EFFECTS OF HERBICIDE
COMBINATIONS FOR BROAD SPECTRUM
WEED CONTROL IN ORNAMENTAL
PLANTINGS

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R.L. SPANGLER

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Progress Report

EFFECTS OF HERBICIDE COMBINATIONS FOR BROAD SPECTRUM WEED CONTROL IN ORNAMENTAL PLANTINGS

TO: G. A. Leonards, Director
Joint Highway Research Project

February 15, 1968

File No: 9-5-3

From: H. L. Michael, Associate Director
Joint Highway Research Project

Project No: C-36-48C

The attached report entitled "Effects of Herbicide Combinations for Broad Spectrum Weed Control in Ornamental Plantings" is submitted as a Progress Report on the HPR Research Project "Research in Roadside Development." The report has been authored by Ronald L. Spangler under the direction of Dr. F. O. Lanphear. The report is from the part of the study concerned with the selection, establishment and maintenance of woody ornamental plants for highway plantings.

The report presents a study of the factors influencing the effectiveness of herbicide combinations, an investigation of the effect of herbicide combinations on plant toxicity, the effect of combinations of herbicide residue and the minimum effective concentrations formulated for herbicide combinations and preliminary field studies.

The report will also be forwarded for comment review, and approval as partial fulfillment of the objective of this research. The report is submitted for the record.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:nf

Attachment

Copy: F. L. Ashbaucher	R. H. Harrell	C. F. Scholer
W. L. Dolch	V. E. Harvey	M. B. Scott
W. H. Goetz	J. A. Havers	W. T. Spencer
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	J. C. Oppenlander	

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by

Ronald L. Spangler
Graduate Assistant in Research

Joint Highway Research Project

Project No: C-36-48C

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ABSTRACT

Spangler, Ronald Lee. M.S., Purdue University, January, 1968. Effects of Herbicide Combinations for Broad Spectrum Weed Control in Ornamental Plantings. Major Professor: F. O. Lanphear.

The objectives of this study were to explore the possibilities of combining herbicides to control a broad spectrum of weeds, to control activity for specific periods of time, and to reduce crop toxicity.

Initially, minimum concentrations necessary to control specific weeds was determined for various herbicides. Combinations of various levels of these herbicides were made to obtain broad spectrum weed control. From greenhouse and field plot studies the combination of simazine (1 lb/A) + diphenamid (4 lb/A) was shown to give the most effective control over a broad spectrum of weeds.

In the second year, additional herbicides were field tested, alone and in combination, to determine their effectiveness for ornamental plantings. These herbicides were applied as surface or soil incorporated treatments during various times of the year. Simazine-diphenamid applied to the surface gave excellent weed control if applied in April or June but was not persistent when applied in November.

The dichlobenil (2 lb/A) + diphenamid (4 lb/A), another good combination, was shown to be more effective if incorporated; in fact, dichlobenil effectiveness in all treatments was dependent on incorporation.

Trifluralin (2 lb/A), incorporated at twice the recommended rate, gave excellent broad spectrum weed control at all times tested.

Injury to various ornamental species was apparent when simazine was applied at its normal recommended rates. When simazine was used at its minimum effective concentration in combination with diphenamid, no injury occurred to the sensitive species, Euonymus fortunei 'Coloratus.' Another sensitive species, Ajuga 'Metallica-crispa,' was slightly injured early in the summer, but the injury was not apparent by late summer. Thus, the reduction in crop toxicity to some species was demonstrated by use of minimum effective concentrations of herbicides in combination.

Trifluralin and bensulide were found to be safe for all species tested. In pre-treated soils, these herbicides were non-toxic to selected species, even at four times the normal rate. Dichlobenil was found to be toxic to all species in the pre-treated soil.

The final phase of the investigations was to determine the amount of residual activity of the various herbicide treatments. A bioassay was conducted which, although

highly variable, showed that bensulide and trifluralin exhibited significant residual activity over 11 months.

INTRODUCTION

Weed control in ornamental plantings can be achieved either mechanically or chemically. Because of high labor costs and the unavailability of labor during the season when weeds must be removed, mechanical or manual methods of controlling weeds are prohibitive. In the past few years there has been an increased use of herbicides to control weeds in ornamental plantings, thus reducing labor costs and providing weed control during critical periods.

Ideally, a herbicide could be applied in the fall or spring and would control a broad spectrum of weeds for long periods of time. The persistence would be affected by:

(1) microbial decomposition, (2) chemical decomposition, (3) adsorption of soil colloids, (4) leaching, (5) volatility, and (6) photodecomposition (Klingman, 1965).

An ideal herbicide would not be toxic to the crop. The diversity of ornamental plants makes it difficult to find non-toxic selective herbicides that will control a broad spectrum of weeds. Considerable variation in the tolerance of several woody ornamental plants to selective herbicides has been reported (Ries, et al., 1959; Chadwick, 1960).

Lastly, an ideal herbicide would control undesirable plants without injury to the crop and then dissipate when weed control is no longer needed. Many herbicides approach the ideal under optimum environmental conditions, but variations in the environment may cause erratic dissipation rates.

Herbicides available are able to perform only a part of the requirements necessary for good weed control. Some herbicides do control particular weeds for long periods of time; however, at effective concentration, they are either toxic to the crop or do not control a broad spectrum of weeds.

Because no single herbicide has been developed that can meet all requirements, new formulations or methods of application should be developed that will meet these requirements more effectively. One possible method to more efficiently control weeds is to combine herbicides using lower concentrations of each to better meet the requirements for broad spectrum weed control, while reducing injury to the crop.

The object of the present research was to explore the possibilities of combining herbicides to control a broad spectrum of weeds, to provide herbicide activity for specific periods of time, and to reduce crop toxicity.

The program of study was to: (1) develop methods in which herbicides can be evaluated as potential components for herbicide combinations; (2) use combinations that may be effective under different environmental conditions;

(3) determine the optimum time to apply herbicides alone and in combination; (4) determine the reduction in crop injury resulting from the use of combinations; and (5) evaluate herbicide combinations as a means of reducing residue problems.

LITERATURE REVIEW

Weed Control in Woody Ornamental Plantings

Weed control in all phases of agriculture is a major production problem. Between 1959 and 1963, the use of herbicides in the United States has more than doubled. Herbicides were applied on an estimated 85 million acres, or about 20 percent of the nation's cropland, in 1962 (Ennis and McClellan, 1964).

In highway plantings and ornamental nurseries, weed control has been recognized as one of the more expensive operations. These weed control problems are accentuated because of the rising costs of labor for hand hoeing and cultivation. If weeds are not controlled, they may retard the growth of valuable plantings and nursery stock by competing for moisture, nutrients, and light. Plants also may be deformed because of weed competition, thereby lowering their value. Carpenter (1967) reported that conventional nursery weed control in established stock is approximately \$195.00 per acre per year. With the use of herbicides, the cost can be reduced to approximately \$25.00 to \$75.00 per acre per year.

Several herbicides being used in nursery situations are providing encouraging results in maintaining partial weed control (Saidak and Nelson, 1962; Bing, 1959; McGuire, 1967). However, results of several herbicide studies (Chadwick, 1960; Havis, 1961) have indicated a need for improvements because of injury to certain species and failure to provide complete broad spectrum weed control.

In an effort to identify these plants that are tolerant to particular herbicides, the 1965 Oregon Weed Control Handbook (Warren, 1965) has compiled an extensive list of woody ornamental plants, bedding plants, perennials, and ground covers, and their known tolerances to herbicides.

Some Herbicides Used in Ornamental Plantings

Several herbicides are currently being used in ornamental plantings, although some appear to perform better than others. The following herbicides have been selected because of their particular attributes which may allow them to be used advantageously in nurseries.

Simazine

Simazine, 2-chloro-4, 6-bis (ethylamino)-s-triazine, is one of the most widely used herbicides in woody ornamental plantings. It is a promising herbicide for ornamental nurseries because of its persistent activity (Havis, 1961; Bing, 1959). However, because of the susceptibility of several ornamental species (Ries et al., 1959; Sherwood and

Kemmerer, 1964), as well as the problem of residue accumulation, use of this compound has been limited.

At field rates (2 to 4 pounds per acre) simazine controls the germinating seedlings of most annual broadleaf and grassy weeds; however, it will not control established annuals or perennials at the rates recommended for application to ornamental plantings.

Simazine is absorbed primarily through the root system and moves in an acropetal direction (Crafts, 1961) in the xylem (Minshall, 1954). Once in the tissue, simazine functions as a Hill Reaction inhibitor, thus preventing photosynthesis in the plant (Moreland et al., 1959).

Because simazine is absorbed primarily through the root system, its activity is dependent upon rainfall or overhead irrigation to move the chemical into the root zone (Schneider, 1958). Mechanical incorporation will improve herbicidal effectiveness when rainfall is insufficient to move the herbicide into the soil. Splittstoesser and Derscheid (1962) suggested that moisture exerts its influence on the herbicide in at least one of the following: (1) by leaching it into the soil, (2) by keeping it in solution in the soil, or (3) a combination of both. Burnside et al. (1961) found that simazine did leach into the soil, but Roadhouse and Birk (1961) found that after two years, simazine was still in the 0-1 inch soil layer.

The tolerance of woody plants to simazine under different environmental conditions has been studied. Davidson et al., (1965) demonstrated that some container grown woody ornamentals are sensitive to simazine. Sherwood and Kemmerer (1964) found less injury to fall planted lining-out grade nursery stock treated with simazine in late fall or early winter than when treated in the spring.

Simazine is recommended for use only after woody plants have been established for at least one year. Sherwood and Kemmerer (1964) suggest that this growing period allows the roots to become established and provides a firm plant bed thus reducing the danger of over-dosage when the chemical becomes impounded around the roots. Gysin (1960) found that young plants take up more herbicide than older plants from a given zone of soil.

Simazine is broken down in the soil through (1) hydrolysis by soil catalysts, (2) microbial activity and (3) uptake and decomposition by tolerant plants (Crafts, 1961).

Ahren (cited by Carpenter, 1967) found that when simazine was applied for six years, less residue was present than in soils which had simazine applied for only two years. He suggested that microorganisms capable of detoxifying simazine apparently increase in the soil over several seasons. As a result, soils may increase their potential to break down herbicides.

Diphenamid

Diphenamid, N, N-dimethyl-2, 2-diphenylacetamide, is a selective pre-emergence herbicide. In ornamental plantings, used at field rates (4 to 8 pounds per acre), diphenamid controls primarily annual grass weeds and a few broadleaf weeds. Its effectiveness in broadleaf weed control is variable. Diphenamid can be applied safely to most woody plants and is non-toxic to most newly set liners and small established plants (Anonymous, 1967).

Since diphenamid is used pre-emergence, presumably the compound is absorbed by the roots and translocated into the foliage. However, diphenamid might also be absorbed by entire seedlings.

Because diphenamid is mobile in the soil (Harris, 1964), rainfall or overhead irrigation is important and will usually improve weed control. Leaching of the herbicide depends upon the amount and distribution of rain or irrigation and soil character. Excessive rainfall may leach diphenamid out of the weed seed zone. Upward movement of diphenamid occurs under subirrigation and also when surface applied water is permitted to evaporate freely from the soil surface.

Dichlobenil

Dichlobenil, 2, 6-dichlorobenzonitrile, has been found effective in woody ornamental plantings. Koopman and Daams

(1960) observed that many full-grown plants are not injured by this compound. Dichlobenil is toxic to most plants but relatively immobile in the soil. Its selectivity is dependent upon the depth to which it is incorporated and the difference in growth stage of the plants concerned.

Persistence of dichlobenil following surface application is short under temperate conditions, but when incorporated mechanically or by irrigation persistence is increased. The modifying influence of soil incorporation and watering is attributed to the high vapor pressure (5×10^{-4} mm Hg at 20°C) and low water solubility (18 ppm. 20°C) of dichlobenil (Barnsley and Rosher, 1961). The persistence of dichlobenil can be extended from a few days to several weeks if the chemical is incorporated into the soil immediately following application.

Dichlobenil applied to the surface may be leached into the soil, thus becoming active in the weed seed zone. Because rainfall does not always occur after dichlobenil application or is insufficient to move the herbicide downwards, other methods have been suggested to facilitate incorporation. Irrigation assures a sufficient amount of water necessary to move dichlobenil into the weed seed zone. However, this method is impractical where large acreages are concerned, or on most landscape plantings.

Mechanical incorporation of dichlobenil is more efficient. This method assures proper herbicide placement in

the soil and minimizes loss through runoff that may occur if rainfall or irrigation is used (Pridham, 1962).

Dichlobenil is generally less toxic to plants than to seedlings. Used in the fall, dichlobenil suppresses or eliminates a number of perennial rhizomatous weeds. However, it is not known if some of the perennial weeds are killed or just suppressed in growth (Pridham, 1966).

The exact physiological system upon which dichlobenil acts is unknown; however, the compound is exceedingly toxic to tissues of high metabolic activity.

Dichlobenil enters the plant predominantly through the roots (Barnsley and Rosher, 1961). Because of its strong affinity for lignin and lipid material, dichlobenil moves slowly upwards in the xylem (Massini, 1961).

One important feature of dichlobenil is its ability to be easily absorbed by seeds to which it is highly toxic (Barnsley, 1960). This uptake occurs from the solution or vapor phase.

Dichlobenil is chemically stable and not subject to appreciable loss by leaching (Miller et al., 1966). Once incorporated into the soil, it is subject to slow microbiological detoxification (Barnsley and Rosher, 1961).

Trifluralin

Trifluralin, α, α, α , trifluoro-2, 6-dinitro-N, N-dipropyl-p-toluidine, is a relatively new herbicide that

must be incorporated for effective weed control (Guse and Schwer, 1964; Hicks and Fletchall, 1964). Incorporation is necessary to prevent photodecomposition.

Trifluralin possesses very little foliar contact activity (Alder and Bevington, 1962). Its primary activity is via absorption by seedling roots.

When applied to the soil, trifluralin may be affected by at least three factors: (1) volatility (Wright, 1964), (2) adsorption and leaching (Freeman et al., 1963; Wright, 1964), and (3) photochemical degradation (Wright, 1965).

Incorporation of trifluralin into the top 2-3 inches of soil greatly enhances its herbicidal activity (Nylund et al., 1963; Pieczarka et al., 1962). Best weed control occurs when trifluralin is applied to dry soil followed by irrigation. Application of trifluralin to moist soil results in a significant decrease in weed control (Bayer et al., 1963). Miller (1962) found that best control is obtained when trifluralin is either rototilled or buried. Incorporation of trifluralin has been shown to be four to six times as effective as trifluralin applied to the soil surface (Ellis and Ilnicki, 1963; Hargan and Sweet, 1962).

Bensulide

Bensulide, N-(2-mercaptoethyl)benzenesulfonamide S-(O, O-diisopropyl phosphorodithioate), is a new herbicide used primarily in turf for pre-emergence crabgrass control.

Bensulide provides excellent control of annual grasses but provides only fair control of annual broadleaf weeds (Ahrens, 1966). Because of its toxicity to grasses, bensulide may become an important herbicide in ornamental plantings.

Very little is known about the mode of action or fate of bensulide in the soil. Skogley and Jagschitz (1964) found that bensulide remained active in the soil for over 16 weeks. Engel and Callahan (1967) reported that after seven months bensulide remained largely in the top two inches of soil.

Herbicide Combinations in Woody Ornamental Plantings

A herbicide treatment is needed that is safe for use in ornamental plantings and effective against most annual broadleaf weeds and grasses. No one herbicide is known that can perform this function. However, by using minimum concentrations of herbicides in combination, it may be possible to reduce woody plant injury and maintain effective weed control.

Reduced concentrations of herbicides can be combined for safe use and effective weed control. Havis et al. (1965) found good to excellent control of both broadleaf weeds and grasses from the combinations: simazine (1 lb/A) + diphenamid (4 lb/A) and simazine (1 lb/A) + Dacthal (10

lb/A). Ornamental injury was not visible from the use of these combinations. Bennett et al. (1966) reported similar results with herbicide combinations using minimum concentrations of the individual herbicides.

Herbicide combinations offer other possible advantages besides the reduction in crop injury and broad spectrum weed control. Colby et al., (1965) suggested that combinations should improve control of particular weeds, reduce crop and soil residue, reduce herbicide cost, extend weed control over long periods of time, assure uniform weed control during weather conditions unfavorable to one of the herbicides, and possibly broaden selectivity by synergistic actions on weeds.

MINIMUM EFFECTIVE CONCENTRATIONS FORMULATED FOR HERBICIDE COMBINATIONS AND PRELIMINARY FIELD STUDIES

Introduction

The principle of combining individual herbicides at minimum concentrations to achieve broad spectrum weed control should be studied first under controlled greenhouse conditions. In using minimum concentrations for each herbicide potentially capable of controlling particular weed species, combinations can be formulated for a broad spectrum of weeds. Reduced injury to sensitive crop plants may be achieved by the herbicide combinations.

This series of experiments was designed to determine the effect of different concentrations of individual herbicides on particular weed species. Having found the minimum concentrations for particular weed species, combinations were then formulated and evaluated in the field.

Materials and Methods

Determination of Minimum Effective Concentrations

Experiments were conducted using three herbicides: simazine, diphenamid, and dichlobenil. Nine species of

weeds were selected for the preliminary weed control studies. These species were: velvet leaf (Abutilon theophrasti, Medic.), pigweed (Amaranthus retroflexus, L.), shepherd's purse (Capsella bursa-pastoris, Medic.), lambsquarter (Chenopodium album, L.), crabgrass (Digitaria sanguinalis, L., Scop.), barnyard grass (Echinochloa crusgalli, L. Beauv.), smartweed (Polygonum pensylvanicum, L.), yellow foxtail (Setaria lutescens, Beauv.), and chickweed (Stellaria media, L., Cyrill.). In the first series of experiments each herbicide was applied at six different concentrations.

A randomized complete block design with four replications was employed. The weeds were planted in plastic trays 7 x 5 x 1-3/4 inches containing sterilized loam. The weeds were sown in rows, each species containing a known number of seeds per row. The seeds were lightly covered with sand to assure uniform penetration of the spray and watered lightly. The herbicide was applied as a spray at a controlled rate of application. The flats were placed in the greenhouse. After approximately one month the number of each species of weed surviving was recorded.

After the minimum concentration required to control individual weeds was determined, the weed species yellow foxtail, velvetleaf, and smartweed were selected and grown for a period of three months. The remaining six species were discarded. After three months these weeds were then removed from the flats (the soil being disturbed as little as

possible) and the same three species used initially were re-sown. At this time no additional herbicide was applied. These flats were treated in the same manner as previously described. At the end of one month the total number of weeds growing was counted. The data for the initial minimum concentration of herbicide required to control weed growth was compared to the residual data of the same concentration.

Field Plot Experiments

After minimum effective concentrations were determined, fifteen herbicide combinations were selected and taken to the field for evaluation. The experiment was conducted at the Ornamental Horticulture Field Laboratory near Lafayette, Indiana, on an Eel silt loam soil. No herbicide was known to have been applied to the soil prior to this experiment.

On June 6, 1966, the 15 herbicide treatments were applied to cultivated plots measuring 5 x 7 feet. The herbicides were applied as wettable powder sprays using a tractor mounted boom-type sprayer. Within 30 minutes following application the field plots were irrigated, primarily to incorporate dichlobenil which is highly volatile.

After irrigation, the plots were left undisturbed for one month, at which time weed counts were taken. Four, one square foot areas were counted in each replication making a total of 16 square feet sampled per treatment. After the weed counts had been taken, the plots were scraped and the

weeds removed. The soil was disturbed as little as possible in order not to alter the herbicide distribution for subsequent weed control. The same procedure was followed at monthly intervals for the remaining two weed counts. Irrigation was applied once in June and once in early August.

Results and Discussion

Greenhouse Experiments

Figure 1 shows the effect of dichlobenil on two species, pigweed and crabgrass. Dichlobenil controlled pigweed at lower concentrations than required for crabgrass. Dichlobenil is usually considered to be more effective on broad-leaf weeds than on grasses. However, at higher concentrations crabgrass can be controlled. It is significant to note that both species were controlled at a concentration less than 4 lb/A. Dichlobenil has the disadvantage of being highly volatile and, as a result, its activity is short lived (Barnsley and Rosher, 1961). Also dichlobenil is very expensive (Carpenter, 1967) and if it could be used at lower rates, the cost could be greatly reduced.

Figure 2 represents the effect of diphenamid on yellow foxtail and shepherd's purse. Diphenamid proved more effective on the grass than on Shepherd's purse. The results are very typical of the selectivity of diphenamid. However, the significant point to consider is the low concentration (< 1 lb/A) of diphenamid required to control yellow foxtail.

Figure 1. Greenhouse comparison of concentration of dichlobenil required to control pigweed and crabgrass.

Figure 2. Greenhouse comparison of concentration of diphenamid required to control yellow foxtail and shepherd's purse.

Diphenamid will remain active throughout the 0 - 9 inch soil depth for 10 - 11 months after field application (Jones et al., 1964) which may be of advantage in a combination.

In Figure 3 the control achieved by simazine from its initial rate of application and the residue after twelve weeks is compared over the concentration of 0.25 lb/A to 3 lb/A when the different herbicides were being studied for minimum concentrations, the question of herbicide persistence became significant. In order to consider the length of time a herbicide might remain active in the soil, a residual test was conducted. Smartweed was controlled equally well at all concentrations both one and four months following application. Simazine is known to be more effective on broadleaved weeds which may explain the persistent effects. However, yellow foxtail was more tolerant and a higher concentration of 1 lb/A was required to obtain the level of control obtained 4 months earlier with 0.25 lb/A.

Table 1 summarizes the minimum concentrations required to control selected species. This supports the conclusion that effective herbicide rates vary with the weed species. Table 2 compares initial and residual effective rates and illustrates the short residual activity of dichlobenil and the loss of effectiveness of certain herbicides on some weeds while others continued to be effectively controlled.

Having an approximation of the minimum concentration required to control a particular weed species and knowing

Figure 3. Initial and residual control of smartweed and yellow foxtail by simazine determined after 4 and 16 weeks, respectively.

Table 1. Summary of minimum concentration required for weed control as indicated by significant differences at the 1% level.

Weed Species*	Simazine	Dichlobenil	Diphenamid
	lb/A	lb/A	lb/A
Chickweed	.25	.50	1
Shepherd's purse	.25	.50	3
Lambsquarter	.50	.50	NC**
Pigweed	.25	.50	1
Crabgrass	.25	.50	1
Barnyard grass	.25	.50	1

* See Appendix Table 1A for list of botanical and common names.

** NC indicates no significant weed control at the 5% level.

Table 2. Summary of residual tests for minimum concentrations required for weed control as indicated by significant differences at the 1% level.

Weed Species*	Simazine		Dichlobenil		Diphenamid	
	Initial Residue		Initial Residue		Initial Residue	
	lb/A		lb/A		lb/A	
Yellow Foxtail	.25	.50	.50	NC*	1.00	1.00
Velvetleaf	.25	1.00	.50	NC	NC	NC
Smartweed	.25	.25	.50	1.50	NC	NC

* See Appendix Table 1A for list of botanical and common names.

** NC indicates no significant weed control at the 5% level.

that the low concentrations lose activity rapidly, it was then possible to make several combinations from these individual herbicides for field experiments.

Field Results

Table 3 compares the effectiveness of diphenamid and dichlobenil alone and in combination. Dichlobenil applied at the normal rate of 4 lb/A controlled the broad spectrum of weeds that were present. Diphenamid was only effective in controlling the grasses and a few broadleaf weeds as indicated by the limited total weed control. In combination, the weed control was comparable to dichlobenil applied alone. After a total period of two months the combinations remained as effective as dichlobenil at the higher concentrations, but less effective than after one month. By the end of three months there was very little difference among treatments. When considering cost (Carpenter, 1967), the combination is less expensive than the dichlobenil applied alone, but the problem of limited residual activity due to the high volatility of the dichlobenil is very evident in these results as compared to the results obtained with the simazine-diphenamid combination (Table 4).

In comparing the simazine-diphenamid combination, simazine at 3 lb/A was the most effective of the three herbicides throughout the summer. However, at 3 lb/A simazine is toxic to many ornamental plants. At the lower rate of

Table 3. The effect of diphenamid and dichlobenil on weed control when applied alone and in combination. Field experiment treated June 6, 1966.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	Ave. no. weeds per sq. ft.		
Control	106.0	11.0	3.6
Dichlobenil (2)	1.3	5.0	2.8
Dichlobenil (4)	0.3	3.0	2.9
Diphenamid (4)	38.0	8.0	4.4
Diphenamid (6)	37.0	7.0	3.9
Dichlobenil (1) + Diphenamid (2)	1.2	4.0	1.4
Dichlobenil (1) + Diphenamid (4)	1.0	5.0	3.9
Dichlobenil (2) + Diphenamid (2)	0.2	3.6	2.4
Dichlobenil (2) + Diphenamid (4)	1.0	3.6	2.8

Table 4. The effect of diphenamid and simazine on weed control when applied alone and in combination. Field experiment treated June 6, 1966.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	Ave. no. weeds per sq. ft.		
Control	106.0	11.0	3.6
Diphenamid (4)	38.0	8.0	4.4
Diphenamid (6)	37.0	7.0	3.9
Simazine (1)	2.3	3.5	3.4
Simazine (3)	0.4	1.0	0.6
Simazine (.5) + Diphenamid (2)	2.2	2.0	2.9
Simazine (.5) + Diphenamid (4)	1.6	4.0	1.3
Simazine (1) + Diphenamid (2)	2.0	1.6	2.5
Simazine (1) + Diphenamid (4)	0.0	1.0	2.9

simazine, weed control was good but not complete and did not persist as well. Diphenamid was very poor alone both at the 4 and 6 lb/A rates. However, the combination of simazine (1 lb/A) + diphenamid (4 lb/A) was quite effective during the first two months and allowed an average of only 2.9 weeds per square foot during the third month. The lower concentrations of simazine applied singly were never as effective as this combination. Reduced injury or no injury to the crop may therefore be possible because of the reduced concentration. Also the possibility of soil residue build-up is considerably reduced.

From the field experiment, the herbicide combination simazine (1 lb/A) + diphenamid (4 lb/A) appears to be a possible combination that effectively controls weeds throughout the growing season, while being less toxic to the crop. In addition, a broad spectrum of weeds is being controlled with less possibility of herbicide build-up in the soil.

Summary

The principle of combining individual herbicides at reduced concentrations that would control weeds as effectively as individual herbicides at higher concentrations was studied. From greenhouse and field plot studies the combination of simazine (1 lb/A) + diphenamid (4 lb/A) was shown to give extended control over a broad spectrum of weeds. Because of the lower concentrations of the individual herbicides,

the possibility of reducing injury to sensitive crop plants is suggested.

FACTORS INFLUENCING THE EFFECTIVENESS OF HERBICIDE COMBINATIONS

Introduction

Herbicides that show promising results one year often show erratic responses in following years. The variation in control shown by some herbicides is known to be a factor of the environment. Kempen et al. (1963) showed that herbicide performance was markedly altered by soil incorporation, soil type, and rainfall.

The use of herbicide combinations may be a means of overcoming some environmental factors. However, even combinations must be used in particular ways to produce uniform results.

The objective of this study was to test individual herbicides and herbicide combinations under different environmental conditions stressing the form and time of application necessary to achieve broad spectrum weed control.

Materials and Methods

Two experiments were conducted at the Ornamental Horticulture Field Laboratory near Lafayette, Indiana, on an Eel silt loam soil. No herbicide was known to have been applied

to the soil prior to these experiments. In an effort to increase the weed population, an assortment of different weed seeds was uniformly sown over the area before the experiments were conducted. The germination percentage of these weed seeds were unknown.

A total of five herbicides were used in two experiments. They were bensulide, dichlobenil, diphenamid, simazine, and trifluralin. Dichlobenil and trifluralin volatilize readily when applied to the soil surface, while simazine and diphenamid do not. Bensulide has not been used sufficiently to ascertain the optimum mode of application required for persistent activity. Because the herbicides selected for this experiment vary with respect to their requirements of application, two separate experiments were performed. The first experiment, designated experiment A, consisted of the four herbicides, bensulide, dichlobenil, diphenamid, and simazine applied to the soil surface, with either rainfall or overhead irrigation used as the method of incorporating the herbicides. The second experiment, designated experiment B, used the five herbicides bensulide, dichlobenil, diphenamid, simazine, and trifluralin incorporated with a hand garden cultivator to a depth of two inches immediately following application. Rainfall and overhead irrigation also supplemented incorporation.

The two experiments were designed and performed identically except for the method of incorporation. A

split-split plot design was employed in the experiments. Date of herbicide application constituted the whole plot units (Nov. 23, 1966, April 25, 1967, or June 1, 1967). The sub-plot treatments were the eight herbicide treatments. The sub-sub-plot treatments were the date of making the weed counts (July 1, Aug. 1, Sept. 1, 1967).

Eight herbicide treatments in both experiment A and B were applied on cultivated plots measuring 4.5 x 15 feet. The herbicides were applied in granular form using a modified tractor mounted Gandy granular spreader. Approximately 1-1/2 inches of irrigation water were applied immediately following the June 1 herbicide application only. Irrigation was applied for the ornamental plants used in the plant toxicity experiment. The plant toxicity experiment will be discussed in a later chapter. Overhead irrigation and rainfall data are recorded in the Appendix, Tables A1 and A2.

Except for the plots treated on November 23, 1966, all plots were left undisturbed until July 1, 1967. Weed counts were taken from the November 23 plots on June 3.

A 1 x 6 foot area from the center of each plot was utilized for weed counts, making a total of 24 square feet sampled per herbicide treatment. After each weed count, the plots were scraped and the weeds removed. The soil was disturbed as little as possible in order to retain the herbicide distribution within the soil for subsequent weed counts. The same procedure was followed after each counting.

Because of excessive rainfall following the November application, the possibility of lateral movement was considered. Soil samples were taken from between the treatments and within the treatments. The samples taken were one inch in diameter and two inches deep. Several samples from each treatment were taken for each bioassay and mixed for uniform sampling. Oat plants (Avena sativa var. Victory) were used as the test species. No significant differences were found between soil known to be free of herbicides and plot samples; thus, indicating no lateral movement from one treatment to an adjacent treatment.

The IBM, 7094 computer using the BMD0 2V program for Analysis of Variance for Factorial Design was used in analyzing the data. To fulfill the statistical requirements of having data independently and normally distributed with a common variance, a square root transformation was performed on all data before the analysis of variance and Duncan's new multiple range test was performed (Steel and Torrie, 1960). Duncan's new multiple range test was performed on all first order interactions. After analysis, the means were transformed back to the original units for presentation in tables.

Results and Discussion

Surface Application of Herbicides

Weed totals are summarized in Table 5, and further subdivided into grasses, purslane and other broadleaved weeds in Tables 6 to 8. The marginal means, herbicides x seasons interaction, and herbicide x counts interactions are shown in Tables A3 to A9. Tables 6 to 8 subdivide the total weed population into separate groups comprising the total number of weeds in Table 5. The total weed population was arbitrarily divided into various groups on the basis of prevailing weeds.

Table 6 is collective for all grass species, because on the sampling dates most of the grasses were too small to identify. Purslane was the predominant broadleaf weed throughout the experiment; therefore, it is listed separately in Table 7. The remaining dicotyledonous weeds were few in number and are presented in Table 8. The dicotyledonous weeds consisted of carpetweed (Mollugo verticillata, L.), Jimson weed (Datura stramonium, L.), galinsoga (Galinsoga parviflora, Cau.), pigweed, yellow wood sorrel (Oxalis europaea, Jord.), bindweed (Convolvulus arvensis, L.), lambs-quarter, velvet leaf, knotweed (Polygonum aviculare, L.), ragweed (Ambrosia artemisifolia L.), dandelion (Taraxacum officinale, L.), curled dock (Rumex crispus, L.), ground cherry (Physalis heterophylla, Nees.), Canada thistle

Table 5. Total number of weeds following surface application of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling	Time of Application		
	Date	Nov. 23	Apr. 25	June 1
	Ave. no. per sq. ft.*			
Check	June 1	6.0	-	-
	July 1	25.2	18.6	110.8
	Aug. 1	4.5	3.5	4.5
	Sept. 1	0.8	1.5	2.9
Bensulide (8)	June 1	1.7	-	-
	July 1	18.2	11.9	9.2
	Aug. 1	2.2	2.5	2.0
	Sept. 1	0.6	0.9	2.0
Dichlobenil (4)	June 1	0.2	-	-
	July 1	14.8	15.4	5.1
	Aug. 1	2.1	2.9	0.6
	Sept. 1	0.3	0.8	1.4
Diphenamid (6)	June 1	0.1	-	-
	July 1	5.3	3.8	21.4
	Aug. 1	1.4	1.0	2.3
	Sept. 1	1.0	0.4	1.7
Simazine (3)	June 1	0.1	-	-
	July 1	3.4	1.5	5.0
	Aug. 1	1.7	1.2	0.5
	Sept. 1	0.5	0.3	0.7
Simazine (1) + Diphenamid (4)	June 1	0.2	-	-
	July 1	8.6	4.0	0.8
	Aug. 1	2.0	1.2	0.3
	Sept. 1	1.0	0.3	0.6
Simazine (1) + Bensulide (4)	June 1	0.4	-	-
	July 1	18.1	4.8	16.8
	Aug. 1	2.3	2.0	2.3
	Sept. 1	0.4	0.6	1.5
Dichlobenil (2) + Diphenamid (4)	June 1	0.8	-	-
	July 1	9.7	9.2	1.2
	Aug. 1	1.1	2.2	1.2
	Sept. 1	0.2	0.8	2.1

* Weeds removed following each counting.

Table 6. Total number of grass plants following surface application of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling	Time of Application		
	Date	Nov. 23	Apr. 25	June 1
		Ave. no. per sq. ft.*		
Check	July 1	4.5	4.9	5.5
	Aug. 1	2.0	0.9	1.9
	Sept. 1	0.5	0.7	0.4
Bensulide (8)	July 1	0.9	0.3	0.2
	Aug. 1	0.2	0.2	0.2
	Sept. 1	0.1	0.1	0.1
Dichlobenil (4)	July 1	0.4	2.6	0.3
	Aug. 1	0.2	0.6	0.3
	Sept. 1	0.0	0.5	0.5
Diphenamid (6)	July 1	1.2	0.1	0.0
	Aug. 1	0.5	0.0	0.1
	Sept. 1	0.5	0.0	0.1
Simazine (3)	July 1	0.7	0.4	0.2
	Aug. 1	0.6	0.2	0.1
	Sept. 1	0.3	0.1	0.2
Simazine (1) + Diphenamid (4)	July 1	0.8	0.4	0.0
	Aug. 1	0.5	0.1	0.2
	Sept. 1	0.5	0.0	0.2
Simazine (1) + Bensulide (4)	July 1	1.1	0.3	0.2
	Aug. 1	0.4	0.5	0.3
	Sept. 1	0.2	0.2	0.1
Dichlobenil (2) + Diphenamid (4)	July 1	0.2	0.6	0.0
	Aug. 1	0.0	0.1	0.7
	Sept. 1	0.0	0.1	0.8

* Weeds removed following each counting.

Table 7. Total number of purslane plants following surface application of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling Date	Time of Application		
		Nov. 23	Apr. 25	June 1
		Ave. no. per sq. ft.*		
Check	July 1	20.4	11.8	104.8
	Aug. 1	2.5	2.0	2.5
	Sept. 1	0.2	0.6	2.4
Bensulide (8)	July 1	16.6	10.6	8.9
	Aug. 1	1.8	1.8	1.7
	Sept. 1	0.5	0.6	1.7
Dichlobenil (4)	July 1	14.3	12.8	4.8
	Aug. 1	1.8	2.2	0.3
	Sept. 1	0.3	0.2	0.9
Diphenamid (6)	July 1	4.6	2.5	21.0
	Aug. 1	0.9	0.4	1.7
	Sept. 1	0.4	0.2	1.5
Simazine (3)	July 1	2.6	1.0	4.8
	Aug. 1	1.1	0.9	0.4
	Sept. 1	0.2	0.2	0.5
Simazine (1) + Diphenamid (4)	July 1	7.8	3.3	0.8
	Aug. 1	1.5	1.0	0.1
	Sept. 1	0.5	0.4	0.4
Simazine (1) + Bensulide (4)	July 1	16.8	4.2	16.5
	Aug. 1	1.9	2.2	2.0
	Sept. 1	0.2	0.4	1.4
Dichlobenil (2) + Diphenamid (4)	July 1	9.1	8.4	1.2
	Aug. 1	0.9	2.0	0.5
	Sept. 1	0.2	0.7	1.2

* Weeds removed following each counting.

Table 8. Total number of dicotyledonous weeds other than purslane following surface application of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling Date	Time of Application		
		Nov. 23	Apr. 25	June 1
		Ave. no. per sq. ft.*		
Check	July 1	0.2	2.0	0.6
	Aug. 1	0.1	0.5	0.1
	Sept. 1	0.0	0.2	0.1
Bensulide (8)	July 1	0.6	1.0	0.2
	Aug. 1	0.1	0.4	0.3
	Sept. 1	0.0	0.1	0.2
Dichlobenil (4)	July 1	0.1	0.0	0.0
	Aug. 1	0.0	0.0	0.0
	Sept. 1	0.0	0.0	0.0
Diphenamid (6)	July 1	0.0	1.2	0.4
	Aug. 1	0.0	0.5	0.1
	Sept. 1	0.0	0.2	0.1
Simazine (3)	July 1	0.0	0.0	0.0
	Aug. 1	0.0	0.0	0.0
	Sept. 1	0.0	0.0	0.0
Simazine (1) + Diphenamid (4)	July 1	0.1	0.3	0.0
	Aug. 1	0.0	0.0	0.0
	Sept. 1	0.0	0.0	0.0
Simazine (1) + Bensulide (4)	July 1	0.2	0.2	0.1
	Aug. 1	0.0	0.0	0.6
	Sept. 1	0.0	0.0	0.0
Dichlobenil (2) + Diphenamid (4)	July 1	0.5	0.2	0.0
	Aug. 1	0.2	0.0	0.0
	Sept. 1	0.0	0.0	0.1

* Weeds removed following each counting.

(Cirsium arvense, L., Scop.) and Red sorrel (Rumex aceto-
sella, L.).

In analysis of total weeds (Table 5), there are certain weed population patterns that should be recognized. First, the small number of weeds present in the June count may be due primarily to the unusually cool spring (see soil temperature data, Table A2). Second, the total number of weeds in the check plots at the July counting was greatest for the June application and unusually low for the November and April applications.

The fewer number of weeds in the July counting for the November subplot may be accounted for by the hand-hoeing following the June 1 weed count. Since the soil was only slightly disturbed in the hoeing operation, no new weed seeds were brought to the soil surface and most of those weed seeds in the top one-half inch of soil had probably germinated prior to the weed count.

The April subplot also had very few weeds in June; and, thus were not counted nor removed. As a result, the weed competition from the few weeds present in June may have been sufficient to shade or crowd out new weed growth by July. In general, the herbicide treatments for April were more effective than for the November or June applications.

Each of the individual herbicide treatments responded differently to the weed population. The individual herbicides were applied at concentrations normally used in

ornamental plantings except for trifluralin which was applied at twice the recommended rates. The control of particular weed groups can be related to the time of application and the date of sampling (Tables 6 to 8).

Simazine (3 lb/A). Simazine was most effective when applied in November or April and was generally effective in the June application (Table 5). Considering over all weed counts, seasons, and replications, simazine resulted in the lowest weed count but was not significantly different from the combinations, simazine-diphenamid and dichlobenil-diphenamid (Table A3). Dicotyledonous weeds excluding purslane were not found in the simazine treatment and only a few grasses and purslane were noted (Tables 6 to 8). Once simazine enters the weed seed zone it persists. Simazine is active when adequate soil moisture is present (Derscheid, 1958; Splittstoesser and Derscheid, 1962; and Schneider, 1958). The results indicate consistent weed control regardless of season of application. Approximately 1-1/2 inches of overhead irrigation was applied immediately following the herbicide application in June, when rainfall was probably insufficient to incorporate the herbicide.

Diphenamid (6 lb/A). Diphenamid was significantly more effective when applied in November or April than when applied in June (Tables 5 and A4). This is primarily due to the emergence of purslane following the June application (Table A6). The herbicide x season interactions (Tables A5

and A6) demonstrate the capacity of diphenamid to control grasses equally at all seasons of application but not purslane. Diphenamid is a persistent herbicide which may remain active in the soil for nine months or longer (Jones et al., 1964).

Dichlobenil (4 lb/A). Dichlobenil applied to the soil surface did not control weeds over long periods of time (Table 5). The persistence of surface applied dichlobenil is very short because of its high vapor pressure and low water solubility (Barnsley and Rosher, 1961). Dichlobenil is recommended for surface application only during late fall, winter, or early spring. Its effectiveness was limited when applied in November or April (Tables A4 to A6); however, June applications were significantly more effective. This may be due to the irrigation following the June treatment which would have increased soil incorporation. These results indicate that dichlobenil should always be incorporated regardless of season of application.

Bensulide (8 lb/A). The June application of bensulide was most effective (Table 5). However, bensulide did not provide the broad spectrum weed control exhibited by the other herbicides. It did control the grasses at all applications (Table 6) and for all sampling dates (Table A7). Bensulide is known to be a persistent herbicide in the control of grasses (Skogley and Jagschitz, 1964; Engel and Callahan, 1967).

Simazine (1 lb/A) + Bensulide (4 lb/A). The simazine-bensulide combination was not particularly effective (Table 5). Only small differences were found between the bensulide alone and the combination simazine-bensulide. The combination did control grasses as effectively as simazine 3 lb/A but was less effective in controlling purslane (Tables 6 and 7). Bensulide alone was nearly twice as effective as when it was used in combination with simazine in the June application (Tables 5 and A4).

Dichlobenil (2 lb/A) + Diphenamid (4 lb/A). Dichlobenil-diphenamid was more effective applied in June than in November or April (Table 5). Although not significantly different, the combination did control more total weeds than did dichlobenil in the November and April times of application (Table A4). Diphenamid, likewise, was significantly less effective than the combination for the June application (Table A4). Diphenamid used alone failed to control purslane in the June application but did in the November and April applications (Table 7). Dichlobenil used alone was more effective in the June application than in the November or April applications (Table 7). Both were effective in controlling grass (Table 6).

Dichlobenil-diphenamid was significantly better in broad spectrum weed control in the July weed count than dichlobenil alone (Table A7). The combination was significantly more effective than dichlobenil in July in controlling

purslane (Table A9); however, diphenamid was as effective as the combination in controlling grasses and purslane in July (Tables A8 and A9).

Simazine (1 lb/A) + Diphenamid (4 lb/A). The simazine-diphenamid combination provided the same broad spectrum weed control throughout all seasons as did the individual herbicide simazine 3 lb/A (Table 5). This combination had been tried the previous year (1966) (Table 4) and had proven effective.

In the June application as well as the July weed count, simazine-diphenamid controlled purslane significantly better than diphenamid 6 lb/A (Tables A5 and A9). No significant differences were found in grass control among the individual herbicides and the combination (see Appendix Table A6).

Soil Incorporation of Herbicides

The total number of weeds observed in the plots of this experiment are summarized in Table 9. Data summarizing the total number of purslane, grasses, and miscellaneous broadleaf weeds are found in Tables 10 to 12, respectively. The dicotyledonous weeds are the same species listed in the surface applied experiment. The marginal means, herbicides x seasons interactions, and herbicides x counts interactions are shown in Tables A10 to A16.

Table 9. Total number of weeds following incorporation of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling Date	Time of Application		
		Nov. 23	Apr. 25	June 1
		Ave. no. per sq. ft.*		
Check	June 1	3.9	-	-
	July 1	21.0	29.8	56.0
	Aug. 1	7.0	6.5	5.2
	Sept. 1	1.5	1.6	1.9
Bensulide (8)	June 1	1.6	-	-
	July 1	15.0	10.1	38.0
	Aug. 1	2.8	1.7	3.6
	Sept. 1	0.9	0.8	1.2
Dichlobenil (4)	June 1	0.1	-	-
	July 1	0.6	1.5	4.4
	Aug. 1	2.4	1.8	2.1
	Sept. 1	1.0	0.3	0.9
Trifluralin (2)	June 1	0.2	-	-
	July 1	0.8	0.7	2.5
	Aug. 1	0.7	0.7	0.9
	Sept. 1	0.9	0.5	0.8
Trifluralin (1) + Simazine (1)	June 1	0.1	-	-
	July 1	6.8	3.9	14.7
	Aug. 1	1.2	0.8	1.9
	Sept. 1	0.7	0.4	0.8
Dichlobenil (2) + Trifluralin (1)	June 1	0.1	-	-
	July 1	3.1	1.1	6.5
	Aug. 1	1.4	1.1	2.0
	Sept. 1	1.3	0.2	1.0
Dichlobenil (2) + Diphenamid (4)	June 1	0.1	-	-
	July 1	9.8	2.8	9.0
	Aug. 1	2.0	1.7	3.0
	Sept. 1	0.8	0.7	1.5
Dichlobenil (2) + Bensulide (4)	June 1	0.0	-	-
	July 1	12.8	1.4	14.5
	Aug. 1	3.3	2.1	2.5
	Sept. 1	2.1	0.5	1.5

Table 10. Total number of grass plants following incorporation of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling Date	Time of Application		
		Nov. 23	Apr. 25	June 1
		Ave. no. per sq. ft.		
Check	July 1	3.1	4.3	2.2
	Aug. 1	2.1	2.4	1.9
	Sept. 1	0.6	0.8	0.8
Bensulide (8)	July 1	0.4	0.4	0.5
	Aug. 1	0.4	0.2	0.7
	Sept. 1	0.3	0.2	0.1
Dichlobenil (4)	July 1	0.2	0.0	0.4
	Aug. 1	0.5	0.6	0.5
	Sept. 1	0.3	0.1	0.2
Trifluralin (2)	July 1	0.3	0.1	0.3
	Aug. 1	0.2	0.2	0.0
	Sept. 1	0.1	0.1	0.1
Trifluralin (1) + Simazine (1)	July 1	0.2	0.2	0.5
	Aug. 1	0.3	0.2	0.5
	Sept. 1	0.2	0.2	0.1
Dichlobenil (2) + Trifluralin (1)	July 1	0.2	0.0	0.4
	Aug. 1	0.2	0.4	0.6
	Sept. 1	0.4	0.2	0.3
Dichlobenil (2) + Diphenamid (4)	July 1	0.8	0.2	1.1
	Aug. 1	0.4	0.2	0.8
	Sept. 1	0.2	0.2	0.5
Dichlobenil (2) + Bensulide (4)	July 1	0.7	0.1	0.5
	Aug. 1	1.2	0.3	0.2
	Sept. 1	0.8	0.0	0.2

Table 11. Total number of purslane plants following incorporation of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling Date	Time of Application		
		Nov. 23	Apr. 23	June 1
		Ave. no. per sq. ft.		
Check	July 1	17.4	23.4	51.8
	Aug. 1	4.6	4.0	2.9
	Sept. 1	0.8	0.6	0.9
Bensulide (8)	July 1	13.5	8.3	36.0
	Aug. 1	2.1	1.1	2.4
	Sept. 1	0.5	0.5	0.9
Dichlobenil (4)	July 1	0.8	1.4	4.0
	Aug. 1	1.9	1.1	1.5
	Sept. 1	0.6	0.1	0.7
Trifluralin (2)	July 1	0.4	0.2	2.0
	Aug. 1	0.6	0.2	0.7
	Sept. 1	0.7	0.0	0.6
Trifluralin (1) + Simazine (1)	July 1	6.5	3.4	13.8
	Aug. 1	0.9	0.5	1.3
	Sept. 1	0.4	0.1	0.5
Dichlobenil (2) + Trifluralin (1)	July 1	2.8	1.0	6.0
	Aug. 1	1.1	0.6	1.2
	Sept. 1	0.9	0.0	0.5
Dichlobenil (2) + Diphenamid (4)	July 1	9.0	2.6	7.8
	Aug. 1	1.6	1.3	2.0
	Sept. 1	0.5	0.2	0.9
Dichlobenil (2) + Bensulide (4)	July 1	12.0	1.2	14.0
	Aug. 1	2.0	1.5	2.1
	Sept. 1	1.3	0.2	1.1

Table 12. Total number of dicotyledonous weeds other than purslane following incorporation of various herbicides applied at three different seasons.

Herbicide (lb/A)	Sampling	Time of Application		
	Date	Nov. 23	Apr. 23	June 1
		Ave. no. per sq. ft.		
Check	July 1	0.5	2.1	2.1
	Aug. 1	0.2	0.2	0.3
	Sept. 1	0.1	0.3	0.2
Bensulide (8)	July 1	1.1	1.4	1.2
	Aug. 1	0.3	0.3	0.5
	Sept. 1	0.0	0.0	0.2
Dichlobenil (4)	July 1	0.0	0.0	0.0
	Aug. 1	0.0	0.1	0.1
	Sept. 1	0.1	0.1	0.0
Trifluralin (2)	July 1	0.1	0.4	0.2
	Aug. 1	0.0	0.3	0.2
	Sept. 1	0.0	0.4	0.1
Trifluralin (1) + Simazine (1)	July 1	0.0	0.3	0.4
	Aug. 1	0.0	0.0	0.1
	Sept. 1	0.0	0.0	0.2
Dichlobenil (2) + Trifluralin (1)	July 1	0.2	0.1	0.1
	Aug. 1	0.0	0.0	0.2
	Sept. 1	0.0	0.0	0.2
Dichlobenil (2) + Diphenamid (4)	July 1	0.1	0.0	0.1
	Aug. 1	0.0	0.1	0.2
	Sept. 1	0.0	0.2	0.1
Dichlobenil (2) + Bensulide (4)	July 1	0.1	0.0	0.0
	Aug. 1	0.1	0.2	0.2
	Sept. 1	0.1	0.2	0.2

The check plots in the incorporation experiment were more uniform than those in the surface application experiment. The June application subplot contained twice as many weeds as did the April or November subplots (Table 9). This may be a result of the June cultivation which brought new weed seeds to the soil surface to germinate. Many of these seeds germinated under favorable climatic conditions of early summer.

Bensulide (8 lb/A). Bensulide was the least effective of all treatments in the incorporation study (Table 9). Bensulide controlled grasses significantly at all times of application and at all sampling dates (Tables A12 and A15). However, the herbicide was ineffective in controlling purslane (Table 10). Bensulide was more effective applied in November and April than in June (Table 9), probably because of the greater proportion of purslane plants emerging at that time.

Dichlobenil (4 lb/A). Broad spectrum weed control was achieved by the incorporation of dichlobenil (Table 9). Time of application showed no significant difference in weed control (Table A11), nor was there any difference observed between the various weed counts (Table A14). The total effectiveness, as shown by the marginal means (Table A10), showed dichlobenil to be second to trifluralin in broad spectrum weed control.

Trifluralin (2 lb/A). Applied at twice the recommended rate, trifluralin was the most effective herbicide in the incorporation study (Table 9). No significant difference in total weed control was noted between times of application (Table All).

Trifluralin activity remained constant throughout the three sampling dates (Table 9). The trifluralin activity is known to be dependent upon incorporation. Pieczarka et al., (1962) found trifluralin to be four to six times more active when incorporated than when applied to the soil surface. Trifluralin persistence is decreased as soil moisture increases (Wright, 1964).

Trifluralin (1 lb/A) + Simazine (1 lb/A). The trifluralin-simazine combination was not as effective as trifluralin applied alone (Table 9). In this combination trifluralin was applied at the recommended rate of one pound per acre. However, even when combined with one pound of simazine, which was shown to be effective in the surface application experiment, the combination did not control all weeds. Weed control in the November and June applications was not as effective as in April (Table 9). The loss in control may be accounted for by (1) trifluralin 1 lb/A was not concentrated sufficiently to control a broad spectrum of weeds, and (2) simazine, mechanically incorporated to a depth of two inches, may be diluted to concentrations too low for effective weed control.

Trifluralin-simazine was least effective in controlling purslane in the July weed count (Table A16). Purslane seeds are very small and probably only germinate in the upper one-half inch of the soil. At two inches the herbicide may have been incorporated too deeply.

Dichlobenil (2 lb/A) + Trifluralin (1 lb/A). The dichlobenil-trifluralin combination was the most effective combination in the incorporation experiment. At all times of application, the combination was as effective as the individual herbicides applied alone (Table A11). Time of application did not affect the control of any particular group of weeds (Tables 10 to 12). The combination remained active throughout the summer.

Dichlobenil (2 lb/A) + Diphenamid (4 lb/A). April application of the dichlobenil-diphenamid combination showed the most effective control of weeds of the three applications (Table A11). Purslane was not controlled as effectively in July as in August and September (Table A16).

This combination utilized a persistent and a non-persistent herbicide. The persistence of dichlobenil-diphenamid was longer when incorporated than when applied to soil surface. However, in Table 9, it can be seen that dichlobenil-diphenamid was most effective if applied in April. This may be possible if dichlobenil volatilized in June because of the high temperatures and low rainfall. When the combination was applied in November, both herbicides may

have lost considerable activity by July and thus control was not effective.

Dichlobenil (2 lb/A) + Bensulide (4 lb/A). Dichlobenil-bensulide was only effective in the April application (Table 9). The June application was less effective, particularly on purslane, which was the most troublesome weed in July (Table 12). Because bensulide is selective only toward grasses and dichlobenil does not remain persistent for long periods, this combination would not be expected to be effective for an extended period of time. However, the combination did give greater purslane control than bensulide 8 lb/A (Table A16).

Comparison of Surface and Incorporated Results

By examining the methods of application separately, it was possible to examine critically possible environmental factors involved in responses from different treatments.

It seems pertinent to compare surface application and incorporation in order to evaluate overall effectiveness. Herbicides used in both modes of application were selected because of their chemical properties and modes of action. Because the herbicide treatments were different for each experiment, it is not possible to compare statistically the two methods of application. However, some comparative observations may be made from an analysis of the separate results.

A comparison of the surface and incorporated applications of dichlobenil demonstrates the necessity of incorporating certain herbicides. Dichlobenil applied to the surface did provide short term weed control, but long term weed control was only possible by incorporation. The striking contrast between the surface and incorporated application of dichlobenil points out the necessity for considering incorporation whenever dichlobenil is used.

Bensulide appeared to be more effective for grass control when applied to the surface than when incorporated. However, since other herbicides provided better grass control, its potential use in ornamental plantings may be limited.

Simazine was shown to be the most effective herbicide treatment in the surface application experiment. Its persistence is advantageous in that it provides full season weed control. However, simazine applied at normal rates is known to be toxic to several ornamental species.

In an attempt to reduce ornamental injury, simazine was combined with diphenamid at a minimum effective concentration. The simazine-diphenamid combination did not persist in the soil from November until June. However, this combination did prove effective throughout the summer when applied in April or June. Simazine-diphenamid combination applied in early spring before weed seeds germinate should provide effective control. The combination would probably

dissipate before the following winter, thus reducing or eliminating the possibility for herbicide buildup in the soil.

Trifluralin was shown to be the most effective herbicide treatment in the soil incorporation experiment. Trifluralin was applied at twice the recommended rate. If crop injury does not occur at this concentration, trifluralin may prove to be an effective herbicide for use in ornamentals.

Simazine and trifluralin were combined in a soil incorporated treatment. Simazine was applied at the minimum effective concentration of one pound per acre while trifluralin was applied at the normal rate of one pound per acre. The simazine-trifluralin combination did not provide effective control; however, the combination might have been more effective if trifluralin had been incorporated and simazine had been applied to the surface. This separate application might be beneficial if trifluralin were incorporated in late fall before ornamental plants are planted and then the simazine application could be made during the spring to strengthen the weed control throughout the summer months and fall.

The method of herbicide application is not normally dictated by the time of herbicide application. However, with the dichlobenil-diphenamid combination, herbicidal effectiveness at certain times is influenced by the method of application. For example, the dichlobenil-diphenamid combination was more effective in April if incorporated; but a surface application was more effective in June (Tables 5 and 9).

The time of application probably influenced the method of application because of the diphenamid mobility. Diphenamid, being highly mobile, is able to move upward when incorporated in April to become concentrated in the upper surface area where weed seeds begin to germinate. However, when incorporated in June, diphenamid could not readily move into the weed seed zone of the soil, and thus the control was less effective. In contrast, the surface applied diphenamid was easily leached into the weed seed zone, and its activity was readily apparent.

Summary

Herbicides, alone and in combination, were field tested to determine their effectiveness for ornamental plantings used as surface applied or soil incorporated treatments during varying times of the year.

The dichlobenil-diphenamid combination was shown to be more effective in April if incorporated; however, it was more effective in June when applied to the soil surface. Simazine-diphenamid applied to the surface gave excellent weed control if applied in April or June but was not persistent when applied in November.

Incorporated trifluralin applied alone at twice the recommended rate was shown to give excellent broad spectrum weed control at all times tested.

EFFECT OF HERBICIDE COMBINATIONS ON PLANT TOXICITY

Introduction

The main objective in the previous experiments was to determine the minimum concentration of herbicides when used in combinations required to provide broad spectrum weed control. Such minimum concentrations of individual herbicides should reduce herbicide injury to susceptible ornamental plants.

Herbicide combinations involving minimum rates should reduce herbicide injury when pre-plant applications are desired. Haramaki (1961-1966) has evaluated various herbicides on different bedding plants and ornamentals in a pre-planting method of application. He has demonstrated the feasibility of planting ornamental cuttings or transplanting bedding plants into pre-treated soil.

The objectives of this series of experiments were to evaluate phytotoxicity of herbicide combinations used in the previous experiments, and to determine the effectiveness of combinations as pre-plant treatments.

Materials and Methods

Field Experiment I

Herbicides were applied to the soil surface and incorporated into the soil as described for the previous experiment. Ornamental species were planted at the time of herbicide application: April 25, and June 1. The herbicide treatments and rates of application are listed in the previous chapter. A randomized complete block design was employed with four plants of each species being planted in each herbicide plot. The test was replicated four times.

Three species were planted in April: Cheyenne privet (Ligustrum vulgare 'Cheyenne,' L.), showy border forsythia (Forsythia intermedia 'Spectabilis,' Zabe.) and dwarf nine-bark (Physocarpus opulifolius 'Nana.'). Two species were planted in June in both forms of incorporation. The species were: ajuga (Ajuga 'Metallica Crispa,' L.) and Dwarf winged Euonymus (Euonymus alata 'Compacta.' Sieb.).

Treated plots were 4-1/2 feet x 15 feet with plants located on 18-inch centers. All plants were cut back to 8 inches or uniform size after planting. Sun shades were placed over the June plantings and overhead irrigation was applied. The shades were removed on July 1, when the first weed count was taken. Overhead irrigation was employed throughout the summer because the 1967 season was unusually

dry. (See Tables A1 and A2 for rainfall and irrigation data.)

On September 6, three months after planting, growth measurements were taken of all species to ascertain the amount of injury caused by the various herbicides. Growth measurements for ninebark, forsythia, and privet were taken by shearing the plants to a 12-inch height. The clippings were weighed and the four plants for each treatment were averaged. Growth measurements for ajuga were taken by measuring the diameter of each plant and then averaging the four plants per treatment. Euonymus produced its new flush of growth early in the spring prior to treatment and grew very little thereafter. Thus, no growth measurements were taken.

Survival counts were taken for each species on September 6. Separate analysis of variance were performed for each species for both survival and growth. Arc sin transformations were conducted on the survival analysis in order to make the data more homogeneous. Means presented in the tables are original data means.

Field Experiment II

Another field experiment was designed to evaluate the toxicity of the combination simazine 1 lb/A + diphenamid 4 lb/A. Purpleleaf wintercreeper (Euonymus fortunei 'Coloratus,') which is sensitive to simazine was selected for this experiment. Simazine at 3 lb/A, and

simazine 1 lb/A + diphenamid 4 lb/A were compared along with a control. The herbicides were applied in granular form. A randomized complete block design, with three replications, was employed. Eight plants were utilized in each treatment. Plots measured 3 x 5 feet and plants were spaced on 12-inch centers. Percent survival and injury was determined but no analysis of variance was performed on this experiment.

Greenhouse Experiment

The greenhouse experiment was designed to measure phytotoxicity of various herbicides applied as a pre-plant soil incorporated treatment to ornamental plants. The herbicides bensulide, dichlobenil, diphenamid, and trifluralin were used in the experiments. A randomized complete block design was employed. Each treatment was replicated four times.

Various annual and perennial flowers and ornamental plants were used in these experiments. The species were: zinnia (Zinnia elegans, Jacq.), marigold (Tagetes patula, L.), chrysanthemum (Chrysanthemum morifolium, Ramat.), Bluemist spirea (Caropteris incana 'Azarc,' Miq.), Cheyenne privet, Ajuga and Purpleleaf wintercreeper. In a second experiment herbicide rates 4 times the normal concentration were used.

The young transplants and rooted cuttings were planted into nine ounce Dixie cups. One plant was placed in each cup. Three plants constituted a replication, thus providing 12 plants for estimating the mean toxicity level per treatment.

Herbicides were applied in units of pounds per acre-inch rather than pounds per acre. Ten milliliters of herbicide solution were pipetted onto a known volume of soil. The soil was placed on top of a sheet of plastic. After the herbicide was pipetted onto the soil, two men held either end of the plastic and turned the soil 30 times by lowering one end and allowing the soil to fall, then lowering the opposite side and allowing the soil to fall over and mix. One complete cycle consisted of lowering both sides. This method has given consistent results in other experiments (Prendeville, 1967)¹.

Plants were transplanted into the treated soil and left undisturbed for three weeks in the greenhouse. After the waiting period, the plants were rated for injury. A one to five scale was used; one indicating no injury and five indicating death. An analysis of variance was performed.

¹Personal communication.

Results and Discussion

Field Experiment I

Results of this experiment are found in Tables 13 to 16. Large variability in survival and growth was found in three of the five species studied (forsythia, euonymus, and ligustrum). This variability may be accounted for in part by the poor condition of the plant material upon arrival from various nurseries. Most of the ornamentals had begun growth prior to planting and the shock of planting was great for many of the plants.

Ajuga and ninebark were the only species that survived the transplanting without serious injury. Ajuga was propagated in our greenhouse and was in excellent condition when transplanted.

Surface Applied Herbicides. Simazine alone and in combination with diphenamid were the most toxic treatments to ajuga in the surface application treatments (Table 13). From previous experiments (Warren et al., 1964), ajuga has been shown to be highly susceptible to simazine. Even in combination with diphenamid, the lower concentration of simazine is still sufficiently toxic to cause death.

To those ajuga plants that did survive the higher rates of simazine, a reduction in growth was not apparent (Table 14). In previous experiments (Warren et al., 1964), it has been found that plants which are injured, but not killed

Table 13. Percent survival of ornamental plants following surface application of various herbicides, alone and in combination.

Herbicide (lb/A)	Ajuga	Euonymus	Forsythia	Ninebark	Privet
Check	94 bc	88 a	75 a	94 a	50 a
Bensulide (8)	94 bc	94 a	81 a	94 a	50 a
Dichlobenil (4)	75 ab	94 a	56 a	100 a	56 a
Diphenamid (6)	100 c	75 a	62 a	94 a	38 a
Simazine (3)	62 a	94 a	75 a	94 a	56 a
Simazine (1) + Bensulide (4)	100 c	81 a	94 a	94 a	50 a
Simazine (1) + Diphenamid (4)	56 a	94 a	62 a	94 a	31 a
Dichlobenil (2) + Diphenamid (4)	81 abc	81 a	88 a	94 a	19 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table 14. Growth measurements of surviving ornamental plants following surface application of various herbicides, alone and in combination.

Herbicide (lb/A)	Ajuga	Forsythia	Ninebark
	inches*	grams**	grams**
Check	6.2 ab	23.2 a	13.8 a
Bensulide (8)	7.2 ab	33.0 a	20.0 a
Dichlobenil (4)	7.2 ab	22.0 a	15.5 a
Diphenamid (6)	3.5 b	32.0 a	28.5 a
Simazine (3)	9.5 a	50.2 a	18.0 a
Simazine (1) + Diphenamid (4)	10.0 a	39.8 a	13.5 a
Simazine (1) + Bensulide (4)	6.7 ab	56.2 a	28.8 a
Dichlobenil (2) + Diphenamid (4)	7.0 ab	43.8 a	19.2 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

* Average growth measured by diameter of surviving plant.

** Average growth for Forsythia and Ninebark measured by weight of clippings.

will show no loss in growth at the end of the growing season. These results illustrate this normal growth response found in simazine applied treatments.

Incorporation of Herbicides. The incorporation of dichlobenil alone and in combination was found to cause injury to ajuga. Survival did not increase even when lower rates of dichlobenil was applied (Table 15).

Survival and growth measurements of euonymus and privet were too variable for comparison against the check (Tables 15 and 16). The remaining two species, forsythia and ninebark, showed no significant difference in percent survival; however, since survival for both species was very high we might conclude that these species were tolerant to the herbicide treatments (Table 15). Variations in growth among herbicide treatments was slight (Table 16). The check plots showed significantly less growth than most of the herbicide treatments. This could have occurred because of weed competition. The fact that growth among all treatments was equal to or significantly greater than the check substantiates the conclusion that the herbicides were not toxic to forsythia and ninebark.

Trifluralin, alone and in combination did not kill or injure any of the species (Tables 15 and 16). Even at twice the recommended rate trifluralin appeared to be safe for use among selected ornamental species.

Table 15. Percent survival of ornamental plants following incorporation of various herbicides, alone and in combination.

Herbicide (lb/A)	Ajuga	Euonymus	Forsythia	Ninebark	Privet
Check	75 ab	69 a	100 a	94 a	81 a
Bensulide (8)	100 b	69 a	94 a	100 a	100 a
Dichlobenil (4)	31 a	69 a	100 a	81 a	69 a
Trifluralin (2)	94 b	94 a	100 a	100 a	100 a
Trifluralin (1) + Simazine (1)	88 b	81 a	100 a	100 a	94 a
Dichlobenil (1) + Bensulide (4)	31 a	69 a	100 a	100 a	94 a
Dichlobenil (1) + Diphenamid (4)	31 a	81 a	94 a	100 a	75 a
Dichlobenil (2) + Trifluralin (1)	31 a	69 a	100 a	100 a	100 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table 16. Growth measurements of surviving ornamental plants following incorporation of various herbicides, alone and in combination.

Herbicide (lb/A)	Ajuga	Forsythia	Ninebark	Privet
	inches*	grams**	grams	grams
Check	5.0 a	52.8 a	22.8 a	10.0 a
Bensulide (8)	6.0 a	59.0 a	29.0 a	27.2 a
Dichlobenil (4)	6.8 a	124.8 b	33.2 a	25.2 a
Trifluralin (2)	9.5 a	101.5 b	38.8 ab	38.2 a
Trifluralin (1) + Simazine (1)	3.5 a	123.2 b	64.5 b	22.5 a
Dichlobenil (2) + Bensulide (4)	10.2 a	105.5 b	45.8 ab	34.5 a
Dichlobenil (2) + Diphenamid (4)	5.8 a	100.5 b	30.2 a	17.0 a
Dichlobenil (2) + Trifluralin (1)	5.8 a	130.0 b	50.0 ab	24.2 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

* Average growth measured by diameter of plant.

** Average growth for Forsythia, Ninebark and Privet measured by weight in grams of clippings.

Field Experiment II

This experiment was designed to determine if injury would be caused by low concentrations of simazine to a simazine-susceptible ornamental species. Wintercreeper, Table 17 shows the results of this experiment. A three fold difference was noted between the normal 3 lb/A rate of simazine and the minimum 1 lb/A in the simazine-diphenamid combination. Bennett et al. (1966) found similar results in other sensitive species. Ahrens (1966) and Havis et al., (1965) also indicated negligible injury when reduced concentrations of simazine were combined with various herbicides.

Symptoms of the simazine injury were decreased growth rate, yellowing and mottling of young leaves at the plant top and, later, a burning of leaf margin and some defoliation. Similar symptoms were also noted by Chadwick (1960) and Schneider (1959).

Table 17. Effect of simazine alone and in combination with diphenamid on *Euonymus fortunei* 'Coloratus.'

Herbicide (lb/A)	% of Total Injured	% Dead
Check	0	4
Simazine (3)	50	8
Simazine (1) + Diphenamid (4)	16	0

Greenhouse Experiment

For some pre-emergence herbicides, it is recommended that plants should be established for at least one year prior to herbicide application (Sherwood and Kemmerer, 1964). The one year delay may allow roots to become established thus providing a firm plant bed which would reduce the danger of injury caused by herbicide concentration around the roots (Sherwood et al., 1964). Haramaki (1961 to 1966) has demonstrated that some herbicides do not require this waiting period before plants can be planted safely. For those plants which are toxic only to higher rates of particular herbicides lower concentrations may be used safely in combination with other less toxic herbicides.

The degree of plant injury occurring if transplants and young rooted cuttings are planted in soil pre-treated with herbicides is reported. Results of this experiment are shown in Tables 18 to 20. The plants have been grouped for convenience into annual and perennial flowers, deciduous shrubs, and ground covers. These species were selected for their known susceptibility to particular herbicides.

Bensulide (8 lb/A and 32 lb/A) showed no signs of being phytotoxic to any of the test species (Tables 18 to 20). Because bensulide provides excellent control of many annual grasses (Skogley and Jagschitz, 1964) and remains persistent for long periods of time, this herbicide might be considered for further study. It's failure to control most broad

Table 18. The susceptibility of annual and perennial flowers to the incorporation of pre-plant herbicides, alone and in combination.¹

Herbicide (lb/A)	Zinnia		Marigold		Chrysanthemum	
	x ²	4x	x	4x	x	4x
Check	1.16 d ³	1.33 c	1.00 b	1.08 c	1.33 cd	1.00 c
Bensulide (8)	1.16 d	1.75 bc	1.16 b	1.08 c	1.33 cd	1.33 c
Dichlobenil (4)	4.41 a	5.00 a	4.66 a	2.33 b	4.08 a	4.83 a
Diphenamid (6)	2.16 c	2.42 b	1.33 b	2.58 b	1.83 cd	2.50 b
Trifluralin (2)	1.83 cd	1.50 bc	1.99	1.50 c	1.25 d	2.58 b
Dichlobenil (2) + Bensulide (4)	4.08 a	5.00 a	4.33 a	4.58 a	2.58 bc	4.58 a
Dichlobenil (2) + Diphenamid (4)	3.16 b	5.00 a	4.08 a	5.00 a	3.75 ab	4.50 a
Dichlobenil (2) + Trifluralin (1)	3.66 ab	5.00 a	4.16 a	5.00 a	2.83 abc	4.58 a

¹ 1 - No injury, 5 - dead.

² Equals rate shown in parenthesis in herbicide column; 4x equals 4 times the rate.

³ Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table 19. The susceptibility of deciduous shrubs to the incorporation of pre-plant herbicides, alone and in combination.¹

Herbicide (lb/A)	Forsythia		Blue Mist Spirea		Cheyenne Privet	
	x ²	4x	x	4x	x	4x
Check	1.00 a ³	1.00 b	1.65 b	1.08 e	1.16 b	-
Bensulide (8)	1.33 a	1.25 b	1.33 b	1.25 de	1.33 b	-
Dichlobenil (4)	2.25	4.08 a	2.83 a	4.33 ab	3.16 ab	-
Diphenamid (6)	1.33 a	1.25 b	1.41 b	1.74 d	1.58 ab	-
Trifluralin (2)	1.33 a	1.33 b	1.33 b	1.08 e	1.33 b	-
Dichlobenil (2) + Bensulide (4)	1.58 a	3.83 a	2.66 a	4.08 bc	3.75 ab	-
Dichlobenil (2) + Diphenamid (4)	1.50 a	3.66 a	2.33 a	4.66 a	3.42 ab	-
Dichlobenil (2) + Trifluralin (1)	1.41 a	3.58 a	2.74 a	3.74 c	4.08 a	-

¹ 1 - No injury, 5 - dead.

² x equals rate shown in parenthesis in herbicide column; 4x equals 4 times the rate.

³ Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table 20. The susceptibility of ground covers to the incorporation of pre-plant herbicides, alone and in combination.¹

Herbicide (lb/A)	Ajuga		Purpleleaf Wintercreeper	
	x ²	4x	x	4x
Check	1.25 c ³	1.50 c	1.00 b	1.00
Bensulide (8)	1.50 c	1.50 c	1.08 b	1.41 b
Dichlobenil (4)	2.42 b	3.41 b	3.50	3.66 a
Diphenamid (6)	2.83 ab	4.41	1.08 b	1.41 b
Trifluralin (2)	1.33 c	1.50 c	1.08 b	1.58 b
Dichlobenil (2) + Bensulide (4)	2.66 b	3.58 ab	1.83 a	3.58 a
Dichlobenil (2) + Diphenamid (4)	3.41 a	3.83 a	2.16 a	3.00
Dichlobenil (2) + Trifluralin (1)	2.83 ab	2.91	1.83 a	3.50 a

¹ 1 - No injury, 5 - dead.

² x equals rate shown in parenthesis in herbicide column;
4x = 4 times the rate.

³ Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

leaved weeds would suggest combining it with other herbicides to achieve broad spectrum weed control.

Dichlobenil (4 lb/A) was toxic to all species tested. At 2 lb/A rate in combination with trifluralin (1 lb/A), dichlobenil was less toxic to chrysanthemums and winter-creeper (Tables 18 and 20). Ajuga was more sensitive to the dichlobenil-diphenamid combination than to either herbicide applied alone at normal concentrations.

Other researchers (Ahrens, 1966; Jones and Bingham, 1965) also found dichlobenil toxic to some ornamentals. Ahrens (1966) found dichlobenil injury to container grown ornamentals occurred first in the shoots of sensitive plants.

Diphenamid (6 lb/A) injured zinnia and ajuga (Tables 18 and 20). Marigold and chrysanthemum were injured when diphenamid was applied at 24 lb/A. With the combination dichlobenil-diphenamid, injury was greater than with diphenamid alone. However, the degree of injury was less than when dichlobenil was applied at 4 lb/A. Because this combination has demonstrated broad spectrum weed control and crop injury is reduced, this combination should be studied further, possibly at lower rates.

Trifluralin at two pounds per acre showed some marigold injury. However, when applied at four times this rate, injury was not apparent (Table 18). No injury was noted in any of the other species tested (Tables 18 to 20).

From the weed control data in the incorporation study and the injury data from both field and greenhouse studies, trifluralin may be an effective herbicide for ornamental plantings. Before this herbicide could be recommended, a greater spectrum of ornamental plants must be studied. This is important since Ahrens (1963) reported trifluralin injury to forsythia.

Summary

Injury to various ornamental species was apparent when dichlobenil and simazine were applied at their recommended rates. When minimum effective concentrations of simazine were combined with low rates of diphenamid Euonymus fortunei 'Coloratus' was not injured, while Ajuga 'Metallica Crispa,' was. Thus, the simazine-diphenamid combination was less toxic only to some species.

Trifluralin and bensulide were found generally to be safe for all species tested. In pre-treated soil these herbicides were non-toxic to selected species even at four times the normal rates.

EFFECTS OF COMBINATIONS ON HERBICIDE RESIDUE

Introduction

Herbicide residues can result in injury to sensitive woody ornamental plants. The accumulation of residues from application rates which exceed the rate of dissipation could cause severe injury to those ornamental species susceptible to particular herbicides.

The main objective in this study was to evaluate various herbicides, alone and in combination for broad spectrum weed control and injury to various ornamentals. The purpose of evaluating herbicides, alone and in combination was to investigate the possibility of combining minimum concentrations of individual herbicides to provide broad spectrum weed control, reduce injury to ornamentals, and decrease herbicide residues in the soil.

Thus, the final objective of this study was to compare residues resulting from lower rates of individual herbicides when used in combination with that from herbicides used individually at normal rates.

Materials and Methods

On October 30, soil samples were collected from both surface applied and incorporation studies described earlier. Ten soil samples were taken from the middle of each plot of the two experiments. Samples were one inch in diameter and four inches deep. Each sample was divided into two subsamples, the upper and lower two inches of soil. Each subsample was placed in a nine-ounce Dixie cup.

A bioassay was conducted to determine the amount of herbicide remaining in the soil. The bioassay consisted of planting 35 German millet (*Setaria italica*, L.) seeds into each cup. The seeds were covered with one-quarter inch of soil and placed in a growth chamber, maintained at a constant temperature of 22°C and a sixteen hour photoperiod.

After three weeks in the growth chamber the cups were removed; the total number of germinating seeds were counted and the above ground growth of the plants was harvested and fresh weight measurements recorded.

A split-plot analysis was conducted on the data, with season as main plot and herbicides as sub-plot.

Results and Discussion

Results of this experiment are presented in Tables 21 and 22. Large variability and very poor stands were found in the bioassay. Germinability was 95% and observations of the soil samples indicated that most of the seeds had

germinated. The variability may have occurred because of soil compaction. The soil structure was very likely altered during sampling, subdividing and seeding. The application of water to the soil may have caused sufficient compaction that seedlings could not penetrate the hard soil crust and thus died. If sand had been applied to the surface of the containers prior to watering or if subirrigation had been employed, more plants may have emerged.

Even though the results were variable, some residue trends are noted. The experiments showed that some herbicides remained in the upper two inches of the soil (Tables 21 and 22). Very little herbicide movement was found in the various treatments.

In the surface application experiment (Table 21), little residual activity was found from the November application. The simazine-bensulide combination was the only treatment that did show significant residual activity. However, because simazine and bensulide alone at higher rates demonstrated no significant residual activity it is suggested that the simazine-bensulide combination only had poorer seed germination and thus, the activity appeared to be present.

In the April and June applications bensulide alone was active, though not significantly. Therefore, in the simazine-bensulide combination the residual effect could have been caused by bensulide.

Table 21. Residual activity of various surface applied herbicides when applied at three different seasons. Bioassay performed with German Millet.

Herbicide (lb/A)	November 23		April 25		June 1	
	2"	4"	2"	4"	2"	4"
	grams		grams		grams	
Check	.533 a	.966 a	.290 ab	.326 a	.289 a	.332 a
Bensulide (8)	.542 a	.456 b	.122 b	.165 a	.000 a	.286 a
Dichlobenil (4)	.535 a	.686 ab	.184 ab	.297 a	.166 a	.272 a
Diphenamid (6)	.322 ab	.756 ab	.295 ab	.337 a	.261 a	.383 a
Simazine (3)	.338 ab	.639 ab	.212 ab	.302 a	.277 a	.520 a
Simazine (1) + Diphenamid (4)	.423 ab	.721 ab	.470 a	.269 a	.285 a	.447 a
Simazine (1) + Bensulide (4)	.179 b	.432 b	.139 ab	.243 a	.144 a	.375 a
Dichlobenil (2) + Diphenamid (4)	.571 a	.821 ab	.221 ab	.300 a	.216 a	.337 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table 22. Residual activity of various incorporated herbicides when applied at three different seasons. Bioassay performed with German Millet.

Herbicide (lb/A)	November 23		April 25		June 1	
	2"	4"	2"	4"	2"	4"
	grams		grams		grams	
Check	.124 b	.302 a	.324 a	.440 a	.073 ab	.212 a
Bensulide (8)	.004 b	.249 a	.012 c	.152 a	.000 b	.543 a
Dichlobenil (4)	.206 ab	.434 a	.328 a	.398 a	.140 ab	.155 a
Trifluralin (2)	.010 b	.234 a	.075 bc	.235 a	.022 b	.184 a
Trifluralin (1) + Simazine (1)	.328 a	.544 a	.214 ab	.330 a	.266 a	.238 a
Dichlobenil (2) + Trifluralin (1)	.197 ab	.485 a	.254 ab	.250 a	.049 b	.204 a
Dichlobenil (2) + Diphenamid (4)	.322 a	.367 a	.208 ab	.256 a	.088 ab	.069 a
Dichlobenil (2) + Bensulide (4)	.089 b	.346 a	.012 c	.146 a	.000 b	.528 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

The remaining herbicide treatments showed no significant residual activity.

In the incorporation experiment (Table 22), bensulide and trifluralin were found to be active in the November application in the upper 2 inches. Other researchers have found similar persistence of bensulide and trifluralin (Skogley and Jagschitz, 1964; Engel and Callahan, 1967; Bardsley, et al., 1967).

The dichlobenil-bensulide combination (Table 21) was also toxic in the November application. Presumably the bensulide component was responsible for the persistent activity.

The remaining treatments in the incorporation experiment did not show any residual activity in the November application. However, residual activity was noted in the April and June applications of trifluralin, bensulide and combinations containing bensulide. Dichlobenil is the only treatment that did not show activity in any of the application times. Dichlobenil is highly volatile and thus probably volatilized in the soil during the hot summer months or was decomposed.

Summary

A bioassay was employed to determine the residual activity of the various herbicide treatments utilized in the 1967 experiment. Although a high variability existed in

the data, certain residual trends were noted. Bensulide incorporated was shown to be persistent for over 11 months. The surface application of bensulide did not show such persistence. Trifluralin activity was also very persistent.

Incorporation of the dichlobenil-bensulide combinations also showed residual activity from the November application. Because dichlobenil alone was not toxic, it is assumed that bensulide was responsible for the residual activity.

The remaining herbicide treatments did not show any significant residual activity. However, because of high variability, it is difficult to validate the lack of residue activity with these herbicides.

BIBLIOGRAPHY

BIBLIOGRAPHY

- Ahrens, J. F. 1963. Chemical control of weeds in deciduous nursery plantings. Proc. Northeastern Weed Control Conf. 17:208-212.
- Ahrens, J. F. 1966. Chemical control of weeds in deciduous nursery shrubs. Proc. Northeastern Weed Control Conf. 20:209-214.
- Ahrens, J. F. 1966. Trials with dichlobenil and diphenamid for controlling weeds in container-grown nursery stock. Proc. Northeastern Weed Control Conf. 20:232-236.
- Alder, E. F. and Bevington, R. B. 1962. Diphenatrile, dipropalin and trifluralin. Pre-emergent turf herbicides. Proc. Northeastern Weed Control Conf. 16:505-510.
- Anonymous. 1967. Enide technical data bulletin. Tuco Products Co., Division of the Upjohn Co., Kalamazoo, Michigan.
- Bardsley, C. E., Savage, K. E., and Childer, V. O. 1967. Trifluralin behavior in soil. I. Toxicity and persistence as related to organic matter. Agron. J. 59:159-160.
- Barnsley, G. E. 1960. An assessment of the new herbicide 2, 6-dichlorobenzonitril. Proc. British Weed Control Conf. 5:597-616.
- Barnsley, G. E. and Rosher, P. H. 1961. The relationship between the herbicidal-effect of 2, 6-dichlorobenzonitrile and its persistence in the soil. Weed Research 1:147-158.
- Bayer, G. H., Hargan, R. P., Cialone, J. C., and Sweet, R. D. 1963. The effect of cultural practices on the herbicidal activity of H-7531, linuron, and trifluralin. Proc. Northeastern Weed Control Conf. 20:215-219.

- Bennett, W., Havis, J., Fitzgerald, R., Johnson, O. 1966. 1965 field trials of herbicide combinations in nursery plantings. Proc. Northeastern Weed Control Conf. 20: 215-219.
- Bing, A. 1959. Effects of some herbicides on nursery stock. Proc. Northeastern Weed Control Conf. 12:407-415.
- Burnside, O. C., Schmidt, E. L., and Behrens, R. 1961. Dissipation of simazine from soil. Weeds. 9:477-484.
- Carpenter, Edwin D. 1967. Herbicide breakdown. Connecticut Nursery Digest. 2: No. 2. 2 pp.
- Carpenter, Edwin D. 1967. Weed control costs. Connecticut Nursery Digest. 2: No. 4. 2 pp.
- Chadwick, L. C. 1960. Response of some woody ornamental plants transplanted to soil immediately after applications of simazine. Proc. North Central Weed Control Conf. 17:50.
- Colby, S. R., Wojtaszek, T. and Warren, G. F. 1965. Synergistic and antagonistic combinations for broadening herbicidal selectivity. Weeds. 13:87-91.
- Crafts, A. S. 1961. The chemistry and mode of action of herbicides. Interscience, New York. pp. 104-124.
- Davidson, Harold and Ries, S. K. 1965. Granular herbicides for weed control in container grown woody ornamental plants. Proc. Northeastern Weed Control Conf. 19:150-154.
- Derscheid, Lyle A. 1958. Weather effects on pre-emergence applications of CDAA and simazine. Proc. North Central Weed Control Conf. 15:23.
- Ellis, J. F. and Illnicki, R. D. 1963. Weed control in transplanted cole crops. Proc. Northeastern Weed Control Conf. 17:51-57.
- Engel, R. E. and Callahan, L. M. 1967. Marion Kentucky bluegrass response to soil residue of pre-emergence herbicides. Weeds. 15:128-130.
- Ennis, W. B., Jr., and McClellan, W. D. 1964. Chemicals in crop production. Yearbook of Agriculture. USDA, U. S. Government Printing Office. p. 107.

- Freeman, J. F., Sigafus, R. E., and Waldrep, T. W. 1963. Response of soybeans to trifluralin and linuron. Research Report Northeastern Weed Control Conf. 17:47.
- Guse, L. R. and Schwer, J. F. 1964. "Trifluralin: field studies in cotton and soybeans." Proc. Southern Weed Conf. 17:67-72.
- Gysin, H. and Knisli, E. 1960. Chemistry and herbicidal properties of triazine derivatives. In R. L. Metcalf (ed.) Advances in pest control research. Vol. 3. Interscience, New York. pp. 289-358.
- Haramaki, C. 1961. Evaluation of several pre-plant herbicides for petunias. Proc. Northeastern Weed Control Conf. 15:130-134.
- Haramaki, C. 1962. Chemical weed control in Taxus. Proc. Northeastern Weed Control Conf. 16:202-204.
- Haramaki, C. 1962. Pre-plant weed control in marigold plantings. Proc. Northeastern Weed Control Conf. 16:212-217.
- Haramaki, C. 1962. Pre-planting herbicide applications for weed control in petunia plantings. Proc. Northeastern Weed Control Conf. 16:218-222.
- Haramaki, C. 1963. Pre-plant weed control in annual flowers. Proc. Northeastern Weed Control Conf. 17:213-217.
- Haramaki, C. 1963. Post-transplant applications of granular herbicides in annual flowers. Proc. Northeastern Weed Control Conf. 17:221-224.
- Haramaki, C. 1964. Pre-transplant weed control in liner beds. Proc. Northeastern Weed Control Conf. 18:231-234.
- Haramaki, C. 1965. Seasonal weed control in annual flowers. Proc. Northeastern Weed Control Conf. 19:175-179.
- Haramaki, C. and Atmore, S. 1964. Effect of post-transplant applications of granular herbicides on marigold. Proc. Northeastern Weed Control Conf. 18:214-219.
- Haramaki, C. and Atmore, S. 1965. Post-transplant applications of herbicides in petunias. Proc. Northeastern Weed Control Conf. 19:131-134.

- Haramaki, C. and Atmore, S. 1966. Selected pre-transplant herbicides in marigold plantings. Proc. Northeastern Weed Control Conf. 20:195-199.
- Haramaki, C. and Koch, G. 1966. Pre-emergence herbicide applications in transplanted annual flowers. Proc. Northeastern Weed Control Conf. 20:200-203.
- Haramaki, C. and Lee, H. 1966. Pre-plant treatment of potting soil and liner beds with trifluralin. Proc. Northeastern Weed Control Conf. 20:226-231.
- Haramaki, C. and Meahl, R. P. 1964. Chemical weed control in transplanted annual flowers. Proc. Northeastern Weed Control Conf. 18:204-207.
- Haramaki, C. and Meahl, R. P. 1965. Post-transplant applications of herbicides in scarlet sage. Proc. Northeastern Weed Control Conf. 19:160-163.
- Hargan, R. P. and Sweet, R. D. 1963. "Carrot herbicides and some factors influencing their activity." Proc. Northeastern Weed Control Conf. 17:37-43.
- Harris, C. I. 1964. Movement of dicamba and diphenamid in soil. Weeds. 12:112-115.
- Havis, John R. 1961. Progress report on weed control in nursery crops. Proc. Northeastern Weed Control Conf. 15:137-145.
- Havis, J. R., Bennett, W. J., Fitzgerald, R. D. 1965. Herbicide combinations for summer weeds in nursery crops. Proc. Northeastern Weed Control Conf. 19:115-159.
- Hicks, R. D. and Fletchall, O. H. 1964. Preplant incorporation studies in cotton weed control. Proc. Southern Weed Conf. 17:157.
- Jones, G. E., Dubey, H. D., and Freeman, J. F. 1964. Persistence of diphenamid in tobacco field soils. Weeds. 12:313-315.
- Jones, Randall and Bingham, S. W. 1965. Effects of dichlobenil on various ornamental species. Proc. Southern Weed Conf. 18:212-221.

- Kempen, H. M., Miller, J. H. and Carter, L. M. 1963. Pre-emergence herbicides incorporated in moist soils for control in annual grass in irrigated cotton. *Weeds*. 11:300-307.
- Klingman, Glenn C. 1965. Weed control: as a science. John Wiley and Sons, Inc., New York 421 p.
- Koopman, H. and Daams, J. 1960. 2, 6-dichlorobenzonitrile: a new herbicide. *Nature (London)* 186:89-90.
- Massini, P. 1961. Movement of 2, 6-dichlorobenzonitrile in soils and in plants in relation to its physical properties. *Weed Research*. 1:142-146.
- McGuire, J. J. 1967. Rhode Island course on pest control. *American Nurseryman*. 125:20.
- Miller, C. W., Demoranville, I. E. and Charig, A. J. 1966. Persistence of dichlobenil in cranberry bogs. *Weeds* 14:296-298.
- Miller, R. A. 1962. Soil incorporation of herbicides on snap beans. *Proc. Northeastern Weed Control Conf.* 19:40.
- Minshall, W. E. 1954. Translocation path and place of action of 3-(4-chlorophenyl)-1:1-dimethylurea in bean and tomato. *Can. J. Bot.* 32:795.
- Noreland, D. E., Centner, L. A., Hilton, J. L. and Hill, K. L. 1959. Studies on the mechanism of herbicidal action of 2-chloro-4, 6-bis (ethylamine)-s-triazine. *Plant Physiology*. 34:432-435.
- Nylund, R. D., Ayres, L. C., and Torfason, W. E. 1963. Variable dosage application of pre-planting and pre-emergence herbicides to four vegetable crops growing in silt loam soil. *Research Report North Central Weed Control Conf.* 20:94.
- Pieczarka, S. J., Wright, W. L., and Alder, E. F. 1962. Trifluralin for pre-emergent weed control in agronomic crops. *Proc. Northeastern Weed Control Conf.* 16:356-361.
- Pieczarka, S. J., Wright, W. L., and Alder, E. F. 1962. Trifluralin as a soil incorporated pre-emergence herbicide for agronomic crops. *Proc. Southern Weed Conf.* 15:92-96.

- Pridham, A.M.S. 1962. Weed control and residual effects of simazine and of atrazine applied to soil prior to planting nursery stock. Proc. Northeastern Weed Control Conf. 16:239-241.
- Pridham, A.M.S. 1966. Suppression or control of some rhizomatous perennial weeds in nursery-landscape plantings, with dichlobenil, amazine and other herbicides. Proc. Northeastern Weed Control Conf. 20:237-239.
- Ries, S. K., Briggsby, B. H. and Davidson, H. 1959. Evaluation of herbicides for several species of ornamentals. Weeds. 7:409-417.
- Roadhouse, F.E.B. and Birk, L. A. 1961. Penetration of and persistence in soil of the herbicide 2-chloro-4, 6-bis (ethyl-amino)-s-triazine (simazine). Can. J. of Plant Science. 41:252-260.
- Saidak, W. J. and Nelson, S. H. 1962. Weed control in ornamental nurseries. Weeds. 10:311-315.
- Schneider, E. O. 1958. Simazine and related triazine herbicides. Proc. North Central Weed Control Conf. 15:10-11.
- Schneider, E. O. 1959. A discussion of the mode of action, tolerance and soil type effects of the triazines. Proc. Northeastern Weed Control Conf. 13:416-420.
- Sherwood, L. V. and Kemmerer, H. R. 1964. The influence of winter applied pre-emergence herbicides on weed growth among woody ornamental plants. Proc. American Soc. Hort. 85:657-662.
- Skogley, C. R., and Jagschitz, J. A. 1964. The effect of various pre-emergence crabgrass herbicides on turf-grass seed and seedlings. Proc. Northeastern Weed Control Conf. 18:523-529.
- Splittstoesser, W. E. and Derscheid, L. A. 1962. Effects of environment upon herbicides applied pre-emergence. Weeds. 10:304-307.
- Steel, R.G.D. and Torrie, J. H. 1960. Principles and Procedures of Statistics. McGraw-Hill Co., Inc. New York. pp. 156-158.

- Warren, G. F., Hoxsie, C. E., Lanphear, F. O., Parochetti, J. V. and Wajtaszek, T. 1964. Results of field experiments on weed control in horticultural crops - 1964. Unpublished mimeo, Purdue University.
- Warren, Rex. 1965. Oregon weed control handbook. Cooperative Extension Service, Oregon State University, Corvallis.
- Wright, William L. 1964. Factors influencing the herbicidal activity of trifluralin in the soil. Ph.D. Thesis, Purdue University. pp. 73-75.
- Wright, W. L., and Warren, G. F. 1965. Photochemical decomposition of trifluralin. Weeds. 13:329-331.

APPENDIX

APPENDIX

Table A1. Overhead irrigation data from the period June 1, 1967 through August, 1967.

Date	Overhead Irrigation (inches)
June 1	1.5
June 5	1.0
July 4	1.0
July 5	2.0
July 7	1.5
July 14	1.5

Table A2. Weekly or monthly rainfall and soil temperature data from the period June 1966 through October 1967.¹

Date	Rainfall (inches)	Ave. Soil Temp. (°F) (4" depth)	Date	Rainfall (inches)	Ave. Soil Temp. (°F) (4" depth)
June 6	0.15	64	Dec. 1 -	4.86	39.3
June 13	0.16	68	31, 1967		
June 20	0.10	68	Jan. 1 - 31	2.23	34.5
June 27	0.00	73	Feb. 1 - 28	1.28	36.0
July 5	0.03	76	March 1 -	2.15	42.6
July 11	0.76	77	31		
July 18	0.82	78	April 10	1.40	57
July 25	0.17	--	April 17	1.11	59
Aug. 1	1.34	80	April 24	0.52	59
Aug. 8	0.28	78	May 1	0.24	57
Aug. 15	1.38	77	May 8	2.35	59
Aug. 22	0.32	79	May 15	0.99	59
Aug. 29	0.00	76	May 22	0.01	63
Sept. 6	0.07	79	May 29	0.30	70
Sept. 12	0.00	74	June 5	0.16	64
Sept. 19	0.48	72	June 12	0.51	75
Sept. 26	2.05	67	June 18	0.00	79
Oct. 3	0.31	63	June 25	0.51	76
Oct. 10	0.12	61	July 3	0.14	76
Oct. 17	0.75	61	July 10	0.22	76
Oct. 24	0.22	56	July 17	0.00	76
Oct. 31	0.00	54	July 24	0.82	78
Nov. 7	0.49	43	July 31	0.05	80
Nov. 14	1.36	53	Aug. 7	1.51	80
Nov. 21	0.00	48	Aug. 14	0.25	77
Nov. 28	3.30	52	Aug. 21	0.69	77
Dec. 5	0.91	43	Aug. 28	0.21	75
Dec. 12	3.69	49			

Table A2. (cont'd.)

Date	Rainfall (inches)	Ave. Soil Temp. (°F) (4" depth)	Date	Rainfall (inches)	Ave. Soil Temp. (°F) (4" depth)
Sept. 4	0.09	71	Oct. 2	0.85	63
Sept. 11	0.05	72	Oct. 9	0.64	67
Sept. 18	T	73	Oct. 16	0.88	58
Sept. 25	0.51	72	Oct. 23	1.24	57
			Oct. 30	0.98	54

¹Rainfall taken at the Purdue Agronomy Farm, six miles northwest of West Lafayette, Indiana.

Source: From Local Climatological Data, Department of Agronomy, Purdue University, West Lafayette, Indiana.

Table A3. Marginal means over total weed counts, seasons, and repetitions following surface application of various herbicides.

Herbicide (lb/A)	Marginal Mean
	No. per sq. ft.
Check	19.1
Bensulide (8)	5.5 a
Dichlobenil (4)	4.8 ab
Diphenamid (6)	4.2 ab
Simazine (3)	1.6 c
Simazine (1) + Diphenamid (4)	2.1 c
Simazine (1) + Bensulide (4)	5.4 ab
Dichlobenil (2) + Diphenamid (4)	3.1 bc

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table A4. Means for herbicide x season interactions for total weed counts following surface application of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	10.2 a	7.8 a	39.4
Bensulide (8)	7.0 ab	5.1 abc	4.4 ab
Dichlobenil (4)	5.8 abc	6.2 ab	2.4 bc
Diphenamid (6)	2.7 bc	1.7 cd	8.3 a
Simazine (3)	1.8 c	1.0 d	2.1 bc
Simazine (1) + Diphenamid (4)	3.9 abc	1.8 cd	0.6 c
Simazine (1) + Bensulide (4)	7.0 abc	2.4 cd	6.9 a
Dichlobenil (2) + Diphenamid (4)	3.7 bc	4.0 bcd	1.5 bc

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A5. Means for herbicides x season interactions for total grass counts following surface application of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	2.4	2.2 a	2.6
Bensulide (8)	0.4 a	0.2 bc	0.2 a
Dichlobenil (4)	0.2 a	1.3 ab	0.4 a
Diphenamid (5)	0.7 a	0.3 c	0.0 a
Simazine (3)	0.5 a	0.2 bc	0.2 a
Simazine (1) + Diphenamid (4)	0.6 a	0.2 c	0.1 a
Simazine (1) + Bensulide (4)	0.6 a	0.4 bc	0.2 a
Dichlobenil (2) + Diphenamid (4)	0.7 a	0.3 bc	0.5 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A6. Means for herbicide x season interactions for total purslane counts following surface application of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	7.7 ab	4.8 a	36.5
Bensulide (8)	6.3 a	4.4 a	4.1 ab
Dichlobenil (4)	5.5 a	5.0 a	2.0 bc
Diphenamid (6)	2.0 bc	1.0 b	8.1 a
Simazine (3)	1.3 c	0.7 b	1.9 bc
Simazine (1) + Diphenamid (4)	3.3 abc	1.6 ab	0.4 c
Simazine (1) + Bensulide (4)	6.3 ab	2.3 ab	6.6 a
Dichlobenil (2) + Diphenamid (4)	3.4 abc	3.7 ab	1.0 bc

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A7. Means for herbicide x count interactions for total weed counts following surface application of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	51.5	<u>4.2 a</u>	<u>1.7 a</u>
Bensulide (8)	13.1 a	<u>2.2 ab</u>	<u>1.2 a</u>
Dichlobenil (4)	11.7 a	<u>1.8 ab</u>	<u>0.8 a</u>
Diphenamid (6)	10.3 ab	<u>1.4 ab</u>	<u>1.0 a</u>
Simazine (3)	<u>3.3 c</u>	<u>1.1 b</u>	<u>0.5 a</u>
Simazine (1) + Diphenamid (4)	<u>4.5 c</u>	<u>1.2 b</u>	<u>0.6 a</u>
Simazine (1) + Bensulide (4)	13.2 a	<u>2.2 ab</u>	<u>0.8 a</u>
Dichlobenil (2) + Diphenamid (4)	<u>6.7 bc</u>	<u>1.5 ab</u>	<u>1.0 a</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A8. Means for herbicide x count interactions for total grass counts following surface application of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	5.0	1.6	0.6 a
Bensulide (8)	0.5 ab	0.2 a	0.1
Dichlobenil (4)	1.1 a	0.4 a	0.3 a
Diphenamid (6)	0.4 b	0.2 a	0.2 a
Simazine (3)	0.4 ab	0.3 a	0.2 a
Simazine (1) + Diphenamid (4)	0.4 b	0.3 a	0.2 a
Simazine (1) + Bensulide (4)	0.5 ab	0.4 a	0.2
Dichlobenil (2) + Diphenamid (4)	0.3 b	0.3 a	0.3 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A9. Means for herbicide x count interactions for total purslane counts following surface application of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	45.6	<u>2.3 a</u>	<u>1.0 a</u>
Bensulide (8)	12.0 a	<u>1.8 a</u>	<u>1.0 a</u>
Dichlobenil (4)	10.5 a	<u>1.4 a</u>	<u>0.5 a</u>
Diphenamid (6)	9.4 ab	<u>1.0 a</u>	<u>0.7 a</u>
Simazine (3)	<u>2.8 c</u>	<u>0.8 a</u>	<u>0.3 a</u>
Simazine (1) + Diphenamid (4)	<u>4.0 c</u>	<u>0.9 a</u>	<u>0.4 a</u>
Simazine (1) + Bensulide (4)	12.5 a	<u>2.0 a</u>	<u>0.7 a</u>
Dichlobenil (2) + Diphenamid (4)	<u>6.2 bc</u>	<u>1.2 a</u>	<u>0.7 a</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A10. Marginal means over total weed counts, seasons, and repetitions following incorporation of various herbicides.

Herbicide (lb/A)	Marginal Mean
	No. per sq. ft.
Check	14.5
Bensulide (8)	8.2
Dichlobenil (4)	1.9 bc
Trifluralin (2)	0.9 c
Trifluralin (1) + Simazine (1)	3.2 ab
Dichlobenil (2) + Triflurain (1)	2.0 bc
Dichlobenil (2) + Diphenamid (4)	3.4 ab
Dichlobenil (2) + Bensulide (4)	4.5 a

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter are significantly different at the 5% level.

Table All. Means for herbicide x season interactions for total weed counts following incorporation of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	9.8 a	<u>12.6</u>	<u>21.0</u> a
Bensulide (8)	6.2 ab	<u>4.2</u> a	14.3 a
Dichlobenil (4)	1.4 cd	1.8 ab	<u>2.5</u> bc
Trifluralin (2)	0.8 d	0.6 b	<u>1.4</u> c
Trifluralin (1) + Simazine (1)	<u>2.9</u> cd	<u>1.1</u> b	<u>5.8</u> b
Dichlobenil (2) + Trifluralin (1)	<u>2.0</u> cd	<u>0.8</u> b	<u>3.2</u> bc
Dichlobenil (2) + Diphenamid (4)	<u>4.2</u> bc	<u>1.7</u> ab	<u>4.5</u> b
Dichlobenil (2) + Bensulide (4)	<u>6.1</u> ab	<u>1.3</u> ab	<u>6.2</u> b

Means for herbicides separated by Duncan's New Multiple Range Test. MEans not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A12. Means for herbicide x season interactions for total grass counts following incorporation of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	<u>1.9</u> - - - -	<u>2.5</u> - - - -	<u>1.6</u>
Bensulide (8)	0.4 ab	0.3 a	0.4 ab
Dichlobenil (4)	0.4 ab	0.2 a	0.4 ab
Trifluralin (2)	0.2 b	0.1 a	0.2 b
Trifluralin (1) + Simazine (1)	0.2 b	0.2 a	0.4 ab
Dichlobenil (2) + Trifluralin (1)	0.3 b	0.2 a	0.4 ab
Dichlobenil (2) + Diphenamid (4)	<u>0.5 ab</u> - - - -	<u>0.2 a</u> - - - -	<u>0.8 a</u>
Dichlobenil (2) + Bensulide (4)	0.9 a	<u>0.2 a</u>	0.3 ab

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A13. Means for herbicide x season interactions for total purslane counts following incorporation of various herbicides.

Herbicide (lb/A)	Time of Application		
	Nov. 23	Apr. 25	June 1
	No. per sq. ft.		
Check	<u>7.6 a</u>	<u>9.3</u>	<u>18.5 a</u>
Bensulide (8)	<u>5.4 a</u>	<u>3.3 a</u>	<u>13.2 a</u>
Dichlobenil (4)	<u>1.1 cd</u>	<u>1.4 ab</u>	<u>2.1 bc</u>
Trifluralin (2)	<u>0.6 d</u>	<u>0.1 b</u>	<u>1.1 c</u>
Trifluralin (1) + Simazine (1)	<u>2.6 bcd</u>	<u>0.6 b</u>	<u>5.2 b</u>
Dichlobenil (2) + Trifluralin (1)	<u>1.6 cd</u>	<u>0.6 b</u>	<u>2.6 bc</u>
Dichlobenil (2) + Diphenamid (4)	<u>3.7 abc</u>	<u>1.4 ab</u>	<u>3.6 b</u>
Dichlobenil (2) + Bensulide (4)	<u>5.1 ab</u>	<u>0.9 ab</u>	<u>5.7 b</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A14. Means for herbicide x count interactions for total weed counts following incorporation of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	35.6	6.2	1.6 a
Bensulide	21.0	<u>2.7 a</u>	<u>1.0 a</u>
Dichlobenil (4)	<u>2.2 c</u>	<u>2.1 a</u>	<u>1.4 a</u>
Trifluralin (2)	<u>1.3 c</u>	<u>0.8 a</u>	<u>0.7 a</u>
Trifluralin (1) + Simazine (1)	8.0 ab	<u>1.2 a</u>	<u>0.6 a</u>
Dichlobenil (2) + Trifluralin (1)	<u>3.6 bc</u>	<u>1.4 a</u>	<u>1.0 a</u>
Dichlobenil (2) + Diphenamid (4)	7.2 ab	<u>2.2 a</u>	<u>1.0 a</u>
Dichlobenil (2) + Bensulide (4)	9.5 a	<u>2.6 a</u>	<u>1.4 a</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A15. Means for herbicide x count interactions for total grass counts following incorporation of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	3.2	2.2	0.7
Bensulide (8)	<u>0.4 ab</u>	<u>0.4 a</u>	<u>0.2 a</u>
Dichlobenil (4)	<u>0.2 b</u>	<u>0.5 a</u>	<u>0.2 a</u>
Trifluralin (2)	<u>0.2 b</u>	<u>0.1 b</u>	<u>0.1 a</u>
Trifluralin (1) + Simazine (1)	<u>0.3 b</u>	<u>0.4 ab</u>	<u>0.2 a</u>
Dichlobenil (2) + Trifluralin (1)	<u>0.2 b</u>	<u>0.4 a</u>	<u>0.4 a</u>
Dichlobenil (2) + Diphenamid (4)	<u>0.7 a</u>	<u>0.5 a</u>	<u>0.3 a</u>
Dichlobenil (2) + Bensulide (4)	<u>0.5 ab</u>	<u>0.6 a</u>	<u>0.3 a</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.

Table A16. Means for herbicide x count interactions for total purslane counts following incorporation of various herbicides.

Herbicide (lb/A)	Sampling Date		
	July 1	Aug. 1	Sept. 1
	No. per sq. ft.		
Check	30.8	3.8 a	0.8 a
Bensulide (8)	19.4	<u>1.9 ab</u>	<u>0.7 a</u>
Dichlobenil (4)	<u>2.1 c</u>	<u>1.5 ab</u>	<u>1.0 a</u>
Trifluralin (2)	<u>0.9 c</u>	<u>0.5 b</u>	<u>0.4 a</u>
Trifluralin (1) + Simazine (1)	7.4 a	<u>0.8 b</u>	<u>0.3 a</u>
Dichlobenil (2) + Trifluralin (1)	<u>3.2 bc</u>	<u>0.9 b</u>	<u>0.6 a</u>
Dichlobenil (2) + Diphenamid (4)	6.4 ab	<u>1.6 ab</u>	<u>0.5 a</u>
Dichlobenil (2) + Bensulide (4)	9.0 a	<u>1.9 ab</u>	<u>0.9 a</u>

Means for herbicides separated by Duncan's New Multiple Range Test. Means not followed by the same letter vertically or connected by a common line horizontally are significantly different at the 5% level.