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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8-21-84 — Date

Peter K Fay — Chairperson, Graduate Committee

Approved for the Major Department

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Dwane G Miller — Head, Major Department

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M P Malone — Graduate Dean

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TABLE OF CONTENTS

TABLE OF CONTENTS–Continued

LIST OF TABLES

Tables | Page

Tables | Page

Tables | Page

LIST OF FIGURES

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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