Chemical fallow in Montana
by Robby Lee Brattain

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Agronomy
Montana State University

Abstract:
Chemical fallow systems using atrazine (2-chloro-4-(ethylamino) -6-(isopropylamino)-s-triazine) were evaluated. Soil residue bioassays for atrazine were conducted at different time periods. Atrazine persistence was correlated with moisture, soil pH, soil organic matter, soil clay content and soil calcium content to devise a method for predicting atrazine residues in field soils. Precipitation and soil pH were the most important factors governing the rate of atrazine degradation. Soils with pH 8.0, or greater, need approximately 43.8 cm of precipitation to completely degrade 0.84 Kg/ha of atrazine. Soils of pH 7.0 to 8.0 and 6.0 to 7.0 must receive 41.1 and 39.6 cm, respectively, to degrade 0.84 Kg/ha of atrazine.

Bioassay techniques for measuring atrazine soil residues were compared. Standard greenhouse pot assay, cone-container assay, petri dish assay, Stanford-DeMent assay and Chlorella algae assay were compared for accuracy, and or time and space requirements. The standard pot and cone-container assays were accurate but required 21 days for completion. The Chlorella algae assay while initially more expensive, was accurate and required only two to three days for completion.

The tolerance of 19 barley, 10 spring wheat, three spring durum and 15 winter wheat cultivars to atrazine soil residues was evaluated. Barley and spring wheat were the most and least tolerant crops to atrazine, respectively. 'Klages' and 'Wapana' were the most tolerant barley cultivars. 'Olaf' and 'Crosby' possessed the highest tolerance among the spring wheat and durum cultivars, respectively, while 'Lancer', 'Winalta' and 'Cheyenne' were the most tolerant cultivars of winter wheat.

Glyphosate (N-(phosphonomethyl)glycine) was applied at different stages of weed growth to evaluate the effect of delaying application on control of weeds. Soil moisture measurements were taken to measure soil moisture loss due to weed growth on fallow ground. By delaying application, more glyphosate is needed for control of existing vegetation and there is a substantial loss of subsoil moisture from weed growth.

Information tours were held at ten locations in Montana in 1980. Tours were based on chemical fallow advantages and disadvantages and economic status of chemical fallow. Tours were directed to inform farmers, commercial applicators, county agents and herbicide dealers.

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Date March 5, 1981

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A thesis submitted in partial fulfillment
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INTRODUCTION

It is common practice to alternate production of cereal crops with summer fallow in semi-arid regions. Fallow is defined as land cultivated but not seeded for one or more seasons to kill weeds, enrich the soil and conserve moisture (127). Approximately 39 million acres of cropland are summer fallowed annually in the United States (127).

Many terms are associated with fallow: bare or black fallow, summer fallow, stubble mulch tillage, chemical fallow and ecofallow. Tilled fallow systems may lose 75% or more of the moisture that the soil receives (127). While only 25% of the total moisture is saved, it is generally adequate for grain production in semi-arid areas.

Chemical fallow involves the use of herbicides to kill weeds during the fallow season, allowing minimum or no tillage. This provides minimal destruction to crop residue on the soil surface which reduces erosion and increases moisture conservation in most soils.

Chemical fallow systems have several advantages:

1. Increased surface residue which results in:
    a) reduced erosion.
    b) increased snowfall retention.
    c) increased rainfall penetration.
    d) increased soil moisture levels.
    e) insulation of crop seedlings.
2. Weed control is achieved when tillage is not possible.
3. Reduced energy, labor and machinery costs.

The importance of chemical fallow systems has been increased due to recent economic factors. The high cost of petroleum products, machinery, and machinery repairs has dramatically increased the cost of summer fallow tillage. Small grain producers in Montana are seeking alternate means of fallowing such as chemical fallow systems.

Chapter 1

LITERATURE REVIEW

A. Early History of Chemical Fallow (to 1960)

Chemical fallow research in Montana began in 1947 (10) when T. S. Aasheim attempted to reduce the number of tillage operations with 2,4-D to maintain protective crop residues on the soil surface. Timmons (10) reported that chemical fallow plots outyielded cultivated plots in Kansas in 1947.

Barnes et al., (11) compared the effects of fallowing techniques on soil water. Chemical fallow was compared with no tillage, subsurface cultivation, and spring plowing followed by subsurface cultivation. Chemical fallow treatments allowed maximum water infiltration (1.52 in/hr). Ninety-five percent of the water volume infiltrated the chemical fallow during the last 30 minutes of the hour duration. Chemical fallow water infiltration was 216% more than the infiltration of plowed soil and 250% more than the infiltration of subsurface cultivation. Barnes (11) attributed the difference in infiltration to the stubble residue eliminating water runoff.

Baker et al., (10) conducted chemical fallow studies in Montana from 1951 to 1955 and found that weed control by chemical treatments lasted longer than control by cultivation. Yields were not reduced by chemical fallow. It was concluded that chemical fallow was more expensive than cultivation. Cost of fallowing was usually reduced when tillage and application of 2,4-D were combined. Chemical fallow supplemented with tillage resulted in firm seedbeds which aided seeding procedures.

Research in the early 1950's indicated that chemical fallow had great potential if lower costs and more consistent weed control were achieved. Decreased cultivation conserved soil moisture and reduced soil erosion.

Wiese and Army (129) in 1957 compared storage of soil moisture following disking, sweep plowing, and chemical fallow. Total moisture in a four-foot soil profile was not affected significantly by any of the treatments. All methods were considered inefficient for moisture storage. Chemical fallow treatments had better erosion control and moisture levels equal to subsurface cultivation. Wiese and Army (129, 131) concluded that if consistent weed control was achieved, soil moisture levels would be higher under chemical fallow treatments.

By 1960, the advantages of chemical fallow included: 1) reduction in operation costs, 2) retention of crop residue, and 3) increase in precipitation retention. However, an inexpensive, consistant, broad spectrum herbicide was needed (39).

Research prior to 1960 showed slight increases in soil moisture conservation in chemical fallowed land (10, 11, 95, 129). In 1960, Wiese and Army (130) observed that a disked soil surface dried more rapidly than chemically fallowed plots because wind speed and evaporation of soil water were greater on bare fallow. Additionally, temperature of the upper six inches of soil was higher under bare fallow which increased evaporation where runoff was prevented, moisture storage for chemical fallow and stubble mulch was equal, indicating that bare fallow under normal field conditions stored less moisture due to runoff (131).

Maintaining surface residue increases soil moisture in the surface two inches of soil and decreases soil crusting (5). The effects of surface plant residue decreased with profile depth. Soil depths below two inches were not influenced significantly by surface residue. Chemical fallow maximized standing stubble which remained intact. The stubble impeded air movement at the soil surface and reduced evaporation. It was concluded that surface residues increase soil moisture reserves especially if precipitation is received frequently.

The development of paraquat (1,1'-dimethyl-4,4' bypyridinium ion) in 1963 was a significant advancement for chemical fallow since it provided broad spectrum grass control (52). Grasses are the primary weeds in many areas and are often hard to control. Areas treated with paraquat were especially resistant to soil erosion due to plant residue.

Fenster (43) concluded that some herbicides such as atrazine and prometon persist too long for chemical fallow cropping systems. Wicks (121) found that chemical fallow reduced dry soil aggregation, nitrification rate, soil nitrate levels, and nematode populations. He concluded that the limitations of chemical fallow systems are inconsistent weed control, herbicide cost, and crop injury from herbicide residues.

B. Recent History of Chemical Fallow (1960-1975)

By the late 1960's, the benefits from maintaining surface crop residue were widely known (132). Erosion control had been a major concern and several studies indicated that chemical fallow maximizes control of soil erosion (3, 4, 15, 16, 65). Hyder and Everson (67) successfully utilized chemical fallow procedures for both seedbed preparation and the rehabilitation of abandoned cropland previously vulnerable to erosion. Bennett (16) tested chemical fallow systems for erosion control on hillsides and found a large reduction in soil erosion.

Soil moisture storage in a Washington study was 35% of the received precipitation with bare fallow compared to 43% of the received precipitation for chemical fallow in a three-year crop rotation system (3). In a two year crop rotation, nearly twice as much moisture (44%) was stored in a chemically fallowed system in contrast to conventional tillage (25%). Additional research was conducted to measure conservation of soil moisture using chemical fallow techniques (4, 37, 58, 59, 124).

Chemical fallow systems have often been reported to increase crop yields (1, 18, 44, 46, 56, 58, 98, 125, 126). Corn yields increased

625 Kg/ha as a result of reduced water stress on chemically fallowed land (66). Sorghum and winter wheat yields increased significantly under chemical fallow (123).

Early chemical fallow research indicated that weed control was more consistent following conventional tillage (43, 124). However, there were several studies which reported satisfactory weed control (37, 44, 73, 92). Fenster et al., (43) suggested that new herbicide formulations such as granular formulations might result in better weed control.

Fenster and Burnside (44) found weed control and wheat yields were highest on chemically fallowed land when compared to three tillage methods and six tillage dates. Eckert and Evans (37) found that weed seed production of downy bromegrass (Bromus tectorum L.) was reduced or eliminated by chemical fallow with atrazine. An increase in soil nitrate levels was also recorded.

Wicks et al., (124) evaluated several formulations of atrazine. When a wettable powder formulation of atrazine was incorporated, the density of seeded wheat plants per unit area was increased when compared to plots which were not soil-incorporated. Soil-incorporation of granular formulations of atrazine had no effect on wheat stands.

Chemical fallow herbicide residues frequently caused yield reductions and crop injury (38, 65, 66, 76, 117). Hutchings and Hicks (65) reported crop yield reductions from herbicide residues and competition which resulted from inconsistent weed control. Seedling vigor of wheat and barley seeded into chemical fallow was reduced by herbicide residues. Eckert (38) observed that planting in furrows removed atrazine residue from the seeded row. Disk furrows were as effective for reducing crop injury from herbicide residue as shovel-opener furrows. Warboys (117) reported that mulches of paraquat treated herbage adversely affected seedling growth and development.

Use of residual herbicides stimulated research on persistence of residues. Lavy (76) found that 2,4-D degraded rapidly under aerobic conditions and atrazine degradation decreased with soil depth. Atrazine treated soil samples placed at a depth of 90 cm contained phytotoxic residues after 41 months.

C. Present Research on Chemical Fallow (1975-1980)

Recent research efforts in Nebraska have identified several benefits of chemical fallow systems when compared to conventional tillage methods (72). Chemical fallow results in:

1) increased yields of sorghum and corn following chemical fallow.
2) equal or increased yields of winter wheat under chemical fallow.
3) production of two crops in three years rather than two crops in four years.
4) conservation of moisture as a result of cooler soil tempera-

tures, reduced evaporation, increased trapping of snow and rainfall, little or no water use by weeds and no loss of soil moisture from tillage. Tillage also promotes weed growth by moving dormant seed to soil depths favorable for germination. Klein (72) stated that chemical fallow systems led to more efficient crop production, reduced energy costs, decreased soil erosion and increased conservation of moisture.

Schroeder (101) reported chemical fallow systems conserved topsoil, soil moisture, fuel, and energy expenses. Additionally, labor, machinery use, and machinery repairs were reduced. Miller (83) also observed no-till farming increased soil moisture retention and reduced energy inputs. It was found that yields were increased by chemical fallow, especially during dry years.

Alternatives to fallowing may increase the number of productive acres. Arnold (6) suggests that where sufficient moisture exists for crop establishment, recropping with minimum tillage systems are feasible.

Timing of herbicide application may be the most crucial factor for a successful chemical fallow program (72). Herbicide application must be precise since erratic weed control has been a major deterrent to adoption of chemical fallow (28). Humburg (62) concluded that herbicide choice, rate, time of application, and tank mixtures were key factors governing the success of chemical fallow.

Effects of chemical fallow and tillage on crop yield and crop quality were evaluated at Moccasin, Montana (75). There were no significant differences in yield, test weight, or protein between the two systems. Soils receiving chemical fallow herbicides remained soft and plastic allowing no-till seeding of winter wheat. Crop residues on the soil surface did not interfere with seeding.

Problems have been noted in no-till seeding. Plugging of drill openers and covering of seed with crop residue have been reported during seeding (45). Crop residues become brittle and fluffy during the weathering process which may promote the plugging of seed drills. Seeding of grain into heavy crop residue requires equipment that will not clog easily (45).

Additional benefits (72) from chemical fallow are as follows:

1) Weed growth is prevented. Conventional tillage controls weeds after they have used soil moisture and nutrients. Chemical fallow with soil active herbicides stops weed growth before soil moisture is utilized.

2) Surface crop residues are increased. Residue enhances rainfall infiltration, decreases erosion, and increases capture of rain and snow.

3) Higher yields in dry years have been reported. Extra moisture stored by chemical fallow will increase yields when moisture is a limiting growth factor. Research has indicated that

wheat yield increases of 200-335 Kg/ha are possible for each additional inch of accumulated moisture.

4) Reduction in tillage operations occurs. Growers have been able to eliminate as many as three to five tillage operations, saving considerable labor and fuel. Machinery wear is reduced. Fewer tillage operations result in less soil compaction, less damage to soil structure, and more surface residue.

5) Chemical fallow adds flexibility since weed control is possible when soils are too wet for tillage or producers are busy with other operations.

6) More nitrate nitrogen is accumulated.

Limitations of chemical fallow systems include:

1) Inconsistent weed control. An effective herbicide must provide consistent, broad spectrum weed control.

2) Residual crop injury from herbicides has hindered development of chemical fallow systems. Herbicide residues must dissipate below injurious levels prior to planting time of sensitive crops.

3) Planting equipment often functions poorly when heavy crop residues are on the soil surface resulting in poor crop stands.

4) Soil temperatures are lower at seeding time.

5) Insect and disease problems may arise.

D. Research on Atrazine:

The first triazine derivatives were synthesized in 1952 in the laboratories of J. R. Geigy and S. A. Basel in Switzerland. Atrazine was synthesized by reacting cyanuric chloride with one equivalent of ethylamine and isopropylamine in the presence of acid acceptors to produce (2 chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine)(Figure 1). Atrazine is classified as a photosynthetic inhibitor that blocks the Hill reaction(8).

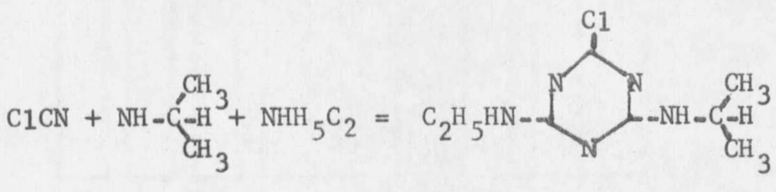

Figure 1. Synthesis of Atrazine.

Greenland (53) and Bailey (9) list seven factors which govern the adsorption of organic molecules onto soil colloids: 1) chemical character, shape and configuration of the molecule; 2) acidity or basicity of the molecule; 3) water solubility; 4) polarizability; 5) polarity; 6) charge distribution on cations; and 7) molecule size. Several of the factors listed above effect the fate of atrazine in field soils (8, 108).

Seven factors influence the fate and behavior of atrazine in soil: 1) microbial decomposition; 2) photochemical decomposition; 3) chemical decomposition; 4) volatilization; 5) leaching; 6) adsorption on soil particles; and 7) plant uptake.

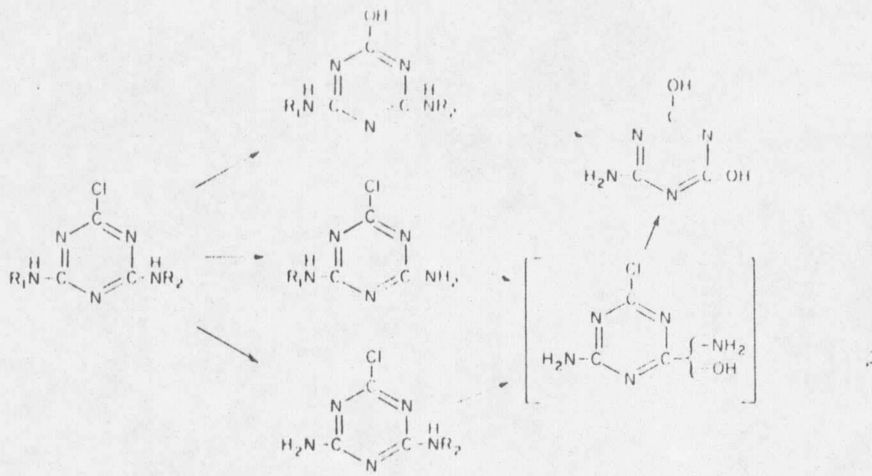

Figure 2. Microbial degradation of chloro-triazines.

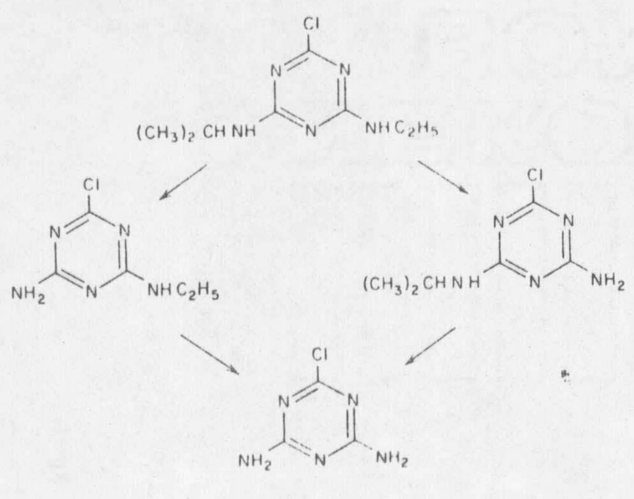

Figure 3. Dealkylation of atrazine.

Microbiological decomposition is the primary degradation pathway for atrazine. Selected soil-borne microorganisms readily accept s-triazine molecules as an energy source (34, 69, 70, 107). Microbial degradation commonly involves dealkylation and subsequent hydroxylation (34, 36, 103) by microbial degradation (Figures 3 and 4).

Application of triazine herbicides, unlike some pesticides, does not effect the overall activity of soil microbes (29, 70). Chandra (29) found that high rates of simazine (2-chloro-4,6bis(ethylamino)-s-triazine) applied to soil, depressed microflora for 28 days after which soil microbiological activity returned to normal.

Soil applications of atrazine increase nitrogen fixation in soil as a result of increased Azotobacter spp. populations in corn root zones (110). Kazubiak (70) reported that atrazine was not toxic to Rhizobium bacteria. Cole (31) concluded that annual applications of atrazine for nine continuous years had little effect on soil microbiology or biochemistry since bacterial growth returned to normal one week after atrazine application.

Gast (51) reported losses of atrazine activity after exposure to ultraviolet and infrared radiation. Losses were highest when atrazine was applied to a dry soil surface. In a second study, atrazine losses ranged from 65% to 80% on a dry soil surface subjected to light radiation (32).

Volatilization may also increase atrazine loss from soil. The rate of loss is regulated by soil properties, temperature, and moisture (36, 71, 108). Davis (36) reported rapid atrazine loss from metal planchets at 60 C. Kearney (71) observed that volatility increased in direct correlation with the sand content of soils and decreased as clay and organic matter content increased. Kearney found that volatilization increased when soil temperature of dry soils increased from 35 C to 45 C.

The most important soil factors influencing activity and degradation of atrazine are: temperature, moisture, clay content, organic matter, and pH (8, 9, 21, 33, 49, 51, 56, 102, 108).

Soil organic matter content is a major determinant to herbicidal activity and persistence of atrazine (35, 56, 102). Upchurch et al., (114) found phytotoxicity to be inversely related to soil organic matter levels. Hance (56) demonstrated that clay and organic matter content determines the amount of total surface area available for herbicide adsorption. Upchurch (114) found that for equal toxicity, about five times more atrazine was required in soils with 20% organic matter compared to 4%. McCormick (81) showed that decomposition of atrazine was directly correlated to soil organic matter and that degradation doubled with each 10 C increase in temperature between 10 to 30 C.

The relationship of atrazine activity, cation exchange capacity, and the exchangeable cations in relation to organic matter has been noted (36). Stancheva (107) reported that soil-applied atrazine reduced copper, zinc, and manganese levels, but slightly increased cobalt levels independent of the atrazine rate applied.

Atrazine residues persisted in plant leaves longer when fertilizers were not used, indicating that optimum soil nutrient levels permit more rapid breakdown of atrazine by plant tissue (106).

Soil texture influences atrazine activity (24, 49, 53, 107). Burnside (24) reported that persistence and phytotoxicity increased with clay content. It was concluded that clay and organic matter content have a greater influence on atrazine activity than climatic factors (25). Organic matter has been reported to absorb 18 times more atrazine molecules than clay colloids (94).

Soil pH influences detoxification of atrazine (17, 33, 56). Soil pH may directly or indirectly influence degradation of atrazine by affecting soil colloid ionic properties, cation exchange capacity, and/or microbial populations in a soil system (24, 56). Frissel and Bolt (49) observed increases in adsorption to soil colloids with decreasing pH due to protonation of the molecule which enters ion exchanges. It has been reported that low soil pH increased displacement of atrazine from soil colloids (82).

Liming of soils may increase phytotoxicity of atrazine. Best (17) concluded that increasing soil pH from 5.5 to 7.5 increased phytotoxicity and persistence of atrazine.

Microbial populations are often sensitive to changes in pH. Soil pH is an important factor regulating the rate of microbial degradation of atrazine (33).

Soil moisture is needed to activate atrazine following application to a soil surface. Audus (8) determined that soil moisture may affect herbicide adsorption on soil colloids and availability for plant uptake. Atrazine activity was significantly increased when soil moisture was increased from 25 to 31% (110).

Atrazine persists longer under dry soil conditions making carryover a major constraint in semi-arid regions (24). Hurle (63) demonstrated degradative half-lives of atrazine to be 151, 37, and 16 days when soil moisture was 4, 35, and 78% of field capacity, respectively.

Cultural practices such as cultivation and crop rotations on atrazine soil residues have been tested. Atrazine used in winter wheat-fallow rotations has been reported to cause crop injury while crop injury is essentially eliminated when sorghum-winter wheat rotations are used (46). Atrazine at recommended rates for sorghum will generally not persist to cause crop injury to winter wheat. Residual toxicity can cause severe crop injury if susceptible crops such as sugarbeets (*Beta vulgaris* L.), oats (*Avena sativa* L.), soybean (*Glycine max* L.), or alfalfa (*Medicago sativa* L.) are planted into soil residues of atrazine.

Tolerant crops such as sorghum are seldom injured by atrazine residues. Burnside (26) concluded that annual applications on sorghum did not reduce yield.

Slack et al., (104) found less atrazine residue in no-tillage conditions than with cultivated areas. Differences in residue levels were more noticeable under dry conditions. Cultivation may increase the persistence of atrazine under dry conditions by mixing atrazine into uncontaminated soil and drying the soil.

Deep plowing and fall cultivation may also reduce herbicide residues (104). Additionally, seeding rate and seeding depth may influence the degree of crop injury.

Hoffman et al., (59) demonstrated that plants compete for atrazine. Increasing plant populations from one to six plants in greenhouse pots reduced atrazine uptake per plant by 50%. Eckert et al., (39) measured an increase in seedling vigor, survival and plant density following deep furrow seeding by placing the seed below treated soil. Plant height and the number of headed plants also increased.

Herbicide residues are often detected by bioassay methods. Plant growth of susceptible species in soil containing unknown residue concentrations is compared to growth in soil treated with known amounts of herbicide. Common plant growth responses which are measured are root or shoot elongation, growth inhibition, chlorosis and total plant weight.

Oats are commonly used in atrazine bioassays (79, 82, 110).

Photosynthetic algae have also been used as indicator organisms for measurement of herbicide residues (2, 7, 18, 54, 73, 94, 99, 120). Addison (2) reported that a bioassay using algae was rapid and accurate for measuring residues of dichloroaniline herbicides. Schackler (99) reported that atrazine inhibited growth of *Chlorella vulgaris* but increased protein and chlorophyll levels indicating *Chlorella* spp. are sensitive bioassay organisms. Wells (119) accurately measured atrazine residues in the range of 0.1 to 0.5 ppm in only 14 hours with *Chlorella pyrenoidosa*. Blass (19) and Wetzel (120) reported similar results and concluded that algae could be used for rapid screening of chemicals for herbicidal activity.

Chemical analysis by chromatographic techniques has become the most accurate method for herbicide detection (77, 80, 88, 96). Hurle (64) cautioned that bioassay results should be verified by chemical analysis.

E. History of Glyphosate

Glyphosate (N-phosphonomethyl) glycine) is a non-selective post-emergence herbicide developed by Monsanto Company (137). The mode of action of glyphosate appears to be inhibition of aromatic amino acid synthesis (153).

Glyphosate has no soil residual properties (163, 176, 168). This characteristic, combined with its broad spectrum of control makes glyphosate a candidate herbicide for chemical fallow.

The effectiveness of glyphosate is influenced by plant growth stage (142, 152, 162). Glyphosate is not translocated to rhizomes of quackgrass (Agropyron repens L. Beauv.) until 3-4 leaf stage of growth and it is translocated by the phloem in the same manner as carbohydrates (144, 148). Claus and Behrens (144) obtained higher rhizome bud kill of quackgrass when application was made to well developed plants.

Parochetti et al., (161) concluded that optimal control of johnsongrass (Sorghum halepense L. Pers.) was achieved when glyphosate was applied in the boot to full head stage rather than earlier growth stages.

Glyphosate affects weed seed production. May (156) found that control of wild oats (Avena fatua L.) was poor when plants were fully headed; however, no viable seeds were produced.

Glyphosate has herbicidal activity on several perennial grasses (136, 137, 140, 145). Johnsongrass control was excellent at rates between 1.12 and 3.36 Kg/ha and eradication was achieved with repeated applications (136, 145, 149, 155, 158, 161, 169).

Glyphosate is effectively translocated throughout the quackgrass plant (134, 135, 137, 140, 143, 148, 150, 152, 153, 159, 161, 169). Claus and Behrens (144) found that glyphosate was concentrated in rhizome nodes farthest from the parent plant. The adsorption and translocation of glyphosate has been studied in Canada thistle

(Cirsium arvense (L.) Scop) (134, 136, 137, 149, 151, 164), leafy spurge (Euphorbia esula L.) (136, 151) and field bindweed (Convolvulus arvenis L.) (136, 165).

Gottrup et al., (151) reported that the uptake and translocation patterns of glyphosate were similar in Canada thistle and leafy spurge. Saidak et al., (164) found no difference in glyphosate susceptibility among Canada thistle ecotypes in contrast to the herbicide amitrole. Environmental factors including temperature, frost, soil moisture, relative humidity and light intensity influence glyphosate activity. Control of quackgrass generally increases as temperatures proceeding herbicide application decrease. Baird and Begeman (135) found that post application temperatures of 16 C resulted in higher control than temperatures of 24 C or 32 C. Conversely, McWhorter (158) reported better control of johnsongrass at 35 C than at 25 C.

Fall applications of glyphosate have generally been more effective than spring applications for Canada thistle (149), field bindweed (165), quackgrass (147, 148) and leafy spurge (151). Glyphosate activity on quackgrass was increased by frost during fall applications (147, 148). In general, maximum activity occurs when application follows the first fall frost. Good control of quackgrass has been achieved with spring applications; however, the optimal planting dates of most crops are too early for satisfactory spring application of glyphosate.

Adequate soil moisture is important for satisfactory activity of glyphosate since plant growth and glyphosate translocations are reduced during water stress. Davis (147) reported reduced control of quackgrass when application was made during drought stress.

Glyphosate activity is affected by relative humidity (143, 147). Caseley (143) demonstrated that quackgrass rhizome weight was reduced from 50 to 90% of the control when the relative humidity was increased from 55 to 95% during herbicide application. Glyphosate is readily washed from leaf surfaces by rainfall within eight hours after application (135, 141).

Control of quackgrass with glyphosate was directly correlated with light intensity as a result of increased photosynthesis and phloem translocation (136, 147).

Application technique may greatly influence glyphosate efficiency (135, 141, 142, 143, 147, 148, 150, 158). The degree of control has been inversely correlated with application volume (166). Surfactants appear to increase the amount of glyphosate absorbed and translocated (143). Tank mixing of glyphosate with most residual herbicides results in a reduction of phytotoxicity due to physical binding within the mix suspension (133).

Baur et al., (139) reported that foliar applications of low rates of glyphosate to sorghum increased fresh weight. As glyphosate levels were increased, the basal growth of sorghum increased; however, fresh weight decreased. Glyphosate inhibited basal bud formation in wheat at optimal growth temperatures but stimulated basal bud formation when temperatures were above optimum.

Glyphosate has also been used in sod seeding and pasture renovation. Bauer et al., (138) found applications of glyphosate increased protein levels of several grasses. Moshier (159) found no decrease in germination and emergence of alfalfa during sod seeding following applications of glyphosate. These results are in agreement with research conducted with glyphosate for the establishment of turfgrasses (154, 160). Application directly over the grass seed had no effect on germination of Kentucky bluegrass (*Poa pratensis* L.), red fescue (*Festuca rubra* Scribn.), tall fescue (*Festuca arundiacea* Schreb.) (154).

Chapter 2

COMPARISON OF BIOASSAY TECHNIQUES FOR MEASURING SOIL RESIDUES OF ATRAZINE

Abstract

Bioassays are commonly used for detecting phytotoxic residues of herbicides in soil. While bioassays are inexpensive and relatively accurate, they are often criticized because they require large amounts of space and time.

Five bioassay methods were compared using atrazine treated soil. Nursery cone-containers filled with atrazine treated soil required very little space and provided inexpensive, accurate results when compared to petri dish or Stanford-DeMent assay techniques. Greenhouse pots were as accurate as the cone-containers but required more space. A bioassay using *Chlorella sorokiniana* algae was the fastest of the assays that were compared, and was accurate.

INTRODUCTION

The use of bioassays to determine herbicide concentrations in soil has been widely used in herbicide research (64, 79). Bioassays often detect toxic herbicide metabolites which may be undetected by chemical assays. Additionally, bioassays do not require expensive analytical equipment.

Several bioassay methods have been used for detection of triazine residues (2, 64, 73, 79, 94, 112). Oats are often used as indicator plants for triazine residues (64, 79, 112). The effects are generally assessed by measuring differences in fresh or dry weight of oat seedlings after a 3-4 week growth period. The time requirement of plant bioassays is a major factor limiting the use of bioassays.

The use of microorganisms (including Chorella spp. algae) as indicator species has produced accurate results in herbicide bioassays and reduced the bioassay time requirement (2, 7, 19, 54, 73, 94, 99, 119, 120). The use of microorganisms for assays purposes is well established in several scientific areas, but relatively untested in pesticide residue studies.

The purpose of this study was to compare the accuracy and efficiency of several plant bioassay methods with an algae assay method for possible development of a soil testing service for farmers using a chemical fallow cropping system. Determination of a superior bioassay for atrazine would be beneficial to farmers for fast and accurate detection of soil residue. This study was performed to compare commonly used bioassays for determination of those assays suitable for commercial soil analysis.

MATERIALS AND METHODS

Experiments were conducted in the greenhouse to compare five bioassay techniques, including (1) a conventional greenhouse pot assay, (2) a nursery cone-container assay, (3) a petri dish assay, (4) the Stanford-DeMent assay (112), and (5) a Chlorella spp. algae assay.

Soil was treated with atrazine by pipetting an aliquot from an aqueous stock solution containing a commercial formulation (80 WP) of atrazine (Ciba-Geigy Co.) to soil followed by homogenous mixing in a revolving drum soil tumbler. Final atrazine concentrations mixed in the soil were 0, 0.2, 0.50, 0.75, and 1.0 ppmw which corresponds to 0, 0.28, 0.56, 0.84 and 1.12 Kg/ha surface applied, respectively. All assays were replicated six times for each atrazine concentration. The soil used was greenhouse potting soil (2:1:1 v/ v/ v/, Gallatin clay loam, sand and peat moss) with four percent organic matter.

Plant assays were performed in the greenhouse at approximately 25 C day and 20 C night temperatures under 16 hours light.

All bioassays were rated for accuracy on percent of control of shoot weight accumulation. Time requirements were measured from initial assembly of each soil sample to recording of weight data for each assay. Space requirements were measured for all assays on a space/ sample basis.

1) Standard Greenhouse Pot Bioassay

Greenhouse pots (7.6 cm deep x 5.1 cm dia) were filled with 100 g atrazine treated soil. Five oat seeds (variety 'Park') were planted

2.5 cm deep. Pots were watered daily with 25 ml of tap water. Oat seedlings were thinned to three plants per pot after emergence.

2) <u>Nursery Cone-Container Bioassay</u>

Atrazine treated soil (140 g) was placed in 3.8 cm dia x 21 cm deep cylindrical nursery cone-containers (Ray Leach Cone-Tainer Nursery, Canby, OR). Four oat seeds were planted 2.5 cm deep per container and thinned to three plants after emergence. Containers were watered daily with 35 ml of tap water.

3) <u>Petri Dish Bioassay</u>

Circular petri dishes (14.5 cm diameter x 1.5 cm deep) were filled with atrazine treated soil (150 g). Seven oat seeds were planted 1 cm deep and thinned to five plants per dish after emergence. Dishes were watered daily with 38 ml of tap water. Dishes were placed in a covered aquarium to reduce moisture loss by evaporation.

4) <u>Stanford-DeMent Bioassay</u>

Polystyrene cups (6.3 cm dia x 8.9 cm deep) were filled with untreated soil (200 g). Five oat seeds were planted 2.5 cm deep and thinned to four plants per cup after emergence. Cups were watered daily with 60 ml of tap water. Plants were allowed to grow 14 days and the bottoms of the cups were removed. The polystyrene cups were placed in pots (12.7 cm dia x 12.7 cm deep) containing atrazine treated soil (300 g). The polystyrene cups were firmly imbedded 2.5 cm deep into the atrazine-treated soil to provide firm contact of the established plant roots. Shoot fresh and dry matter production were measured twenty one days after planting for assays, one, two and three above and twenty one days after transplaning in assay four. Plants were clipped at the soil surface, dried in a forced air oven at 38 C and weighed.

5) Chlorella sorokiniana Algae Bioassay

A culture of *Chlorella sorokiniana* high temperature strain algae (American Type Culture Collection, Rockville, MD) was maintained in aerated Gorhams nutrient solution (61). The nutrient solution contained dilutions of five aqueous medium compositions (Table 1).

Table 1. Chlorella growing medium composition

Solution No.	Compound	Quantities
1	$NaNO_3$	4.96 g/100 ml water
	$CaCl_2 - 2H_2O$	0.36 g/100 ml water
2	K_2HPO_4	0.39 g/100 ml water
3	$MgSO_4 - 7H_2$	0.75 g/100 ml water
4	Citric acid	0.60 g/L water
	$Na_2EDTA - 2H_2O$	0.10 g/L water
	Fe Citrate	0.60 g/L water
5	$Na_2SiO_3 - 9H_2O$	0.58 g/100 ml water
	Na_2CO_3	0.20 g/100 ml water

Ten ml aliquots of each stock solution were diluted with 1 L of distilled water. Equal volumes of the diluted solutions were combined for the algae growing media. Mixing of the stock solutions (Table 1) must be done in numerical order to avoid precipitation of nutrients.

The assay procedures of Kratky and Warren (73) were modified as follows: Atrazine treated soil (75 g) was placed in 250 ml Erlenmeyer flasks with 150 ml of distilled water. Flasks were continuously shaken on an oscillating shaker for 24 hrs. The soil solution was vacuum filtered through a Buchner funnel lined with Whatman #2 filter paper.

A 50 ml aliquot of each soil filtrate was centrifuged (17,000 RPM) for 10 min to remove clay particles and placed in 125 ml Erlenmeyer flasks containing 50 ml of nutrient solution and 10 ml of the algae growing media (approximately 50 x 10^6 algae cells per ml).

Flasks were placed under constant illumination with an artificial light bank containing fluorescent and incandescent lights (19 Klux) in a randomized complete block design. Air was supplied to each flask by an aquarium air pump through tygon tubing. The temperature was maintained at 23 C. Aliquots (3 ml) were removed from each flask at 24 hr intervals, placed in a spectrophotometer (Beckman DB) and absorbance read at 670 mμ.

Efficiency measurements Time and space requirements, and accuracy were compared for each bioassay. Time requirements were calculated from initiation to recording of final data. The total space requirement was measured for single soil samples. Accuracy for atrazine detection was determined by analysis of the slope and linearity of the standard curves of each bioassay.

RESULTS AND DISCUSSION

Bioassay techniques were compared in an attempt to initiate an assay service for producers using atrazine for chemical fallow in Montana. An acceptable assay must be accurate, rapid, inexpensive and occupy little space per soil sample.

Accuracy is a function of the slope and the linearity of the standard curve. The steeper the slope the more sensitive the assay. The standard curve should be relatively linear within the expected range of concentrations of herbicide residues. The recommended rate of atrazine for chemical fallow ranges from 0.82 to 1.12 Kg/ha for a 12 to 14 month fallow period. The range of sensitivity for an atrazine soil assay to be conducted near the end of a fallow period should range from 0 to 0.82 Kg/ha.

The standard greenhouse pot assay and the cone-container assays were the most accurate of the plant bioassays studied (Figure 1). The standard curve slopes were steep and relatively linear. The standard curve of the petri dish assay was linear but the slope was not large enough to provide acceptable sensitivity. Oat roots in the petri dish system were restricted to the bottom of the dish which may have allowed less uptake of atrazine.

The Standard-DeMent assay was originally used for studies measuring plant available phosphorus in soil (112). Sensitivity of radioisotope detection of $P^{32}O_4$ is sufficient to utilize this system. However, oat seedling growth was erratic in the range of 0 to 0.56 Kg/ha of atrazine and significant growth stimulation was unexpectedly observed (Figure 2) resulting in inaccurate measurement of atrazine concentrations. The growth stimulation may have been due to plant response to uptake of small amounts of atrazine. The plants may have increased photosynthesis and transpiration to overcome the effect of atrazine.

The Chorella spp. assay provided a linear standard curve in the expected range of recovery when measured after 24 and 48 hrs of growth (Figures 3 and 4) indicating good sensitivity to atrazine. Readings at 48 hrs had an increase in slope of the standard curve at the 0.84 Kg/ha rate indicating that high levels of atrazine soil residue may be measured more accurately at the later reading.

Initial assembly time was longer for the standard pot assay, petri dish assay and Stanford-DeMent assay than the Chlorella spp. algae and cone-container assays (Table 2). The total time requirements for the plant bioassays was considerably longer than the Chlorella spp. algae assay (Table 2). Three weeks were required to complete the plant bioassays compared to only one to two days for the algae system. The longer time requirement of plant bioassays limits the number of soil samples that can be analyzed.

Table 2. Comparison of assembly time, duration and space requirements of five bioassay techniques

	Assembly Time/Sample	Duration	Space Requirement/Sample
Greenhouse pot	1.28 min	20 days	6.33 cm^2
Cone container	0.85 min	20 days	3.80 cm^2
Petri dish	1.20 min	20 days	8.20 cm^2
Stanford-DeMent	1.32 min	20 days	49.1 cm^2
Chlorella algae	0.90 min	1-2 days	21.16 cm^2

The algae system was fast, accurate and had a relatively small space requirement making it suitable for analysis of large numbers of soil samples. However, it was the most expensive of assay techniques because of the required laboratory equipment.

CONCLUSIONS

A herbicide residue analysis service must have a short "turn around" time because soil samples are usually taken shortly before seeding. The decision to seed a crop is determined by the amount of atrazine residue left in the soil.

The standard pot, cone-container, and algae assay are sufficiently sensitive for accurate analysis of atrazine residues. However, the algae system facilitates soil sampling and bioassaying immediately before seeding.

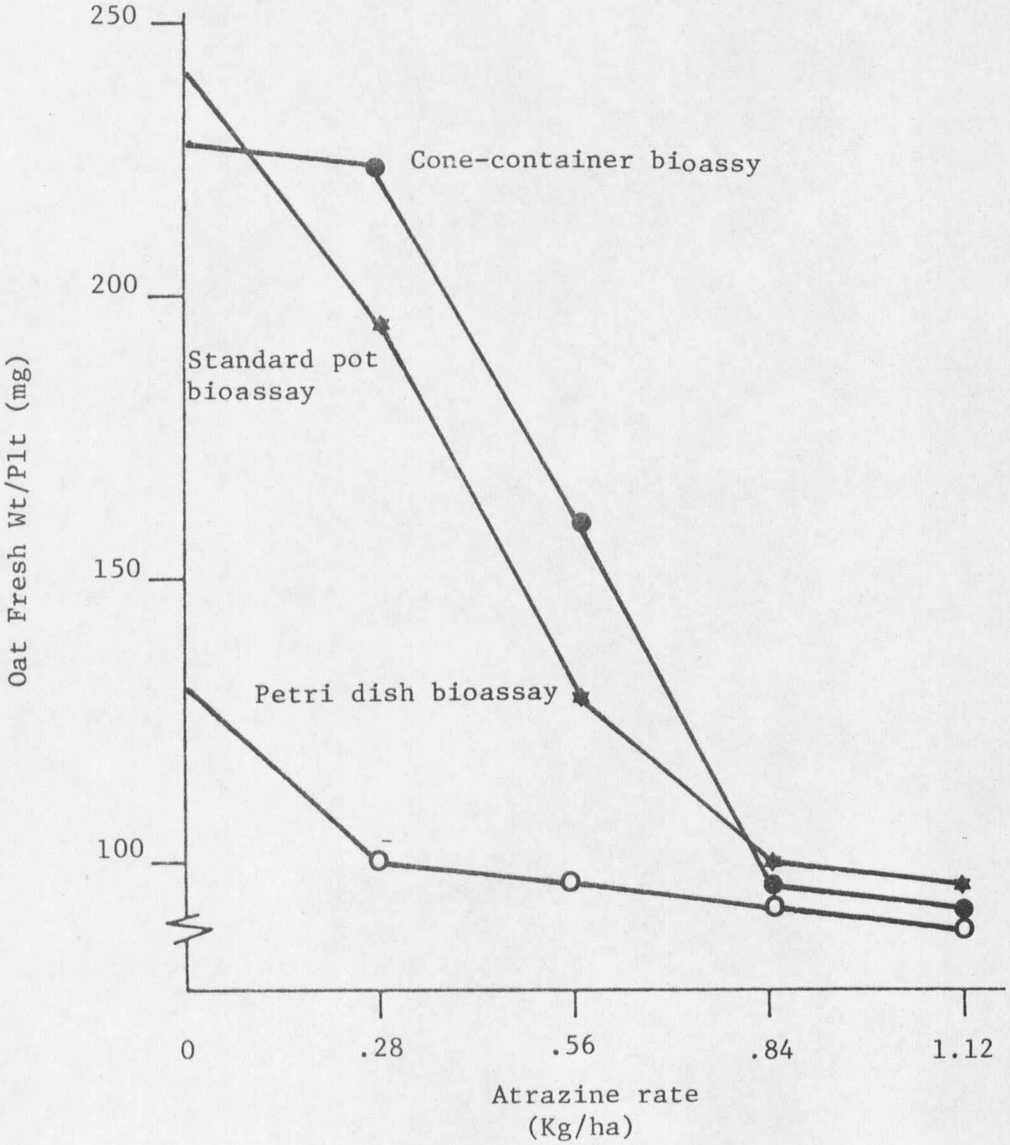

Figure 1. Effect of increasing concentrations of atrazine in soil on oat fresh weight accumulation 21 days after planting in 3 bioassay systems.

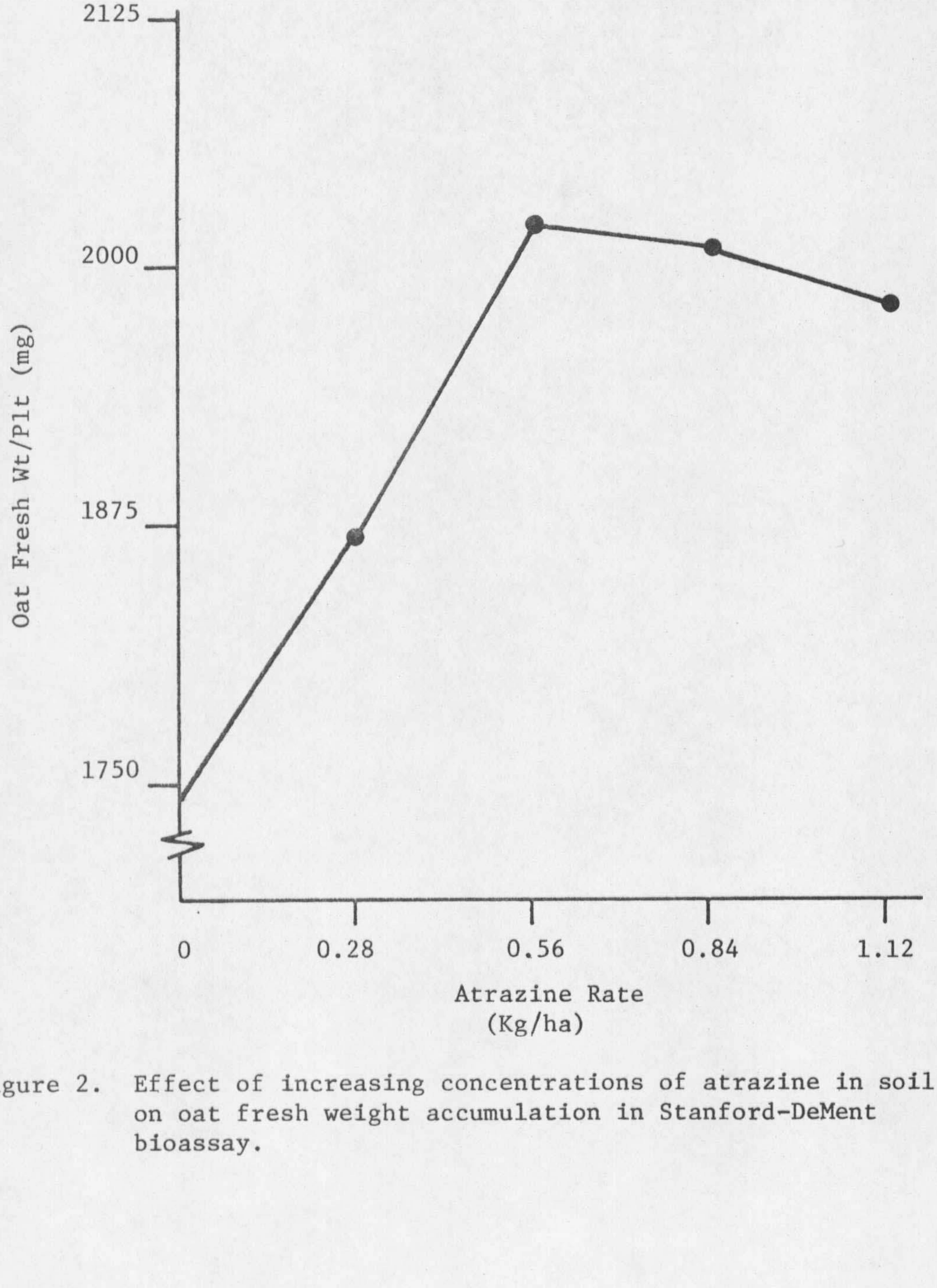

Figure 2. Effect of increasing concentrations of atrazine in soil on oat fresh weight accumulation in Stanford-DeMent bioassay.

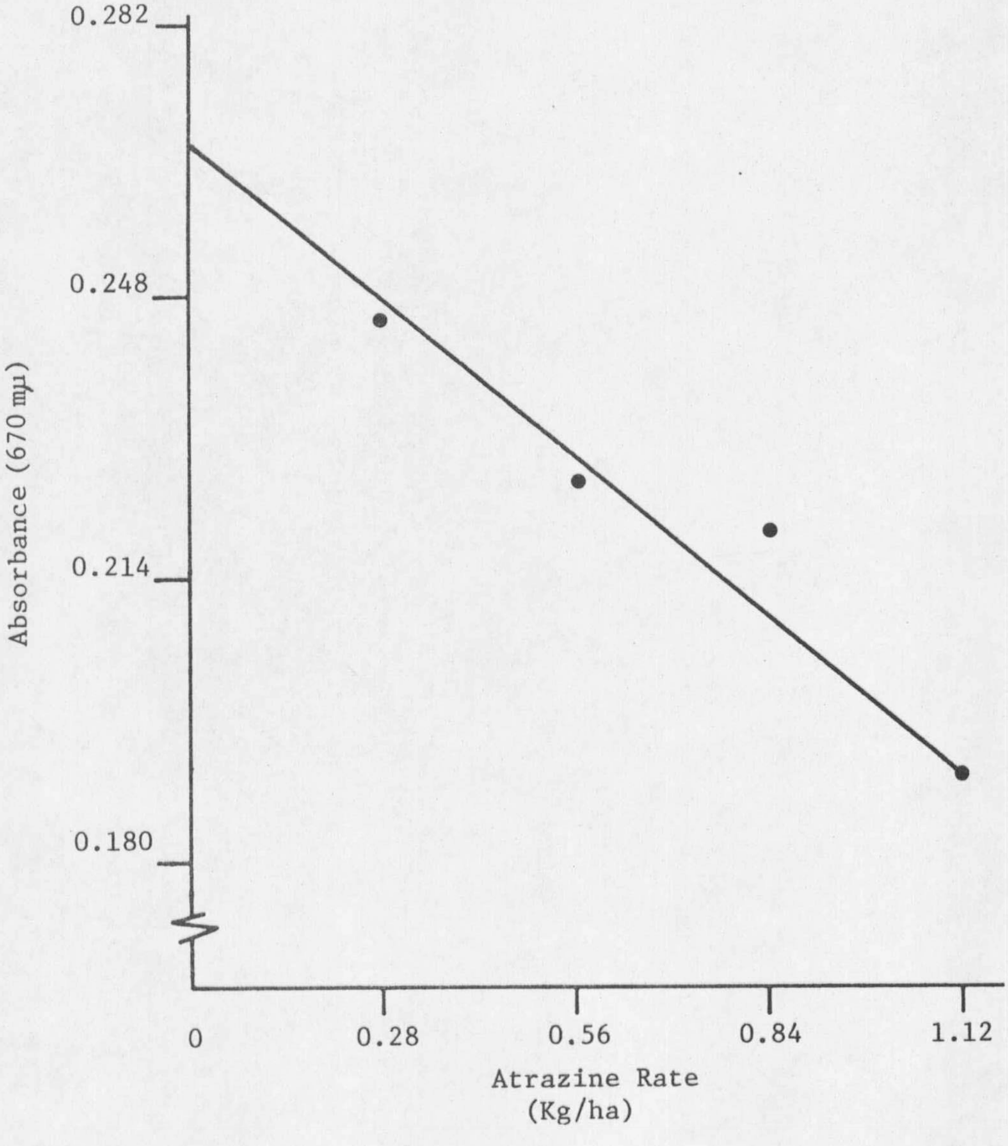

Figure 3. Effect of increasing concentrations of atrazine in soil on Chlorella sorokiniana algae growth after 24 hours in soil extract.

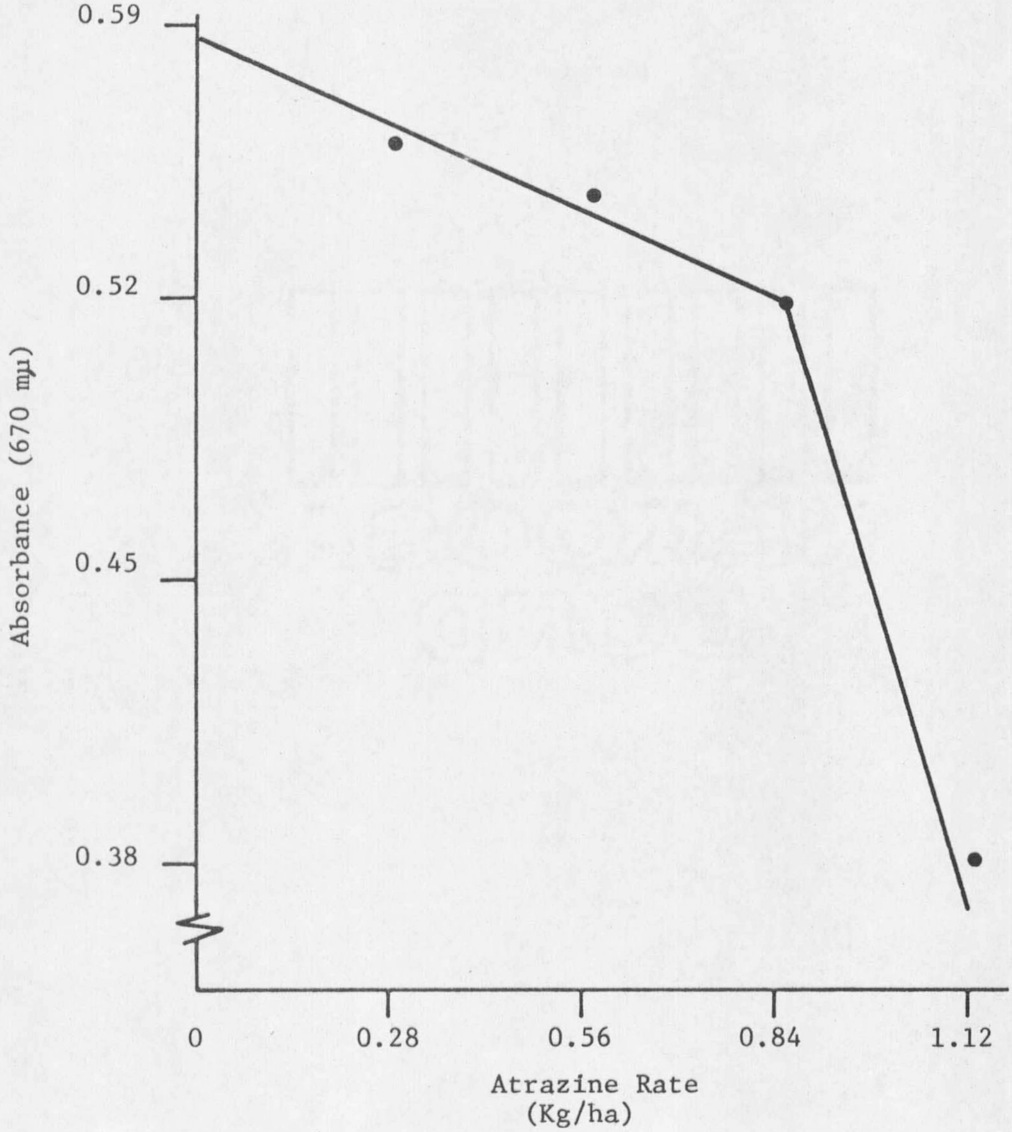

Figure 4. Effect of increasing concentrations of atrazine in soil on Chlorella sorokiniana algae growth after 48 hours in soil extract.

Chapter 3

Abstract

THE USE OF ATRAZINE FOR CHEMICAL FALLOW

Experiments measuring the degradation of atrazine in field soils were conducted at eight locations in Montana from September 1978 to September 1979. The rate of degradation was correlated with various edaphic factors in an attempt to predict the rate at which atrazine was lost.

Precipitation and soil pH were the most important factors regulating the rate of atrazine degradation. Atrazine rates of 0.84 Kg/ha provided satisfactory weed control, however, after 12 months, crop injurious amounts still remained. Using higher rates of atrazine caused an increase in residual levels but no significant difference in weed control.

INTRODUCTION

The use of atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) for chemical fallow has increased in Montana because it provides inexpensive, long term weed control (21, 28, 39, 126). However, atrazine persists in the soil, causing a major crop injury risk for grain producers (24, 43, 44).

Considerable research has been directed toward atrazine crop injury (25, 45, 48, 64, 101, 111). Atrazine is degraded primarily by soil microorganisms. Soil and climatic conditions exert a major influence on these microbial populations (24, 69). Moisture, organic matter and pH may also influence the population and activity of the microorganisms.

The objective of this study was to measure the rate of atrazine degradation during a one-year fallow period. The rate of degradation was correlated with numerous edaphic factors to identify predictive variables for atrazine loss.

MATERIALS AND METHODS

Field studies were conducted to measure the rate of atrazine degradation at eight diverse locations. The locations differed in annual precipitation and soil characteristics.

A commercial formulation of atrazine (80 WP, Ciba-Geigy Co.) was applied to stubble in September 1978 at 0, 0.28, 0.56, 0.84, 1.12 and 2.24 Kg/ha with a bicycle wheel type sprayer. Applications were made in 337 to 393 L/ha of water at 2.4 Kg/cm^3 pressure. Plots were 2 m x 10 m with four replications arranged in a randomized complex block design.

Sampling and Residue Analysis

Soil samples and visual weed ratings were taken from plots treated with 0, 0.84, 1.12 and 2.24 kg atrazine per ha on five dates (9/78, 5/79, 6/79, 7/79 and 9/79). At each location, soil samples were taken to a depth of 7.6 cm with 10.2 cm x 5.1 cm tapered bulb planters. This depth was chosen because atrazine will generally remain within 7.6 cm under semi-arid conditions.

The soil samples were analyzed for atrazine by bioassay using 3.8 cm diameter x 21 cm deep nursery cone-containers (Ray Leach Cone-Tainer Nursery, Canby, OR). Five oat seeds (*Avena sativa* L.) were planted per container and later thinned to three plants. A randomized complete block design was utilized with four replications. The experiment was conducted twice.

Aliquots of an atrazine stock solution were pipetted onto known amounts of untreated soil to produce a standard curve. Concentrations of 0.0625, 0.125, 0.375, 0.50, 0.75, 1.0 and 2.0 ppmw corresponding to 0.07, 0.14, 0.28, 0.42, 0.56, 0.84, 1.12 and 2.24 Kg/ha surface applied were used. The treated soil was then mechanically mixed with a revolving soil tumbler to ensure homogenous mixing. As with the unknown samples, five oat seeds were planted and thinned to three plants in each container. A randomized complete block design was utilized with four replications.

Shoots were harvested at the soil surface 21 days after planting and oven dried at 60 C for 24 hrs. Shoot dry weight as percent of control was plotted on a standard curve to calculate atrazine residue levels in each soil sample. The rate of atrazine degradation at each location was correlated with several soil and climatic conditions (Table 1).

Table 1. Climatic and edaphic soil characteristics of chemical fallow locations.

Location	Precipitation[1/]	pH	Organic Matter	Clay Content	Calcium Content
	cm		%	%	%
Havre	29.3	8.0	1.35	31	12.8
Huntley	36.6	8.4	1.20	53	29.2
Fort Benton	38.0	8.3	3.15	44	37.5
Conrad	34.2	7.8	2.50	37	10.8
Cascade	34.3	7.2	3.20	38	13.3
Moccasin	44.5	7.5	3.25	43	22.5
Sidney	37.0	6.2	2.25	33	7.9
Bozeman	40.5	6.8	2.20	33	11.8

1/ Precipitation was measured from 9/1/78 to 9/1/79 by National Oceanic and Atmospheric Administration stations.

Weed Control Ratings Visual weed control ratings were recorded for each weed species to determine the rates of atrazine needed for good control. Zero percent = no control and 100% = complete control (80% control was considered satisfactory). Glyphosate was applied at 1.12 Kg/ha after each rating to eliminate established weeds.

RESULTS AND DISCUSSION

The decline of atrazine in soil was measured at eight locations in Montana from September, 1978 to September, 1979. Precipitation ranged from 29 cm at Havre to 44 cm at Moccasin (Table 1). A wide range in soil pH, organic matter, soil clay content and soil calcium existed among the locations. A standard curve for atrazine detection at each location was established using oats as an indicator species (Table 2). Soil samples were taken at each location five times from September, 1978 to September, 1979 and frozen until bioassayed during the fall of 1979. Oat growth as percent of control was determined (Table 3).

Oat growth was reduced more than 50% in soil sampled from all locations one year after application of atrazine at 1.12 and 2.24 Kg/ha (Figures 1-8). Growth was reduced approximately 35 to 50% in samples from Moccasin, Huntley, Conrad and Fort Benton one year after application of atrazine at 0.84 Kg/ha. This is the recommended rate of application (Figures 2, 3, 4 and 6). Oat growth was reduced 15 to 30% in samples from Havre, Cascade, Sidney and Bozeman one year after

Table 2. Standard curve calculations measuring shoot dry weight of oat seedlings grown in soils from eight locations treated with eight rates of atrazine.

Atrazine Rate Kg/ha	Oat Shoot Growth (% of Control)							
	Location							
	Havre	Huntley	Fort Benton	Conrad	Cascade	Moccasin	Sidney	Bozeman
0.07	105.2	97.8	91.8	91.7	99.0	89.9	89.8	77.3
0.14	87.6	74.7	64.6	58.2	76.1	52.2	62.1	51.3
0.28	83.1	52.3	46.8	46.1	56.1	37.3	37.1	42.1
0.42	37.9	34.5	35.6	26.5	33.2	26.9	23.3	28.9
0.56	25.7	21.7	26.9	13.8	23.3	19.1	21.4	22.9
0.84	30.6	23.6	18.4	16.3	18.9	19.2	16.1	22.0
1.12	25.5	15.7	9.9	11.4	15.0	10.7	11.2	12.0
2.24	14.5	7.9	7.7	6.8	9.8	5.5	4.8	5.9
LSD 5% =	7.9	2.0	11.6	7.4	15.2	4.4	10.1	5.2
C.V. =	4.8	3.0	9.1	6.2	11.4	2.8	8.6	4.5

Table 3. Dry weight of oat seedlings, expressed as a percent of the untreated control, at eight locations following use of atrazine for chemical fallow, as measured by a standard greenhouse bioassay.

Sampling Date	Application Rate Kg/ha	Oat Shoot Growth (% of Control) Location							
		Havre	Huntley	Fort Benton	Conrad	Cascade	Moccasin	Sidney	Bozeman
9/78	0.84	29.0	23.1	20.6	25.9	20.2	21.3	16.8	23.5
	1.12	23.2	20.0	15.8	12.0	16.8	17.0	12.4	15.6
	2.24	11.1	11.0	9.7	9.6	6.1	6.5	4.5	4.9
5/79	0.84	41.0	27.1	26.8	22.3	28.4	40.1	27.7	37.7
	1.12	26.2	21.8	20.7	16.9	17.2	27.3	20.7	23.6
	2.24	14.9	13.3	12.0	10.1	12.1	19.0	13.7	17.3
6/79	0.84	54.8	49.3	34.4	28.1	28.3	44.9	33.4	49.4
	1.12	32.8	24.4	25.9	23.0	23.9	27.7	20.0	39.8
	2.24	21.8	15.2	16.3	15.1	24.0	23.3	19.0	24.9
7/79	0.84	74.1	55.8	44.3	39.4	39.4	52.5	51.7	70.0
	1.12	37.9	24.6	30.7	30.9	29.9	33.9	35.3	42.1
	2.24	25.4	15.8	19.3	19.9	28.2	26.8	18.6	27.0
9/79	0.84	82.0	63.1	52.9	53.2	69.7	55.3	77.3	76.9
	1.12	43.3	35.4	36.5	39.1	54.8	39.3	44.6	45.3
	2.24	31.2	16.3	25.8	20.0	24.9	34.2	27.0	33.4
LSD 5% =		2.2	2.7	2.5	2.7	4.4	1.6	4.3	5.4
C.V. =		3.1	5.4	5.8	4.4	6.1	3.3	8.5	8.4

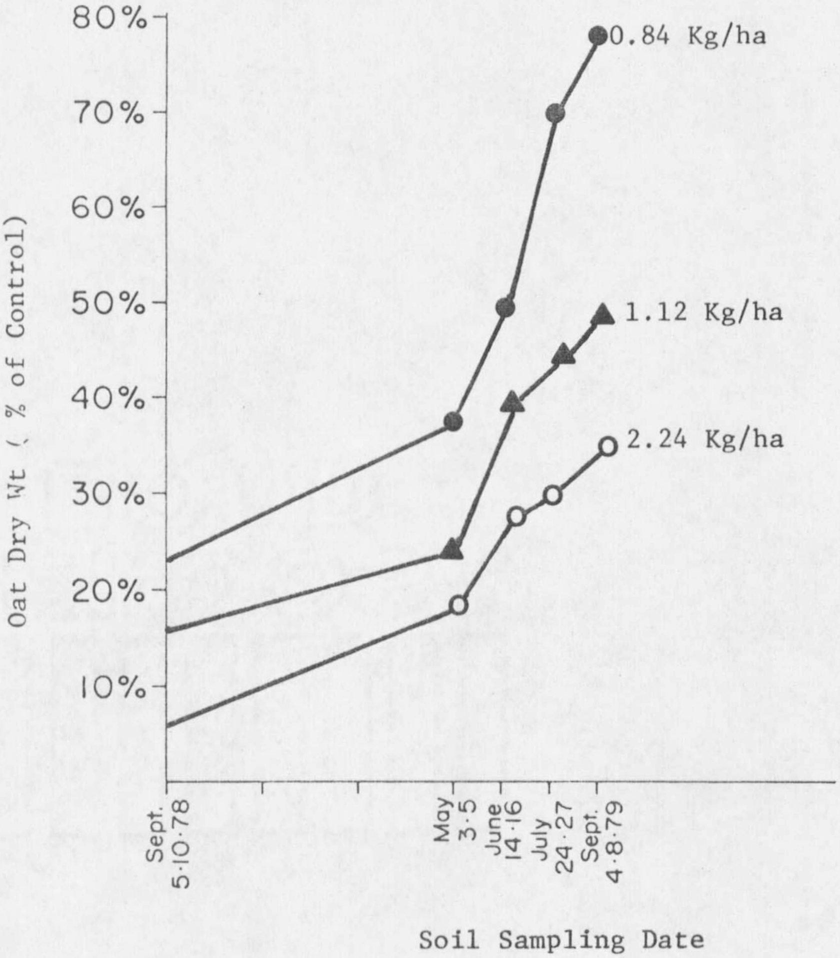

Figure 1. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Havre.

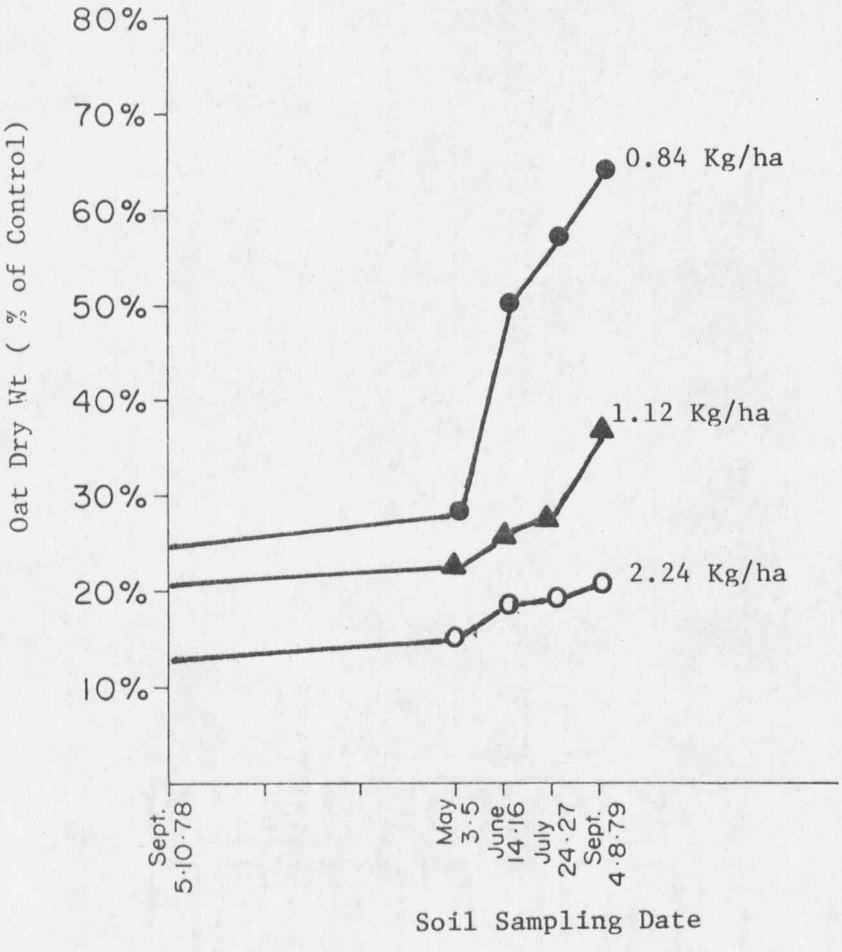

Figure 2. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Huntley.

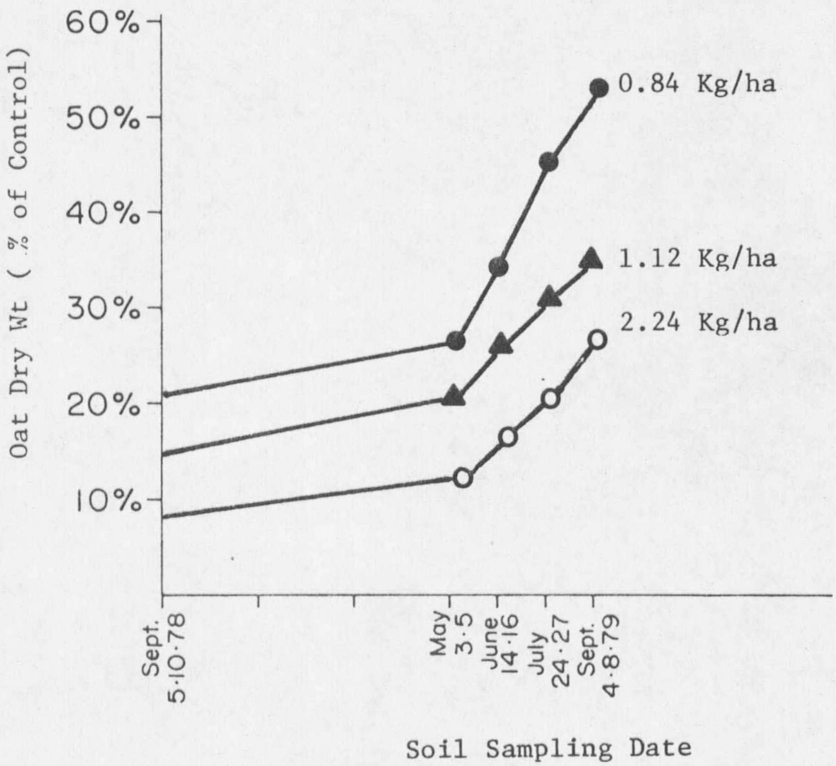

Figure 3. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Fort Benton.

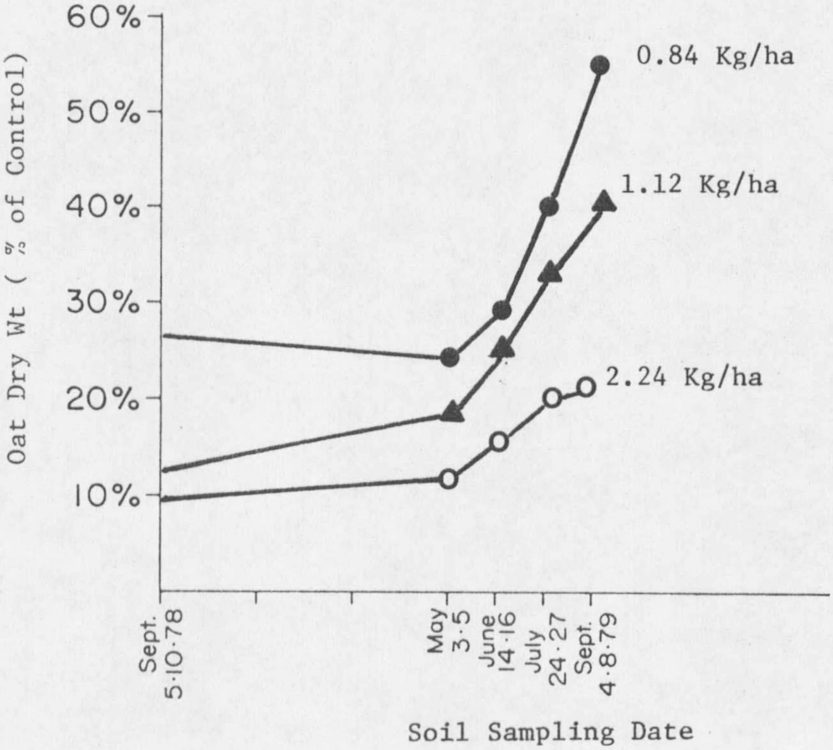

Figure 4. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chem-fallow at Conrad.

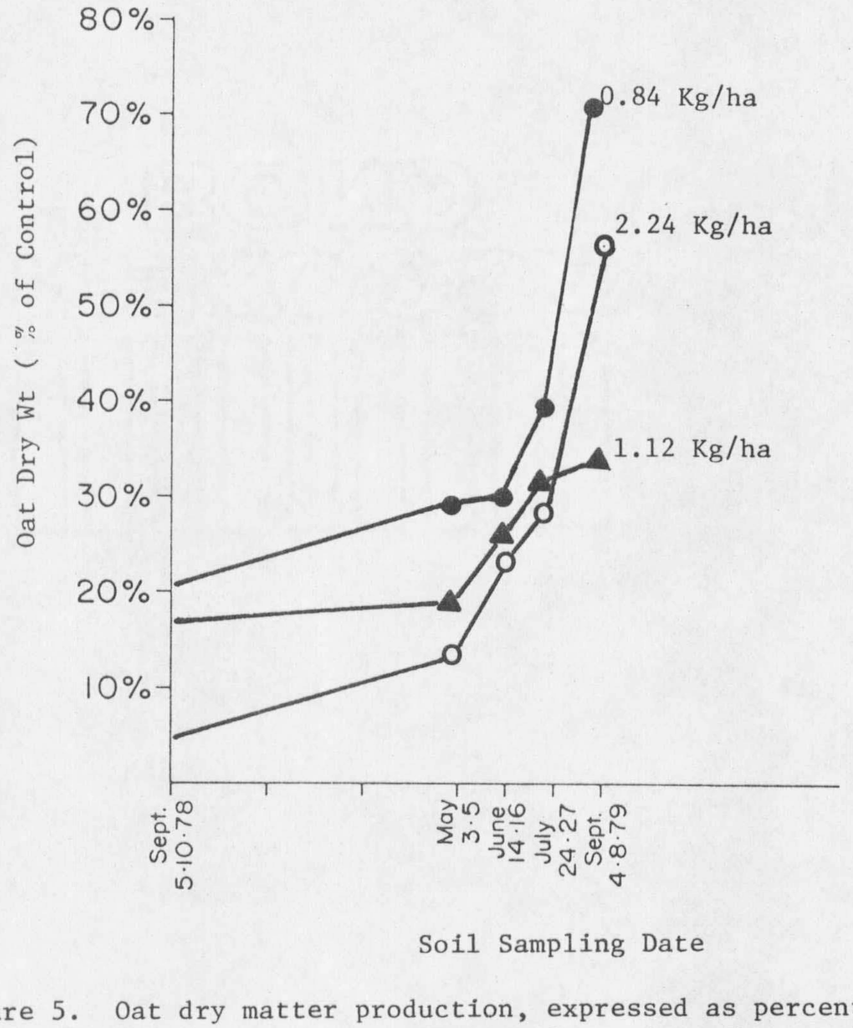

Figure 5. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemcal fallow at Cascade.

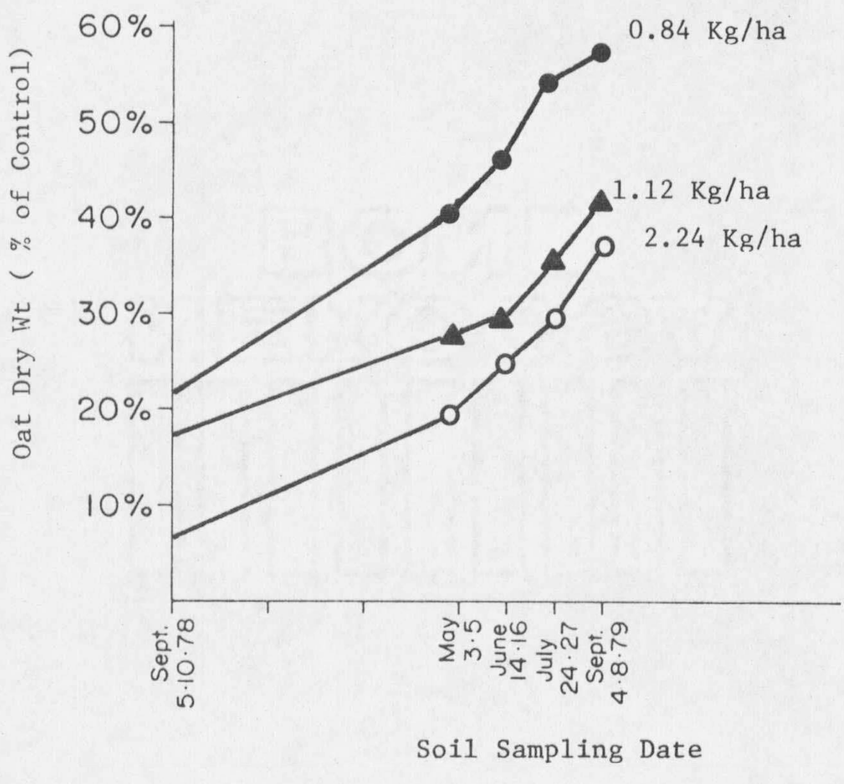

Figure 6. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Moccasin.

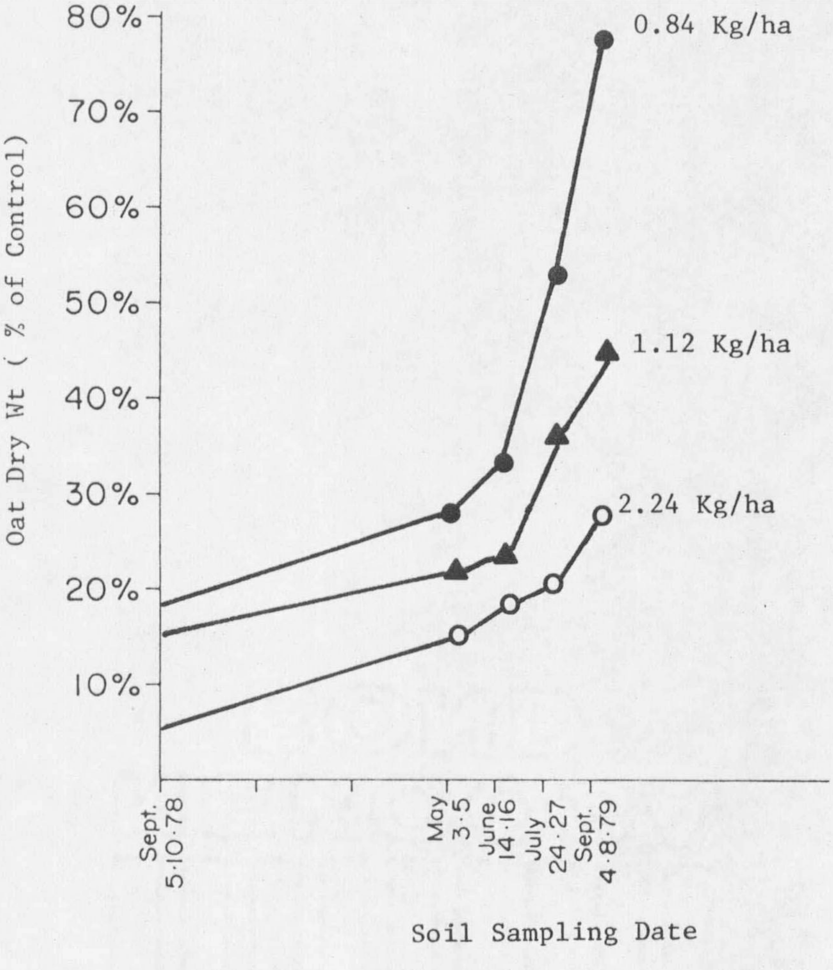

Figure 7. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Sidney.

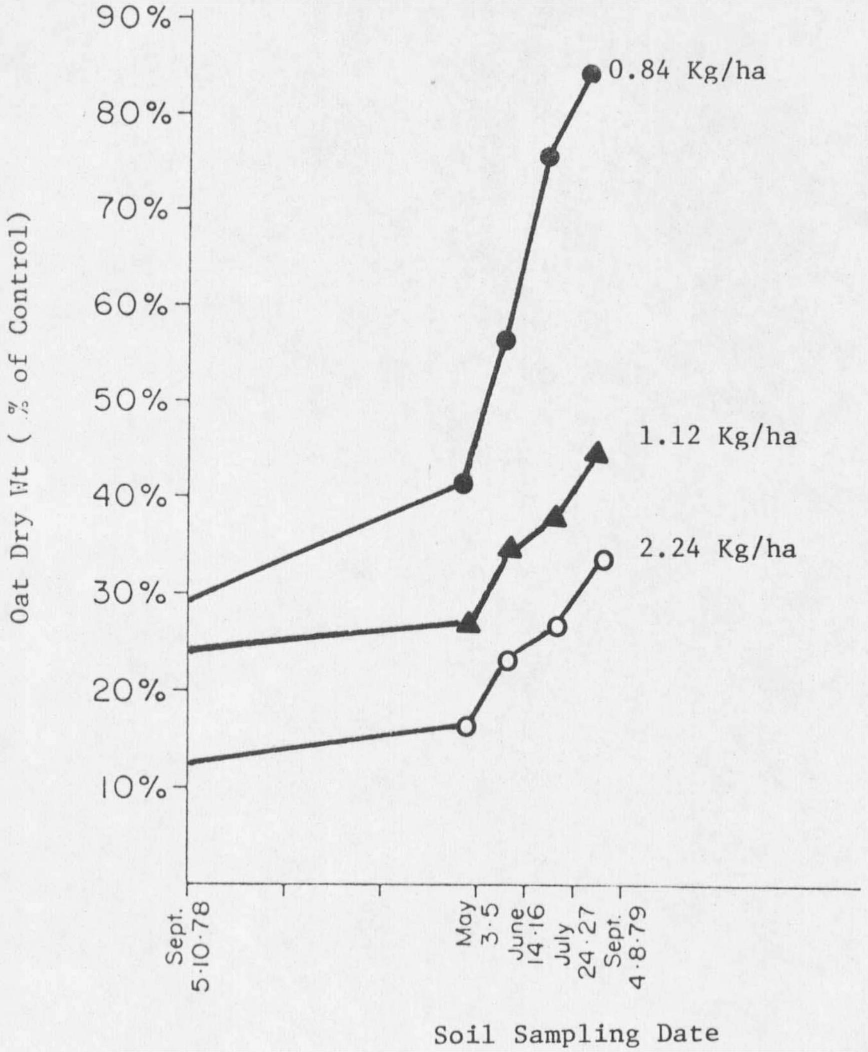

Figure 8. Oat dry matter production, expressed as percent of untreated control, from soil samples taken on five different dates following atrazine applied for chemical fallow at Bozeman.

application of 0.84 Kg/ha (Figures 1, 5, 7 and 8). The quantity of atrazine remaining in soil one year after application was estimated using a standard curve (Table 4).

To identify factors governing degradation, two-way correlations were performed between oat seedling injury and all climatic and edaphic variables for each location. Precipitation was most influential with a correlation (R) value of 0.614. Soil pH was the second most important factor with an R value of -0.575. This supports reported data that the rate of atrazine degradation is reduced in soils with high pH (17). Together, precipitation and pH had an overall R value of 0.91 in a three way-correlation. Thus, atrazine was generally found to degrade fastest under low pH, high moisture conditions.

The soil organic matter content, clay content and soil calcium content had less influence on atrazine degradation. The data was further analyzed using the two-way correlation with multiple regression to predict moisture requirements for complete atrazine degradation (Table 6). Soils of high pH theoretically require more moisture than low pH soils for total degradation because of increase in persistence.

Predictions for precipitation requirements were based on regression lines and multiple correlation values (Tables 8 and 9) using the equation $Y' = a + b_1X_1 + b_2X_2$. Values a and b were used to minimize the difference in sums of squares between actual values and predicted values. The value of a is determined by $a = Y - b_1\overline{X}_1$ -

$b_2\overline{X}_2$ which forms a predictive regression equation $Y' = Y + b_1x_1 + b_2x_2$ where $x_1 = X_1 - \overline{X}_1$.

Table 4. Estimates of soil atrazine levels remaining in soil 12 months after application at eight locations (Kg/ha).

	Atrazine Application 1/ (Kg/ha)		
Location	0.84	1.12	2.24
Havre	0.210	0.490	0.631
Huntley	0.210	0.420	0.631
Fort Benton	0.210	0.420	0.560
Conrad	0.140	0.350	0.560
Cascade	0.140	0.280	0.560
Moccasin	0.070	0.280	0.420
Sidney	0.070	0.210	0.420
Bozeman	0.070	0.210	0.420

1/ Atrazine was applied in September, 1978.

Table 5. Two-way correlations of the effect of climatic and soil characteristics on oat shoot dry matter production.

Characteristic	Dry Wt R Value
Precipitation	0.614
pH	-0.575
Organic Matter	0.233
Clay Content	0.352
Calcium Content	-0.268

Table 6. Predicted precipitation requirements for complete atrazine degradation.

Soil pH	Precipitation Requirements for Complete Atrazine Degradation
8.0 or greater	3.7 cm per 0.07 Kg/ha
7.0 - 8.0	3.4 cm per 0.07 Kg/ha
6.0 - 7.0	3.3 cm per 0.07 Kg/ha

Table 7. Multiple linear regression equation for prediction of precipitation requirements for complete atrazine degradation.[1/]

Equation: $Y' = a + b_1X_1 + b_2X_2$

$b_1 = 0.9064$

$b_2 = 0.0785$

Variables:

b_1 = regression coefficient of oat dry weight data

b_2 = regression coefficient of soil pH

X_1 = oat dry weight with no atrazine residue

X_2 = soil pH at location

$a = Y - b_1\overline{X}_1 - b_2\overline{X}_2$

Y' = predicted moisture for degradation

Y = precipitation received at location

1/ Overall correlation had $R^2 = 0.91$

The amount of atrazine degraded was estimated by subtracting the estimated remaining residue levels from initial application rates. Multiplication of degraded concentrations by predicted moisture requirements nearly equalled the total precipitation for locations grouped according to soil pH (Table 9). This indicates that the predicted values are faily accurate when applied to this particular fallow season. Soils of pH 8.0 or higher had a mean annual precipitation of 34.6 cm. Estimation of the actual precipitation received by using the predictive values calculated to 33.1 cm.

Table 8. Predicted precipitation requirement for complete atrazine degradation.

Location	Predicted Precipitation Required to Degrade 0.84 Kg/ha (cm)	Precipitation[1/] (cm)
Havre	43.7	29.3
Huntley	43.9	36.6
Fort Benton	45.4	38.0
Conrad	42.1	34.2
Cascade	40.8	34.3
Moccasin	41.1	44.5
Sidney	39.5	37.0
Bozeman	40.7	40.5

1/ Precipitation from 9/1/78 to 9/1/79

This closeness held constant for the other pH classifications. Locations with 7.0 to 8.0 pH had a mean actual precipitation reception of 37.6 cm. This compares to a predicted value of 36.8 cm. Locations of 6.0 to 7.0 pH had a mean actual precipitation of 38.8 compared to a predicted level of 36.6 cm.

A normal precipitation distribution over the fallow season may cause a more consistent rate of atrazine degradation and increase the

Table 9. Comparison of moisture requirement predictions for atrazine degradation to actual precipitation and degradation estimates.

Location	Estimate of Degraded Atrazine of 0.84 Kg Application in 9/78 (DA)	Predicted Moisture for Degradation of 0.07 Kg Atrazine (PMV)	Received Precipitation (RP)	Comparison Calculation[1/] $MRP = (PMV)\frac{DA}{0.07\ Kg}$
Havre	0.631 Kg	3.65 cm	29.3 cm	$MRP = (3.68\ cm)\frac{(0.631\ Kg)}{(0.07\ Kg)}$
Huntley	0.631 Kg	3.65 cm	36.5 cm	$MRP = 33.19\ cm$
Fort Benton	0.631 Kg	3.78 cm	38.0 cm	
Mean	0.631 Kg	3.68 cm	34.6 cm	
Conrad	0.700 Kg	3.50 cm	34.2 cm	$MRP = (3.45\ cm)\frac{(0.724\ Kg)}{(0.07\ Kg)}$
Cascade	0.700 Kg	3.40 cm	34.3	$MRP = 35.73\ cm$
Moccasin	0.771 Kg	3.42 cm	44.5 cm	
Mean	0.724 Kg	3.45 cm	37.6 cm	
Sidney	0.771 Kg	3.27 cm	37.0 cm	$MRP\ (3.32\ cm)\frac{(0.771\ Kg)}{(0.07\ Kg)}$
Bozeman	0.771 Kg	3.37 cm	40.5 cm	$MRP = 36.65\ cm$
Mean	0.771 Kg	3.32 cm	38.7 cm	

1/ By using multiple regression values, actual precipitation levels can be approximated. (33.2 cm : 34.62 cm), (35.7 cm : 37.6 cm), (36.6 cm : 38.7 cm).

total amount of atrazine degraded. Soil microbial populations are less dynamic with consistent precipitation. Thus, they can maximize atrazine detoxification and degrade atrazine residues faster.

Consistent moisture distribution may lower the predicted values of moisture required for total degradation. The abnormal distribution of precipitation (Table 6, Chapter 5) of the 1978-1979 fallow season probably disrupted microbial activity resulting in a lower than normal rate of degradation.

Weed Control Ratings

Green foxtail (Setaria viridis (L) Beauf.), Russian thistle (Salsola kali (L) var tenuifolia Tausch.) and pigweed spp. (Amaranthus L.) were more tolerant to atrazine than downy bromegrass (Bromus tectorum L), common lambsquarter (Chenopodium album L.), or tansy mustard (Descurainia pinnata (Walt.) Britt.)(Table 10). A fall application of 0.28 Kg/ha of atrazine controlled most weeds through May, 1979. Weed control became erratic in June, 1979 indicating sufficient herbicide degradation had occurred to permit growth of atrazine tolerant species. Atrazine at 0.56 Kg/ha or higher was required for adequate weed control through June. Prostrate pigweed (Amaranthus blitoides S. Wats.), dandelion (Taraxacum officinale Weber) and green foxtail were tolerant to atrazine (Table 10) after June.

Ratings taken in July indicated that rates of 0.28 and 0.56 Kg/ha atrazine did not provide satisfactory weed control. The mini-

Table 10. Visual weed control ratings of plots treated with atrazine in September, 1978[1/].

Weed Species	Rating Date: May 5, 1979	June 15, 1979	July 31, 1979
	(Atrazine Needed for 80% Weed Control)		
	Kg/ha	Kg/ha	Kg/ha
Volunteer Wheat (*Triticum aestivum*)	0.28[2]	0.84	0.84
Kochia (*Kochia scoparia*)	0.28	0.56	0.56
Field Pennycress (*Thlaspi arvense*)	0.28	0.28	not present
Volunteer Barley (*Hordeum vulgare*)	0.28	0.56	0.56
Russian Thistle (*Salsola kali*)	not present	0.84	0.84
Prickly Lettuce (*Lactuca scariola*)	not present	0.56	0.84
Redroot Pigweed (*Amaranthus retroflexus*)	not present	0.56	0.84
Prostrate Pigweed (*Amaranthus blitoides*)	not present	2.24	2.24
Tansy Mustard (*Descurainia pinnata*)	0.28	0.28	not present

Table 10. (continued)

Weed Species	May 5, 1979	June 15, 1979	July 31, 1979
	(Atrazine Needed for 80% Weed Control)		
	Kg/ha	Kg/ha	Kg/ha
Wild Buckwheat (*Polygonum convolvulus*)	not present	0.56	0.84
Green Foxtail (*Setaria viridis*)	not present	1.12	2.24
Downy Bromegrass (*Bromus tectorum*)	not present	0.28	0.28
Shepherd's Purse (*Capsella bursa-pastoris*)	not present	0.28	0.56
Dandelion (*Taraxacum officinale*)	not present	1.12	2.24
Yellow Goatsbeard (*Tragopogon pratensis*)	not present	0.56	0.84
Common Lambsquarters (*Chenopodium album*)	not present	0.28	0.56
Common Roundleaf Mallow (*Malva neglecta*)	not present	0.56	1.12
Foxtail Barley (*Hordeum jubatum*)	not present	not present	0.28

Table 10. (continued)

Weed Species	Rating Date May 5, 1979 (Atrazine Needed for 80% Weed Control)	June 15, 1979	July 31, 1979
	Kg/ha	Kg/ha	Kg/ha
Wild Oats (*Avena fatua*)	not present	0.28	0.28

1/ Data was averaged for eight locations in Montana.

2/ Each amount represents the quantity of fall-applied atrazine needed to provide satisfactory control at the time of rating.

mum atrazine rate of application for satisfactory season long weed control is 0.84 Kg/ha. When the lower application rates are used, some weeds escape atrazine control and so need to be controlled with a contact herbicide such as glyphosate.

CONCLUSIONS

Precipitation and soil pH are the major limiting factors for atrazine degradation. Atrazine residues remaining after one year varied among locations. Sites at Havre, Huntley and Fort Benton had the least atrazine breakdown while Sidney and Bozeman had the most degradation (comparing Tables 2 and 3).

The precipitation requirements for total atrazine degradation were estimated for soils with different pH values. Soils with pH 8.0 or greater need approximately 44.1 cm of precipitation to completely degrade 0.84 Kg/ha of atrazine. Soils with pH 7.0 to 8.0 and 6.0 to 7.0 must receive 41.4 and 39.8 cm, respectively to degrade 0.84 Kg/ha. The predicted values are conservative since they were probably biased by the abnormal distribution of precipitation during the fallow period. The actual precipitation requirements would probably be lower under more normal precipitation patterns. Herbicide residue measurements and weed control ratings indicate that a fall application of approximately 0.84 Kg/ha of atrazine is needed for satisfactory weed control of most weed species and residue degradation.

Chapter 4

Cultivar Tolerance of Barley, Spring Wheat, Spring Durum and Winter Wheat to Soil Residues of Atrazine

Abstract

The tolerance of 19 barley, 10 spring wheat, 3 spring durum and 15 winter wheat cultivars to atrazine soil residues was evaluated. Barley and spring wheat were the most and least tolerant crops to atrazine, respectively. All crops tested possessed large variation in cultivar sensitivity to atrazine.

'Klages' and 'Wapana' were the most tolerant barley cultivars. 'Olaf' and 'Crosby' possessed the highest tolerance among the spring wheat and durum cultivars, respectively, while 'Lancer', 'Winalta' and 'Cheyenne' were the most tolerant cultivars of winter wheat.

INTRODUCTION

The soil persistence of triazine herbicides in semi-arid regions limits the use of atrazine for chemical fallow in winter wheat-fallow rotations because of the risk of crop injury (45, 126). Atrazine would be an effective herbicide for chemical fallow in the northern Great Plains if tolerant small grain cultivars could be found.

Variability in cultivar tolerance to various herbicides has been noted. Smith and Caviness (105) reported differences in tolerance to propanil (3', 4'-dichloropropionanilide) in soybeans. Grogan (55) found that atrazine susceptibility in corn (Zea mays L.) was regulated by a single recessive gene. Wax et al. (118) discovered differential tolerance toward metribuzin (4-amino-6-tert-butyl 3 - (methylthio)-as-triazin - 5(4H)-one) among 250 cultivars of soybean. Andersen (4) reported that soybean tolerance to atrazine increased as seed size increased.

Modification of cultural practices has been utilized to avoid crop injury from soil residues of atrazine. The duration of persistence of atrazine has been shortened by the use of no-till cropping systems, deep plowing, and autumn cultivation; however, cultivation during the fallow season enhanced persistence (104). Seeding rate and seeding depth also influenced the degree of crop injury from atrazine residues (43).

The objectives of this study were to determine: a) if variability in tolerance to atrazine exists among small grain cultivars grown under greenhouse conditions; b) if variable tolerance to atrazine exists among four winter wheat cultivars planted in field soils; and c) if different seed treatments would increase atrazine tolerance among winter wheat cultivars.

MATERIALS AND METHODS

Greenhouse Experiment

Experiments were conducted to measure the response of 19 barley, 10 spring wheat, 3 spring durum and 15 winter wheat varieties to soil residues of atrazine (Table 1). Four seeds of each variety were planted in greenhouse potting soil (2:1:1 V/V/V Gallatin clay loam, sand and peat moss) with 4% organic matter contained in a 3.8 dia by 21 cm deep nursery cone-containers and thinned to three plants after emergence.

Atrazine was applied before planting by pipetting an aliquot from an aqueous stock solution containing commercial atrazine (80 WP, Ciba-Geigy Co.) to soil followed by homogenous mixing in a revolving soil tumbler. Final atrazine concentrations in soils were 0 and 0.25 ppmw which corresponds to a surface application of 0 and 0.28 Kg/ha. The experiment, which was conducted twice, had six replications in a randomized complete block design.

Plants were grown in the greenhouse at approximately 25 C day and 20 C night temperatures under 16 hrs light. Shoots were clipped at the soil surface 30 days after planting, dried in a forced air oven at 38 C and weighed.

Field Experiment

Atrazine (80 WP) was applied in water at rates of 0, 0.28, 0.56, 0.84, 1.12 and 2.24 Kg/ha pressure to 2 m by 6 m plots at Bozeman, Huntley, Moccasin, Cascade, Fort Benton, Havre and Conrad, Montana during the first week of September, 1978. Four cultivars of winter wheat ('Winalta', 'Cheyenne', 'Centurk' and 'Warrior') were seeded at a rate of 67 Kg/ha in rows 30 cm apart by 6 m long at each location during the first week of September, 1979.

There were four replications arranged in a randomized complete block design at each location. Crop injury was visually rated the second week of June, 1980 using a scale of 0 = no injury and 100 = complete kill.

Seed Treatment Experiment

Five winter wheat cultivars (Table 3) were planted at Bozeman in field soil treated with atrazine to compare the effect of additional phosphorus fertilizer and carboxin (5,6-dihydro-2-methyl-1,4-oxathin-3-carboxanilide) seed treatment on tolerance to soil residues of atrazine. Carboxin treated seed and untreated seed of each cultivar were planted at a rate of 67 Kg/ha. Untreated seed was planted in soil amended with 44.8 Kg/ha of 0-46-0 fertilizer and in unfertilized soil. Carboxin treated seed was planted in unfertilized soil. The fungicide carboxin (trade name, 'Vitavax' Uniroyal Inc.) is used for seed treatment, and has been effective as a crop protectant from herbicide injury (84).

Atrazine (80 WP) was applied in water after planting at rates of 0, 0.14, 0.28 and 0.42 Kg/ha with a backpack type sprayer delivering 225 L/ha at 2.4 Kg/cm^3 pressure to plots 2 m by 20 m.

Crop injury was visually rated the first week of July, 1980 using a scale of 0 = no injury and 100 = complete kill. A randomized split plot design was utilized with three replications.

RESULTS AND DISCUSSION

Greenhouse Experiment

Barley and winter wheat were more tolerant to atrazine than spring wheat or spring durum (Table 1). The shoot dry weight production of 'Klages' and 'Wapana' barley was reduced 24 and 30%, respectively. Shoot dry weight of barley cultivars 'Karl' and 'Kimberly' was reduced 80 and 71%, respectively by 0.28 Kg/ha of atrazine. Most barley cultivars were quite sensitive to atrazine since growth of 90% of the cultivars tested was reduced more than 50%.

Growth of winter wheat cultivars 'Lancer', 'Winalta' and 'Cheyenne' was reduced 20 to 36% (Table 1). The growth of 12 winter wheat cultivars was reduced more than 50%.

There were no spring wheat or spring durum cultivars with notable atrazine tolerance (Table 1). The growth of 'Olaf' spring wheat

Table 1. Effect of atrazine (0.28 Kg/ha) on shoot dry weight of 47 cultivars grown in in nursery cone-containers for 30 days in the greenhouse.

Cultivar	Shoot dry wt. (% of control)	Cultivar	Shoot dry wt. (% of control)	Cultivar	Shoot dry wt. (% of control)
<u>Barley</u>		<u>Winter Wheat</u>		<u>Spring Wheat</u>	
Klages	76	Lancer	71	Olaf	45
Wapana	70	Winalta	66	Newana	41
Purcell	51	Cheyenne	64	Norana	37
Hector	50	Marias	49	Solar	33
Kombar	48	Sundance	48	Tioga	32
Piroline	48	Winoka	38	Wared	32
Shabet	48	Hi-Plains	36	Fortuna	28
Unitan	48	Trapper	36	Lew	10
Steptoe	48	Warrior	32		
Harsford	45	Centurk	31	<u>Spring Durum</u>	
Stepford	43	Froid	25		
Summit	42	Speltz	20	Crosby	37
Vireo	41	Roughrider	16	Ward	23
Vanguard	35	Minter	14	Wells	22
Ingrid	34	Crest	10		
Compana	32				
Larker	29				
Kimberly	29				
Karl	20				
Mean	44.1		38.5		29.9
L.S.D. 5%	5.9		8.2		3.3

and 'Crosby' durum (the most tolerant cultivars) was reduced 55 and 63%, respectively.

Tolerance of corn to atrazine has been reported to be regulated by a single recessive gene (55). There is no apparent genetic relattionship among the tolerant and susceptible cultivars in this study since tolerant varieties do not have similar genotypes. Two of most tolerant winter wheat cultivars ('Lancer' and 'Winalta') are crosses of 'Turkey' x 'Cheyenne', and 'Minter' x 'Wichita', respectively. 'Hiplains' ('Gage' x 'Lancer'), 'Warrior' ('Pawnee' x 'Cheyenne'), cultivars with pedigrees nearly identical to 'Lancer' were very susceptible to atrazine. Growth of 'Cheyenne' winter wheat was reduced 36% while growth of 'Warrior' and 'Trapper', both with 'Cheyenne' parentage, was reduced 68 and 66%, respectively. The growth of 'Klages' and 'Wapana' barley was reduced less than 30% while sister selections ('Kimberley' and 'Compana') were highly susceptible to atrazine.

The nursery cone-container assay system may have accentuated crop injury since all root growth occurred in soil which contained atrazine. Tolerance of the cultivars evaluated might be higher if planted under field conditions since root growth would permit some roots to avoid contact with atrazine treated soil.

<u>Field Experiment</u>

Winter wheat cultivars selected on the basis of seeded acreage in Montana, and greenhouse growth response to atrazine (Table 1) were seeded into field soils containing soil residues of atrazine. The cultivars 'Winalta', 'Cheyenne', 'Centurk', and 'Warrior', the major winter wheat varieties were seeded on 29, 26, 28 and 3% of the Montana winter wheat acreage, respectively in 1977 (87). 'Winalta' and 'Cheyenne' were most tolerant to atrazine while 'Centurk' and 'Warrior' possessed low tolerance in the greenhouse experiment (Table 1).

'Winalta' and 'Cheyenne' experienced less crop injury than 'Centurk' or 'Warrior' from field soil residues of atrazine (Table 2).

Visible injury from atrazine was detected with 'Centurk' and 'Warrior' at higher residue concentrations. The yield of 'Centurk' and 'Warrior' was significantly lower than 'Winalta' or 'Cheyenne' at atrazine rates of 0.84 Kg/ha and higher.

Seed Treatment Experiment

Application of phosphorus fertilizer decreased crop injury from atrazine for the winter wheat cultivars 'Centurk' at all rates of atrazine and 'Crest' at 0.14 Kg atrazine per ha (Table 3), while the other varieties tested responded only slightly to the fertilizer treatment. Carboxin treatment of seed did not decrease crop injury in any of the tested cultivars (Table 3).

Carboxin treatments did not significantly increase crop yields of any of the tested cultivars. Crop yield of all cultivars was increased by the addition of phosphorus fertilizer, However, 'Cen-

Table 2. Yield and crop injury of four winter wheat cultivars following chemical fallow with atrazine. Atrazine was applied in September 1978. The cultivars were seeded in September 1979, and harvested in September 1980. Visual crop injury and yield data is average of seven locations.

	Atrazine Rate (Kg/ha) applied in September 1978											
Cultivar	0		0.28		0.56		0.84		1.12		2.24	
	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)
Winalta	1	3368	0	3450	0	3510	0	3271	6	2409	20	2113
Cheyenne	0	3560	0	3470	0	3401	0	3170	4	2290	22	2245
Centurk	0	3005	0	3210	0	3160	15	2720	20	1810	40	1541
Warrior	0	2949	0	3051	0	3025	15	2681	30	1741	45	1555

L.S.D. .05 = 6%, 440 Kg/ha

1/ 0 = no injury; 100 = complete kill

Table 3. Effects of phosphorus fertilizer and carboxin seed treatment on crop injury from soil residues of atrazine on 5 winter wheat cultivars at Bozeman, Montana. Atrazine was applied post-plant in September, 1979 to simulate soil residues. Crop injury was determined by visual ratings in June, 1980.

Seed or treatment	AT rate (Kg/ha)	Winter Wheat Cultivar									
		Centurk		Cheyenne		Crest		Warrior		Winalta	
		(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)	(%) Crop injury	Yield (Kg/ha)
Untreated seed in unfertilized soil	0.0	0.0	4204	0.0	4206	0.0	3620	0.0	4204	0.0	4210
	0.14	5.0	4054	1.7	4487	8.3	3576	5.0	4487	0.0	4056
	0.28	10.7	3716	5.0	4224	28.4	3492	6.7	4224	5.0	3716
	0.42	16.7	3347	5.0	3930	31.7	3722	8.3	3930	5.0	3347
Untreated seed with phosphorus fertilizer added to soil	0.0	0.0	5897	0.0	4740	0.0	4421	0.0	4657	0.0	4106
	0.14	0.0	4964	0.0	4614	0.0	4614	0.0	3694	0.0	3897
	0.28	5.0	4549	3.3	4290	10.0	3671	5.0	3914	3.3	3806
	0.42	11.3	4170	5.0	4204	21.7	3962	11.7	3377	8.3	3845
Carboxin treated seed in unfertilized soil	0.0	0.0	4552	0.0	3846	0.0	3946	0.0	3845	0.0	4552
	0.14	5.0	4435	0.7	4102	5.7	3528	5.0	4102	0.0	4435
	0.28	15.7	4035	5.0	3949	6.7	3352	6.7	5949	5.0	4035
	0.42	16.7	3608	3.3	4008	8.3	3206	6.7	4009	5.0	3608
Mean		10.3	4294	3.2	3894	13.4	2682	6.1	4071	3.5	3967
L.S.D. 5%		4.9	419	4.4	321	6.3	318	6.3	318	6.4	350

turk' and 'Crest' were the only cultivars "protected" from crop injury from atrazine (Table 3).

Crop injury to the cultivars tested was probably influenced by cultural and edaphic conditions since wheat was planted prior to the application of atrazine. The cultivars were able to undergo root development before atrazine was activated by soil moisture. Planting into an activated residue of atrazine below the soil surface would place seedling roots in contact with atrazine sooner and probably increase crop injury levels.

Seed size has been reported to effect crop injury from herbicides (4). Only one seed source was used for all the cultivar experiments with no attempt to partition cultivars by seed size. This may have influenced the degree of crop injury.

CONCLUSIONS

Selection of small grain cultivars consistently tolerant to low levels of atrazine soil residues may reduce or eliminate crop injury. This would enable farmers to plant in atrazine treated soil with confidence that crop injury and economic losses would not occur. These data indicate that tolerance does exist among small grain cultivars. Future research should be directed toward increasing crop tolerance. Selection of present cultivars or breeding of new cultivars tolerant to atrazine could increase the amount of atrazine used in a chemical fallow system.

Chapter 5

The Use of Glyphosate for Chemical Fallow

Abstract

The use of glyphosate (N-(phosphonomethyl)glycine) for chemical fallow is increaseing in Montana because of its broad spectrum weed control and non-residual soil properties. A major problem faced by farmers is determination of the proper time and rate of application of glyphosate. Farmers tend to delay application of glyphosate because of its non-residual soil properties. Therefore, more glyphosate is needed to control existing vegetation, and soil moisture is lost through weed growth.

The objective of this study was to determine the rate of glyphosate needed to control 15 species of weeds at three stages of growth. Soil samples were taken to a depth of 107 cm to measure soil moisture loss due to weed growth during the season. Glyphosate was applied approximately June 10, June 24 and July 8, 1979 at 0, 0.14, 0.28, 0.56 and 1.12 Kg/ha at four locations in Montana.

Prickly lettuce (*Lactuca scariola* L.), dandelion (*Taraxacum officinale* Weber), Russian thistle (*Salsola kali* (L.) var. tenuifolia Tausch.), yellow goatsbeard (*Tragopogon pratensis*), Canada thistle (*Cirsium arvense* (L.) Scop.) and hoary cress (*Cardaria draba* (L.) Desv.) require 1.12 Kg of glyphosate per ha or more for control (Table 1). Conversely, field pennycress (*Thlaspi arvense* L.) and downy brome (*Bromus tectorum* L.) are susceptible to low rates of glyphosate

(0.14 to 0.28 Kg/ha). Usually one or more of the species present was tolerant to glyphosate at rates below 1.12 Kg/ha. Allowing weeds to reach mature stages of growth increased glyphosate requirements for control substantially. Most species of weeds are capable of extracting water from the soil profile in excess of 90 cm. Each two-week delay in application of gyphosate resulted in substantial loss of subsoil moisture.

Glyphosate is an effective tool for chemical fallow, however, farmers must pay close attention to the stage of plant growth due to soil moisture loss as well as the degree of weed control after application of glyphosate.

INTRODUCTION

The use of glyphosate, (N-(phosphonomethyl) glycine), for chemical fallow is increasing in the northern Great Plains because of its broad spectrum of control and non-residual properties (134, 135, 163, 167, 168). A major problem faced by farmers is the determination of the proper time and rate of application of the herbicide. Farmers tend to delay application of glyphosate because of its non-residual soil properties. The consequences are more glyphosate is needed to control existing vegetation (142, 152, 161, 162) and excessive soil moisture is lost as a result of weed growth.

This study was conducted to determine the rate of glyphosate needed to control 15 species of weeds at different stages of growth. Soil moisture loss due to weed growth during the season was also measured.

Herbicide concentrations generally need to be increased to control weeds as they mature. Weeds use valuable soil moisture when allowed to grow. This study evaluated the effects of glyphosate application on several weed species to determine if amounts of glyphosate need to be increased to control weeds as they mature. The loss of soil moisture from weed growth was measured to determine the benefit of early weed control.

MATERIALS AND METHODS

Glyphosate was applied in water at rates of 0.28, 0.56, 0.84 and 1.12 Kg/ha with a backpack type sprayer delivering 112 L/ha at

2.4 Kg/cm^3 pressure on three dates at four locations. Plot size was 2 m by 10 m with three replications arranged in a split-plot design.

Weed control ratings were taken two weeks after each application (0% = no control; 100% = total control with 80% considered commercially acceptable control).

Table 1. Dates of application of glyphosate at four locations in Montana in 1979.

Application No.	Location			
	Bozeman	Cascade	Havre	Plentywood
1	6/5	6/7	6/8	6/12
2	6/19	6/22	6/22	6/26
3	7/3	7/6	7/7	7/11

Soil Moisture Loss

Soil samples were taken with a hydraulic soil probe (3.2 cm i.d.) at each location to a depth of 107 cm 14 days after the last date of spraying. Moisture samples were taken from plots which received 0 and 1.12 Kg/ha of glyphosate. Three soil samples were taken from each plot and sectioned into subsamples from the following depths: 0 - 15 cm, 15 - 31 cm, 31 - 60 cm, 60 - 90 cm and 90 - 107 cm. Soil moisture content was determined gravimetrically for each air-dried subsample.

RESULTS AND DISCUSSION

Higher concentrations of glyphosate were required to achieve satisfactory weed control for each succeeding date of application (Tables 2 to 5). Glyphosate provided excellent control of volunteer wheat, (*Triticum aestivum* L.), wild oats (*Avena fatua* L.) and downy

Table 2. Effectiveness of 4 rates of glyphosate applied on 3 dates for control of weeds at Bozeman, Montana.

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Prickly Lettuce	15-18 cm tall	6-5-79	45	80*	85	95
Dandelion	Flowering 25-30 cm rosette		10	30	60	85*
Yellow Goatsbeard	20-23 cm tall		10	25	55	80*
Canada Thistle	15-20 cm tall		10	55	82*	94
Tansy Mustard	25-30 cm tall		85*	90	99	100
Field Pennycress	Flowering 20-25 cm tall		84*	95	100	100
Shepherd's Purse	Bud stage 15-20 cm tall		35	50	80*	85
Volunteer Wheat	4 leaf stage		72	90*	100	100
Prickly Lettuce	20-25 cm tall	6-19-79	15	40	79*	34
Dandelion	Post-flowering 25-30 cm rosette		10	15	35	50
Yellow Goatsbeard	Bud stage 25-30 cm tall		10	20	30	55
Canada Thistle	Bud stage 25-35 cm tall		5	30	62	80*
Tansy Mustard	35-40 cm tall		80*	85	100	100
Field Pennycress	Flowering		81*	85	100	100
Shepherd's Purse	Flowering 25-25 cm tall		25	40	80*	86
Volunteer Wheat	5-leaf stage 60-76 cm tall		65	75	95*	100
Prickly Lettuce	Flowering 60-76 cm tall	7-3-80	5	30	62	80*
Dandelion	Post flowering 40-50 cm rosette		5	10	25	40
Yellow Goatsbeard	Flowering 30-40 cm tall		10	10	30	50

Table 2. (continued)

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Canada Thistle	Flowering 66-96 cm tall		5	15	40	65
Tansy Mustard	Flowering 45-60 cm tall		65	88*	97	100
Shepherd's Purse	Flowering 35-45 cm tall		20	45	60	80*
Volunteer Wheat	Soft dough 30-40 cm tall		67	71	90*	99
Bedstraw	0-15 cm tall		65	82*	90	100

1/ Satisfactory control is considered 80%. Rates achieving satisfactory control are designated * (0 - no control; 100 = complete control).

Table 3. Effectiveness of 4 rates of glyphosate applied on 3 different dates for control of weeds at Cascade, Montana.

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Prickly Lettuce	15-20 cm tall	6-7-79	50	85*	89	86
Hoary Cress	15-20 cm tall		45	68	85*	100
Tansy Mustard	35-45 cm tall		90*	100	100	100
Field Pennycress	Flowering 20-25 cm tall		90*	95	100	100
Wild Buckwheat	5 cm tall		70	85*	95	100
Kochia	5-10 cm tall		80*	83	95	99
Volunteer Wheat	Milk stage 25-30 cm tall		60	75	90*	100
Wild Oats	3-4 leaf stage		70	81*	92	99
Downy Bromegrass	Heading 15-20 cm tall		98	100	100	100
Prickly Lettuce	25-35 cm tall	6-22-79	30	45	60	82*
Hoary Cress	Bud stage 20-25 cm tall		50	60	82*	100
Tansy Mustard	Bud stage 40-45 cm tall		70	85*	95	99
Field Pennycress	Post-flowering 25-35 cm tall		83*	90	100	100
Wild Buckwheat	7-12 cm tall		60	75	90*	96
Kochia	10-20 cm tall		45	75	90*	100
Volunteer Wheat	Soft dough 25-30 cm tall		63	75	95*	100
Wild Oats	25-35 cm tall		45	75	90*	100
Downy Bromegrass	Near maturity		90*	100	100	100
Prickly Lettuce	Flowering 60-70 cm tall	7-6-79	10	25	45	60
Hoary Cress	Flowering 20-30 cm tall		35	70	83*	95
Tansy Mustard	Flowering		70	85*	95	100

Table 3. (continued)

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Tansy Mustard	Flowering 45-50 cm tall		70	85*	95	100
Wild Buckwheat	7-12 cm tall		40	60	85*	95
Kochia	20-30 cm tall		30	55	70	90*
Volunteer Wheat	30-45 cm tall		15	40	70	95*
Wild Oats	Heading 25-50 cm tall		30	65	84*	90

1/ Satisfactory control is considered 80%. Rates achieving satisfactory control are designated * (0 = no control; 100 = complete control).

Table 4. Effectiveness of 4 rates of glyphosate applied on 3 different dates for control of weeds at Havre, Montana.

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Prickly Lettuce	20-25 cm tall	6-8-79	20	50	82*	86
Canada Thistle	15-20 cm tall		15	40	80*	90
Tansy Mustard	35-45 cm tall		82*	85	90	100
Kochia	5-10 cm tall		81*	87	96	100
Russian Thistle	2-8 cm tall		35	60	82*	90
Bedstraw	10 cm tall		60	85*	90	95
Volunteer Wheat	Milk stage 15-20 cm tall		55	75	95*	100
Prickly Lettuce	25-25 cm tall	6-22-79	10	30	63	80*
Canadian Thistle	Bud stage 25-30 cm tall		5	25	55	82*
Tansy Mustard	Bud stage 40-50 cm tall		65	80*	95	100
Kochia	20-30 cm tall		10	43	67	80*
Russian Thistle	5-15 cm tall		10	45	80*	84
Bedstraw	10-12 cm tall		56	81*	85	90
Volunteer Wheat	Soft dough 30-40 cm tall		60	75	95*	100
Prickly Lettuce	Flowering 70-90 cm tall	7-7-79	0	0	15	45
Canada Thistle	Flowering 60-70 cm tall		0	0	10	30
Tansy Mustard	Flowering 50-60 cm tall		45	80*	84	95

Table 4. (continued)

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Kochia	20-45 cm tall	7-7-79	10	38	64	86*
Russian Thistle	15-30 cm tall		15	35	50	80*
Bedstraw	12-20 cm tall		60	80*	85	83
Volunteer Wheat	Hard dough 30-40 cm tall		30	52	63	95*

1/ Satisfactory control is considered 80%. Rates achieving satisfactory control are designated * (0 = no control; 100 = complete control).

Table 5. Effectiveness of 4 rates of glyphosate applied on 3 different dates for control of weeds at Plentywood, Montana.

Weed species	Stage of growth	Date of glyphosate application	% control Glyphosate (Kg/ha) 0.14	0.28	0.56	1.12
Yellow Goatsbeard	20-15 cm tall	6-12-79	0	10	40	79*
Tansy Mustard	25-30 cm tall		80*	85	95	100
Shepherd's Purse	15-20 cm tall		43	70	82*	85
Russian Thistle	5-15 cm tall		25	50	75	88*
Volunteer Wheat	5 leaf-milk stage 15-30 cm tall		55	70	98*	100
Wild Oats	3 leaf		66	85*	90	100
Yellow Goatsbeard	25-30 cm tall	6-26-79	0	5	32	48
Tansy Mustard	Bud stage 40-45 cm tall		50	83*	100	100
Shepherd's Purse	25-30 cm tall		10	40	82*	90
Russian Thistle	12-20 cm tall		0	10	50	80*
Volunteer Wheat	Milk stage 25-30 cm tall		65	75	95*	100
Wild Oats	30-35 cm tall		45	55	80*	0
Yellow Goatsbeard	Bud stage 25-25 cm tall	7-11-79	0	0	15	35
Tansy Mustard	Flowering 45-55 cm tall		60	80*	82	96
Shepherd's Purse	Flowering 25-30 cm tall		20	60	83	87
Russian Thistle	15-20 cm tall		0	10	40	81*
Volunteer Wheat	Soft dough 25-30 cm tall		55	70	90*	95
Wild Oats	Heading 40-45 cm tall		40	45	80*	85

1/ Satisfactory control is considered 80%. Rates achieving satisfactory control are designated*. (0 = no control; 100 = complete control).

bromegrass (Bromus tectorum L.) at all stages of growth. Effective control of volunteer wheat up to the hard dough stage occurred following glyphosate application at 0.56 Kg/ha.

Wild oats and downy bromegrass, major weed problems in small grain producing areas, were effectively controlled with low rates of glyphosate. Glyphosate controlled downy bromegrass at 0.14 Kg/ha in the head stage. The rate of glyphosate needed for wild oat control increased slightly as the plants matured; however, control was still satisfactory with 0.56 Kg/ha of glyphosate.

Wild buckwheat (Polygonum convolvulus L.), kochia (Kochia Scoparia (L.) Roth), and Russian thistle (Salsola kali L. var. tenuifolia Tausch) were controlled with low rates of glyphosate during the seedling stage (Tables 2, 3 and 4). Wild buckwheat was easily controlled when plants were 5 cm or less in height but a four-fold increase in rate was needed to achieve control as the plant matured. Kochia required an eight-fold increase in rate when plants were taller than 10 cm.

Tansy mustard (Descurainia pinnata (Walt.) Britt.) was controlled by a low rate of glyphosate at all stages of growth (Tables 2 to 5). Tansy mustard, a winter annual, nears maturity by the time summer fallowed ground is first cultivated in the spring. The plant is resistant to low rates of phenoxy herbicides at that time. Bedstraw (Galium aparine L.), resistant to phenoxy herbicides, is very sensitive to glyphosate. Excellent control occurred with 0.28 Kg glyphossate per ha.

Perennial weed species, and species containing latex were less affected by low rates of glyphosate (Tables 2 to 5). Canada thistle (Cirsium arvense (L.) Scop.) increased in tolerance to top growth kill with glyphosate as the growth stage advanced. The top growth of Canada thistle plants 7.5 to 20 cm tall was controlled with glyphosate at 0.56 Kg/ha while applications of 1.12 Kg/ha at flowering did not provide adequate control (Table 2). Hoary cress (Cardaria draba (L.) Desv.), a perennial species did not require an increase in the rate of glyphosate since a rate of 0.56 Kg/ha controlled hoary cress in all stages of growth (Table 3).

Prickly lettuce (Lactuca scariola L.), dandelion (Taraxacum officinale Weber), yellow goatsbeard (Tragopogon pratensis Jacq.) contain latex and become more tolerant to glyphosate with advancing maturity. The highest rate of glyphosate tested (1.12 Kg/ha) did not control the latex-bearing species during the later stages of growth.

Soil Moisture Loss

Delayed application of glyphosate allowed significant loss of soil moisture, for weeds extracted water from a soil profile in excess of 90 cm (Figures 1, 3, 5 and 7).

Bozeman Delay in glyphosate application resulted in a substantial loss of soil moisture (Figures 1 and 2). Applications of glyphosate in July did not result in storage of significantly higher

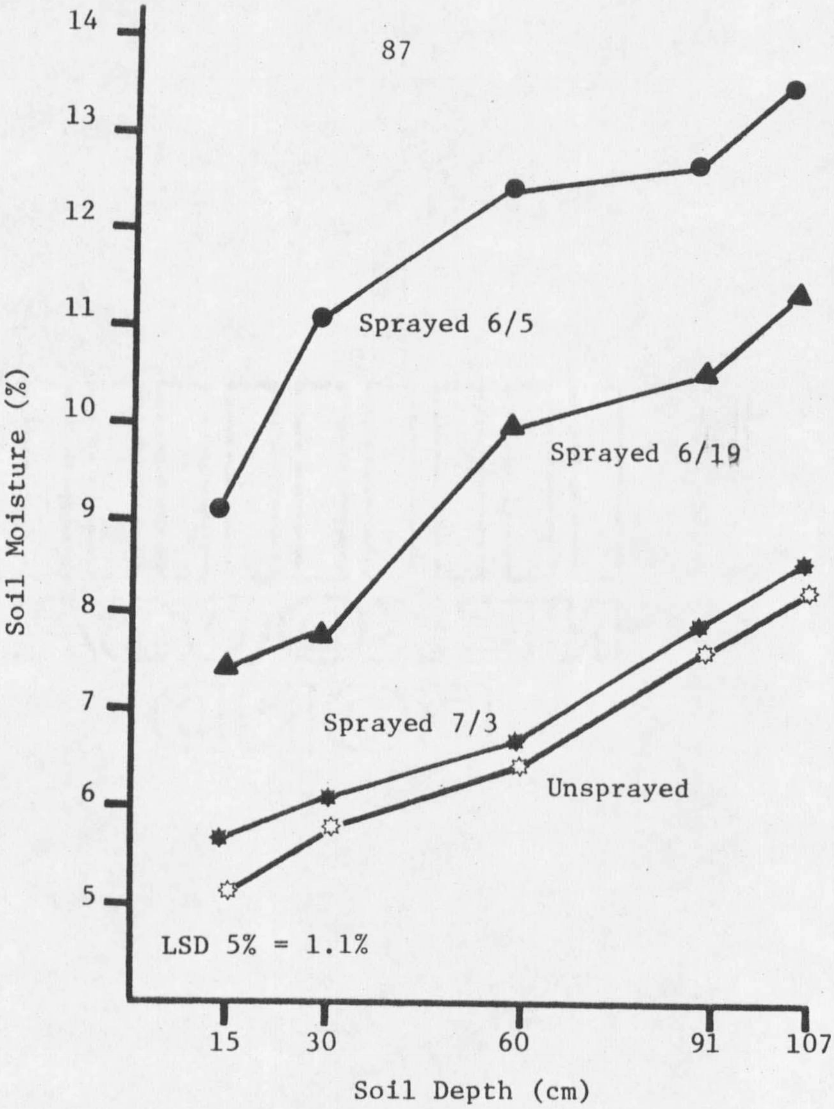

Figure 1. Percent soil moisture on 7/23/79 at Bozeman in plots sprayed with 1.12 Kg/ha of glyphosate.

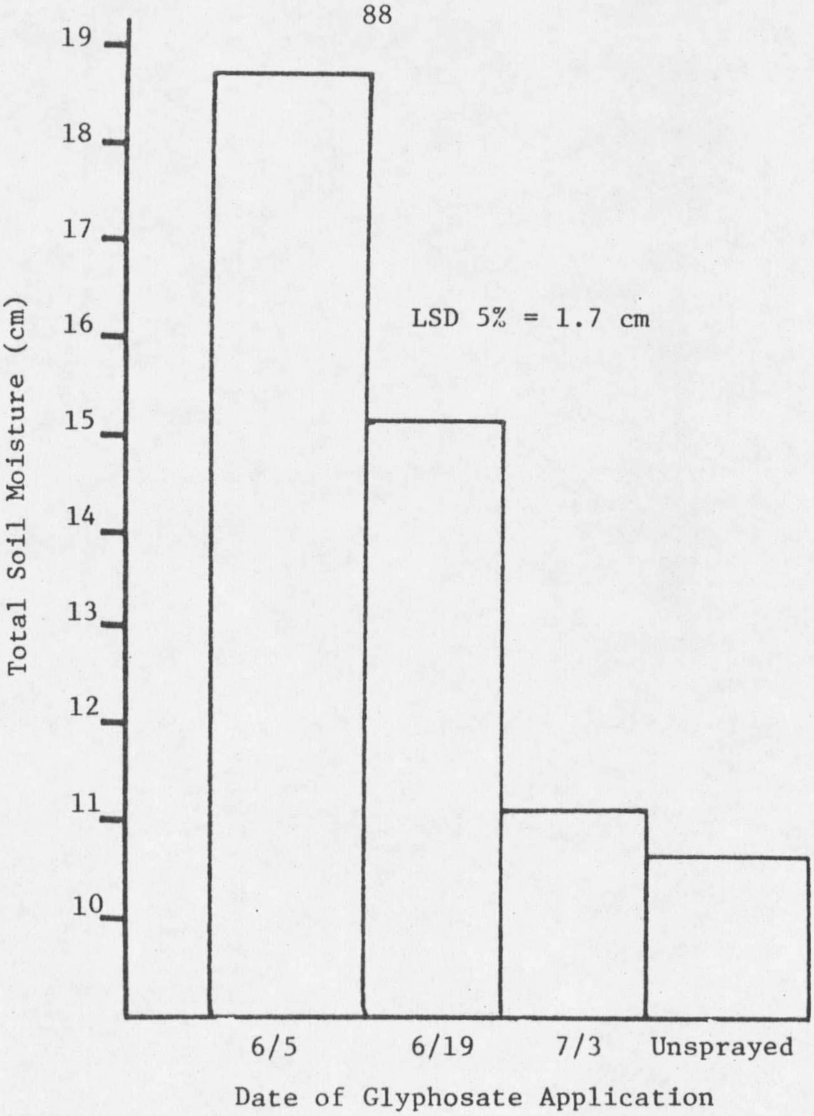

Figure 2. Total soil moisture (cm) in a 107 cm profile at Bozeman in plots sprayed with 1.12 Kg/ha of glyphosate.

amounts of moisture than unsprayed plots.

Weed growth reduced moisture content of soil to a depth of 107 cm when left uncontrolled. The root systems of winter annual species including tansy mustard and volunteer winter wheat were well developed before the first application of glyphosate in June. Additionally, the deep root systems of perennials such as Canada thistle and dandelion permitted the extraction of water from each point in the soil profile.

Cascade

Soil moisture levels were not significantly different between the first and second dates of application (Figures 3 and 4). Subsoil moisture below 60 cm was lost due to uncontrolled growth of winter annuals. Delayed application resulted in increased moisture loss at all points of the soil profile. Application of glyphosate on the third date (7/6/79) did not result in conservation of significant moisture levels compared to unsprayed plots.

Annual and winter annual species were the predominant weeds at Cascade. Downy bromegrass has a relatively shallow root system which uses large amounts of moisture from the upper 15 cm of the soil profile. Alternatively, prickly lettuce, tansy mustard and volunteer wheat develop deep root systems which use moisture from the entire soil profile.

Hoary cress, a deep rooted perennial was present and may extract

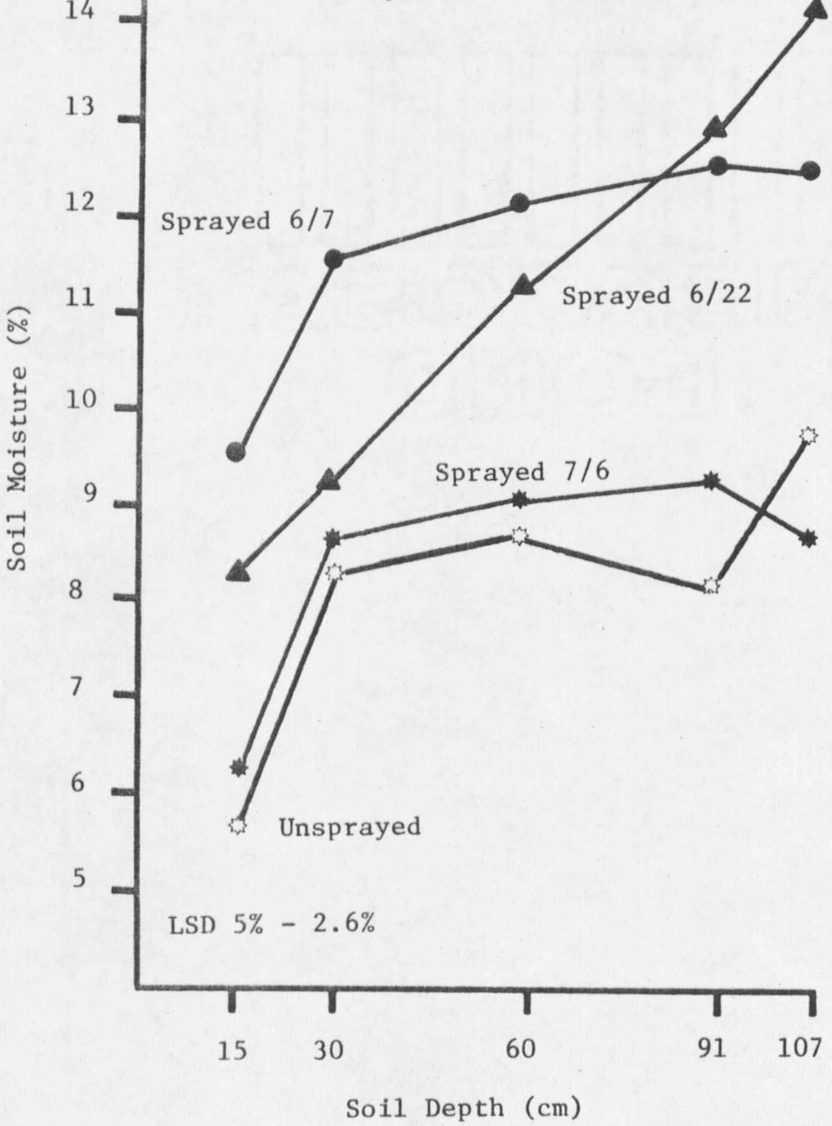

Figure 3. Percent soil moisture on 7/22/79 in plots at Cascade sprayed with 1.12 Kg/ha of glyphosate.

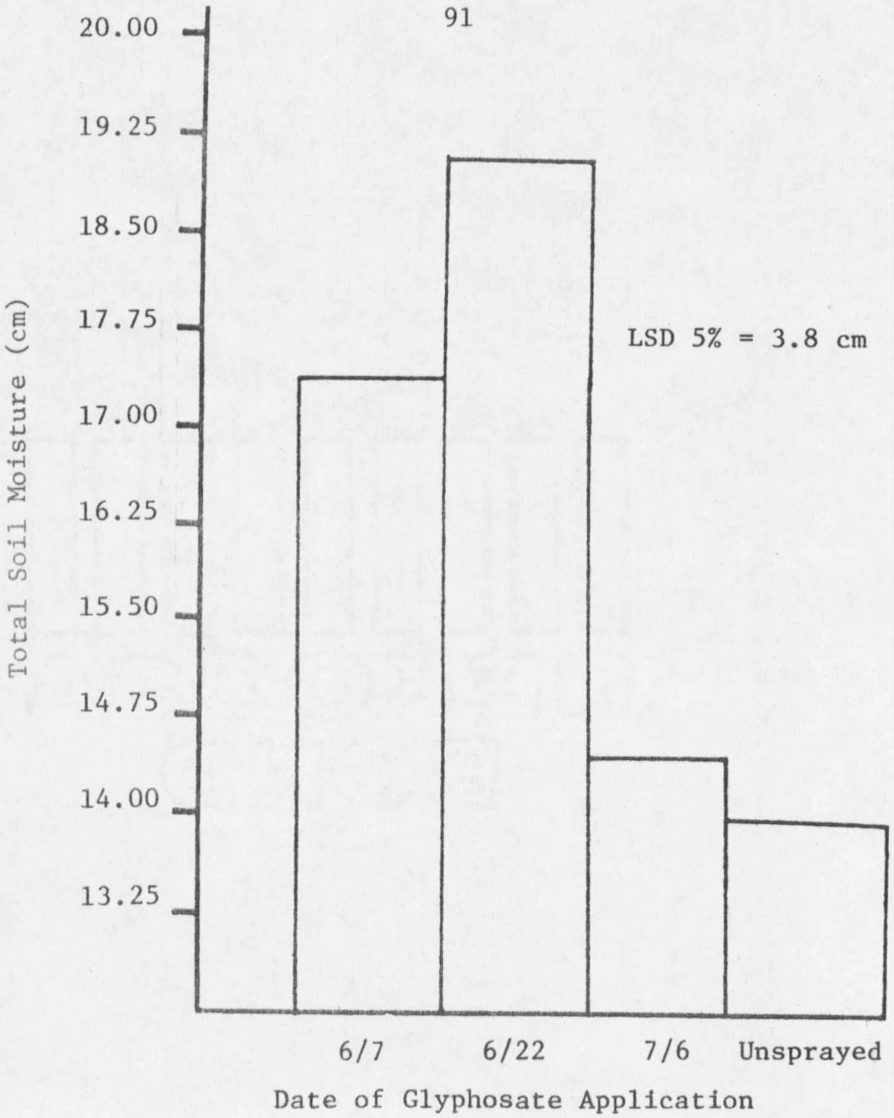

Figure 4. Total soil moisture (cm) in a 107 cm profile at Cascade in plots sprayed with 1.12 Kg/ha of glyphosate.

soil moisture deep in the soil profile. Significant amounts of weed growth on summer fallow are detrimental since the subsoil portion of the soil profile requires large quantities of precipitation to be fully recharged.

Havre

Results at Havre were similar to results at Bozeman and Cascade except the moisture content at a soil depth of 90 cm was not greatly affected by delayed application (Figure 5). Moisture content nearer the soil surface was reduced significantly if application of glyphosate was delayed until July 7 (Figures 5 and 6). The first and second dates of application of glyphosate conserved significantly more moisture than the third date.

Plentywood

Four centimeters of total soil moisture were conserved by the first application of glyphosate in eastern Montana (Figures 7 and 8). The second and third dates of application of glyphosate did not result in significant amounts of soil moisture conservation compared to the unsprayed plots.

The soil profile at Plentywood contained a gravel layer at a depth of 60 cm. The shallow soil combined with a heavy infestation of tansy mustard, volunteer wheat and Russian thistle resulted in large differences between the amount of soil moisture stored in plots which received the first glyphosate application and all other applications.

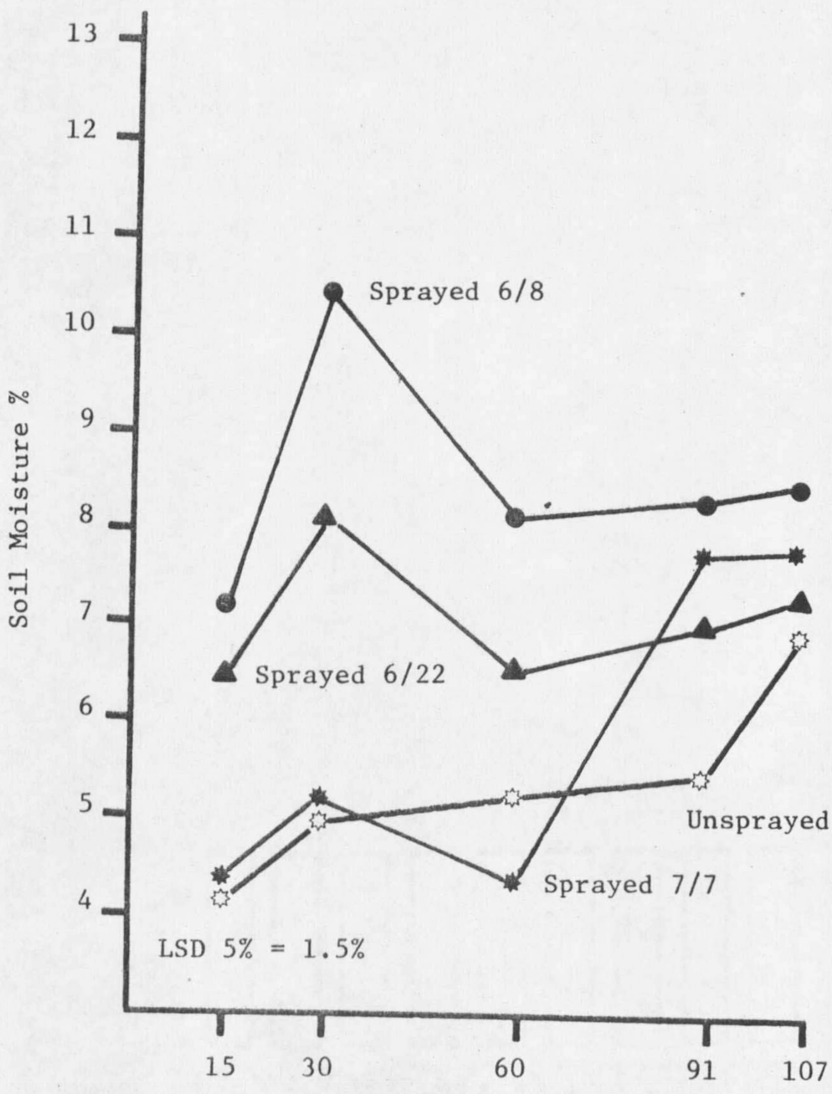

Figure 5. Percent soil moisture on 7/21/79 in plots at Havre sprayed with 1.12 Kg/ha of glyphosate.

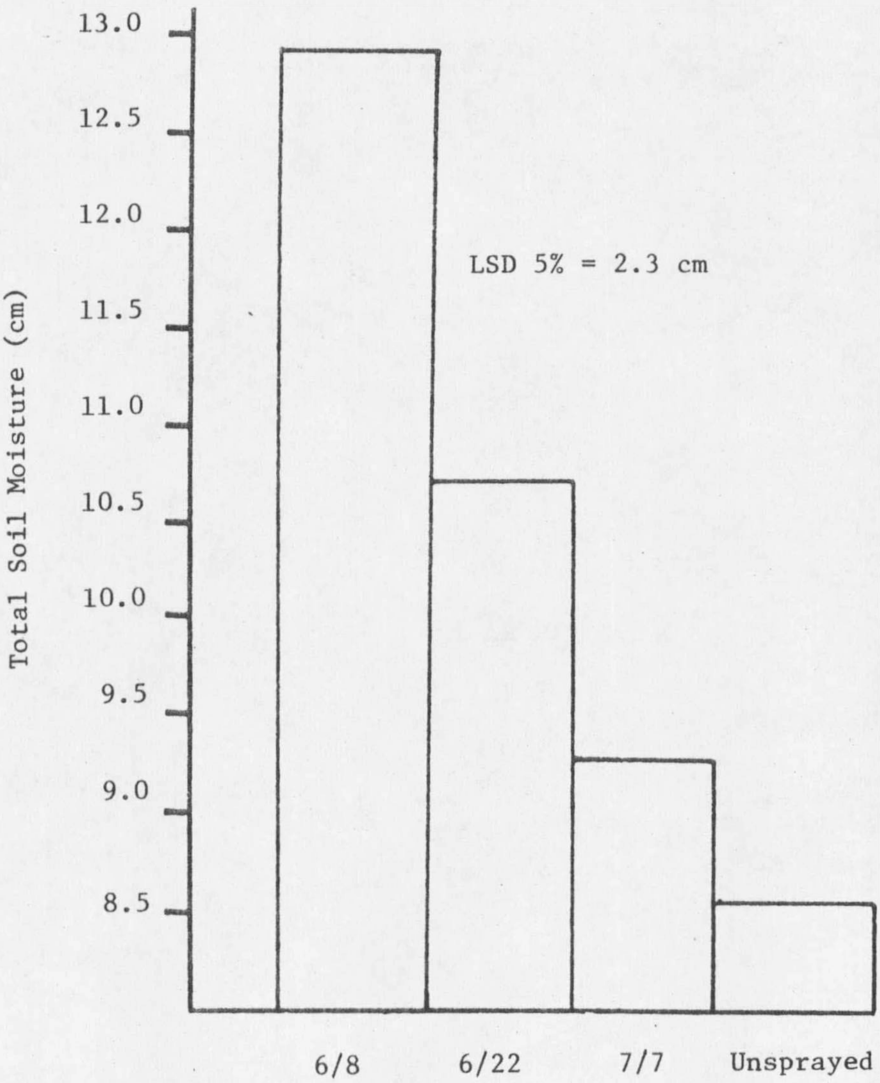

Figure 6. Total soil moisture (cm) in a 107 cm profile at Havre in plots sprayed with 1.12 Kg/ha of glyphosate.

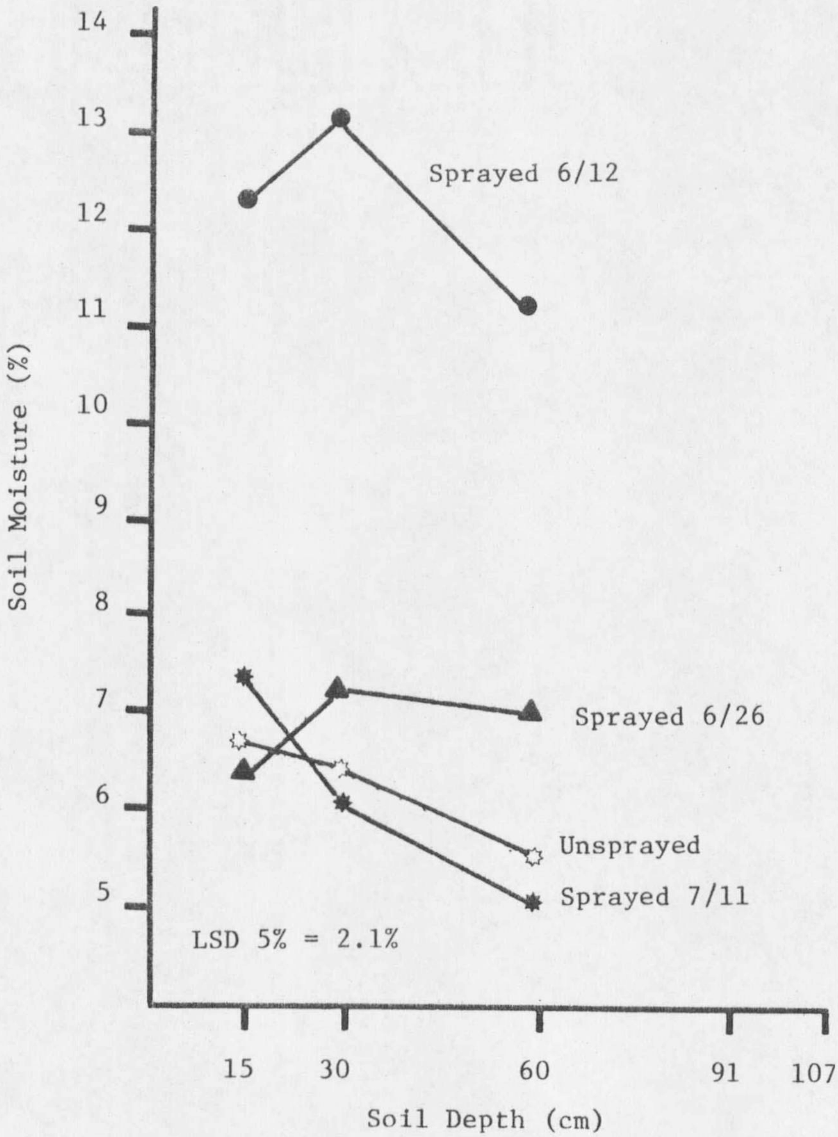

Figure 7. Percent soil moisture on 7/20/79 in plots at Plentywood sprayed with 1.12 Kg/ha of glyphosate.

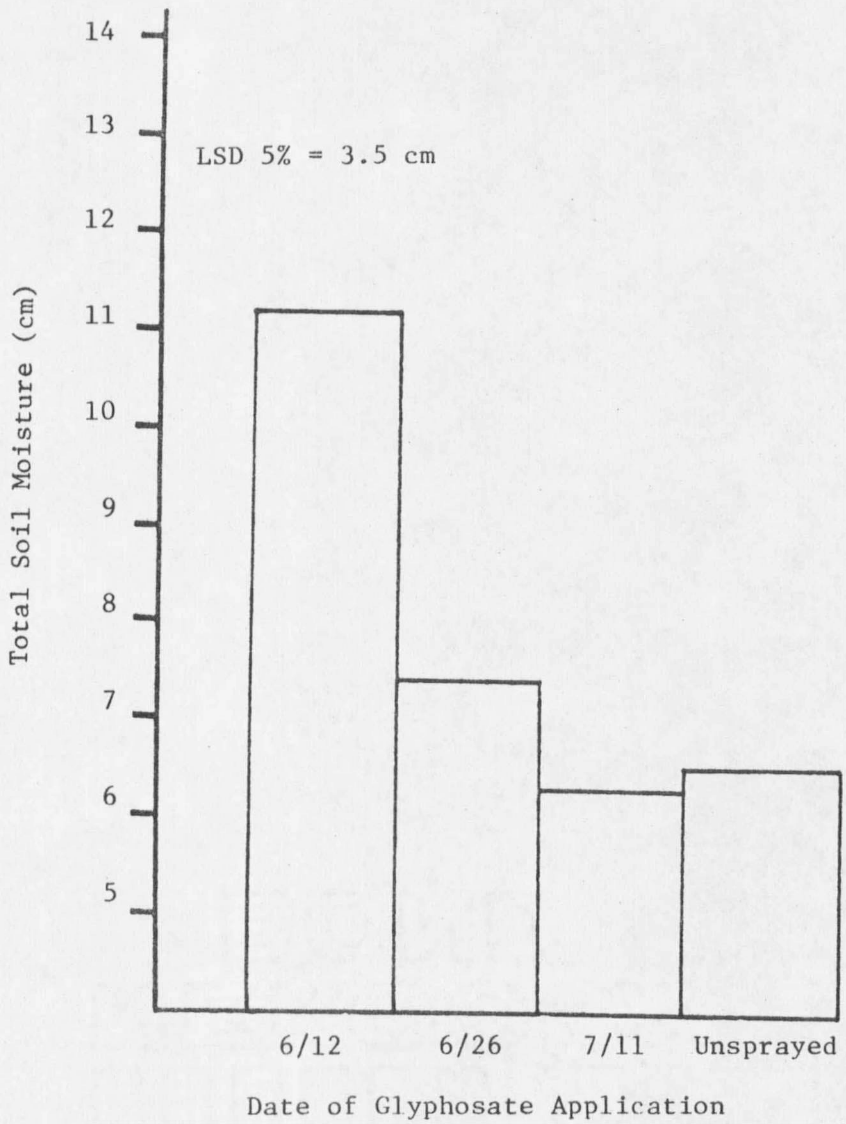

Figure 8. Total soil moisture (cm) in a 60 cm profile at Plentywood in plots sprayed with 1.12 Kg/ha of glyphosate.

Table 6. Normal precipitation and precipitation in 1979, for four locations where glyphosate experiments were conducted.[1/]

Period	Bozeman	Cascade	Havre	Plentywood
	Experimental locations			
	Precipitation (cm)			
May 1979 total	4.06	1.32	2.20	5.00
May Normal	4.41	6.32	3.74	4.67
June 1-7/79	0.55	1.24	1.52	6.09
June 7-14/79	0.00	1.01	0.00	3.81
June 14-21/79	5.99	5.30	2.54	6.35
June 21-28/79	1.04	1.01	0.02	0.05
June 1979 Total	7.58	8.56	4.08	16.30
June Normal	6.47	10.66	7.38	22.92
June 28-7-5/79	0.00	1.55	1.57	0.00
July 5-12/79	0.00	0.00	0.00	0.20
July 12-19/79	0.00	0.00	0.00	0.00
July 1979 Total	0.00	1.55	1.57	0.20
July Normal	1.80	1.93	2.07	1.52

1/ Precipitation amounts obtained from National Oceanic and Atmospheric Administration.

The weed species depleted much of the soil moisture in the shallow soil profile prior to the second application of glyphosate.

There was a substantial decrease in soil moisture levels at each location when weeds were allowed to grow. Winter annual and perennial species extracted large quantities of soil moisture throughout the soil profile by early June. Glyphosate applications should have been made earlier than June, perhaps in late fall, to prevent soil moisture loss since heavy weed infestations were present at each location when the first glyphosate application was made.

Less than normal amounts of precipitation during the last week of June and all of July (Table 6) resulted in small differences in soil moisture content in samples taken from plots which were sprayed on the second and third dates of application. The low level of precipitation received permitted measurement of baseline levels of water extraction from the soil profile by weeds. More normal precipitation patterns would produce considerable differences in soil moisture since the soil moisture reserves used by uncontrolled weeds would have been replenished. Weed control early in the season is important since precipitation in Montana is usually inconsistent and unevenly distributed (Table 6).

CONCLUSIONS

Higher concentrations of glyphosate were required to achieve satisfactory weed control of many species for each succeeding date of application.

Glyphosate provided excellent control of volunteer wheat, wild oats and downy bromegrass at all stages of growth at relatively low rates. Many species such as kochia, Russian thistle and wild buckwheat required a four to eight-fold increase in glyphosate to achieve control as the plants matured. Many perennial species reacted the same way.

Early control of most weed species requires lower concentrations of glyphosate. Early control is therefore, less expensive and will generally result in better control than later applications.

All locations experienced significant losses of soil moisture from weeds when allowed to grow. Early control of weeds eliminates use of soil moisture and can effectively conserve soil moisture under semi-arid conditions. Delaying application of glyphosate results in use of soil moisture by weeds and necessitates an increase in glyphosate concentration for good weed control.

Chapter 6

CHEMICAL FALLOW DEMONSTRATION TOURS

Abstract

Field tours demonstrating chemical fallow herbicides were held at ten locations in Montana in July, 1980 for small grain producers. Three registered chemical fallow treatments were applied and compared to conventional summer fallow cultivation. The advantages, disadvantages, costs and management problems inherent in each technique were discussed. The herbicides compared were cyanazine (2-((4-chloro-6-(ethylamino)-s-triazin-2-yl) amino)-2-methylpropionitrile) with paraquat (1,1'-ethyl-4,4'-bipyridinium ion), terbutryn (2-tert-butylamino)-4-(ethylamino)-6-(methylthio)-s-triazine with paraquat, atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine) or 2,4-D(2,4-dichlorophenoxy acetic acid) and glyphosate (N-(phosphonomethyl)glycine).

MATERIALS AND METHODS

Three acre demonstration plots were established in May, 1980 at ten locations (Tables 1 and 2). Herbicides were applied with a McGregor tri-tank sprayer (McGregor Co., Colfax, WA) with a 6 m boom at 2.4 Kg/cm^3 in 225 L/ha water. Glyphosate was reapplied to control weed growth during the third week of June, 1980. Weed control ratings were taken based on a scale of 0 = no control and 100 = total control (Table 3). Tours were conducted in cooperation with county extension agents at each location from June 30 to July 23 (Table 1).

Table 1. Locations and dates of chemical fallow field tours.

Location	Date
Cascade County	6-30-80
Lewis & Clark County	7-7-80
Teton County	7-11-80
Stillwater County	7-14-80
Custer County	7-15-80
Roosevelt County	7-16-80
Sheridan County	7-17-80
Daniels County	7-18-80
Phillips County	7-22-80
Toole County	7-23-80

RESULTS AND DISCUSSION

Tank mixes which included terbutryn provided the most effective weed control (Table 3). Cyanazine and terbutryn should have been applied one to two weeks earlier for best results since some weeds were at an advanced stage of growth at the time of application. Glyphosate was applied one to two weeks early since weeds emerged after the herbicide was applied.

Dry soil conditions prevailed at all locations at the time of herbicide application. Most locations received rainfall soon after application which stimulated weed seed germination which resulted in unsatisfactory results with glyphosate. Terbutryn and cyanazine were not fully activated before emerged weed seedlings reached an advanced stage of growth.

A number of interesting comments were made by farmers attending the tours:

1) The decrease in erosion, and the potential for increased soil moisture as a result of chemical fallow are important attributes to producers.

2) The reduction in erosion potential with chemical fallow will permit block farming instead of strip farming, a practice adopted exclusively for erosion control. Block farming would increase farming efficiency.

3) More research is needed on the effects of minimum tillage on soil structure. Tour participants felt that one question that emerged was how long does it take for minimum tillage to improve soil structure, and what changes, if any, occur in the subsoil profile?

4) The participants felt that more research is needed on no-till planting and no-till stubble management.

5) More research is needed on no-till fertilization recommendations, and recropping recommendations.

6) Is chemical fallow more economical than cultivation? Many felt they would use atrazine if the potential herbicide residue problems could be eliminated. Most farmers thought they would use chemical fallow if more effective, less expensive herbicides were available.

7) Many indicated concern for potential increases in disease and insect problems from no-till planting. Most felt there is

not enough known about the long-term effects of no-till or minimum-till systems.

8) Many felt that better marking methods need to be developed for application of residual herbicides to avoid over- or under-lapping during spraying.

The majority of farmers present at the tours felt that minimum or no-till cropping systems will be common in the future. Herbicide costs are becoming more competitive with the cost of cultivation.

Chemical fallow is a relatively new concept in Montana not widely adopted at the present time. Interest is spreading rapidly. Further research and the timely dissemination of extension information is needed.

Table 2. Application dates and herbicide treatments for chemical fallow demonstration tours.

Location	Date of herbicide Application[1/]	Herbicide treatments (rate Kg/ha)
Cascade County Dale Marxer farm, Great Falls	5-15-80	
Chouteau County Charles Withrow farm, Geraldine	5-15-80	cyanazine (2.24 Kg/ha) + paraquat (.56 Kg/ha) terbutryn (2.24 Kg/ha) + paraquat (.56 Kg/ha)
Teton County Ross Fitzgerald farm, Power	5-16-80	glyphosate (.56 Kg/ha)
Toole County John McCann farm Shelby	5-16-80	
Phillips County Loren Bruckner farm, Malta	5-17-80	
Daniels County Art Bernard farm, Scobey	5-17-80	cyanazine (2.24 Kg/ha + paraquat (.56 Kg/ha) terbutryn (2.24 Kg/ha) + atrazine (.56 Kg/ha)
Sheridan County Rasmussen farm, Plentywood	5-17-80	glyphosate (.56 Kg/ha)

Table 2. (continued)

Location	Date of herbicide Application[1]	Herbicide treatments (rate Kg/ha)
Custer County Larry Scanlan farm, Kinsey	5-19-80	
Stillwater County Fred Weiler farm, Columbus	5-19-80	cyanazine (2.24 Kg/ha + paraquat (.56 Kg/ha) terbutryn (2.24 Kg/ha) + 2,4-D Ester (.56 Kg/ha)
Lewis & Clark County Dennis Hatlelid farm, Helena	5-20-80	glyphosate (.56 Kg/ha)

1/ Supplemental applications of glyphosate were applied to glyphosate plots June 23-27 at 0.56 Kg/ha.

Table 3. Effectiveness of herbicide treatments for chemical fallow on control of several weed species at 10 locations in Montana, 1980.

Location	VW	TM	WO	RT	K	FB	YB	GE	DB	PL	CC	GP	WM	%GC
	Percent control													
Cas Co														
Cy + Pa	60[2]	60			80	5			100					75
Ter + Pa	100	100	75		100	10			100					60
Gly	100	100	90		100	30			100					70
Cho Co.														
Cy + Pa	75	70	90	70	75				95	60				30
Ter + Pa	100	100	100	100	95				100	100				1
Gly	100	100	100	80	75				100	70				20
Tet Co.														
Cy + Pa	75			5	5									80
Ter + Pa	90			10	20									75
Gly	100			5	5									75
Too Co.														
Cy + Pa	80	60		50	70				90					40
Ter + Pa	100	100		80	60				100					15
Gly	100	70		60	50				100					20
Phil Co														
Cy + Pa	70	80		50	60	0			100					60
Ter + At	100	100		100	100	5			100					0
Gly	100	100		50	70	20			100					5
Dan Co														
Cy + Pa		60		80		20		40			30			50
Ter + At		100		100		40		50			100			0
Gly		100		20		60		0			10			50

Table 3. (continued)

Location	VW	TM	WO	RT	K	FB	YB	GF	DB	PL	CC	GP	WM	%GC
	Percent control													
Sher Co														
Cy + Pa	70	40	10		60					100			70	50
Ter + At	100	100	100		100					100			100	10
Gly	100	10	80		75					0			100	30
Cu Co														
Cy + Pa	80	100		80	80			100						20
Ter + 2,4-D	100	100		100	100			100						10
Gly	100	100		10	20			100						60
Sti Co														
Cy + Pa	85				90	5	60		100		90	80	100	15
Ter + 2,4-D	100				100	10	100		100		100	100	100	0
Gly	100				100	15			100		100	90	100	40
L & C Co														
Cy + Pa	90	100		80	85				100					15
Ter + 2,4-D	100	100		100	100				100					1
Gly	100	100		99	100				100					2

1/ Key to abbreviations:

VW = Volunteer wheat
TM = Tansy mustard
WO = Wild oats
RT = Russian thistle
K = Kochia
FB = Field bindweed
YB = Yellow goatsbeard
GF = Green foxtail
DB = Downy bromegrass
PL = Prickly lettuce
CC = Cow cockle
GP = Green pepperweed
WM = Wild mustard
%GC = Ground cover
Cy = Cyanazine
Pa = paraquat
Ter = Terbutryn
Gly = Glyphosate
At = Atrazine

2/ 0 = no control; 100 = complete control

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