc	0.08 a	94.77 bcd	2.77 bcd	0.80 a	91.67 d

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 33. Percent Canopy Cover of Each Annual Forb Species and Annual Forbs as a Group on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

	Annual Forb Species[1]				
Treatment	*Androsace* spp.	*Draba nemorosa*	*Medicago lupulina*	*Solanum triflorum*	Annual Forbs[1]
1982					
Ungrazed:					
Unsprayed	0.62 ab	0.03 a	8.30 b	0.00 a	8.93 c
Sprayed	1.42 c	0.00 a	2.37 a	0.00 a	3.78 b
Grazed:					
Unsprayed	1.22 bc	0.00 a	10.03 b	0.00 a	11.25 c
Sprayed	1.02 bc	0.00 a	2.12 a	0.00 a	3.13 ab
1983					
Ungrazed:					
Unsprayed	0.28 a	0.03 a	0.10 a	0.00 a	0.42 a
Sprayed	0.37 a	0.00 a	0.00 a	0.00 a	0.37 a
Grazed:					
Unsprayed	0.58 ab	0.03 a	0.37 a	0.00 a	0.98 ab
Sprayed	0.12 a	0.00 a	0.00 a	0.02 b	0.14 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 34. Percent Canopy Cover of Each Perennial and Biennial Forb Species on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

	Perennial and Biennial Forb Species[1]							
Treatment	*Euphorbia esula*	*Achillea millefolium*	*Antennaria parviflora*	*Antennaria racemosa*	*Artemesia frigida*	*Artemesia ludoviciana*	*Aster falcatus*	*Bahia oppositifolia*
1982								
Ungrazed:								
Unsprayed	8.35 ab	5.33 e	0.00 a	0.10 ab	1.77 c	0.67 b	2.40 c	0.07 a
Sprayed	17.30 d	2.93 cd	0.00 a	0.00 a	1.62 bc	0.00 a	2.23 bc	0.00 a
Grazed:								
Unsprayed	26.70 e	3.18 cd	0.00 a	1.30 b	1.08 abc	0.37 ab	2.03 abc	0.07 a
Sprayed	10.45 bc	1.57 b	0.00 a	0.00 a	1.68 bc	0.67 b	2.77 c	0.07 a
1983								
Ungrazed:								
Unsprayed	15.83 de	4.60 de	0.02 a	0.00 a	1.20 abc	0.17 ab	2.88 c	0.00 a
Sprayed	2.57 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Grazed:								
Unsprayed	39.20 f	2.30 bc	1.70 b	0.00 a	0.48 ab	0.05 a	2.43 c	0.00 a
Sprayed	2.32 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.17 ab	0.00 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 35. Percent Canopy Cover of Each Perennial and Biennial Forb Species on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

	Perennial and Biennial Forb Species[1]							
Treatment	*Cirsium undulatum*	*Gaura coccinea*	*Liatris punctata*	*Melilotus officinalis*	*Penstemon albidus*	*Potentilla pensylvanica*	*Ranunculus glaberrimus*	*Ratibida columnifera*
1982								
Ungrazed:								
Unsprayed	0.00 a	0.25 ab	0.00 a	6.93 b	0.00 a	0.08 a	0.00 a	0.63 c
Sprayed	0.00 a	0.03 ab	0.00 a	1.17 a	0.00 a	0.07 a	0.00 a	0.20 ab
Grazed:								
Unsprayed	0.00 a	0.27 b	0.00 a	4.70 b	0.00 a	1.33 b	0.00 a	0.20 ab
Sprayed	0.00 a	0.03 ab	0.00 a	1.13 a	0.00 a	0.20 a	0.00 a	0.23 ab
1983								
Ungrazed:								
Unsprayed	0.00 a	0.17 ab	0.10 b	0.08 a	0.02 b	0.03 a	0.03 b	0.50 bc
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Grazed:								
Unsprayed	0.03 a	0.07 ab	0.00 a	0.00 a	0.00 a	0.08 a	0.00 a	0.15 a
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 36. Percent Canopy Cover of Each Perennial and Biennial Forb Species and Perennial and Biennial Forbs as a Group on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

Treatment	Perennial and Biennial Forb Species[1]							Perennial and Biennial Forbs[1]
	Solidago missouriensis	*Solidago mollis*	*Sphaeralcea coccinea*	*Taraxacum officinale*	*Tragopogon dubius*	*Trifolium* spp.	*Vicia americana*	
1982								
Ungrazed:								
Unsprayed	3.57 c	1.63 cd	0.77 c	0.60 c	0.03 a	3.52 a	1.50 b	29.82 e
Sprayed	1.20 ab	0.97 abcd	0.10 a	0.00 a	0.00 a	1.50 a	.03 a	12.08 bc
Grazed:								
Unsprayed	1.47 b	1.17 bcd	0.07 a	0.67 c	0.20 ab	7.27 c	1.03 b	25.00 d
Sprayed	1.02 ab	1.97 d	0.18 ab	0.13 ab	0.00 a	0.50 a	1.10 b	13.45 cd
1983								
Ungrazed:								
Unsprayed	3.22 c	0.68 abc	0.43 b	0.38 bc	0.40 b	0.27 a	0.58 ab	15.77 c
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Grazed:								
Unsprayed	3.67 c	0.37 ab	0.07 a	0.15 ab	0.50 b	0.22 a	0.10 a	9.07 b
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.18 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 37. Percent Canopy Cover of Each Shrub Species and Shrubs as a Group on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

	Shrub Species[1]				
Treatment	*Artemisia cana*	*Chrysothamnus nauseousus*	*Gutierrezia sarothrae*	*Rosa arkansans*	Shrubs[1]
1982					
Ungrazed:					
Unsprayed	0.00 a	0.00 a	0.32 b	0.20 a	0.52 ab
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Grazed:					
Unsprayed	0.00 a	0.00 a	0.33 b	0.90 b	1.23 b
Sprayed	0.00 a	0.00 a	0.07 ab	0.20 a	0.27 a
1983					
Ungrazed:					
Unsprayed	0.00 a	0.02 a	0.07 ab	0.17 a	0.25 ab
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Grazed:					
Unsprayed	0.00 a	0.00 a	0.12 ab	0.50 ab	0.62 ab
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 38. Percent Canopy Cover of Pertinent Elements and Perennial Grasses on All Treatments in 1983 on Site Two at the N-Bar Ranch.

Treatment	Bare Ground[1]	Rock[1]	Litter[1]	Lichens[1]	Moss[1]	Perennial Grasses[1]
1983						
Grazed:						
Unsprayed	1.83 a	0.00 a	96.63 a	0.40 a	0.32 a	77.00 a
Sprayed	2.27 a	0.00 a	93.57 a	1.20 a	0.40 a	87.83 b

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 39. Percent Canopy Cover of Each Annual Forb Species and Annual Forbs as a Group on All Treatments in 1982 and 1983 on Site One at the N-Bar Ranch.

	Annual Forb Species[1]				
Treatment	*Androsace* spp.	*Draba nemorosa*	*Medicago lupulina*	*Solanum triflorum*	Annual Forbs[1]
1983					
Grazed:					
Unsprayed	0.05 a	0.00 a	0.07 a	0.00 a	0.12 a
Sprayed	0.02 a	0.00 a	0.00 a	0.00 a	0.02 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 40. Percent Canopy Cover of Each Perennial and Biennial Forb Species on All Treatments in 1983 on Site Two at the N-Bar Ranch.

	Perennial and Biennial Forb Species[1]							
Treatment	*Euphorbia esula*	*Achillea millefolium*	*Antennaria parviflora*	*Antennaria racemosa*	*Artemesia frigida*	*Artemesia ludoviciana*	*Aster falcatus*	*Bahia oppositifolia*
1983								
Grazed:								
Unsprayed	47.83 b	0.03 a	0.00 a	0.00 a	0.08 a	0.40 a	0.53 a	0.00 a
Sprayed	0.37 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 41. Percent Canopy Cover of Each Perennial and Biennial Forb Species on All Treatments in 1983 on Site Two at the N-Bar Ranch.

	Perennial and Biennial Forb Species[1]							
Treatment	*Cirsium undulatum*	*Gaura coccinea*	*Liatris punctata*	*Melilotus officinalis*	*Penstemon albidus*	*Potentilla pensylvanica*	*Ranunculus glaberrimus*	*Ratibida columnifera*
1983								
Grazed:								
Unsprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 42. Percent Canopy Cover of Each Perennial and Biennial Forb Species and Perennial and Biennial Forbs as a Group on All Treatments in 1983 on Site Two at the N-Bar Ranch.

	Perennial and Biennial Forb Species[1]							Perennial and Biennial Forbs[1]
Treatment	*Solidago missouriensis*	*Solidago mollis*	*Sphaeralcea coccinea*	*Taraxacum officinale*	*Tragopogon dubius*	*Trifolium* spp.	*Vicia americana*	
1983								
Grazed:								
Unsprayed	0.03 a	0.02 a	0.00 a	0.02 a	0.37 b	0.00 a	0.00 a	1.98 b
Sprayed	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.01 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.

Table 43. Percent Canopy Cover of Each Shrub Species and Shrubs as a Group on All Treatments in 1983 on Site Two at the N-Bar Ranch.

	Shrub Species[1]				
Treatment	*Artemisia cana*	*Chrysothamnus nauseousus*	*Gutierrezia sarothrae*	*Rosa arkansans*	Shrubs[1]
1983					
Grazed:					
Unsprayed	2.33 a	0.33 a	0.00 a	0.30 a	2.97 a
Sprayed	0.42	0.00 a	0.00 a	0.00 a	0.42 a

[1] Means within each column followed by the same letter are not statistically different at the 5% level as determined by the LSD test of significance.