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INVESTIGATIONS OF FIELD PERFORMANCE AND PHYSIOLOGICAL EFFECTS OF METSULFURON AND METSULFURON COMBINATIONS ON FIELD BINDWEED (*Convolvulus arvensis* L.)

by

Hamid Rahimian Mashhadi

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Plant Science

Approved:

UTAH STATE UNIVERSITY

Logan, Utah

1987

DEDICATION

To the people of my country

and

to my lovely family and parents

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I would like to express my appreciation to Dr. John O. Evans for his assistance and guidance as my major professor while I have been engaged in the research, coursework and writing of this Ph.D. program. Appreciation is also expressed to Dr. Schuyler D. Seeley, Dr. Coburn M. Williams, Dr. Donald W. Davis and Dr. Bruce G. Bugbee for serving on my advisory committee and for their useful suggestions and critical review of this manuscript. Special thanks to Bruce for his help in the design and construction of the open gas exchange system.

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Hamid Rahimian Mashhadi

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ABSTRACT

Investigations of Field Performance and Physiological Effects of Metsulfuron and Metsulfuron Combinations on Field Bindweed (Convolvulus arvensis L.)

by

Hamid Rahimian Mashhadi, Doctor of Philosophy

Utah State University, 1987

Major Professor: Dr. John O. Evans
Department: Plant Science

Field bindweed (Convolvulus arvensis L.) is a noxious perennial weed of many fallow and cropland fields all over the world. Present control methods are not satisfactory for field bindweed. Metsulfuron, 2[[[[(4-methoxy-6-methyl-1,3,5-triazine-2-yl) amino] carbonyl] amino] sulfonyl] benzoic acid, is a new herbicide that has been shown to have activity on bindweed especially when tank mixed with other herbicides. This study was conducted to investigate the field performance and some physiological effects of metsulfuron on field bindweed.

Neither metsulfuron alone nor metsulfuron combinations gave persistent control of field bindweed. Metsulfuron usually increased the activity of other bindweed herbicides. Herbicide application to field bindweed in the full bloom growth stage did not control the weed as well as the same treatments in prebloom growth stages and treating regrowth the fall after tilling bindweed in full blossom. Application of metsulfuron at full bloom decreased seed weight, seed size, seed viability and seedling vigor of field bindweed but did not alter seed set.

Metsulfuron at 23 g/ha and above caused unacceptable injury to barley (Hordeum vulgaris L.) and oats (Avena sativa L.). Higher rates of metsulfuron resulted in greater phytotoxicity.

Metsulfuron stopped photosynthesis of field bindweed within two weeks regardless of herbicide dosage used. Field bindweed seedlings were observed growing in the field under light intensities of 28 to 62 µmoles m^{-2} s^{-1} which was below the light compensation point obtained for greenhouse grown bindweed plants (about 65 µmoles m^{-2} s^{-1}).

Higher quantities of ^{14}C labelled metsulfuron per mg plant dry weight were recovered in the above treated leaf sections than in any other parts of bindweed plants. Metsulfuron applied as a foliage spray two days prior to administering ^{14}C metsulfuron significantly increased absorption of the radiolabelled herbicide in field bindweed plants.

(133 pages)

INTRODUCTION

Field bindweed (Convolvulus arvensis L.) is considered one of the world's worst weeds. It is most troublesome as a weed in Europe, Western Asia, Canada and the United States and is a special problem in several cropping systems in the temperate region. Field bindweed is native to Europe and its infestation extends from 60° N to 45° S. Forty-four countries have reported it as a weed in 32 different world crops (Holm et al. 1977).

Field bindweed is a problem weed in many agricultural fields in Utah. Particularly troublesome in fallow land, field bindweed is listed among the 12 noxious weeds of the state.

In spite of being a noxious weed, there has been inadequate research conducted in the long term control of field bindweed. No method has yet been found to control this plant successfully in the field.

A new family of broad spectrum, broadleaf herbicides developed by DuPont has shown good activity against field bindweed. Among these herbicides, metsulfuron has given the best results. As a new herbicide there exists limited information about metsulfuron alone or in combination with other herbicides to control field bindweed. Research is also needed regarding metsulfuron in the area of soil residue as it relates to succeeding crop safety and also more work is needed concerning its plant physiological relationships. The objectives of this study were to:

1. Compare the effectiveness of metsulfuron alone and in combinations with picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid), dicamba (3,6-dichloro-2-methoxybenzoic

acid), 2,4-D ((2,4-dichlorophenoxy) acetic acid), glyphosate (N-(phosophonomethyl) glycine) and MCPA ((4-chloro-2-methylphenoxy) acetic acid) in controlling field bindweed with applications at preemergence, prebloom, bloom and bloom-disked fall treatment.

2. Study the effects of metsulfuron applied at full bloom on seed size, seed set, seed viability and seedling vigor of field bindweed.
3. Evaluate the safety of metsulfuron applied during a fallow year to spring and fall planted small grains.
4. Determine the effect of metsulfuron, picloram, dicamba, 2,4-D, glyphosate and MCPA on photosynthetic rates of field bindweed.
5. Investigate the absorption and translocation of metsulfuron in field bindweed.

LITERATURE REVIEW

Field bindweed is a low-growing, deep rooted perennial weed with prostrate vigorous stems or climbing on upright plants or other objects. They even twine upon themselves. The leaves are relatively small and smooth, somewhat arrow shaped, but not so narrow near the point as in some related species. The leaves on different plants, and to some extent on the same plant, vary in shape and size. The plants have a long central taproot capable of reaching depths of 20 feet or more. Numerous lateral roots develop along the taproots, mostly in the top 2 feet of the soil. Buds formed along lateral roots or rhizomes are capable of developing into shoots, which upon reaching the surface, become new plants (Call and Getty 1923; Swan 1980; Stahlman, 1984).

The plant spreads horizontally by means of a series of permanent lateral roots. The primary permanent lateral roots arise from the main vertical root. Succeeding orders of permanent lateral roots arise at a bend where a permanent lateral root of the proceeding order turns down to become a vertical root. At the end of one growing season (7 months), bindweed plants not subjected to competition had a vertical penetration of 4 feet and a radial spread of 10.5 feet. After 30 months of growth, many of the vertical roots had reached a depth of 14 to 16 feet. One was traced to a depth of 23 feet. The root system attained a radial spread of 17 feet in 19 months (Frazier, 1943a). Best (1962) reported as many as 25 shoots arose from a vegetatively propagated bindweed plant four months after transplanting it to a field. The nearest shoot was 18 inches from the transplant, and the farthest had emerged at 52 inches. The following year, after 14 months the lateral spread of this transplant had reached 72 inches in one direction. Fifteen months after planting, a shoot was observed at a distance of 114 inches from the parent plant.

The form of development taken by the root system is frequently related to the soil type and water table. It has been observed that in localities with a high water table, the tap root may branch at a depth of 2 feet or less, while in others, it may penetrate to a depth of 10 feet or more before branching profusely (Kennedy and Crafts, 1931).

Bindweed stems are pubescent, heavily cutinized and difficult to wet. The leaf epidermis is rough (like cobble stone) and has thin-walled cells that are not heavily cutinized. Vines and leaves often contain a milky juice which exists in the laticifer cells of both stem and leaves. Stomata are present on both the upper and lower leaf surfaces with most on the dorsal side (Kennedy and Crafts 1931).

Field bindweed flowers are bell-shaped, 3/4 to 1 inch in diameter and vary from white to pink. Each flower produces a nearly round seed pod containing up to 4 dark brown or black 3-sided seeds about 1/8 inch long (Stahlman, 1984). Under normal conditions, bindweed flowers open early in the day and close shortly after noon. If conditions are cloudy, bindweed plants may respond differently (Brown and Porter 1942, Hanson et al. 1943). Flowers open once, and if they are not pollinated during the period when they are open, fail to set seed. Seed production is variable and difficult to predict, although it has been shown that disturbed plants produce less seed than undisturbed plants. Seed yield is favored by dry sunny weather and high temperatures (Brown and Porter 1942). Higgens and Seely (1961) estimated that in a pure stand of bindweed, 22 million seeds per acre can be produced annually. Wiese and Rea (1959) estimated a density of 226 to 258 bindweed seeds per square meter of bindweed infestation. The mature seed is hard, brown and black in color, has a rough papilose surface, and the basal end shows various markings. The integument is 15-20 cells thick. All walls of these cells become thickened and microchemical tests indicate that they are lightly impregnated with lignin and contain cutin or suberin. This is undoubtedly the layer that is responsible for the imperviousness of the seedcoat to water. The seedcoat is fully matured in 30 days but is germinable in 10-15 days after pollination (Sripleng and Smith 1960).

Brown and Porter (1942) in an extensive study on viability and germination of field bindweed reported that the percentage of germinable and impermeable seeds was significantly different with the year and place of production. A test of fifty plump seeds obtained from a 50-year-old herbarium specimen showed that 8 percent were germinable, 54 percent were impermeable and 38 percent were dead. Two of the hard seeds were treated with acid, and they germinated readily. This indicated a possible total 62 percent live seed in the 50-year-old seeds. Brown and Porter (1942) also tested the relation of moisture content and age of seeds to the development of germinability and impermeability of bindweed seeds. Their results showed that germinability began 10 to 15 days after the flower opened when the moisture content was reduced to 81 percent. Impermeability began 23 to 25 days after flowers opened when the moisture content was reduced to 13 percent. When seeds of field bindweed were buried in soils to determine the effect of overwintering on germination, they found an average of 31.8 percent germinated which is an increase of 17.8 percent over the laboratory test of 14 percent.

Field bindweed seeds germinate in both fall and spring. The optimum germination temperature is 30° C with a range from 0.5 to 40° C. Both seedling and mature bindweeds are quite frost tolerant but -8 to -10° C will kill the vegetative growth. Therefore, fall germinated seedlings won't overwinter in cold climates if roots are insufficiently established (Swan 1980). Dexter (1937) found one-third of the test roots of field bindweed survived -6° C. Roots and rhizomes increase in hardiness during the fall and display true frost hardiness during the winter. If the ground is frozen, however, bindweed roots in the upper soil profile (the portion that is frozen) are severely injured or killed. Bindweed regrowth begins in the spring when daytime temperatures near 14° C and lows at night are not below 2° C.

Clones of field bindweed have been shown to have different growth and reproductive characteristics. Degennaro and Weller (1984) identified five biotypes among clones collected in a field population near Lafayette, IN. Consistent variations in leaf morphology, floral characteristics and accumulation of shoot and root biomass were found between biotypes when grown in a controlled environment. The biotypes also differed in flowering capacity. The earliest flowering biotype formed flowers 23 days before the late flowering biotype and produced 19 times more flowers per plant. Vegetative reproduction potential of the biotypes varied from 1.8 to 74.5 percent in the number of root buds that developed into shoots. Whitesides (1978) found that three ecotypes of field bindweed from differing climatic regions were morphologically different when grown under the same environmental conditions. Differences occurred in maximum vine length, number of vines per plant; and number of leaves, flower buds, flowers, seed pods and seed yield. Uptake and translocation of ^{14}C-glyphosate did not differ in the three bindweed ecotypes. Rashed (1981) reported different responses of two field bindweed ecotypes to glyphosate treatment. The most prevalent Nebraska ecotypes of field bindweed were more tolerant to glyphosate treatments.

Different clones of field bindweed have been observed to vary in their degree of susceptibility to herbicides. Whitworth and Muzik (1967) examined 12 clones of field bindweed to determine a mechanism for the selective action of 2,4-D. The experiment showed no correlation between degree of pubescence, number of stomata, absorption of the chemical into and its translocation within the plant with the degree of the susceptibility to foliage applications of 2,4-D. The most pronounced physiological differences between resistant and susceptible clones of bindweed occurred at the cellular level. When incubated in nutrient agar containing 2,4-D, susceptible clones produced twice as much callus as resistant clones on both volume and dry weight basis.

Whitworth (1964) studied the reaction of many strains of field bindweed to 2,4-D and noticed marked differences among them. There appeared a continuous range in reaction of the 51 strains of field bindweed collected from 20 states of the U.S. and one province of Canada, from an 87 percent decrease to an 83 percent increase in weight one month after treatment. Many of the resistant strains showed incomplete top kill followed by resprouting from roots within one month after 2,4-D treatment. Plants that were classified as being more susceptible showed complete top kill, near death of all root tissue, and there was no resprouting.

Field bindweed has been shown to greatly reduce the yield of many crops. Experiments in Kansas showed that bindweed reduced the yield of barley, oat, wheat, corn, sorgo and milo by 32, 26, 42, 67, 66 and 89 percent respectively (Phillips and Timmons 1954).

Field bindweed tissue has been shown to have inhibitory effects on germination and vigor of some crop seeds. Helgeson and Richards (1950) reported that a 1:20 aquious extract of dried field bindweed tops inhibited radicle length of flax and wheat 24 and 42 percent respectively. Increasing concentration of the extract resulted in a progressive decrease in germination and growth of roots and shoots.

Bindweed is disseminated by both roots and seed. The seed is spread through impure crop seed, manure, threshing outfits, running water, agricultural machinery and the feet of animals. The use of weed-free seed and clean farm machinery are not to be rivaled (Zahnley and Pickett, 1934).

Field bindweed seedlings can be controlled easily in early stages of growth, therefore, recognition is very important. Bindweed seedlings can be recognized by their notched cotyledons. Under favorable conditions, 6-week-old seedlings are capable of re-establishment after top growth removal. Monthly tillage or many postemergence broadleaf herbicides can control young seedlings (Swan, 1980; Stahlman, 1984).

Numerous experiments and observations have shown that when bindweed-infested land is cultivated repeatedly at frequent intervals, the plants are eventually killed. They are probably not all killed at once because of reserves stored in their roots. They finally die only when this supply has been exhausted. Timmons (1941) demonstrated a gradual decline of both bindweed roots and their readily available carbohydrates with repeated cultivation.

Timmons (1941) used several different experiments to compare the effectiveness of cultivating bindweed at different intervals after emergence. These included cultivating immediately after the bindweed appeared (about 9 days after first tillage) and then tilling at 4, 8, 12, 16, 20 or 28 day intervals after emergence. The results of the study showed that bindweed was eradicated when cultivated 12 days after each emergence or cultivating about every 3 weeks. Approximately sixteen cultivations were required to kill bindweed by this method. When this method was used, the field was free of bindweed by the end of the second season. The time when cultivations were started did not affect the number of cultivations necessary to eradicate bindweed. No advantage was found in cultivating bindweed deeper than necessary (about 4 inches) to cut off all plants well below the surface at each operation. Sherwood and Fuelleman (1948) investigated the relationship between depth and frequency of cultivating bindweed by cutting the shoots at different depths, including scraping just below the soil surface, 3, 6, 9, 12, 18, 24-30 and 36 inches immediately after each reemergence. All operations eradicated bindweed in two years or less with 40, 19, 17, 13, 9, 8, 8, 5 and 4 cultivations, respectively, for the different depths. The average intervals between cultivations varied from 6 to 49 days. It was concluded that 3 inches was the most economical depth of cultivation.

Timmons and Bruns (1951) reported that cultivation 12 days after each emergence of bindweed or every 18 to 20 days, required with about twice as many operations as did cultivations immediately after each emergence. Longer intervals between cultivations required longer times for eradication and tended to require more cultivation. Frazier (1943b) found that cultivation every 14 days destroyed a fifth more of the readily available carbohydrates and more than doubled the loss of protein nitrogen in the roots and shoots as compared with two cultivations at intervals of 7 days in a given unit of time. Barr (1940) in a similar study reported that cultivation at 2-week intervals reduced the readily available carbohydrates to 2.30 percent compared to 16 percent in undisturbed plants. Such cultivation also prevented any accumulation of nitrogen in the bindweed roots.

In a study to determine the effect of reduced light intensity on the aerial and subterranean parts of bindweed, Bakke and Gaessler (1940) published evidence showing that a reduction in light intensity from 2,000 to 120 umoles m^{-2} s^{-1} reduced the amount of aerial and subterranean growth of bindweed and exhausted the available carbohydrates to the point that there was not sufficient root reserves for plant regeneration. Reducing the light to about 120 umoles m^{-2} s^{-1} for three years should bring about eradication of bindweed and should be as effective as three years of intensive cultivation.

Early work by Phillips and Timmons (1954) with use of soil sterilants indicated that sodium chlorate at 3 to 4 pounds per square rod followed by retreatment in subsequent years satisfactorily controlled field bindweed. Bindweed stands were greatly reduced with 2,4-D treatment but even repeated applications did not, in most cases, completely eradicate established stands.

Schweizer and Swink (1971) reported at least 90 percent control of field bindweed with 4.5 and 6.7 kg/ha of dicamba applied the year before. Dicamba at 2.2 kg/ha, a mixture with 2,4-D and 2,4-D alone were less effective. High rates of dicamba, however, caused phytotoxicity to sugarbeet and field beans.

In a long-term field bindweed control experiment conducted by Swan (1982), three herbicides (2,4-D amine salt, glyphosate and dicamba) were tested. Field bindweed control with 2,4-D at 1.1 kg/ha averaged 25 percent when applied in July, 35 percent when applied in August and 40 percent when applied in July and August of the summer fallow years. Control using 3.4 kg/ha 2,4-D averaged 50 percent when applied in July and 75 percent when applied in August and 40 percent when applied in July and August of the summer fallow years. Field bindweed control averaged 17 percent higher when 2,4-D was applied in August than in July. The 3.4 kg/ha rate gave 45 percent better field bindweed control than the 1.1 kg/ha rate. The best control was obtained in the summer fallow years when fields were cultivated until July 1 and then treated in August with 2,4-D at 3.4 kg/ha. Field bindweed control with 2,4-D treatments averaged 62 percent, 73 percent with glyphosate, 90 percent with dicamba and 67 percent with 2,4-D plus dicamba. Dicamba at 6.7 kg/ha applied in the summer fallow years reduced winter wheat yield significantly. However, when this rate of dicamba was applied to post-harvest stubble and followed by a fallow year (14 months before the next crop was seeded), there was no yield reduction. Swan (1982) concluded that these systems of bindweed control would probably never eradicate field bindweed.

Bank et al. (1979) reported 80 to 100 percent control of field bindweed, rated 310 days after application of 4.5 and 5.6 kg/ha glyphosate and 3.4, 5.6 and 6.7 kg/ha of dicamba. Glyphosate controlled field bindweed more effectively when applied at the bloom rather than at prebloom stage of growth. Glyphosate at 4.5 kg/ha provided 80 percent control applied at bloom compared to 60 percent when applied prebloom.

Dicamba controlled field bindweed but severely damaged the wheat. Even though the herbicides were applied prior to planting, dicamba at rates above 3.4 kg/ha caused up to 90 percent visible injury, which was also indicated by significantly lowered wheat yields. Glyphosate applied 26 days prior to harvest at rates of 3.4 kg/ha or higher, controlled field bindweed plants in standing wheat and also reduced harvesting difficulties. Treatment with 2,4-D amine was not as successful since only 60 to 70 percent of the field bindweed plants were controlled. Several dinitroanaline herbicides applied as subsurface layer (SSL) treatments controlled field bindweed for more than 8 months after treatment. However, these treatments caused visible injury and affected the yield of the first crop of wheat but had little effect on the second crop. Dicamba applied SSL at lower rates resulted in excellent field bindweed control.

Agbakoba and Goodin (1970) reported that bindweed seedlings absorbed less 2,4-D than mature plants. However, translocation of 2,4-D was greater in seedlings. More 2,4-D reached the roots of seedling plants than mature plants.

Wiese and Rea (1961) obtained maximum field bindweed control with 0.9 kg/ha of 2,4-D when vigorous growth had been produced and when bindweed runners were from 6 to 10 inches long and when the soil profile had 1.5 inches of available soil moisture in the surface 3 feet. Under these conditions, the total available carbohydrate level was high in the leaves and low in the roots, and was followed by conditions that indicated rapid carbohydrate movement to roots. Their investigations showed that soil moisture and percentage total carbohydrates in bindweed tops and roots were responsible for 78 percent of the variability in bindweed control from applications of 2,4-D.

Looking at phenoxy herbicides as possible soil sterilants, Wiese and Rea (1958) reported an average of 66 percent bindweed control one year after soil application of 2,4-D at 71.3 kg/ha. The herbicide residue from the application persisted in the soil for about three months.

Schweizer et al. (1978) attempted to control field bindweed in irrigated corn. After four years, field bindweed covered 9 percent of the soil surface in plots that received both fall and spring application of 2.2 kg/ha dicamba and 3.4 kg/ha of 2,4-D. Field bindweed covered 72 percent of the surface in plots that received only fall applied herbicides compared with 80 percent in untreated plots.

Russ and Anderson (1960), in a 3-year experiment to investigate the best combination of cropping, cultivation and 2,4-D applications for field bindweed control, concluded that a 3-year system of intensive cultivation in combination with an annual application of 2,4-D resulted in the most effective bindweed control. They concluded that under their existing conditions, complete bindweed eradication on a field scale may not be realized or it may be impractical from an economic standpoint.

Derscheid et al. (1970) reported that over 90 percent of the field bindweed can be eliminated in 3 years if every landowner will use the appropriate control methods. Using 2,4-D alone or in combination with cultivation reduced the stand of field bindweed by 90 percent or more in 3 years in various crop rotations tested. A .75 lb/A dosage of 2,4-D to small grains applied in June prevented seed production, killed susceptible plants and weakened the remaining plants, however, a followup treatment with 2,4-D, postharvest cultivation or postharvest treatment with herbicides such as 2,3,6-TBA (trichlorobenzoic acid), dicamba or picloram was necessary to kill them.

When perennial grasses were used as competitive crops, no reduction in stand of field bindweed was observed. When a single application of 2,4-D was added to the grass rotation, bindweed stands were reduced by 90 percent (Derscheid and Stritzke 1968).

Rashed (1981) tested several growth regulators in combination with glyphosate to control field bindweed. A single application of glyphosate after July discing was found to be more effective during rapid vegetative phase than during fruiting. Growth regulators, such as dicamba, 2,4-D, chlorflurenol (methyl 2-chloro-9 hydroxyfluorene-9-carboxylate) or ethephon ((2-chloroethyl) phosphonic acid) in combination with 0.8 kg/ha glyphosate did not perform better than glyphosate alone. Lowering the rate of glyphosate to 0.6 kg/ha and combining with growth regulators increased field bindweed control from 25 percent with 0.6 kg/ha glyphosate alone, up to 98 percent in combinations of glyphosate and growth regulator. The best results were obtained when 2,4-D or dicamba were combined with glyphosate.

Metsulfuron (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]-sulfonyl]benzoate) is a newly registered herbicide for selective broadleaf weed control in wheat and barley. It possesses both foliar and soil activity as well as pre and postemergence activity. It also has residual broad spectrum activity in reduced tillage fallow proceeding wheat.

Metsulfuron belongs to the sulfonylurea family of herbicides. Its characteristics are very similar to chlorsulfuron (2-chloro-N-[[(4-methoxy-6 methyl-1,3,5-triazin-2yl) amino] carbonyl] benzenesulfonamide) which has been extensively researched during the past few years. Uptake of chlorsulfuron and metsulfuron is via the roots and foliage of plants, and once absorbed they are readily translocated (Ray, 1982, Sweetser et al. 1982). Death of treated plants is generally slow. Plant injury symptoms following chlorsulfuron or metsulfuron application consist of chlorosis, necrosis, terminal bud death, vein discoloration and complete inhibition of plant growth (Ray 1982). Reduction of the number of cell divisions is found to be mainly responsible for plant growth inhibition. Ray (1982) showed 87 percent reduction of mitotic index of Vicia faba roots in one ppm chlorsulfuron. Chlorsulfuron was also found to have no direct effect on plant photosynthesis and respiration. Ray (1982) showed high levels of chlorsulfuron (100 ppm) caused no inhibition of ferricyanide-catalyzed photosynthetic O_2 evolution in isolated pea chloroplasts. Photosynthetic $^{14}CO_2$ fixation in isolated spinach leaf cells was also unaffected by chlorsulfuron. Like photosynthesis, plant respiration was also initially unaffected by chlorsulfuron. Rates of O_2 uptake by pea roots treated with 10 ppm chlorsulfuron for 48 hr did not differ from the controls. Sweetser et al. (1982) showed that metabolism of chlorsulfuron by tolerant plants was the basis for its selectivity. Tolerant plants such as wheat, oats and barley rapidly metabolized chlorsulfuron to a polar inactive product. This metabolite has been characterized as the O-glycoside of chlorsulfuron in which the phenyl ring has undergone hydroxylation followed by conjugation with a carbohydrate moiety. Sensitive broadleaf plants showed little or no metabolism of chlorsulfuron. Hutchison et al. (1984), in a similar study, reported that tolerant broadleaf plants like flax and blacknightshade, as well as tolerant grasses, metabolize chlorsulfuron.

Metsulfuron can be applied any time after the 2 to 3-leaf stage of crop growth all the way to booting (Anonymous n.d.). Metsulfuron is used at the ultra low rate of 4.2 g/ha. This rate had been shown to be very safe on cereal crops (Warner et al. 1986). Barley, oat, and wheat have marginal tolerance to postemergence applications of metsulfuron. Behrens et al. (1983) reported that metsulfuron applied at 22 g/ha to oats and wheat in the 2 to 3 leaf stage caused 42 and 22 percent injury respectively. Metsulfuron applied at 22 g/ha to oats or hard red spring wheat in the 4 to 5-leaf stage caused 28 percent injury in both species. Nalewaja and Miller (1982a) reported that metsulfuron applied at 9, 12, and 18 g/ha to red hard spring wheat in the 3 to 5 leaf stage caused 11 to 35 percent injury. Evans and Gunnell (1985) reported no spring wheat injury from postemergence application of 4 and 9 g/ha of metsulfuron.

Herbicide dissipation from soil is a multifactor process that involves microbial and chemical degradation, leaching, volatilization, photodecomposition, and metabolism of the herbicide by plants (Miller et al. 1978). Norwood (1982) reported that chlorsulfuron applied at 52 g/ha to a soil with a pH of 7.75 reduced grain sorghum yield one year after application; however, chlorsulfuron applied at 110 g/ha to a soil with a pH of 6.75 did not reduce grain sorghum yield one season after application. Chemical hydrolysis is believed to be the mechanism of degradation of sulfonylurea herbicides in acidic soil. A study by Flom et al. (1986) tested the degradation rates of six autoclaved soil with pH of 4.0, 5.1, 6.0, 6.8, 8.0, and 9.0. Degradation rates increased as soil pH decreased. After 6 weeks, approximately 90 percent of the ^{14}C-chlorsulfuron applied to the pH 4 soil samples were converted to primary metabolites whereas in the pH 9 soil samples over 90 percent remained as parent chlorsulfuron molecules. Joshi et al. (1984) reported that hydrolysis is the main factor involved in chlorsulfuron degradation in acid soils, while chlorsulfuron degradation in alkaline soils is more dependent on microbial activity.

The half-life of metsulfuron in keyport silt loam has been determined to be 2-3 weeks under laboratory conditions. A longer half-life is expected in cool alkaline soils. Metsulfuron is not appreciably adsorbed to soil particles (Anonymous 1983). Nalewaja and Miller (1982b) reported that hard red spring wheat injury exceeded 30 percent following a preemergence incorporated application of metsulfuron at 18 g/ha, and metsulfuron applied preemergence at 9, 18, and 27 g/ha caused from 5 to 25 percent injury to hard red spring wheat. Stahlman (1983) evaluated the effect of metsulfuron on six winter wheat cultivars in a crete silty loam soil with 1.6 percent organic matter and a pH of 6.6. Metsulfuron applied preemergence at 18 g/ha caused grain yield reduction of 33 to 42 percent compared to the appropriate controls (Stahlman, 1986).

Ulrich (1984) reported 6 percent or less injury to wheat following 1.5 to 5 g/ha chlorsulfuron. Metsulfuron at 9 to 70 g/ha injured the wheat 21 percent or less. He also reported higher rotational crop injury with metsulfuron when compared to chlorsulfuron.

MATERIALS AND METHODS

Field Experiments

Three field experiments were established on fallow fields heavily infested with field bindweed and studied for two years in one location and three years in the other two. Experimental plots at Sherwood Hills and Smithfield were established in the summer of 1984 and evaluated for three years. The plots at Hyrum were established in the summer of 1985 and evaluated for two years. Sherwood Hill's soil was silty loam, pH 7.4 and 3.07% organic matter; Smithfield had silty clay loam soil, pH 8.0 and 2.76% organic matter; and Hyrum soil was silty loam, pH 8.2 and 1.32% organic matter.

Single herbicide treatments were made to field bindweed at one of four growth stages: preemergence, prebloom, bloom, and fall treatment of bindweed regrowth after plants were rototilled at full bloom. From here after this stage is referred to as fall. Plots were sprayed with a 2.4 m boom type hand held sprayer pressurized by compressed air to 200 kilo pascals. The plots were 2.4 x 6.1 m size and were sprayed with a volume of 75 L/ha. All treatments were replicated four times in a split plot design. Fall treatments at Sherwood Hills and preemergence treatment at Hyrum were not established.

Treatments included three rates of metsulfuron (23, 47, 70 g/ha) alone and in tank mixes with picloram (140 g/ha), dicamba (560 g/ha), 2,4-D (1,120 g/ha), glyphosate (840 g/ha) and MCPA (1,120 g/ha). For comparison purposes, each of the above five herbicides was also applied without metsulfuron. All herbicide treatments included .25 percent V/V WK surfactant.

The plots were evaluated visually for percent biomass reduction (control plots = 0 percent control and bindweed free plots = 100 percent control), 30 and 45 days after application in the first year and during early summer of the subsequent years. Bloom and fall treated plots were evaluated during late season once or not at all respectively because of interference of early fall frost in Cache Valley. To eliminate competition by annual weeds with field bindweed, all experimental plots were sprayed with paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at one L/ha. Paraquat killed all the existing vegetation, but bindweed quickly recovered.

Seed Viability

Sulfonyl urea herbicides have been shown to inhibit viable seed formation in dyer's woad (Isatis tinctoria L.), (Evans and Gunnell, 1984). To determine the effect of metsulfuron on seed size, viability and seedling vigor of field bindweed, 50 seed capsules were randomly sampled from plots treated with metsulfuron during full bloom in Sherwood Hills and Hyrum. Capsules were weighed, opened and the number of seeds per capsule counted. Seeds were weighed and evaluated with regard to shrunken seed. The seeds were then soaked in concentrated sulfuric acid for one hour and rinsed with water for 15 minutes. Scarified seeds were germinated in petri dishes at 20° C in 100 ppm ceresan in water. After 5 days, the number of seeds that germinated were counted and seedling radicle lengths were measured.

Soil Bioassay

Soil bioassay was conducted to determine crop safety following metsulfuron applications at different times during the fallow year to fall planted small grains. Approximately 8-10 kg soil samples from the top 30 to 50 cm of the middle of each metsulfuron treated plot were collected on September 25, corresponding to the date when small grain is usually planted in Cache Valley. Each soil sample was completely mixed and was potted in 1/2 liter plastic pots. Three pots were prepared from each soil sample taken from Sherwood Hills. Four lentils (Lens culinaris Medic) and 4 barley (Hordeum vulgaris L. var. Steptoe) seeds were planted in each pot and thinned out to 2 each after emergence. Hyrum soil samples were potted using six pots per plot; 3 of the pots were planted to lentils and the other 3 to barley, 4 lentil and 4 barley seeds were planted and later thinned to 1 each. The latter method of planting lentils and barley in different pots decreased competition between these two species that might otherwise occur if they were planted in the same pot.

Lentils are among crops susceptible to metsulfuron and were chosen to detect the existence of metsulfuron in the soil Barley (var. Steptoe) is one of the sensitive small grain varieties sensitive to sulfonylurea herbicides and is recommended for bioassay experiments using these herbicides.

The bioassay experiment was conducted in a greenhouse with a 16-hr photoperiod using a combination of natural and artificial (high pressure sodium) lights. The greenhouse was kept at $25/18^{\circ}$ C ($\pm 4^{\circ}$ C) day/night temperature. The plants were watered with 100 ppm Peters 20, 20, 20 fertilizer as needed. The pots were irrigated carefully to reduce drainage and possible washout of the herbicide from the soil. Forty-five days after planting, the plants were cut at the soil level and their height and fresh weight measured. Lentil plants were also visually evaluated for vigor reduction compared to control plants. The plants were given an index of 0 to 10; 0 for no injury (control) and 10 for complete kill.

The soil bioassay in Smithfield was conducted in the field. All plots were planted to spring oats (Avena sativa L.) the year after treatment. Plots were visually evaluated in bloom stage for percent crop injury based on plant vigor and height compared to control plants.

In a separate greenhouse study, the effect of soil applied metsulfuron to field bindweed seedlings was determined by planting 10 scarified bindweed seeds in 1/2 liter plastic pots. Immediately after planting the pots were sprayed with 8.8, 17.5, 35.0 and 70.0 g/ha metsulfuron with a laboratory precision sprayer. The pots were irrigated with 50 ml water after spraying and as needed later. After germination the seedlings were evaluated on percent germination and vigor reduction 10 and 21 days after planting.

Photosynthesis and Transpiration Measurement

Although the mode of action of many herbicides is known, few studies on the short and long term effects of herbicides on photosynthesis, respiration, and transpiration have been conducted. These measurements are necessary to determine stomatal apertures, translocation, and rapid physiological changes. To determine the effect of metsulfuron, and other herbicides used in combination with it, on photosynthesis and transpiration of field bindweed, a gas exchange system with the following description was built.

Gas exchange system. An open gas exchange system was designed and built to continuously measure photosynthesis, transpiration and dark respiration of whole plants. The plants were enclosed in six, 35-liter, plexiglass cylinders, which were placed inside a growth chamber. Air was collected six meters above the building and passed through three, 155-liter tanks to buffer and stabilize the carbon dioxide (CO_2) concentration. Flow rate into the chambers was measured with rotometers that were calibrated volumetrically. A small fan was placed inside each chamber to insure complete mixing of the internal air. The cylinders were operated at a positive pressure of 25 cm water column, which corresponds to the pressure at which the rotometers were calibrated. This positive pressure insures that no external gas can leak into the system and because this was an open system, gas leaks from the cylinders to the external environment had no effect on system accuracy.

The mole fraction of water vapor was determined with a dew point hygrometer. Mole fraction of CO_2 was determined with an infrared gas analyzer (IRGA), which was used in the differential mode. The IRGA was operated in the differential mode because it gives more precise measurement of CO_2 concentration and adjusts for gradual changes in the incoming CO_2 concentration. Six, normally closed, solenoid valves were cycled so that measurements could be made in each chamber for seven minutes every hour. The remaining 18 minutes of each hour were used to calibrate the IRGA and to determine the dew point of incoming air.

Temperature and humidity control. A thermocouple was placed inside each plexiglass cylinder to monitor air temperature. Desired air temperature inside the cylinder was obtained by changing the temperature setting of the growth chamber. Because of greenhouse effects, cylinder air temperatures were always 5-7^{o} C warmer than chamber air temperatures during the light period. Desired relative humidity was obtained by adjusting the air flow rates through cylinders.

Construction materials. Materials that did not absorb or transmit CO_2 and water vapor were used throughout the system. Tubing in the system was made of high density polypropylene (Bev-A-Line). Solenoids and manifolds were made from either stainless steel or nickel-plated aluminum. These precautions greatly enhanced system response time and accuracy. Prior to plant measurements, the system was tested without plants to insure that no changes in CO_2 concentration or dew point temperatures occurred in the chambers. This test helped to establish that all changes in CO_2 and water vapor in subsequent plant studies were only from photosynthesis and transpiration.

Plant culture. Bindweed seeds were scarified for one hour in 16 molar sulfuric acid, rinsed with tap water for 15 minutes and planted in vermiculite. One-month-old plants were then transferred to half-strength, modified Hoagland nutrient solution and grown in a greenhouse under 16-hour photoperiod at 25°C (± 4°C) temperature. Eighty-day-old plants were transferred to the plexiglass analysis cylinders in a growth chamber and grown under a 16-hour photoperiod with a photosynthetic photon flux (PPF) of 430 μmoles m^{-2} s^{-1} and 24/21°C day/night temperature. A closed-cell foam plug separated the root and shoot environments. This plug prevented root-zone gas transfer into the shoot environment.

Herbicide application. After determining the pretreatment photosynthesis and transpiration rates of each plant for six days, they were removed from the cylinders and sprayed to drip with five metsulfuron concentrations, 0.05, .21, .84, 3.36, 13.44 mmol/l (20, 80, 320, 1280, 5120 ppm). In other trials, picloram, dicamba, 2,4-D, glyphosate and MCPA at rates of 140, 560, 1,120, 840, 1,120 g/ha respectively were sprayed on field bindweed with a precision laboratory sprayer. The control plant was sprayed with tap water. All treatments contained .25% V/V WK surfactant. Plants were then placed back into the analysis cylinders, and their photosynthesis and transpiration rates were monitored until photosynthesis in treated plants had stopped.

System evaluation. Unstable ambient CO_2 concentrations made it difficult to obtain a steady measurement of photosynthesis. To minimize this problem some modifications were made to the system. The air intake was raised six meters above the single-level building to minimize exhaust air into the system. Three, 155-liter tanks were connected in series after the blower to buffer and stabilize the CO_2 concentration. Buffering capacity of these tanks was dependent on the flow rates through the cylinders. An additional 4-liter buffering chamber was also added to the pre-analysis line before it went to the IRGA. This made pre- and post-chamber buffering capacities more identical. Air circulation inside the cylinder was found to be important in stabilizing CO_2 concentrations when input flow rates were low. Two miniature fans with capacities of 1,000 and 500 L/min were tested. The larger fan caused excessive shaking of leaves, while the latter resulted in gentle leaf flutter and more desirable air circulation.

Absorption and Translocation

Field bindweed seeds were collected at North Logan in 1985. The seeds were scarified in concentrated sulfuric acid for 1 hour and water rinsed for 15 minutes. The seeds were planted in vermiculite under greenhouse conditions with $25/18^{\circ}$ C ($\pm$ 4) day/night temperature and 16 h photoperiod received from natural and artificial (high pressure sodium) lights. Seedlings were irrigated with 1/2 strength modified Hoagland solution.

Three-week-old seedling bindweed were transplanted to one liter nutrient solution bottles containing 1/2 strength modified Hoagland solution. MES buffer (2 (N-Morpholino) ethanesulfonic acid) pH 5.7, to final concentration of 1 mmolar was added to the nutrient solutions to stabilize the pH (Bugbee and Salisbury, 1985). Metsulfuron labelled uniformly with ^{14}C in the phenyl ring (specific activity 8.6 μ ci/mg) was used for this study. The labelled metsulfuron was dissolved in a 1:3 acetone:water solution containing 25% V/V WK surfactant to obtain desired activity.

The plants were treated with ^{14}C labelled metsulfuron at 5 weeks age. The treatment was made with a microsyringe with ten μl of the radiolabelled metsulfuron applied in small droplets uniformly to the abaxial side of the third oldest and fully developed leaf on the longest runner. Treated plants were harvested at 6, 12, 24, 48, 96 and 192 h after treatment. The harvested plants were sectioned into 4 parts: treated leaf, foliage above treated leaf, foliage below treated leaf and roots. Treated leaves were soaked in 10 ml acetone for 30 seconds, then rinsed with an additional 4-5 ml acetone to remove all unabsorbed herbicide. Plant materials were then oven dried at 70° C for 48 hours and dry weights measured. The samples were oxidized in a Packard model 306 auto oxidizer set to deliver 5 ml Carbosorb and 10 ml Permafluor. Acetone in treated leaf wash was evaporated under the hood, and the same proportion of Carbosorb to Permafluor was added to each vial containing leaf wash. The activity of each oxidized sample was measured by a Beckman Model 8000 Scintillation Counter.

A similar study was conducted to determine if herbicides used in combination with metsulfuron would increase its absorption-translocation in field bindweed. In this experiment bindweed plants were sprayed with metsulfuron (4 g/ha), picloram (140 g/ha), dicamba (500 g/ha), 2,4-D (1,120 g/ha), glyphosate (840 g/ha) and MCPA (1,120 g/ha) and then a single leaf treatment was performed immediately after spraying with radioactive metsulfuron as described previously. Metsulfuron (4 g/ha) was also sprayed on field bindweed 1, 2, 4, 6 days before a single leaf treatment of ^{14}C metsulfuron was applied. Control plants where only the single leaf ^{14}C metsulfuron treatment was conducted were also established. Treated plants were harvested 8 days after ^{14}C metsulfuron treatment and similarly sectioned, dried, oxidized and their radioactivity determined by the scintillation counter. The experimental design was a complete randomized block design with three replications.

One plant from each treatment of the latter experiment was mounted, pressed and exposed to Kodak 35 by 43 cm XAR-5 film for 4 weeks for autoradiographs. The audioradiographs were developed in accordance with film instructions.

RESULTS AND DISCUSSION

Field Experiment

Three study sites were used in the field study. Smithfield, Hyrum and Sherwood Hills, all in Cache County, appear representative of the great diversity of field bindweed infestations in northern Utah. The Smithfield experiment will be discussed first since all treatment levels and bindweed growth stages were included in this study. The results from the other two locations will be discussed in depth when the results deviate noticeably from those recorded at Smithfield.

Smithfield. Preemergence treatments in Smithfield applied the first year, did not control field bindweed during the first and the third year of evaluation following herbicide treatment. However, in the second year, metsulfuron treated plots showed some effects on field bindweed (Fig. 1). Injury was expressed by leaf chlorosis and sometimes necrosis or death. The injury was generally greater as metsulfuron rates increased (Table 1). One explanation for field bindweed injury in the second and not the first and third years may be due to a failure to move sufficient quantities of the compound during the winter of the first year to the field bindweed root zone. It was taken into the soil eventually and picked up by plants in the second year. In the third year, however, no such injury occurred, probably because of the herbicide breakdown in the soil.

Spraying field bindweed in the prebloom stage damaged the weed to a greater extent than treating the weed before it emerged (Table 2). A trend was observed for increase of the activity of all herbicide tank mixes when combined with metsulfuron especially in the second and third year of evaluation. Picloram alone did not seem to be very active

Table 1. Percent field bindweed control by visual evaluation following preemergence herbicide treatment and evaluated annually for three years; Smithfield.

Treatment	Rate g/ha	1st year	2nd year	3rd year
Picloram	140	0	7.5	0
Picloram + metsulfuron	140 23	0	11.2	0
Picloram + metsulfuron	140 47	0	28.1	0
Picloram + metsulfuron	140 70	0	26.2	0
Dicamba	560	0	0	0
Dicamba + metsulfuron	560 23	0	13.7	0
Dicamba + metsulfuron	560 47	0	26.2	0
Dicamba + metsulfuron	560 70	0	22.5	0
2,4-D ester	1,120	0	0	0
2,4-D ester + metsulfuron	1,120 23	0	5.0	0
2,4-D ester + metsulfuron	1,120 47	0	21.2	0
2,4-D ester + metsulfuron	1,120 70	0	27.5	0
Glyphosate	840	0	0	0
Glyphosate + metsulfuron	840 23	0	3.7	0
Glyphosate + metsulfuron	840 47	0	20.0	0
Glyphosate + metsulfuron	840 70	0	36.2	0
MCPA	1,120	0	0	0
MCPA + metsulfuron	1,120 23	0	7.5	0
MCPA + metsulfuron	1,120 47	0	27.5	0
MCPA + metsulfuron	1,120 70	0	28.7	0
Metsulfuron	23	0	17.5	0
Metsulfuron	47	0	23.7	0
Metsulfuron	70	0	36.2	0
Control	--	0	0	0
LSD (.05)		--	20.0	--

Table 2. Percent field bindweed control based on visual evaluation following herbicide treatments to field bindweed in prebloom stage, and evaluated annually for three years; Smithfield.

Treatment	Rate g/ha	1st year	2nd year	3rd year
Picloram	140	66.7	73.2	15.0
Picloram + metsulfuron	140 23	89.0	67.5	22.5
Picloram + metsulfuron	140 47	92.0	93.5	45.0
Picloram + metsulfuron	140 70	93.7	95.0	40.0
Dicamba	560	90.7	82.0	40.0
Dicamba + metsulfuron	560 23	93.0	92.0	32.5
Dicamba + metsulfuron	560 47	96.2	94.5	41.2
Dicamba + metsulfuron	560 70	94.7	93.5	37.5
2,4-D ester	1,120	93.0	89.0	40.0
2,4-D ester + metsulfuron	1,120 23	94.0	89.5	45.0
2,4-D ester + metsulfuron	1,120 47	95.0	90.7	40.0
2,4-D ester + metsulfuron	1,120 70	92.0	90.5	47.5
Glyphosate	840	49.5	85.2	20.0
Glyphosate + metsulfuron	840 23	90.0	83.2	33.7
Glyphosate + metsulfuron	840 47	95.0	92.5	38.7
Glyphosate + metsulfuron	840 70	97.2	97.7	56.2
MCPA	1,120	95.0	86.7	33.7
MCPA + metsulfuron	1,120 23	93.0	91.0	36.2
MCPA + metsulfuron	1,120 47	95.5	95.5	50.0
MCPA + metsulfuron	1,120 70	97.5	96.2	55.0
Metsulfuron	23	89.0	80.5	31.2
Metsulfuron	47	91.2	89.5	36.2
Metsulfuron	70	95.0	90.2	35.0
Control	--	0	0	0
LSD (.05)		7.5	20.0	15.5

against field bindweed, but like others, when combined with metsulfuron, it gave a good field bindweed control during the first and second evaluation. Glyphosate alone did not result in a high level of control in the first evaluation. Glyphosate activity was slow to appear and probably wasn't expressed by the first year evaluation date but became evident by the second year. Visual evaluations three years after herbicide treatments revealed that percent field bindweed control dropped by 50 percent or more as compared to those taken the second year. Metsulfuron tank mixing increased the effects of picloram, glyphosate and MCPA against field bindweed. Tank mixing metsulfuron with other herbicides generally resulted in a better field bindweed control than metsulfuron treatments alone. None of the herbicide tank mixes appeared superior to the others in prebloom stage.

Overall, the bloom stage treatments (Table 3) provided much less field bindweed control than prebloom and fall treatment (Fig. 1, 2). Metsulfuron increased the effects of other herbicides in tank mixes except 2,4-D. Picloram at the rate used in this experiment, resulted in poor bindweed control when applied at bloom stage as was also recorded in prebloom application. Likewise, glyphosate did not control field bindweed during the first year, but the second year it resulted in satisfactory control, particularly when tank mixed with metsulfuron. As described earlier, poor bindweed control in glyphosate treated plots may have been due to slow action of glyphosate and too early an evaluation. 2,4-D and MCPA gave good control in the first year. In the second year, MCPA, tank mixed with metsulfuron, gave significantly higher control than 2,4-D. Metsulfuron alone did not adequately control field bindweed when applied in the bloom stage. In the second year, the level of bindweed

Table 3. Percent bindweed control based on visual evaluation following herbicide treatments to field bindweed in bloom stage and evaluated annually for three years; Smithfield.

Treatment	Rate g/ha	1st year	2nd year	3rd year
Picloram	140	30.0	13.5	0
Picloram + metsulfuron	140 23	36.2	13.7	0
Picloram + metsulfuron	140 47	46.0	28.7	2.5
Picloram + metsulfuron	140 70	51.2	36.7	3.7
Dicamba	560	67.5	6.2	2.5
Dicamba + metsulfuron	560 23	75.0	41.7	7.5
Dicamba + metsulfuron	560 47	78.7	40.0	7.5
Dicamba + metsulfuron	560 70	81.2	40.0	5.0
2,4-D ester	1,120	80.0	59.2	0
2,4-D ester + metsulfuron	1,120 23	82.5	58.0	2.5
2,4-D ester + metsulfuron	1,120 47	83.7	55.0	0
2,4-D ester + metsulfuron	1,120 70	86.2	61.2	7.5
Glyphosate	840	25.0	51.5	7.5
Glyphosate + metsulfuron	840 23	43.7	91.0	15.0
Glyphosate + metsulfuron	840 47	61.2	91.7	16.2
Glyphosate + metsulfuron	840 70	67.5	94.7	30.0
MCPA	1,120	72.5	49.2	0
MCPA + metsulfuron	1,120 23	82.5	93.2	0
MCPA + metsulfuron	1,120 47	86.2	88.0	10.0
MCPA + metsulfuron	1,120 70	87.5	92.7	33.7
Metsulfuron	23	45.0	21.2	0
Metsulfuron	47	48.7	25.0	2.5
Metsulfuron	70	50.0	38.0	25.0
Control	--	0	0	0
LSD (.05)		7.5	20.0	15.5

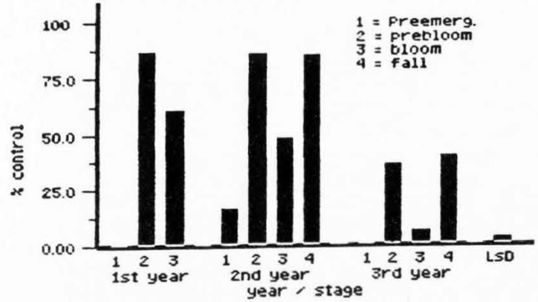

Figure 1. Percent field bindweed control based on visual evaluation as influenced by stage of treatment and evaluation year when combined over all herbicide treatments; Smithfield.

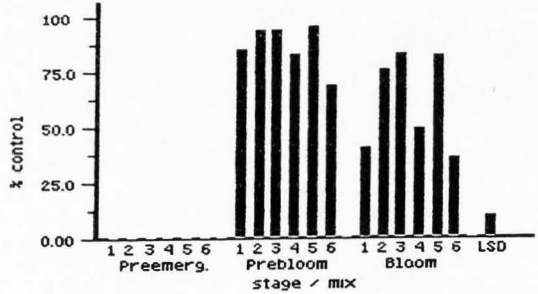

Figure 2. Percent field bindweed control as influenced by herbicide tank mixes and stage of treatment when combined over metsulfuron rate and evaluation year; Smithfield. (1 = picloram, 2 = dicamba, 3 = 2,4-D ester, 4 = glyphosate, 5 = MCPA, 6 = metsulfuron alone, no tank mixes).

control dropped for picloram, dicamba, 2,4-D and metsulfuron treatments. Bindweed control was much better in the second year using MCPA or glyphosate treatments combined with metsulfuron. The level of bindweed control in the third year was uniformly poor for all herbicide treatments applied in bloom stage.

The results of bindweed control when herbicide treatments were applied in the fall is summarized in Table 4. An early frost following fall treatments prevented evaluating them the first year. During spring of the second year, field bindweed control was generally satisfactory. Like in other treatment stages, metsulfuron increased the activity of other herbicides when used in tank mixes. This was especially significant in the third year evaluation. The level of field bindweed control was significantly increased when the metsulfuron rate was increased. Metsulfuron at 70 g/ha resulted in 94.5 percent field bindweed control in the second year. Metsulfuron at 70 g/ha when tank mixed with other herbicides resulted in excellent (94-99 percent) field bindweed control. Evaluations the spring of the third year showed a drop in control from the second year in all treatments. Field bindweed control in the third year following fall treatments, however, was significantly better than field bindweed control in the third year following bloom treatments. Glyphosate, tank mixed with metsulfuron at 70 g/ha, gave better control (78.7 percent) than other treatments.

When field bindweed control levels were combined over all treatments and growth stages, no significant difference existed between the first and second year. The level of bindweed control was significantly lower the third year (Fig. 3). The year/stage interaction shown in Figure 1 shows that when combined over treatments, prebloom treatments in the

Table 4. Percent field bindweed control based on visual evaluations following herbicide treatments in the fall and evaluated annually for three years; Smithfield.

Treatment	Rate g/ha	1st year	2nd year	3rd year
Picloram	140	--	52.5	0
Picloram + metsulfuron	140 23	--	64.2	21.2
Picloram + metsulfuron	140 47	--	93.0	32.5
Picloram + metsulfuron	140 70	--	94.0	45.0
Dicamba	560	--	86.2	40.0
Dicamba + metsulfuron	560 23	--	97.0	40.0
Dicamba + metsulfuron	560 47	--	98.5	73.7
Dicamba + metsulfuron	560 70	--	95.2	61.0
2,4-D ester	1,120	--	91.7	27.5
2,4-D ester + metsulfuron	1,120 23	--	95.2	40.0
2,4-D ester + metsulfuron	1,120 47	--	96.0	57.7
2,4-D ester + metsulfuron	1,120 70	--	97.5	63.7
Glyphosate	840	--	94.2	52.5
Glyphosate + metsulfuron	840 23	--	96.2	46.2
Glyphosate + metsulfuron	840 47	--	97.0	67.5
Glyphosate + metsulfuron	840 70	--	99.2	78.7
MCPA	1,120	--	77.7	17.5
MCPA + metsulfuron	1,120 23	--	89.7	27.5
MCPA + metsulfuron	1,120 47	--	93.7	51.2
MCPA + metsulfuron	1,120 70	--	95.5	53.7
Metsulfuron	23	--	55.0	2.5
Metsulfuron	47	--	84.5	21.2
Metsulfuron	70	--	94.5	40.0
Control	--	--	0	0
LSD (.05)		--	20.0	15.5

second year produced the same level of control as the first year, but bloom treatments resulted in lower levels of field bindweed control compared to the same stage from treatments the first year. The level of bindweed control dropped significantly the third year from treatments in all stages, but the decrease was greater at the bloom stage applications. Treatments at bloom stage in all three years resulted in lower control than prebloom and fall treatments. Preemergence treatments did not control field bindweed during the first and third years, but the weed was slightly injured the second year (<20 percent). No significant difference between prebloom and fall applied treatments appeared when field bindweed control results were combined over all treatments.

Control levels averaged for all herbicide tank mixes and treatment stages (Fig. 4) revealed no differences between metsulfuron rates the first year, but increasing dosages of metsulfuron increased bindweed control the second and third years. It was also evident that the level of bindweed control in each dosage dropped with time (years). In all three years, tank mixing metsulfuron increased the level of activity of other herbicides when compared to each herbicide alone.

When results were combined for all metsulfuron rates and treatment stages (Fig 5) a decline of the level of bindweed control occurred with time (years) in all herbicides. Glyphosate tended to show more lasting control than other herbicides. Other herbicides, when tank mixed with metsulfuron, gave better bindweed control than metsulfuron alone.

When results were combined for all metsulfuron rates and years of evaluation, (Table 5) all herbicides when applied at bloom stage gave much less bindweed control than when applied in prebloom or fall.

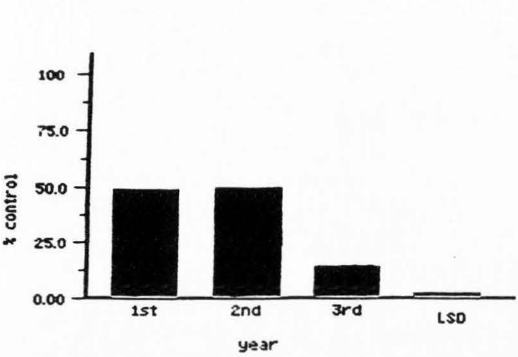

Figure 3. Percent bindweed control evaluated annually for three years following herbicide treatments. Results are average of all treatments and grwoth stages; Smithfield.

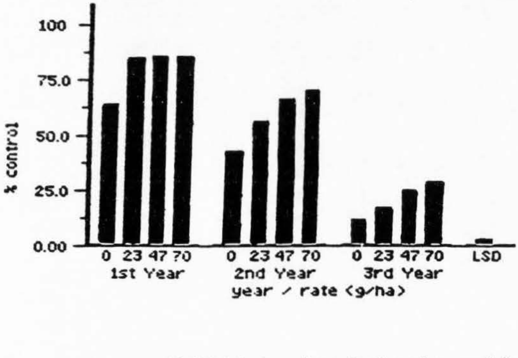

Figure 4. Percent field bindweed control using combined data for all treatments with metsulfuron; Smithfield.

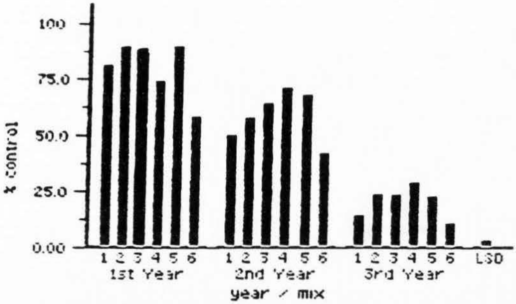

Figure 5. Percent field bindweed control as influenced by herbicide tank mixes evaluated annually for three years. Results are averaged for all metsulfuron rates and treatment stages. (1 = picloram, 2 = dicamba, 3 = 2,4-D, 4 = glyphosate, 5 = MCPA, 6 = metsulfuron alone); Smithfield.

Table 5. Percent field bindweed control, average of three years, as affected by stage of treatments and herbicide tank mixes; Smithfield.

Herbicide tank mixes	Picloram	Dicamba	2,4-D	Glyphosate	MCPA	Metsulfuron alone
Stage						
Preemergence	6.1	5.2	4.5	5.0	5.3	6.5
Prebloom	66.1	73.1	75.5	70.2	76.9	55.0
Bloom	21.9	37.7	48.2	49.6	55.5	19.4
Fall	50.0	74.0	71.2	79.0	63.5	37.2

LSD (.05) = 10.4

When results were combined for all stages of treatments and years of evaluation (Table 6) metsulfuron increased the activity of all other herbicides. Increasing the rate of metsulfuron, when tank mixed with other herbicides, generally increased the level of bindweed control. Metsulfuron increased the activity of glyphosate more than any other herbicide.

When results were combined for all herbicide tank mixes and years of evaluation (Table 7) it was shown that each metsulfuron rate increase resulted in an increase in the level of bindweed control in all treatment stages. It was also evident from Table 7 that treating plants in bloom gives less control than treating them in prebloom or in the fall at all rates. The reason for this may be explained by the fact that at bloom stage, blossom and developing seeds act more as metabolite sinks, and since herbicides move in phloem with the photosynthates, they accumulate in the foliage of the bindweed plants, and thus do not cause adequate underground root and rhizome destruction of field bindweed which is necessary for long lasting control. The prebloom and fall treatments cause higher amounts of photosynthates partitioned in the underground portion of the plant, a higher amount of the herbicides were translocated to the roots and rhizomes and resulted in better and longer lasting control.

<u>Sherwood Hills</u>. The results of field bindweed control experiments in the Sherwood Hills location were very similar to those at Smithfield. Preemergence treatments did not control field bindweed in any year (Fig. 6). Prebloom treatments gave better control than bloom treatments during the first and second years, but no difference was observed between them in the third year (Fig. 7). Although field bindweed control at Sherwood

Table 6. Percent bindweed control, average of three years, as affected by metsulfuron rates and herbicide tank mixes; Smithfield.

Herbicide tank mixes	Picloram 140 g/ha	Dicamba 560 g/ha	2,4-D 1120 g/ha	Glyphosate 840 g/ha	MCPA 1120 g/ha	Control
Metsulfuron rate g/ha						
0	22.9	30.9	40.2	26.8	37.2	0
23	26.7	39.5	41.8	40.1	41.6	31.6
47	37.4	42.7	42.9	46.1	50.4	35.2
70	38.5	41.6	45.8	53.3	54.6	38.5

LSD (.05) = 5.2

Table 7. Percent field bindweed control, average of three years, as affected by stage of treatments and metsulfuron rates; Smithfield.

Stage	metsulfuron rate g/ha			
	0	23	47	70
Preemergence	.4	3.2	8.2	9.8
Prebloom	53.9	69.7	76.2	78.0
Bloom	25.8	37.7	42.9	48.3
Fall	45.0	56.4	72.2	76.6

LSD (.05) = 10.5

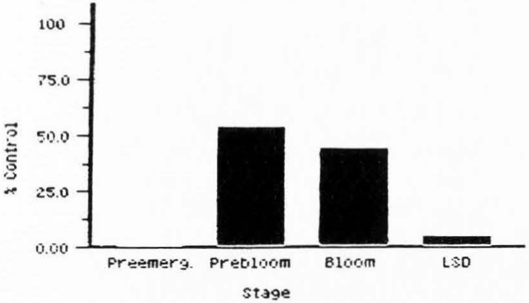

Figure 6. Percent field bindweed control as influenced by stage of treatment when combined for all treatments and evaluation years; Sherwood Hills.

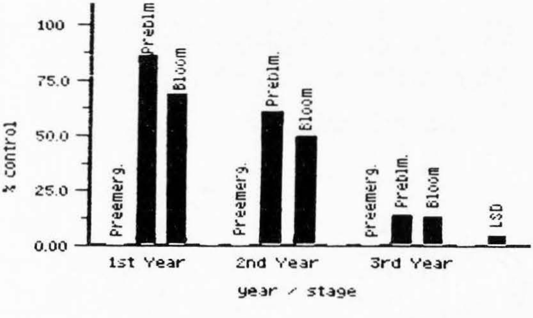

Figure 7. Percent field bindweed control as influenced by stages of treatment and evaluation year when combined for all herbicide treatments; Sherwood Hills.

Hills was as good as at Smithfield the first year, in the second and third years, less bindweed control was observed in Sherwood Hills. This may have been because of lower soil pH in Sherwood Hills which would result in a faster hydrolysis of metsulfuron in the soil.

Field bindweed control was better when metsulfuron was tank mixed with other herbicides (Fig. 8). Increasing rates of metsulfuron improved bindweed control in both bloom and prebloom treatments (Fig. 9). The level of field bindweed control dropped significantly with time (Fig. 10). Similar to Smithfield, field bindweed control at Sherwood Hills was better in all three years when metsulfuron was tank mixed with other herbicides. Increasing the rate of metsulfuron increased its activity on field bindweed, especially in the second and third year (Fig. 11).

Field bindweed control was improved when 2,4-D was used in the bloom stage. All other herbicides performed better in prebloom than in bloom treatments (Fig. 12). This was especially true for picloram and metsulfuron. These two herbicides showed less bindweed control over the three year study (Fig. 13). The results indicated that other herbicides tank mixed with metsulfuron gave better control than metsulfuron alone. When results were combined for all metsulfuron rates and treatment stages, it is evident that the level of field bindweed control drops with time (year) for every herbicide. Among the herbicides used, 2,4-D and glyphosate gave better and longer lasting results (Fig. 14).

When results were combined for all evaluation years and three treatment stages, as shown in Table 8, tank mixing metsulfuron increased the activity of each herbicide compared to its use alone. Increasing the rate of metsulfuron generally increased the activity on field bindweed both when used alone or in a tank mix with other herbicides.

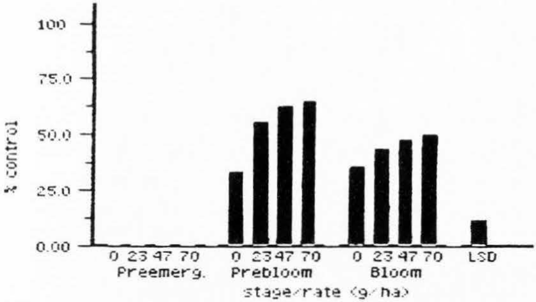

Figure 8. Percent field bindweed control as influenced by metsulfuron rate and treatment stages when combined for all herbicide tank mixes and evaluation years; Sherwood Hills.

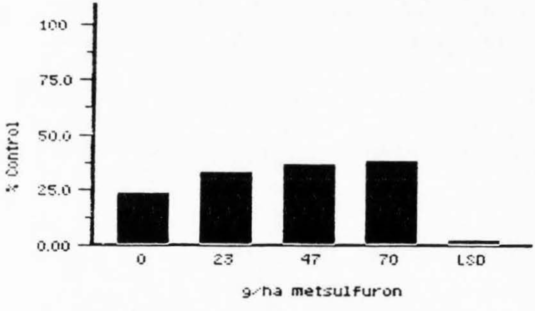

Figure 9. Percent field bindweed control as influenced by metsulfuron rates when combined for all herbicides, tank mixes, treatment stages and evaluation years; Sherwood Hills.

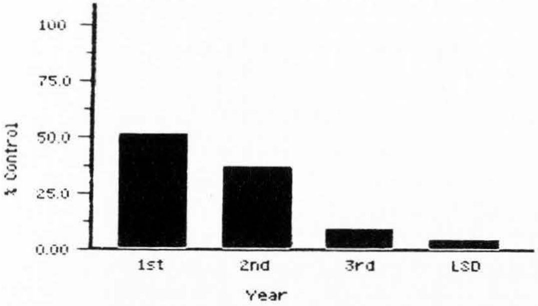

Figure 10. Percent field bindweed control evaluated annually for three years following treatments. Results are the average of all treatments and growth stages; Sherwood Hills.

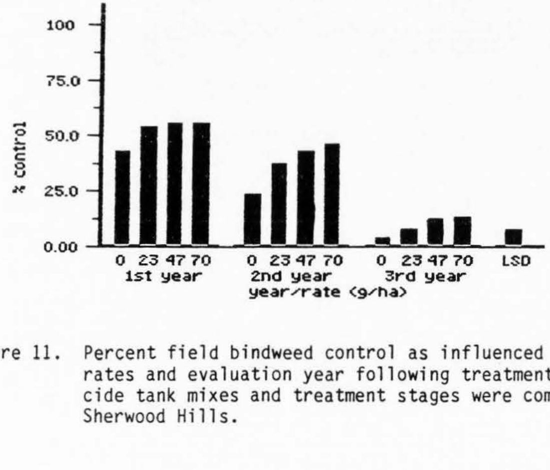

Figure 11. Percent field bindweed control as influenced by metsulfuron rates and evaluation year following treatments when herbicide tank mixes and treatment stages were combined; Sherwood Hills.

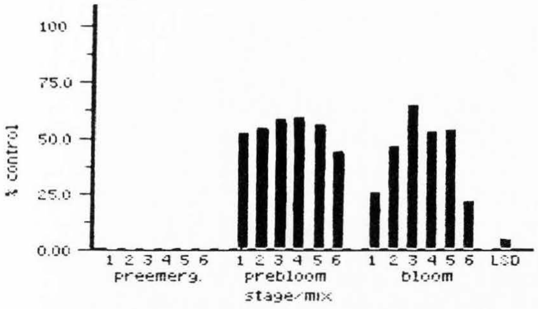

Figure 12. Percent field bindweed control as influenced by stage of treatment and herbicide tank mixes when combined for all metsulfuron rate and evaluation year (1 = piclroam, 2 = dicamba, 3 = 2,4-D, 4 = glyphosate, 5 = MCPA, 6 = metsulfuron alone); Sherwood Hills.

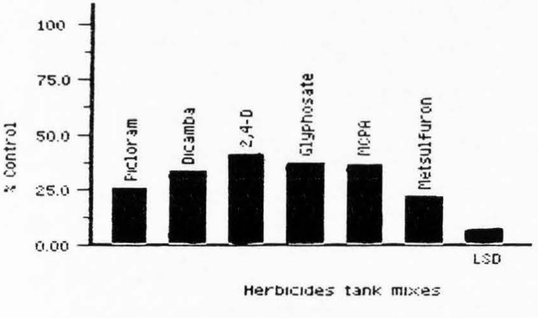

Figure 13. Percent field bindweed control as influenced by different herbicide tank mixes at different stages of treatment with combined metsulfuron rates and evaluation years; Sherwood Hills.

Table 8. **Field bindweed control, average of three years, as a result of a combination of four rates of metsulfuron with five herbicides; Sherwood Hills.**

Herbicide tank mixes	Picloram 140 g/ha	Dicamba 560 g/ha	2,4-D 1,120 g/ha	Glyphosate 840 g/ha	MCPA 1,120 g/ha	Control
Metsulfuron rate g/ha						
0	17.2	24.5	37.0	31.4	28.6	0
23	25.7	33.8	41.1	31.1	34.9	25.9
47	30.1	37.9	43.3	39.3	40.2	30.1
70	30.4	39.2	43.3	42.2	43.1	31.1

LSD (.05) = 4.9

Hyrum. Results of the field study conducted at Hyrum, and evaluated only for two years, showed that field bindweed control was significantly lower in the second year compared to the year of treatment (Fig. 15). Similar to the other two locations, bloom applications of herbicides resulted in less field bindweed control than prebloom or fall treatment. This was true both in the first and second year. Prebloom and fall treatments gave close to the same results. (Fig. 16).

In both the first and second year, higher rates of metsulfuron gave more effective bindweed control. Metsulfuron when tank mixed with other herbicides, gave better control than when any of the herbicides were used alone (Fig. 17). Tank mixing metsulfuron with other herbicides also gave better control than when metsulfuron was used alone (Fig. 18). Among tank mixes, 2,4-D and MCPA gave the best results in the first year, but the level of control dropped significantly in the second year. Glyphosate when used in combination with metsulfuron, gave the best results in the second year.

When the results were combined for all treatment stages and years (Table 9), metsulfuron when tank mixed with the other five herbicides increased their activity on field bindweed compared to their use alone. Increasing the rate of metsulfuron in all herbicide tank mixes increased the level of control. Metsulfuron at 70 g/ha when tank mixed with glyphosate, more than doubled the control of field bindweed. MCPA and 2,4-D in tank mixes with metsulfuron at 70 g/ha resulted in satisfactory control.

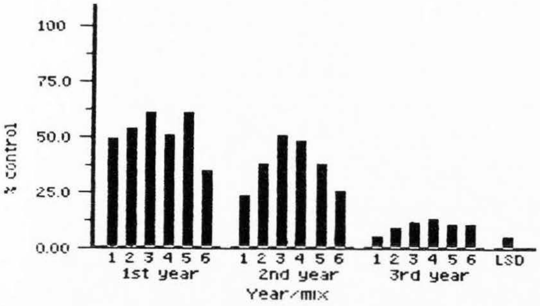

Figure 14. Percent field bindweed control as influenced by herbicide tank mixes and year of evolution with combined metsulfuron rates and treatment stages (1 = piclroam, 2 = dicamba, 3 = 2,4-D, 4 = glyphosate, 5 = MCPA, 6 = metsulfuron alone); Sherwood Hills.

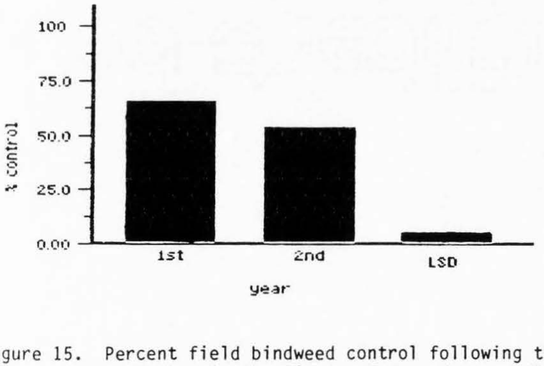

Figure 15. Percent field bindweed control following treatments evaluated in the first and second year. Results are the average of all treatments and growth stages; Sherwood Hills.

Table 9. Field bindweed control, average of three stages and two years, as a result of four rates of metsulfuron combined with 5 herbicides; Hyrum.

Herbicide tank mixes	Picloram 140 g/ha	Dicamba 560 g/ha	2,4-D 1120 g/ha	Glyphosate 840 g/ha	MCPA 1120 g/ha	Control
Metsulfuron rate g/ha						
0	36.2	54.5	69.7	33.5	57.7	0
23	42.7	66.9	79.4	58.5	69.9	37.3
47	56.2	67.6	76.0	70.1	77.1	41.1
70	65.1	73.6	85.0	76.0	81.7	55.8

LSD (.05) = 6.7

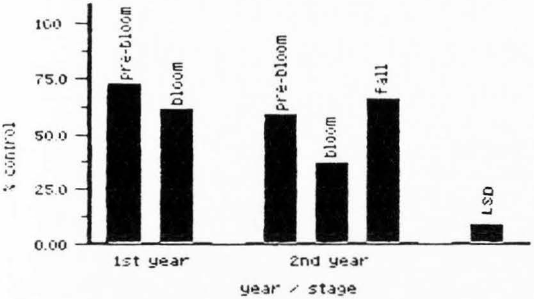

Figure 16. Percent field bindweed control at different stages of treatment in the first and second year. Results are average of all herbicide treatments; Hyrum.

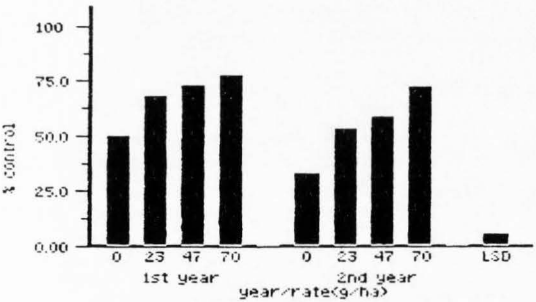

Figure 17. Percent field bindweed control as influenced by metsulfuron rate in the first and second year with combined treatment stages and herbicide mixtures; Hyrum.

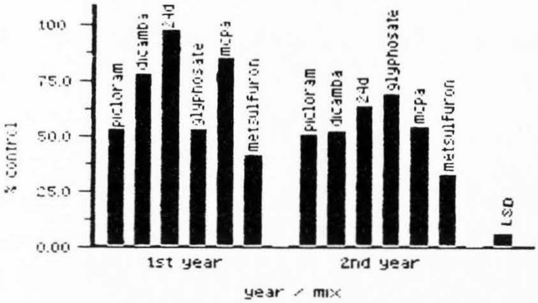

Figure 18. Percent field bindweed control as influenced by herbicide tank mixes in the first and second year with combined metsulfuron rates and treatment stages; Hyrum.

Seed Viability

Seed harvested from experimental plots at Sherwood Hills indicated that metsulfuron treatments significantly decreased seed and capsule weight of field bindweed (Fig. 19, 20). No statistical significance was observed between weights based on metsulfuron dosages. Most seeds from treated plots appeared to contain a seed coat only and could easily be shattered with slight pressure. No differences were observed between treatments in the number of bindweed seeds per capsule (Table 10). Percentage of shrunken seeds was significatnly higher in treated plots than in controls. Germination varied from 4.5 percent in the highest rate to 8.5 percent in the lowest rate compared to 70.5 percent in the control (Fig. 21). Seeds from treated plots with the higher percentage of shrunken seeds germinated less than the seeds from control plots. However, many apparantly normal looking seeds from treated plots did not germinate. Five days after germination, seedlings from seeds recovered in treated plots were significantly less vigorous than the controls. This was indicated by average radicle length of 8, 4 and 2.8 mm in 23, 47 and 70 g/ha metsulfuron treatments respecitvely, and 25 mm for the control (Fig. 22).

Capsule weight was closely correlated with seed weight with a correlation coefficient of 0.919 (Table 11). There was also a close negative correlation between seed weight and percent shrunken seed indicating that reduced seed weight was a function of shrunken seeds. Seed weight was closely and positively correlated with radicle length which may mean that it was the lack of seed food reserves that caused less vigorous seedlings. Radicle length was very closely (0.944) correlated with germination, indicating that the seeds with higher

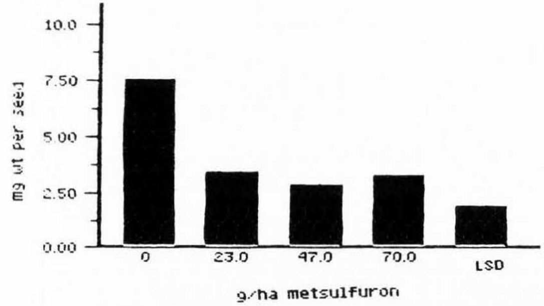

Figure 19. Effect of metsulfuron applied at full bloom on field bindweed seed weight; Sherwood Hills.

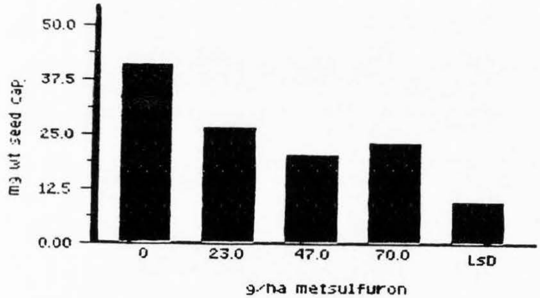

Figure 20. Effect of metsulfuron applied at full bloom on field bindweed seed capsule weight; Sherwood Hills.

Table 10. **Effect of bloom application of metsulfuron on seed set, seed size, seed viability and seedling vigor of field bindweed; Sherwood hills.**

Metsulfuron rate g/ha	Wt. of capsule with seed mg	Wt./seed mg	Ave. # of seed/capsule	Shrunken seed % of Total	Radicle length cm	Germination %	Germination % of control
0	41.10	7.55	3.17	7.60	2.52	70.50	100.00
23.0	26.40	3.47	2.97	28.28	.82	7.00	11.50
47.0	20.42	2.90	2.90	40.47	.40	5.00	7.50
70.0	23.20	3.30	3.27	31.80	.27	4.50	6.25
LSD	9.60	1.96	--	--	.02	8.01	11.93

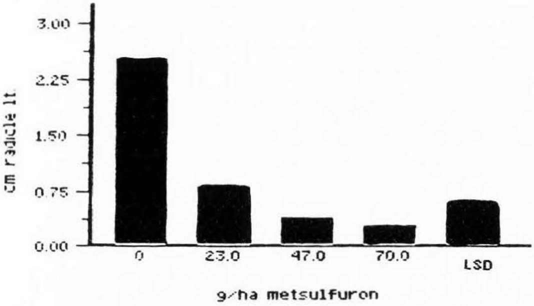

Figure 21. Effect of metsulfuron applied at full bloom on germination of field bindweed seed; Sherwood Hills.

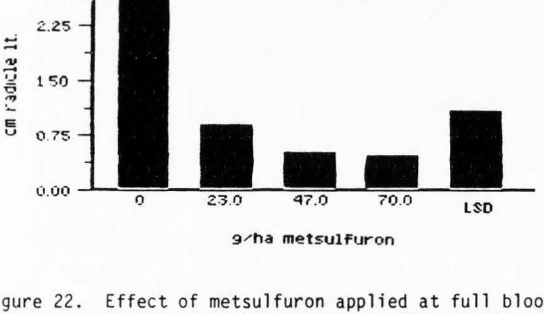

Figure 22. Effect of metsulfuron applied at full bloom on radicle length of field bindweed seedlings, five days after germination; Sherwood Hills.

Table 11. Correlation coefficients table among different parameters measured in bindweed seed viability study; Sherwood Hills.

	Wt/seed capsule	Wt/seed	Number of seed/capsule	Percent shrunken	Radicle length
Wt/seed	0.919				
Number of seed/capsule	0.184	0.149			
Percent shrunken	-0.778	-0.713	0.369		
Radicle length	0.802	0.782	0.015	-0.532	
Germination percent of control	0.825	0.862	0.071	-0.608	0.944

germination were also able to grow vigorously and develop greater radicle lengths.

Because of a severe drought during the summer of 1985 when Hyrum field plots were established, few bindweed palnts blossomed and their bloom period was very short. Herbicides applied during the bloom stage were actually applied at late bloom or early seed stage. Results from Hyrum seed samples indicated that both germination and radicle length decreased significantly with metsulfuron treatments vs. control but there were no significant differences among metsufluron rates (Fig. 23, 24). While a greater number of shrunken seeds was observed in metsulfuron treated plots than in the control (Table 12), it was not statistically significant. The number of shrunken seeds in the control plots were a lot higher than the corresponding treatment in Sherwood Hills. Differences may be due to the drought stressed plants in Hyrum (Table 12). No significant differences were observed in number of seed per capsule among treatments. Field bindweed seed and capsule weights were higher in the controls than in metsulfuron treated plots but, unlike Sherwood Hills, this difference was not significant.

Because of drought interference, the correlation coefficients do not all agree with the corresponding coefficients in the Sherwood Hills study. Bindweed seedling's radicle length showed a close positive correlation with germination (Table 13). Also, percent shrunken seeds was negatively correlated with seed weight indicating the higher the shrunken seed count, the lower the seed weight. Weight of bindweed seeds were also positively correlated (0.74) with weight of seed capsule. These results are similar to those obtained in the Sherwood Hills study.

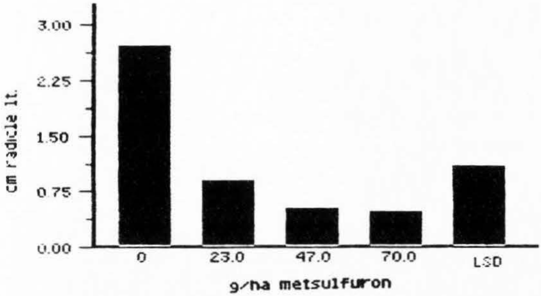

Figure 23. Effect of metsulfuron applied at full bloom on radicle length of field bindweed seedling. Five days after germination; Hyrum.

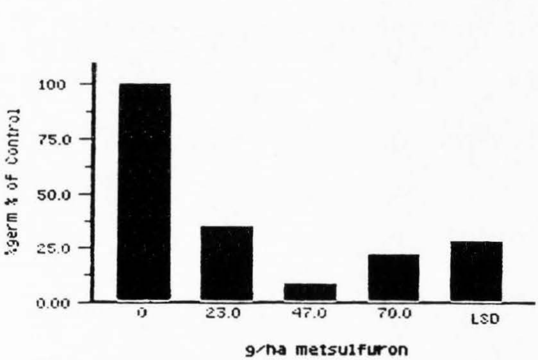

Figure 24. Effect of metsulfuron applied at full bloom on germination of field bindweed seed; Hyrum.

Table 12. Effect of bloom application of metsulfuron on seed set, seed size, seed viability, and seedling vigor of field bindweed; Hyrum.

Metsulfuron rate g/ha	Wt. of capsule with seed mg	Wt./seed mg	Ave. # of seed/capsule	Shrunken seed % of total	Radicle length cm	Percent germination	Germination % of control
0	37.17	9.97	3.17	21.00	2.72	41.00	100.00
23.0	33.37	7.52	3.15	30.25	.90	14.50	35.00
47.0	24.50	4.55	3.25	45.50	.52	3.50	8.70
70.0	30.50	4.62	3.17	35.50	.47	9.00	21.75
LSD	--	--	--	--	1.09	11.78	28.14

Table 13. Correlation coefficients table among different parameters measured in bindweed seed viability study; Hyrum.

	Wt/seed capsule	Wt/seed	# of seed/capsule	% shrunken	Radicle length
Wt/seed	0.74				
# of Seed/ capsule	0.016	-0.144			
% shrunken	-0.859	-0.754	-0.185		
Radicle length	0.449	0.586	-0.103	-0.413	
Germination % of control	0.489	0.514	-0.110	-0.465	0.936

Although detailed anatomical studies were not conducted, it is speculated that reduced seed size, weight and germination could be attributed to lack of mitotic activity of both embryo and endosperm. Since bindweed is an indeterminate flowering plant, the fertilized eggs and endosperms that had already undergone sufficient cell division before metsulfuron treatments, were able to germinate while seeds with undeveloped embryos and endosperms failed. Existence of shrunken weed without normal embryos as well as non-shrunken (normal-appearing) seed without normal embryos in metsulfuron treated plots may be attributed to the ovular developmental stage at treatment. Plants with well developed ovules but rudimentary embryos and endosperms appeared normal, but they did not develop normal embryos and viable seeds. Smaller food reserves in the endosperm of germinated seeds from emtsulfuron treated plots may have contributed to less vigorous seedlings.

Soil Bioassay

Results of soil bioassays conducted in the field at Smithfield and in the greenhouse from the soil samples brought in from Hyrum and Sherwood Hills indicated that dosages of metsulfuron used in this study caused unacceptable injury to fall planted small grains regardless of when it was applied during the fallow year.

Field bioassay results showed a linear increase in phytotoxicity to spring planted oats in response to increasing metsulfuron rates from all stages of application (Fig. 25). Significant differences existed among metsulfuron rates when combined for all treatment stages (Fig. 26). The closer metsulfuron was applied to planting time for oats, the higher the phytotoxicity. An exception was shown from the bloom stage application (Fig. 27). This is probably due to degradation of metsulfuron in the soil by microbial breakdown of the herbicide and by chemical hydrolysis. The degree of phytotoxicity in Smithfield was generally higher than that recorded at Hyrum and Sherwood Hills. Higher susceptibility of oat at Smithfield compared to barley at the other two locations may account for some of the differences noted and also field bioassays are often different from those conducted in greenhouses. Larger volumes of soil available to plant roots growing in field bioassays as compared to that available to the roots of plants in small pots in the greenhouse may explain the higher toxicity at Smithfield. Field bioassays may be more dependable for practical purposes. None of the five herbicides used in the tank mixes showed significant soil residual activity at the rates used and consequently, no phytotoxicity was attributed to them. No interactions were observed between tank mixes and dosages and tank mixes and treatment stages.

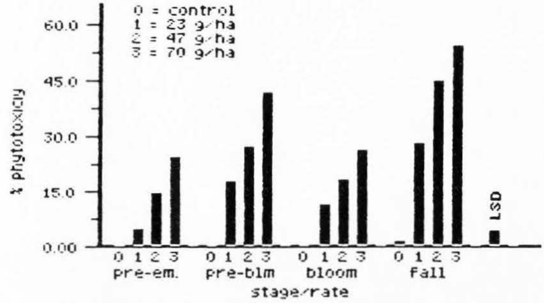

Figure 25. Percent phytotoxicity as influenced by different rates of metsulfuron applied at four growth stages of field bindweed; Smithfield.

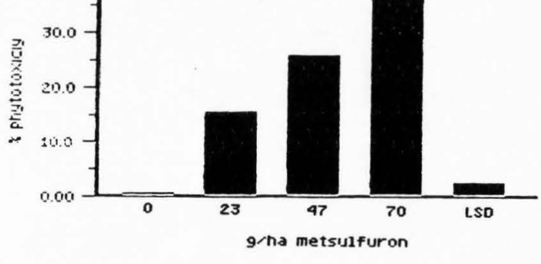

Figure 26. Percent phytoxicity as influenced by different rates of metsulfuron. Results are average of all growth stages and herbicide tank mixes; Smithfield.

The soil bioassay from Sherwood Hills involved only applications made at prebloom and bloom stages. Lentils were generally injured much more than barley. Both lentil height and weight decreased significantly with metsulfuron treatments. Lentil height and weight appeared to be affected more by higher metsulfuron dosages but not proven significantly (Fig. 28, 29). Lentil injury was greater from bloom stage treatments than from the prebloom treatments (Fig. 30). Lentil vigor was also significantly decreased with metsulfuron treatment. This was especially pronounced in the highest metsulfuron rate (Fig. 31). Barley weight decreased with increasing metsulfuron rates, but it also was not significant (Fig. 32). Barley weight was generally lower following bloom stage treatments than in prebloom (Fig. 33). Barley height, however, decreased significantly with metsulfuron treatment (Fig. 34). Correlation coefficients between the above measurements show a fair correlation (.587) between lentil weight and lentil height but the correlation between barley height and barley weight was poor (Table 14). This may mean that something other than barley height, like more tillering or higher leaf area ratio, was responsible for the greater weight of barley. The poor correlation between barley weight and height and between lentil weight and height at Hyrum may be due to the fact that two barley and two lentils were planted in the same pot and the competition between crops resulted in meaningless correlations.

In Hyrum, soil samples were taken from all three treatment stages (prebloom, bloom and fall) and only one plant (lentil or barley) was grown in each pot containing soil from a treated plot in the field. Metsulfuron treatments cause a decrease in lentil weight and height over non-treated controls. Increasing rates of metsulfuron caused further

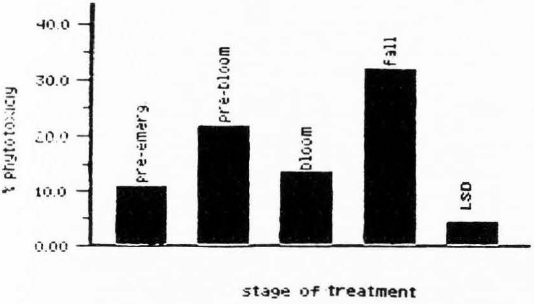

Figure 27. Percent phytotoxicity as influenced by stages of treatment using combined metsulfuron rates and herbicide combinations; Smithfield.

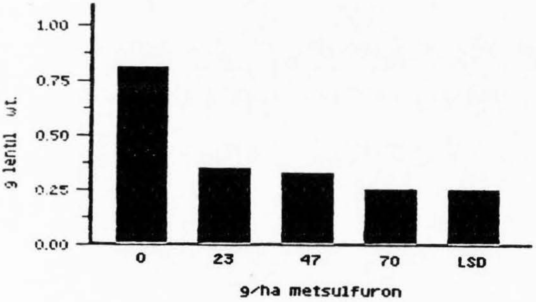

Figure 28. Lentil fresh weight in grams as influenced by different rates of metsulfuron when results were averaged over treatment stages; Sherwood Hills.

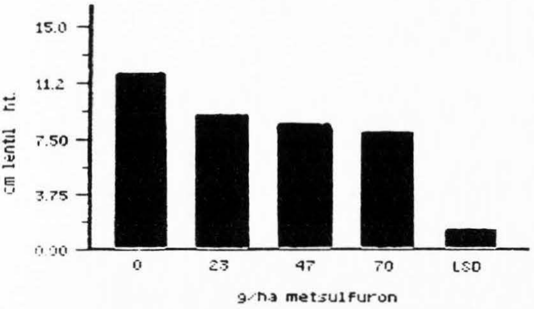

Figure 29. Lentil height in cm as influenced by different rates of metsulfuron at prebloom and bloom stage; Sherwood Hills.

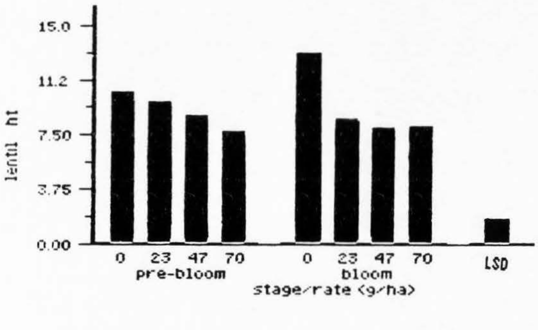

Figure 30. Lentil height in cm as influenced by different rates of metsulfuron. Results were averaged over all treatment stages; Sherwood Hills.

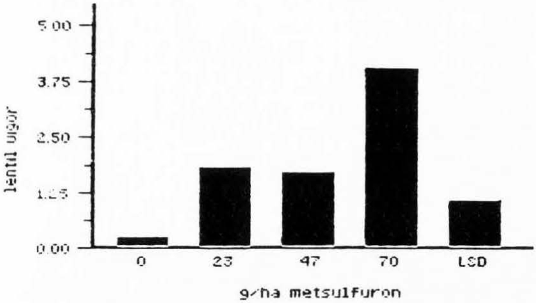

Figure 31. Effect of metsulfuron soil carry over on lentil vigor; Sherwood Hills.

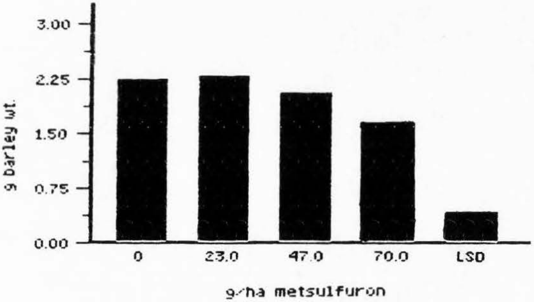

Figure 32. Barley fresh weight in grams as influenced by different rates of metsulfuron when stages are combined; Sherwood Hills.

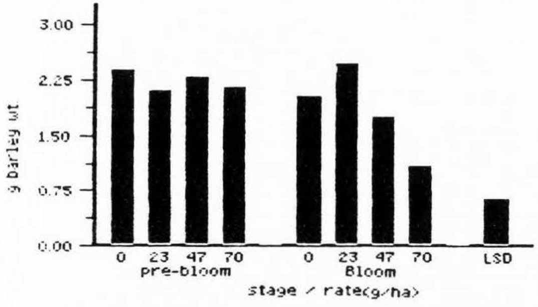

Figure 33. Fresh barley weight in grams as influenced by different rates of metsulfuron applied at prebloom and bloom stage; Sherwood Hills.

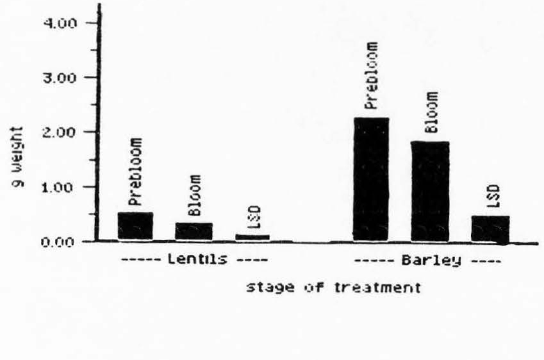

Fig. 34. Barley and lentil fresh weight in grams as affected by metsulfuron treatments in prebloom and bloom stages; Sherwood Hills.

Table 14. Correlation coefficients among parameters measured in soil bioassay; Sherwood Hills.

	Barley wt.	Lentil wt.	Barley ht.	Lentil ht.
Lentil wt.	.230			
Barley ht.	.199	.093		
Lentil ht.	.092	.587	.082	
Lentil vigor	.363	.529	.006	.399

decreases in lentil weight and height, but they were not statistically different (Figs. 35, 36). Barley height and weight decreased significantly from metsulfuron treatment, but significant differences did not exist among metsulfuron dosage levels (Fig. 37, 38). Slight injury to both barley and lentil were observed by shortening the time interval between treatments and planting but the increased injury was not measurable. Eliminating competition between crops in the pot allowed more meaningful correlations among all four parameters measured at Hyrum (Table 15). Correlation coefficients were greater than .70 indicating a good correlation between measured parameters. Correlation coefficients between barley weight and height and between lentil weight and height were .82 and .85 respectively, indicating that an increase in weight of both species was a function of their height. Factors such as more tillering and leaf area ratio did not play an important role in bioassays of soil taken from Hyrum. This is in contrast to the results obtained from soil taken from Sherwood Hills.

The results of the separate experiment to study the effects of soil applied metsulfuron on germination and seedling vigor of field bindweed indicate that metsulfuron did not affect the germination of field bindweed seeds, but the seedlings became chlorotic and died soon after emergence. This was evident by the number of live seedlings 10 and 21 days after planting (Fig. 39). The remaining live seedlings in each metsulfuron treated pots were greatly injured (Fig. 40). There were no significant differences among 17.5, 35, 70 g/ha treatments in seedling vigor reduction or the number of live seedlings per pot, but 8.8 g/ha treatment caused less injury to bindweed seedlings than higher rates. From the results of this study, one can speculate that soil applied

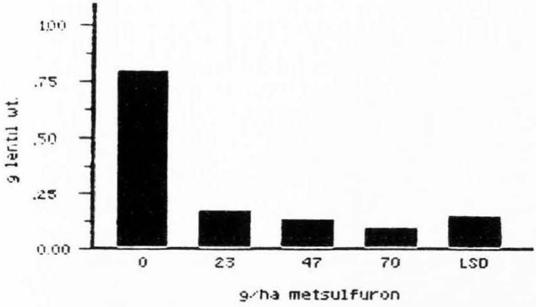

Figure 35. Lentil fresh weight in g as influenced by different rates of metsulfuron. Results were averaged over all treatment stages; Hyrum.

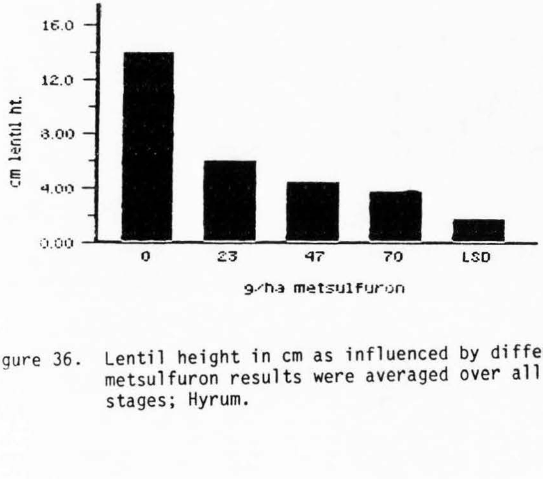

Figure 36. Lentil height in cm as influenced by different rates of metsulfuron results were averaged over all treatment stages; Hyrum.

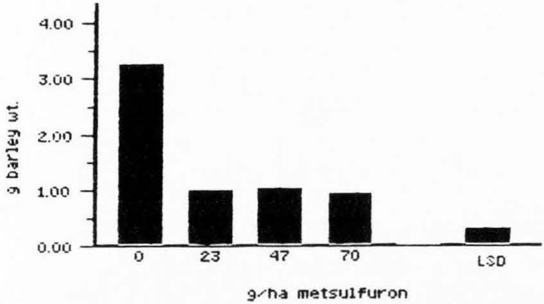

Figure 37. Barley fresh weight in grams as influenced by different rates of metsulfuron. Results were averaged over all treatment stages; Hyrum.

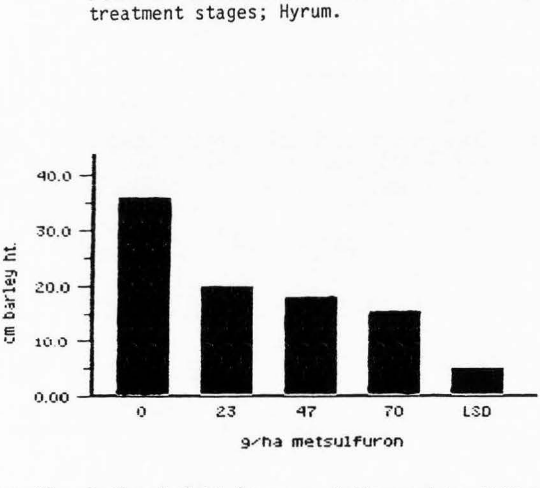

Figure 38. Barley height in cm as influenced by different rates of metsulfuron. Results were averaged over all treatment stages; Hyrum.

Table 15. Correlation coefficients among parameters measured in Hyrum soil bioassay; Hyrum.

	Barley weight	Lentil weight	Barley height
Lentil weight	0.742		
Barley height	0.821	0.696	
Lentile height	0.746	0.850	0.773

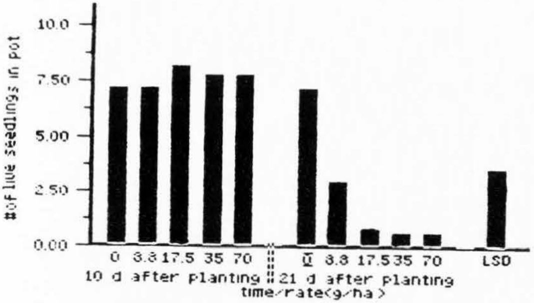

Figure 39. Effect of soil applied metsulfuron on seed germination (10 days after planting) and seedling survival (21 days after planting) of field bindweed.

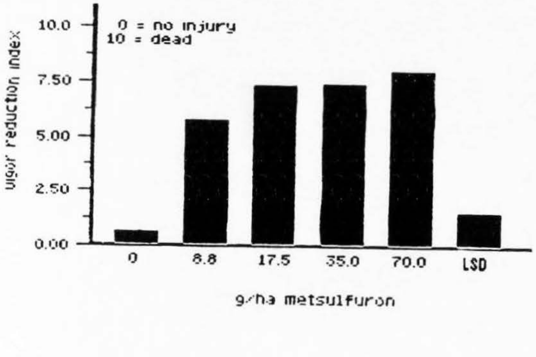

Figure 40. Effect of soil applied metsulfuron on the seedling vigor of field bindweed (21 days after planting).

metsulfuron is taken up by bindweed plants through roots. This is why emerging bindweed seedlings in treated soil looked healthy at first but after sufficient root growth, which included herbicide uptake and translocation, the seedlings lost their vigor and died.

Photosynthesis and Transpiration Measurement

Photosynthesis and transpiration rates of field bindweed showed a diurnal fluctuation (Fig. 41). They were highest during the first hours of the light period and lowest during the final hours of the light period in the apparatus used in this study (Fig. 42).

Photosynthesis of field bindweed showed a linear response to photosynthetic active radiation (PAR). They reached light compensation at about 65 μmoles m^{-2} s^{-1} PAR (Fig. 43). Transpiration also decreased proportionally with photosynthesis to decreasing radiation. Small amounts of transpiration occurred even when the plants were in the dark. This was probably due to cuticular transpiration.

Field bindweed plants growing naturally and competing with dense 1/2 to 1 meter juniper plantings were observed to grow with light intensities between 28 and 62 μm m^2 s^{-1} at the point where the stem and soil join. These intensities were recorded at noon on a sunny day and the range was attributable to variations in juniper density. Lower leaves on the bindweed stem below the junipers were mostly abscised or chlorotic. Bindweed stems near the soil surface and further from sunlight had longer internodes. The amount of light deep under the juniper canopy was below that found to be the light compensation point for bindweed plants grown in the greenhouse. Bindweed apparently can not depend on such dim light to support growth and development, and probably dropped their lower unproductive leaves once the leaves reached full sunlight above the junipers. Two possible explanations exist why bindweed is able to grow under such low light intensities. Plants may have adapted to low light environments and thus able to use the low light for growth. The other possibility is that bindweed can use food reserves in the roots to

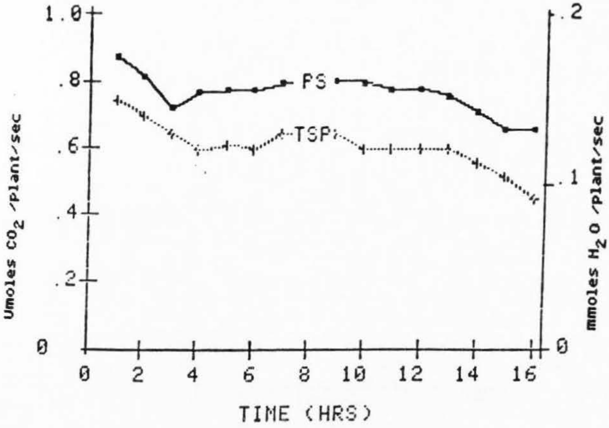

Figure 41. Typical daytime changes in photosynthesis and transpiration of field bindweed grown in hydroponic culture.

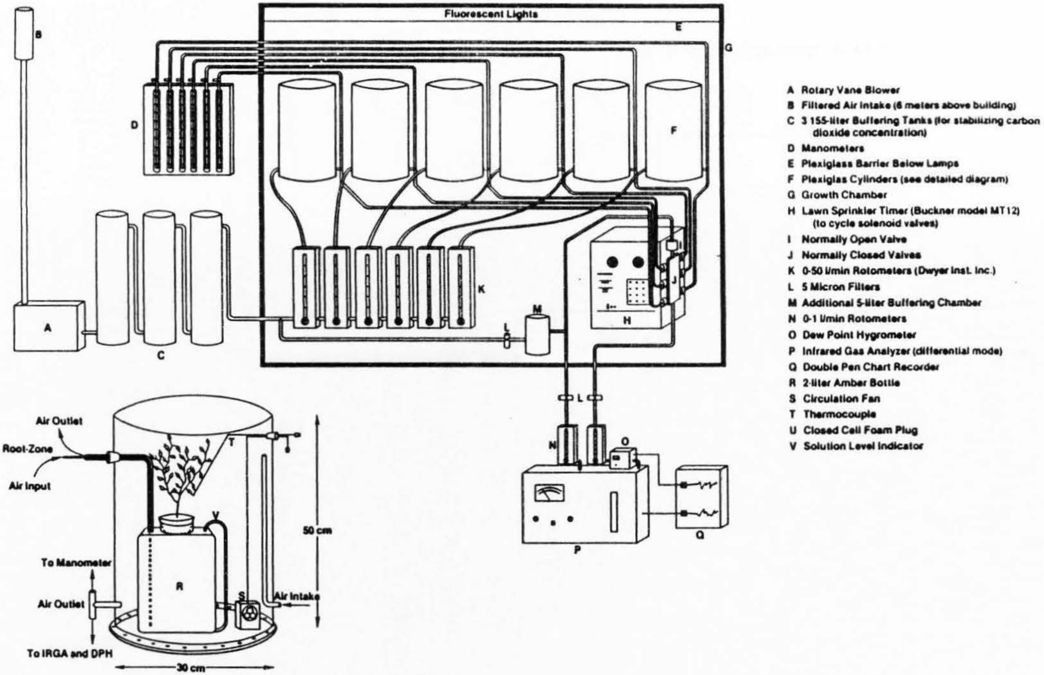

Figure 42. Diagram of the open gas exchange system used in this experiment.

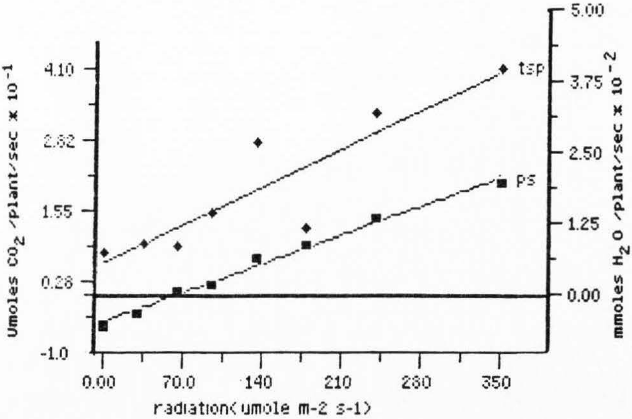

Figure 43. Effect of different radiation levels on photosynthesis (PS) and transpiration (TSP) of field bindweed.

support initial growth until plants grow tall enough to capture sufficient light to become self-sustaining. Additional experiments could determine which of the two mechanisms are involved or if other explanations exist.

Field bindweed plants sprayed with metsulfuron showed a sudden decline in photosynthesis and transpiration but the rates gradually increased during the following three days. Rates gradually declined for about two weeks beyond the three day increase until they died (Fig. 44). Unexpectedly all different metsulfuron concentrations reduced photosynthesis and transpiration at about the same degree (Fig. 44, 45). Higher dosages of metsulfuron were more effective in controlling field bindweed probably due to higher absorption and translocation within plants. However, higher rates did not kill plants faster. Since metsulfuron does not inhibit photosynthesis directly (Ray, 1982), and its effect on susceptible plants is through inhibition of leucine and isoleucine, it is speculated that regardless of the amount of metsulfuron, the synthesis of these two amino acids in inhibited. Without these two amino acids chlorophyll and enzymes synthesis would not take place once existing levels were broken down resulting in inhibition of photosynthesis.

Field bindweed photosynthesis was measured in response to the herbicide treatments. Except for picloram, the other four herbicides inhibited the photosynthesis of field bindweed more rapidly than metsulfuron. A sharp decline in photosynthesis was observed following each of the herbicide treatments and the control treated just with water plus surfactant. This decline was very rapid in glyphosate treated plants and minimal in control. The decline in photosynthesis was

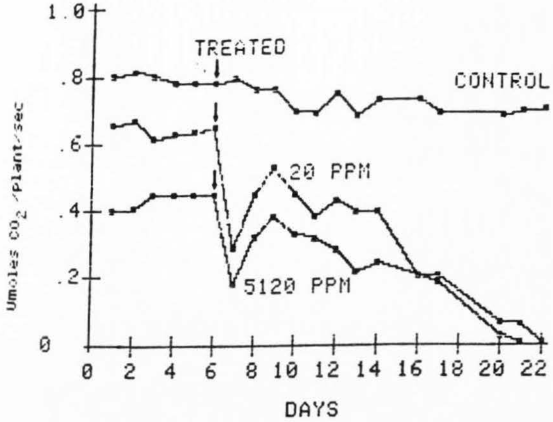

Figure 44. The effect of metsulfuron on photosynthesis of field bindweed. Plants were sprayed on day 6.

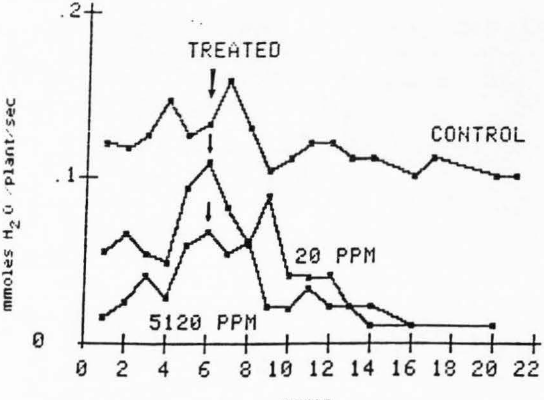

Figure 45. The effect of metsulfuron on transpiration of field bindweed. Plants were sprayed on day 6.

followed by a partial recovery in treated plants. The reason why such a sudden drop in photosynthesis of field bindweed happens following treatments with herbicides that do not have a direct effect on photosynthesis is not clear and needs further study.

Treatments with picloram, dicamba, 2,4-D and MCPA, all hormone-type herbicides, resulted in a slow decline in photosynthesis until the photosynthesis of treated plants was completely halted 18, 12, 14 and 9 days respectively after herbicide treatment (Fig. 46, 47, 48, 50). Treatment with glyphosate showed a pronounced drop followed by a small recovery the next day and then a sharp drop until no photosynthesis were recorded 5 days after treatment (Fig. 49). At this point glyphosate treated plants looked green like the control plants and no apparent injury symptoms were noticeable. The control plant which was sprayed with water and surfactant also showed a small decline following spraying, but it recovered the next day. The photosynthesis of the control plant increased during the study period. This was because of plant growth during the study period (Fig. 51). The photosynthesis rate of the control plant on day 22 was 30 percent higher than the initial rate.

Because of the very extensive root system of the field bindweed plant in the field, a herbicide that is not a direct photosynthetic inhibitor can successfully control it by foliage treatment if it can be readily absorbed and translocated to the root system of the plant. Absorption and translocation of a herbicide is a function of its chemistry (e.g., its molecular size and water solubility), and because herbicides are co-transported in the phloem along with photosynthesates, the plant's photosynthetic ability must not be adversely affected by the herbicide treatment so that more of the absorbed herbicide can be

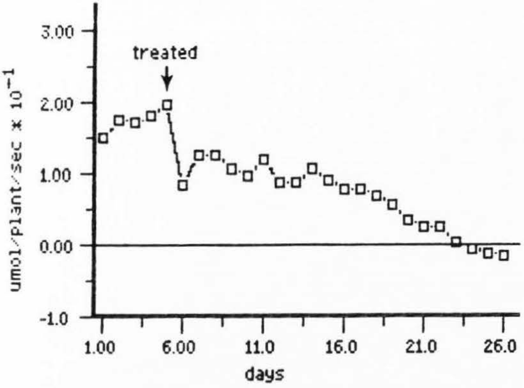

Figure 46. The effect of picloram on photosynthesis of field bindweed. Treatment made on day 5.

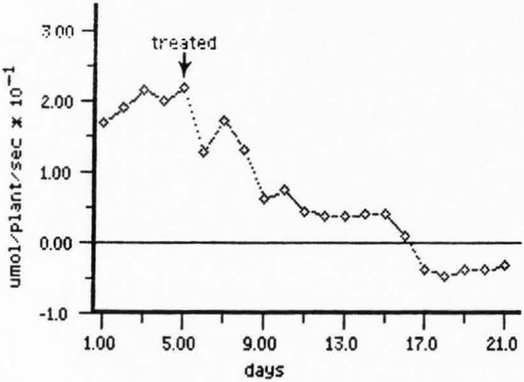

Figure 47. The effect of dicamba on photosynthesis of field bindweed. Treatment made on day 5.

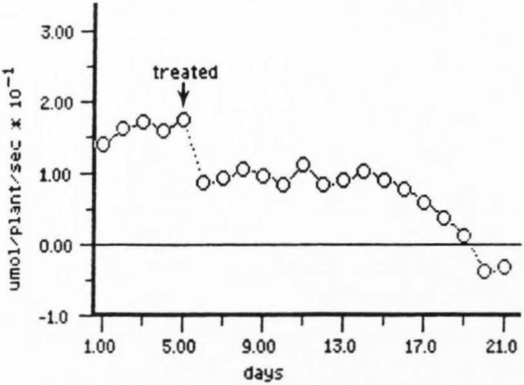

Figure 48. The effect of 2,4-D on photosynthesis of field bindweed. Treatments made on day 5.

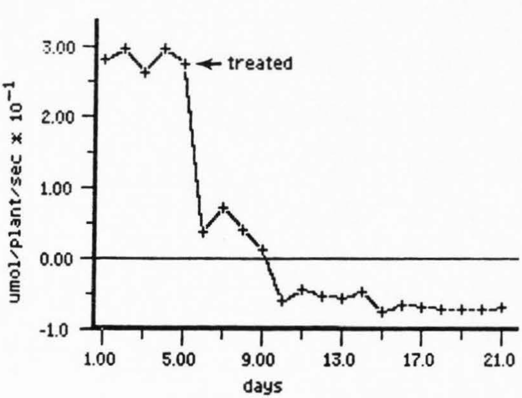

Figure 49. The effect of glyphosate on photosynthesis of field bindweed. Treatments made on day 5.

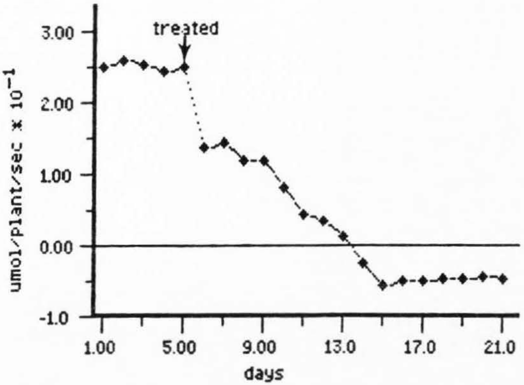

Figure 50. The effect of MCPA on photosynthesis of field bindweed. Treatments made on day 5.

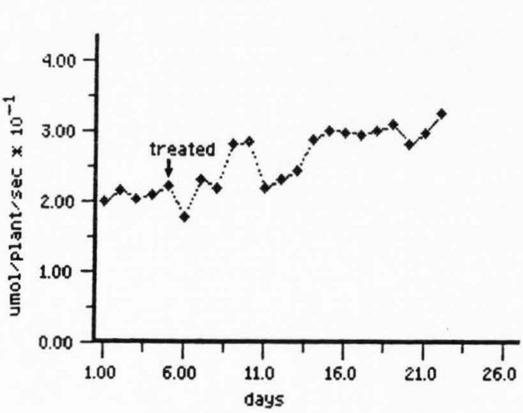

Figure 51. Photosynthesis rate of field bindweed control plant. The plant was sprayed with water and WK surfactant.

translocated in the plant. The translocation patterns is also important in achieving proper control. Plants should be treated at a physiological stage when there is a basipetal translocation of photosynthesates in the plant.

In all the herbicides tested in this study, except for glyphosate which halted the photosynthesis of field bindweed in 5 days, all other herbicides allowed adequate time for the herbicide to be translocated in the plant. Studies with ^{14}C labelled herbicides are needed to obtain more information about other barriers to translocation.

Absorption and Translocation

As the interval between ^{14}C metsulfuron treatment and plant harvest increased, greater quantities (Disintegration Per Minute, DPM) of labelled metsulfuron were translocated from the treated leaf to different segments of field bindweed. Residual ^{14}C in the treated leaves decreased with longer intervals from treatment to harvest. Apparently movement of metsulfuron from point of treatment to other plant parts is highly correlated with time (Table 16). For example, the highest quantity of metsulfuron exported from treated leaves occurred in 192 hours.

Field bindweed treatments with any of six systemic herbicides immediately before applying labelled metsulfuron to a fully expanded leaf appeared to increase absorption slightly in most instances (Fig. 52). Dicamba being one exception and metsulfuron another exception especially when they were applied more than two days ahead of applying the labelled herbicide. Metsulfuron applied as a foliage spray two days prior to administering the labelled herbicide significantly increased ^{14}C absorption into the plant (Fig. 53).

Averaged over all treatments, higher quantities of labelled metsulfuron were translocated acropetally from the treated leaf. This was true whether the results were expressed on the basis of total labelled metsulfuron translocated to a segment (Fig. 54) or labelled metsulfuron per unit dry weight of a segment (Fig. 55). The quantity of labelled metsulfuron translocated below the treated leaf segment, however, was higher than the rest of the shoot or root segments when expressed in total DPM per segments. Lower dry weights of below treated segments were responsible for this difference. When results were expressed based on percent distribution of absorbed labelled metsulfuron

Table 16. Effect of different treatment to harvest intervals in absorption and translocation of ^{14}C metsulfuron in field bindweed.

	DPM/Plant Segment			
Treatment to harvest intervals (hrs)	Treated leaf (TL)	Above TL	Below TL	Root
6	2454	74	45	55
12	1662	99	57	58
24	1561	96	57	53
48	1376	123	67	73
96	1047	220	54	70
192	1044	235	123	88

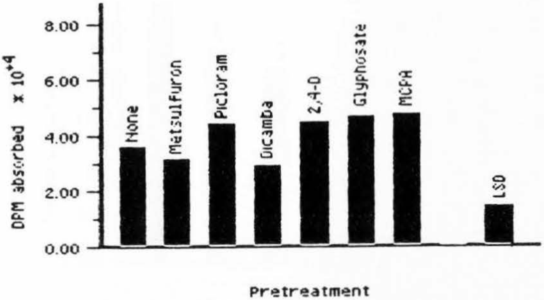

Figure 52. Total ^{14}C metsulfuron absorbed when field bindweeds are pretreated with different herbicides immediately prior to ^{14}C application.

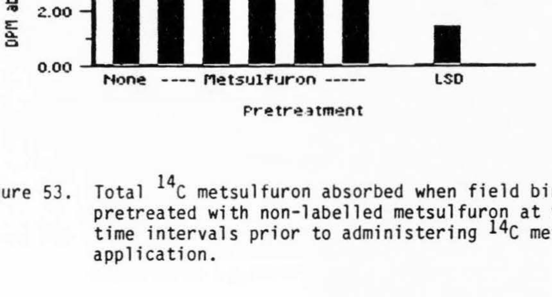

Figure 53. Total ^{14}C metsulfuron absorbed when field bindweeds are pretreated with non-labelled metsulfuron at various time intervals prior to administering ^{14}C metsulfuron application.

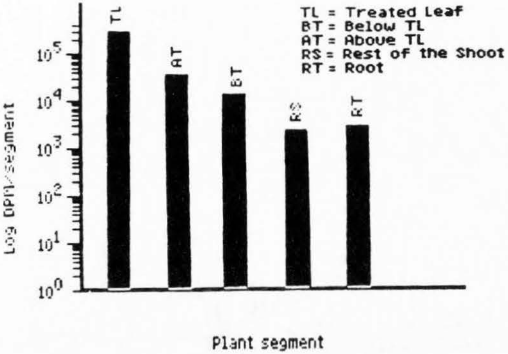

Figure 54. Total ^{14}C recovered in each segment of field bindweeds 192 hours after application of labelled metsulfuron.

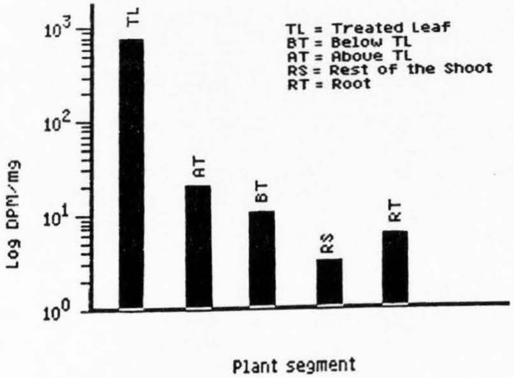

Figure 55. ^{14}C metsulfuron recovered and expressed per mg of dry weight of field bindweed plants 192 hours after labelled metsulfuron application.

in each segment of field bindweed, they indicated that about 75 percent of total quantity of labelled metsulfuron was recovered in the treated leaf and the rest translocated out of the treated leaf (Fig. 56). Higher proportions of labelled metsulfuron were translocated above the treated leaf portion and roots of field bindweed.

Plants pretreated with dicamba and glyphosate had higher percentage of labelled metsulfuron in their roots than did the controls, based on total labelled metsulfuron absorbed (Table 17, 18). When the results were expressed in ^{14}C activity per unit dry weight (DPM/mg), these treatments did not result in highest activity per mg of dried root segments (Table 19).

Percent recovery of the ^{14}C labelled metsulfuron applied to the single leaf of field bindweed ranged from 81 to 97 percent. From the total ^{14}C metsulfuron recovered 80 to 90 percent was in the leaf wash and the rest was absorbed into the plant (Table 20). No statistical significance was observed among treatments in percent ^{14}C recovery and percent absorption of total ^{14}C recovered.

No qualitative differences were observed among treatments in autoradiographs. The tendency of acropetal translocation, however, could easily be recognized (Fig. 57, 58). Metsulfuron was also shown to be accumulated in the shoot meristems.

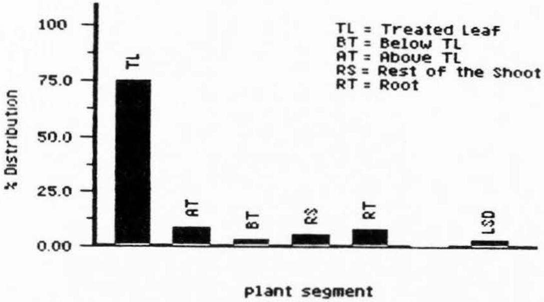

Figure 56. Distribution of labelled metsulfuron in different plant segments as a percentage of total labelled metsulfuron absorbed.

Table 17. Distribution of ^{14}C metsulfuron recovered in each segment as a percentage of total ^{14}C metsulfuron absorbed.

Treatments	Rate g/ha	Plant Segment				
		Treated leaf (TL) %	Above TL %	Below TL %	Rest of the shoot %	Root %
Control (no pretreatment)	-	65.45	11.64	4.05	8.02	10.84
Metsulfuron 6 days before	4	85.12	5.64	4.41	1.98	2.46
Metsulfuron 4 days before	4	85.42	5.52	2.20	3.44	3.39
Metsulfuron 2 days before	4	76.28	8.57	4.17	6.02	5.01
Metsulfuron 1 day before	4	79.54	9.66	2.70	3.39	4.67
Metsulfuron 0 day before	4	75.79	6.53	2.99	5.05	9.72
Picloram 0 day before	140	67.25	10.93	4.14	8.64	9.01
Dicamba 0 day before	560	60.63	13.29	3.22	8.65	14.19
2,4-D 0 day before	1,120	82.72	6.46	1.45	2.80	3.00
Glyphosate 0 day before	840	65.76	7.03	3.10	8.63	15.43
MCPA 0 day before	1,120	85.65	4.07	1.23	5.02	3.98

Table 18. Total ^{14}C metsulfuron (DPM) in plant segments in each treatment.

		DPM/Plant Segment				
Treatments	Rate g/ha	Treated leaf TL	Above TL	Below TL	Rest of the shoot	Root
Control (no pretreatment	-	23611	4308	1428	3306	3837
Metsulfuron 6 days before	4	35539	2399	1608	736	875
Metsulfuron 4 days before	4	34605	2217	891	1412	1346
Metsulfuron 2 days before	4	46136	5935	2625	3962	3144
Metsulfuron 1 day before	4	39855	4882	1366	1510	2511
Metsulfuron 0 day before	4	24290	2014	948	1626	3039
Picloram 0 day before	140	31404	4374	1759	3411	3477
Dicamba 0 day before	560	17521	4015	937	2532	4151
2,4-D 0 day before	1,120	37787	4591	790	1265	1358
Glyphosate 0 day before	840	30105	3483	1447	4662	7110
MCPA 0 day before	1,120	41158	1767	543	2158	1736

Table 19. ^{14}C metsulfuron (DPM/mg) recovered in plant segments in each treatment.

		Plant Segment				
Treatments	Rate g/ha	Treated leaf (TL)	Above TL	Below TL	Rest of the shoot	Root
Control (no pretreatment)	-	1627	12.94	6.64	2.73	5.89
Metsulfuron 6 days before	4	765	13.88	10.00	1.94	3.71
Metsulfuron 4 days before	4	927	24.17	13.69	3.81	10.62
Metsulfuron 2 days before	4	725	17.56	11.70	2.96	9.41
Metsulfuron 1 day before	4	1272	24.80	7.50	1.93	3.53
Metsulfuron 0 day before	4	1109	32.40	17.95	5.07	10.31
Picloram 0 day before	140	527	7.91	5.20	2.64	4.59
Dicamba 0 day before	560	1234	25.20	15.47	4.30	6.75
2,4-D 0 day before	1,120	756	32.07	8.10	2.41	2.22
Glyphosate 0 day before	840	657	11.48	7.27	1.99	5.70
MCPA 0 day before	1,120	492	24.29	11.87	2.81	6.90

Table 20. Percent ^{14}C recovery and percent ^{14}C metsulfuron absorbed of total ^{14}C recovered in each treatment.

Treatments	Rate	% Recovery	% absorbed of total recovered
Control (no pretreatment)	-	91.65	14.45
Metsulfuron 6 days before	4	91.01	16.15
Metsulfuron 4 days before	4	96.48	16.62
Metsulfuron 2 days before	4	96.56	21.66
Metsulfuron 1 day before	4	92.80	20.56
Metsulfuron 0 day before	4	91.86	11.95
Picloram 0 day before	140	83.32	18.56
Dicamba 0 day before	560	94.68	10.60
2,4-D 0 day before	1,120	86.36	18.62
Glyphosate 0 day before	840	93.48	18.99
MCPA 0 day before	1,120	81.45	19.99

Figure 57. Field bindweed plant mounted and pressed for autoradiography.

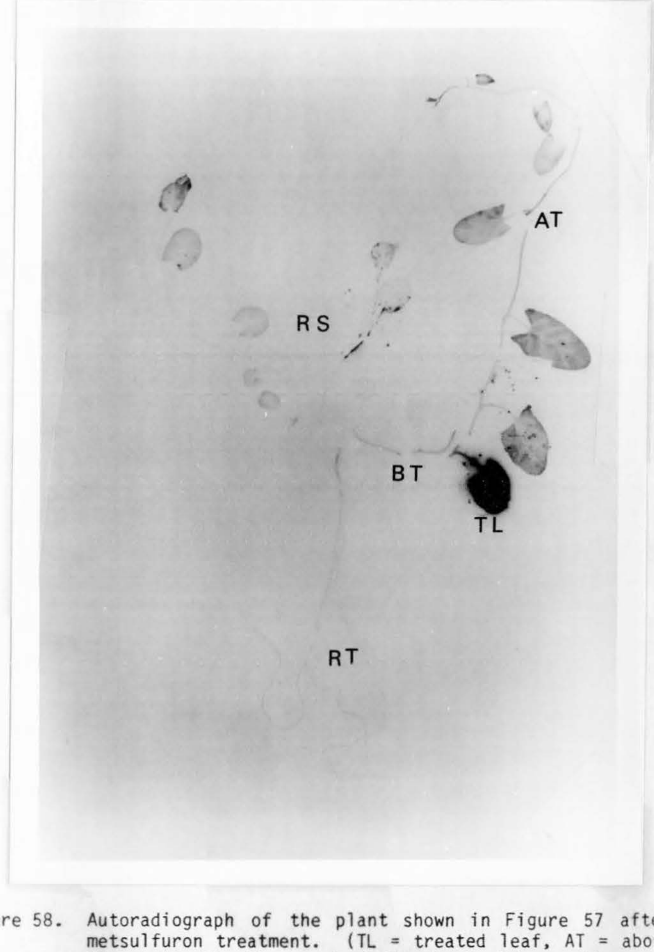

Figure 58. Autoradiograph of the plant shown in Figure 57 after ^{14}C metsulfuron treatment. (TL = treated leaf, AT = above TL, BT = below TL, RS = rest of the shoot, RT = root)

SUMMARY

The following summary of the field performance and physiological effects of metsulfuron and metsulfuron combinations on field bindweed appear appropriate:

Metsulfuron has no preemergence activity on field bindweed. Increasing the dosage of metsulfuron in postemergence applications increased field bindweed control. This was true both when metsulfuron was used alone or in combinations with other herbicides. Metsulfuron generally increased the activity of other herbicides when tank mixed with them. This was more evident in evaluations recorded the second and third year after treatment. Herbicide treatments at bloom stage resulted in less bindweed control than the same treatments made in prebloom and fall.

Among the herbicide treatments used in the field experiment, glyphosate, 2,4-D and MCPA resulted in the highest field bindweed control when tank mixed with metsulfuron. However, a single application of metsulfuron or metsulfuron in any combination did not result in longterm field bindweed control.

Metsulfuron applied to field bindweed at full bloom decreased seed size, seed weight, seed viability and seedling vigor of field bindweed but did not alter seed set.

Metsulfuron at 23 g/ha and above applied during the fallow season caused an unacceptable injury to barley and oats. Higher rates of metsulfuron resulted in greater injury. In general the closer metsulfuron was applied to planting small grains, the higher the phytotoxicity to the grain.

Photosynthetic rate of field bindweed showed a large daytime fluctuation. Field bindweed seedlings were observed growing in the field under light intensities of 28 to 62 μmoles m^{-2} s^{-1} which was below light compensation point obtained for greenhouse grown bindweed plants (about 65 μmoles, m^{-2} s^{-1}). The exact mechanism for this finding is not clear and needs further study.

Metsulfuron stopped photosynthesis of field bindweed within two weeks. This effect appeared to occur regardless of herbicide dosage used. Picloram, dicamba, 2,4-D and MCPA stopped photosynthesis of field bindweed plants in 18, 12, 14 and 9 days after treatment respectively while glyphosate treated plants had no photosynthesis after five days.

Higher quantities of labelled metsulfuron per mg plant dry weight were recovered in the above treated leaf sections than in any other parts of the plants. This was evident from both the scintillation countings and autoradiography. Metsulfuron applied as a foliage spray two days prior to administering labelled metsulfuron significantly increased the absorption of metsulfuron into the bindweed plants.

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APPENDICES

Appendix A: Common Name, Chemical Name and Molecular Weight of Herbicides Used in this Study

Table 21. Common name, trade name, chemical name and molecular weight of herbicides used in this experiment.

Common name	Trade name	Chemical name	Molecular weight
Metsulfuron	Ally	2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid	381
Picloram	Tordon	4-amino-3,5,6-trichloro-2-Pyridinecarboxylic acid	241
Dicamba	Banvel	3,6-dichloro-2-methoxybenzoic acid	221
2,4-D ester	2,4-D	(2,4-dichlorophenoxy) acetic acid	221
Glyphosate	Roundup	N-(Phosphonomethyl) glycine	169
MCPA	Chiptox	4-(4-Chloro-2-methylphenoxy)butanoic acid	201
Paraquat	Gramoxone	1,1'-dimethyl-4,4'bipyridinium ion	186

Appendix B: Modified Hoagland Solution

Table 22. Modified Hoagland Solution

	Stock Soln. Conc.	Mol. Wt.	PPM of Nutr. in Final Soln.	mL Nutr. G L^{-1} Stock	mL Nurt. L^{-1} D.H_2O Full Strength	mL Nurt. L^{-1} D.H_2O 1/2 Strength
Major Nutrients:						
KH_2 PO_4	1 M	136.04	P 31	136.04	1	0.5
K_2 SO_4	1 M	174.30	K 234	174.30	5	2.5
Ca CO_3	1 M	100.09	Ca 200	100.04	5	2.5
MG SO_4, $7H_2O$	1 M	246.48	Mg 48 S 64	246.48 ------	2	1.0
Micro Nutrients:						
H_3BO_3	500 ppm	61.83	B 0.5	2.860	1.0	0.5
M_nCL_2, $4H_2O$	500	169.01	Mn 0.5	1.810	1.0	0.5
Zn SO_4, $7H_2O$	500	287.56	Zn 0.5	2.20	1.0	0.5
Cu SO_4, H_2O	20	249.64	Cu 0.02	.078	1.0	0.5
Na Mo O_4, $2H_2O$	10	241.95	Mo 0.01	.025	1.0	0.5
Fe Chelate	4 g L^{-1}	932.00	Fe 2.4	4.000	10.0	5.0
KOH	4 g L^{-1}	50.20	------	-----	----	---

The pH of the final solution was adjusted with KOH to 6.2.

Appendix C: ANOVA Tables

Table 23. ANOVA for field bindweed control treatments; Smithfield.

Source	DF	SS	MS	F
REPS	3	201.96	67.32	
STAGE	2	591017.02	295508.51	3402.549**
ERROR A	6	521.09	86.84	
RATE	3	43802.93	14600.97	121.042**
MIX	5	37922.62	7584.52	62.875**
RxM	15	16574.83	1104.98	9.160**
SxR	6	6175.02	1029.17	8.532**
SxM	10	32688.27	3268.82	27.098**
SxRxM	30	14785.63	492.85	4.086**
ERROR B	207	24969.93	120.62	
YEAR	2	243607.88	121803.94	450.304**
ERROR C	6	1622.95	270.49	
SxY	4	93057.64	23264.41	206.392**
RxY	6	6442.60	1073.76	9.526**
MxY	10	16631.16	1663.11	14.754**
RxMxY	30	7598.96	253.29	2.247**
SxRxY	12	7085.73	590.47	5.238**
SxMxY	20	27227.02	1361.35	12.077**
SxRxMxY	60	7598.15	126.63	1.123
ERROR D	426	48018.54	112.71	
TOTAL	863	1227550.00	1422.42	

** Significant at $P < 0.01$.

Table 24. ANOVA for field bindweed control treatments; Sherwood Hills.

Source	DF	SS	MS	F
REPS	3	960.52	320.17	
STAGE	2	480278.97	240139.49	481.651**
ERROR A	6	2991.40	498.56	
RATE	3	30163.94	10054.64	91.535**
MIX	5	40217.00	8043.40	73.225**
RxM	15	9679.46	645.29	5.875**
SxR	6	22811.72	3801.95	34.612**
SxM	10	38953.62	3895.36	35.462**
SxRxM	30	8764.34	292.14	2.660**
ERROR B	207	22737.99	109.84	
YEAR	2	270129.18	13506.459	211.064**
ERROR C	6	3839.53	639.92	
SxY	4	140589.16	35147.29	332.069**
RxY	6	4518.88	753.14	7.116**
MxY	10	16264.78	1626.47	15.367**
RxMxY	30	8968.31	298.94	2.824**
SxRxY	12	3941.49	328.45	3.103**
SxMxY	20	17585.15	879.25	8.307**
SxRxMxY	60	7693.52	128.22	1.211**
ERROR D	426	45089.30	105.84	
TOTAL	863	1176178.30	1362.89	

* Significant at $P < 0.05$
** Significant at $P < 0.01$

Table 25. ANOVA for field bindweed control treatments; Hyrum.

Source	DF	SS	MS	F
REPS	3	924.93	308.31	
STAGE	2	9228.3	4614.17	12.198**
ERROR A	6	2269.68	378.28	
RATE	3	74058.13	24686.04	120.687**
MIX	5	122162.24	24432.44	119.447**
RxM	15	19780.38	1318.69	6.447**
SxR	6	2475.90	412.65	2.017
SxM	10	16415.74	1641.57	8.025**
SxRxM	30	5445.48	181.51	<1
ERROR B	207	42341.00	204.54	
YEAR	1	18168.79	18168.79	19.983*
ERROR C	3	2727.60	909.20	
SxY	2	45450.00	22725.00	128.721**
RxY	3	4269.29	1423.09	8.061**
MxY	5	52748.07	10549.61	59.756**
RxMxY	15	11429.04	761.93	4.316**
SxRxY	6	704.76	117.46	<1
SxMxY	118	130546.91	1106.32	6.267**
SxRxMxY	30	6081.30	202.71	1.148
ERROR D	213	37604.02	176.54	
TOTAL	575	480587.37	835.80	

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

Table 26. ANOVA for the field soil bioassay; Smithfield.

Source	DF	SS	MS	F
Reps	3	4286.71	1428.90	
Stage	3	25887.76	8029.25	48.343**
Error A	9	1606.51	178.50	
Rate	3	68146.61	22715.53	276.50**
Mix	5	253.04	50.72	<1
RxM	15	1365.10	91.00	1.107
SxR	9	8944.53	993.83	12.087**
SxM	15	864.58	57.63	<1
SxMxR	45	2818.75	62.63	<1
Error B	276	22694.27	82.22	
Total	383	136868.49	357.36	

** Significant at $P < 0.01$

Table 27. ANOVA for Sherwood Hill's soil bioassay; barley weight.

Source	DF	SS	MS	F
Block	3	5.73	1.91	
Stage	1	6.01	6.01	7.307
Error A	3	2.47	.82	
Treatment	3	8.82	2.94	4.188*
Error B	18	12.64	.70	
Sampling	96	33.54	34.94	
Total	127	77.76	.61	

* Significant at $P < 0.05$.

Table 28. ANOVA for Sherwood Hill's soil bioassay; lentil weight.

Source	DF	SS	MS	F
Block	3	0.23	0.076	
Stage	1	0.94	0.94	10.200*
Error A	3	0.27		0.092
Treatment	3	5.92	1.97	8.176**
SxT	3	0.23	0.075	<1
Error B	18	4.34	0.241	
Sampling	96	2.15	0.022	
Total	127	14.09	0.110	

* Significant at $P < 0.05$

** Significant at $P < 0.01$

Table 29. ANOVA for Sherwood Hills soil bioassay; barley length.

Source	DF	SS	MS	F
Block	3	99.00	33.00	
Stage	1	0.78	0.78	<1
Error A	3	95.85	31.94	
Treatment	3	80.43	20.81	2.425
SxT	3	35.03	11.67	1.056
Error B	18	186.40	10.35	
Sampling	96	572.50	5.96	
Total	127	1070.00	8.42	

Table 30. ANOVA for Sherwood Hills soil bioassay; lentil height.

Source	DF	SS	MS	F
Block	3	1.00	.33	
Stage	1	2.97	2.97	1.084
Error A	3	8.22	2.74	
Treatment	3	285.41	95.13	16.778**
SxT	3	76.21	25.43	4.486*
Error B	18	102.06	5.67	
Sampling	96	190.43	1.98	
Total	127	666.43	5.25	

* Significant at $P < 0.05$
** Significant at $P < 0.01$

Table 31. ANOVA for Sherwood Hills soil bioassay; lentil vigor.

Source	DF	SS	MS	F
Block	3	14.31	4.77	
Stage	1	87.78	87.78	55.078**
Error[3] A	3	4.78	1.59	
Treatment	3	237.31	79.10	18.454**
SxT	3	63.52	21.17	4.940*
Error B	18	77.15	4.29	
Sampling	96	105.00	1.09	
Total	127			

* Significant at $P < 0.05$
** Significant at $P < 0.01$

Table 32. ANOVA for Hyrum soil bioassay; barley weight.

Source	DF	SS	MS	F
Blocks	3	11.65	3.88	
Stage	2	4.62	2.30	<1
Error A	6	22.24	3.70	
Treatments	3	136.17	45.39	105.483**
SxT	6	19.10	3.18	7.401**
Error B	27	11.61	0.430	
Sampling	96	42.94	0.447	
Total	143	248.36	1.73	

** Significant at $P < 0.01$.

Table 33. ANOVA for Hyrum soil bioassay; barley height.

Source	DF	SS	MS	F
Blocks	3	674.72	224.90	
Stage	2	1184.00	592.00	3.628
Error A	6	978.94	163.15	
Treatments	3	8649.50	2883.16	51.725**
SxT	6	671.16	111.86	2.007
Error B	27	1505.00	55.74	
Sampling	96	1010.66	10.52	
Total	143	14674.00	102.61	

** Significant at $P < 0.01$.

Table 34. ANOVA for Hyrum soil bioassay; lentil weight.

Source	DF	SS	MS	F
Blocks	3	0.679	0.226	
Stage	2	0.189	0.094	1.691
Error A	6	0.335	0.056	
Treatments	3	12.73	4.24	39.455**
SxT	6	0.42	0.070	<1
Error B	27	2.9	0.107	
Sampling	96	4.39	0.045	
Total	143	21.65	0.151	

** Significant at $P < 0.01$

Table 35. ANOVA for Hyrum soil bioassay; lentil height.

Source	DF	SS	MS	F
Blocks	3	144.57	48.19	
Stage	2	94.01	47.00	1.891
Error A	6	149.15	24.85	
Treatments	3	2278.07	759.35	64.134**
SxT	6	139.48	23.24	1.963
Error B	27	319.68	11.84	
Sampling	96	416.66	4.34	
Total	143	3541.65	24.76	

** Significant at $P < 0.01$.

Table 36. ANOVA for bindweed seed capsule weight; Sherwood Hills.

Source	DF	SS	MS	F
Reps	3	47.61	15.87	
Treatments	3	1017.59	339.19	9.418**
Error	9	324.15	36.01	
Total	11	1389.36	92.62	

** Significant at $P < 0.01$

Table 37. ANOVA for bindweed seed weight; Sherwood Hills.

Source	DF	SS	MS	F
Reps	3	3.90	1.30	
Treatments	3	56.81	18.93	12.573**
Error	9	13.55	1.50	
Total	11	74.26	4.95	

** Significant at $P < 0.01$.

Table 38. ANOVA for number of bindweed seed per capsule; Sherwood Hills.

Source	DF	SS	MS	F
Reps	3	0.646	0.215	
Treatments	3	0.361	0.121	<1
Error	9	1.45	0.161	
Total	11	2.46	0.164	

** Significant at $P < 0.01$.

Table 39. ANOVA for shrunken bindweed seed (percent of total); Sherwood Hills.

Source	DF	SS	MS	MS	F
Reps	3	340.86	113.62		
Treatments	3	2330.38	776.79		3.360
Error	9	2080.84	231.20		
Total	11	4752.09	316.80		

** Significant at $P < 0.01$

Table 40. ANOVA for bindweed seedling radicle length; Sherwood Hills.

Source	DF	SS	MS	F
Reps	3	1.23	0.410	
Treatments	3	12.96	4.32	28.802**
Error	9	1.35	0.150	
Total	11	15.54	1.03	

** Significant at $P < 0.01$.

Table 41. ANOVA for germination of bindweed seed (percent of control); Sherwood Hills.

Source	DF	SS	MS	F
Reps	3	390.18	130.06	
Treatments	3	25222.08	8407.56	151.166**
Error	9	500.56	55.61	
Total	11	26113.43	1740.89	

** Significant at $P < 0.01$.

Table 42. ANOVA for bindweed seed capsule weight; Hyrum.

Source	DF	SS	MS	F
Blocks	3	308.81	102.93	
Treatments	3	342.68	114.22	1.467
Error	9	700.62	77.85	
Total	15	1352.11	90.14	

Table 43. ANOVA for bindweed seed weight; Hyrum.

Source	DF	SS	MS	F
Blocks	3	41.03	13.67	
Treatments	3	81.32	27.10	1.557
Error	9	156.72	17.41	
Total	15	279.07	18.60	

Table 44. ANOVA for number of bindweed seed per capsule; Hyrum.

Source	DF	SS	MS	F
Blocks	3	.122	.041	
Treatments	3	.022	.0075	<1
Error	9	.912	.101	
Total	15	1.05	.070	

Table 45. ANOVA for % shrunken bindweed seed (percent of total); Hyrum.

Source	DF	SS	MS	F
Blocks	3	2338.68	779.56	
Treatment	3	1256.18	418.73	1.416
Error	9	2662.06	295.78	
Total	15	6256.93	417.13	

Table 46. ANOVA for bindweed seedling radicle length; Hyrum.

Source	DF	SS	MS	F
Blocks	3	.376	.125	
Treatments	3	13.56	4.52	41.264**
Error	9	.98	.109	
Total	15	14.91	.995	

** Significant at $P < 0.01$.

Table 47. ANOVA for germination of bindweed seed (percent of control); Hyrum.

Source	DF	SS	MS	F
Blocks	3	680.01	226.72	
Treatments	3	1959.11	6530.40	21.096**
Error	9	2786	309.56	
Total	15	13057.44	1507.16	

** Significant at $P < 0.01$.

Table 48. ANOVA for number of bindweed seed germinated following soil application of metsulfuron.

Source	DF	SS	MS	F
Reps	4	11.32	2.83	
Rate	4	74.12	18.53	3.452*
Error A	16	85.85	5.37	
Time	1	31.25	312.50	376.647**
Error B	4	3.40	0.85	
RxT	4	94.20	23.55	7.331**
Error C	16	51.40	3.21	
Total	49	632.82	12.91	

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.

Table 49. ANOVA for bindweed seedling vigor following soil application of metsulfuron.

Source	DF	SS	MS	F
Reps	4	10.07	2.51	
Rate	4	370.20	92.54	56.125**
Error A	16	26.38	1.65	
Time	1	118.58	118.58	395.927**
Error B	4	1.20	0.30	
RxT	4	25.48	6.37	9.112**
Error C	16	11.18	0.70	
Total	49	563.10	11.49	

** Significant at $P < 0.01$

Table 50. ANOVA for absorption and translocation of ^{14}C metsulfuron with different treatment to harvest intervals.

Source	DF	SS	MS	F
Time	5	2912311100	582462220	2.159
Error A	18	4856180800	269787820	
Segment	4	197184030000	49296007000	182.87 **
TxS	20	11287997000	564399860	2.09 *
Error B	72	19408744000	269565890	
Total	119	235649260000	1980245900	

*Significant at $P < 0.05$
**Significant at $P < 0.01$

Table 51. ANOVA for total ^{14}C metsulfuron (DPM) in plant segments in each treatment.

Source	DF	SS	MS	F
Reps	2	877	438	
Treatments	10	1276246	127625	3.79**
Error A	20	673622	33681	
Segment	4	21165730	5291432	102.10**
TxS	40	3680559	92014	1.77**
Error B	88	4560855	51828	
Total	164	31357891	191206	

**Significant at $P < 0.01$

Table 52. ANOVA for ^{14}C metsulfuron (DPM/mg) recovered in plant segments in each treatment.

Source	DF	SS	MS	F
Reps	2	101135870	50567937	
Treatments	10	487412360	48741236	3.22**
Error A	20	302874280	15143714	
Segment	4	24390592000	6097647900	292.98**
TxS	40	1931907200	47847679	2.30**
Error B	88	1831479700	20812270	
Total	104	29027401000	176996350	

**Significant at $P < 0.01$

Table 53. ANOVA for distribution of ^{14}C metsulfuron recovered in each segment as a percentage of total ^{14}C metsulfuron absorbed.

Source	DF	SS	MS	F
Reps	2	2.58	1.29	
Treatment	10	9.32	0.93	1.15
Error A	20	16.17	0.81	
Segment	4	127406	31851	776.11**
TxS	40	3672	91.80	2.23**
Error B	88	3612	41.05	
Total	164	134718	821.45	

**Significant at $P < 0.01$

Table 54. ANOVA for percent recovery of ^{14}C metsulfuron in field bindweed.

Source	DF	SS	MS	F
Reps	2	16.88	8.341	
Treatment	10	770.33	77.03	1.34
Error	20	1142.71	57.13	
Total	32	1929.73	60.30	

Table 55. ANOVA for percent ^{14}C metsulfuron absorbed in field bindweed of total ^{14}C recovered.

Source	DF	SS	MS	F
Reps	2	101.55	50.77	
Treatment	10	377.95	37.79	2.08
Error	20	362.02	18.10	
Total	32	841.53	26.29	

VITA

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Doctor of Philosophy

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