COMBINATION EFFECT OF ACP 2100, IMAZAQUIN AND TRICLOPYR ON COMMON DANDELION AND THREE KENTUCKY BLUEGRASS TURF TYPES

by

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(ABSTRACT)

The compatibility of ACP 2100, a member of the imidazolinone family (chemistry not released), imazaquin (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-quinolinecarboxylic acid) and triclopyr {[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid} was investigated for use in a turf management program, including growth regulation and broadleaf weed control. Field and greenhouse results indicated an antagonistic interaction between triclopyr and imazaquin for control of common dandelion (Taraxacum officinale Weber in Wigger). Addition of imazaquin at 276 g ha^{-1} to triclopyr at 138 g ha^{-1} resulted in less dandelion control than 138 plus 138 g ha^{-1}, respectively. Greenhouse and laboratory studies indicated a synergistic interaction between ACP 2100 and triclopyr, not apparent in the field. Addition of ACP 2100 to triclopyr at 34 and 69 g ha^{-1} resulted in less than expected dandelion biomass, indicating increased dandelion control. ACP 2100 initially decreased triclopyr uptake, but resulted in

greater uptake 48 hours after treatment. ACP 2100 also increased triclopyr translocation to the crown, root and middle rosette leaves.

In the field and greenhouse, triclopyr did not influence growth regulation and decreased turf injury caused by ACP 2100. Studies showed that as the rate of ACP 2100 increased with the rate of triclopyr an antagonism occurred, resulting in decreased turf injury. The low rate of both ACP 2100 and imazaquin in combination resulted in equal turf growth regulation activity to the high rate of either chemical alone or in combination. One greenhouse study indicated that the interaction was synergistic for height suppression with ACP 2100 and imazaquin at rates of 12 plus 17 or 24 g ha^{-1}, respectively. However, field studies showed that ACP 2100/imazaquin combinations resulted in unacceptable injury to '190' and 'Glade-Plush-Ram' Kentucky bluegrass (_Poa pratensis_ L.).

The best turf quality, growth regulation and dandelion control was achieved with a combination of ACP 2100 at 96 and 144 g ha^{-1} plus triclopyr at 276 g ha^{-1}. These results indicate that turf management costs may be reduced without sacrificing dandelion control by incorporating a chemical mowing program into a spring herbicide treatment.

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LITERATURE REVIEW

A high quality, fine turf enhances a landscape as much as a turfgrass pest, such as weeds, lowers the aesthetic and functional value of a turf (76). Turf in which weeds often invade are golf course fairways, home lawns, industrial lawns and parks. The management practices for these lawns frequently vary in maintenance activity from daily to biweekly intervals. Management practices often include mowing, fertilization, irrigation and weed control. The two components of concern here are the mowing regime and weed control, specifically broadleaf control.

Management of large areas such as industrial lawns and parks requires a significant amount of time, labor and fuel spent on mowing and trimming. A cost comparison analysis of mechanical mowing versus chemical mowing shows the cost of chemical mowing to be approximately equivalent to the cost of two mowing/trimming operations (22, 50, 51). McElroy et al (50), in a report for utilization of plant growth regulators in Michigan, stated that during the growing season the average number of mowings of some home lawns, ornamental gardens, office building lawns and golf course fairways is twelve or more operations per season. Turf for school grounds, industrial grounds, institutions and medium quality home lawns was estimated to receive between six and eleven mowings per season (50). In Virginia the number of mowings per year for each of these turf care programs would increase due to the longer growing season, therefore, chemical mowing would greatly reduce mechanical mowing costs. To date, several turf growth retardants are on the market which adequately inhibit vertical growth of Kentucky bluegrass (Poa pratensis L.). Examples are chlorflurenol (methyl 2-chloro-9-hydroxy-fluorene-9-carboxylate) (14, 48, 68, 84, 86), mefluidide [N-(2,4-dimethyl-5-((trifluoromethyl)sulfonyl)amino)phenyl)acetamide] (18, 22, 51, 68, 88), and amidochlor (N-[(acetylamino)methyl]-2-chloro-N-(2,6-diethylphenyl)acetamide) (6, 28, 29, 33). However, negative side effects have limited these chemicals to use in hard to mow situations and low aesthetic value turf (14, 17, 20, 22, 23, 24, 36, 50, 80, 84, 87, 88). Several of the growth retardants also result in moderate to severe phytotoxicity to Kentucky bluegrass, especially noticeable in better stands of turfgrass (14, 29, 50, 84, 85, 87, 88). Because of these drawbacks, new chemicals are continually being developed.

A chemical with potential for use as a growth regulator in fine turf, under development by American Cyanamid

Company, is ACP 2100, a member of the imidazolinone family (exact chemical structure not released)[1], which was selected for this research. Previous research with ACP 2100 on 'Rebel' tall fescue (Festuca arundanacea L.), maintained as a home lawn, has shown this potential turf growth retardant to afford good height suppression with little injury to the turf (10). ACP 2100 was also found to afford adequate growth regulation activity on three Kentucky bluegrass turf types (78, 79). Another experimental growth regulator is ACP 2110, also under development by American Cyanamid Company[1]. ACP 2110 is a prepackaged mix of ACP 2100 and imazaquin. Sawyer and Jagschitz (66) found ACP 2110 to afford effective growth suppression of roadside turf for up to six weeks without objectionable turf injury at 77 and 110 g ha^{-1}. Seedhead suppression, an important quality factor with the use of turf growth retardants, was inadequate with 77 g ha^{-1} of ACP 2110, however, the 110 g ha^{-1} rate resulted in good suppression of seedheads. Duell, et al. (21) reported ACP 2110 to afford good plant growth regulation of 'Palmer' ryegrass (Lolium perenne L.), but caused notable discoloration in 'Repell' ryegrass and 'Banner' chewing fescue (Festuca spp.). Poor seedhead suppression with 45 g

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[1] P. R. Bhalla and R. E. Deems, American Cyanamid, Princeton, NJ, personal communication.

ha^{-1} of ACP 2110 was also reported.

Imazaquin alone has been reported to afford growth regulation of Kentucky bluegrass (77, 78, 79). The degree of seedhead suppression is equal to ACP 2100; however, foliar suppression occurs for only a period of three weeks with greater injury to the turf than that caused by 2100 (77, 78, 79). Broadleaf weed control has been thoroughly documented for imazaquin as a broad spectrum herbicide for use in soybeans (39, 40, 42, 43, 44, 63, 89), and for control of wild garlic, wild onion, and nutsedges in warm season turf (4, 12, 57, 77). Imazaquin was used in this research due to its potential of aiding ACP 2100 in turf growth regulation and because it is a broad spectrum herbicide. A broadleaf weed that both imazaquin and ACP 2100 have little activity on is common dandelion (Taraxacum officinale Weber in Wiggers) (10, 79). Further research of application timing, use rates and chemical combinations is needed on ACP 2100 and imazaquin to achieve less phytotoxicity, greater weed control and greater turfgrass seedhead and foliar suppression.

It has been noted by several researchers that turf thinning often results from turf growth suppression treatments (20, 26, 29, 50). Phytotoxicity, thinning and decreased horizontal growth of turf results in the encroachment of weeds, causing a further reduction of turf quality (18, 26, 48, 50, 67). Dernoeden (18) observed turf treated with mefluidide as affording canopy and seedhead suppression; however, fair to poor color and some loss in turf density occurred. The low density ratings were attributed to the presence of numerous large crabgrass (Digitaria sanguinalis (L.) Scop.) and dandelion plants. Dernoeden (18) conceived that the use of a herbicide prior to mefluidide application may increase turf quality by making a decrease in turf density less noticeable. Elkins et al. (22) observed that a severe color loss in a mefluidide treated plot was commonly followed by a severe weed infestation proportional to the stand loss. McElroy et al. (50) reported similar results of less vigorous growth and greater weed encroachment on fine turfgrasses when a chemical mowing program was practiced. The use of MH (1,2-dihydro-3,6-pyridazinedione) on roadside turf was effective as a growth retardant, however, Foote and Himmelman (27) found that when turf was not vigorous, annual populations of crabgrass, foxtails (Setaria spp. Beauv.) and ragweeds (Ambrosia spp. L.) often increased and gave roadsides an undesirable appearance.

Broadleaf weeds are often present in fine turf. If the turf growth retardant affords no broadleaf weed suppression the turf will appear ragged and uneven due to continued growth of the weeds (26, 50, 67, 72, 81). A major weed problem in turf is common dandelion. Dandelions left uncontrolled greatly reduce the quality of a growth regulated turf. Although the turfgrass is suppressed, mowing is still needed to remove the unsightly flower stalks and obvious flower heads (73). A dandelion flower left uncut in a lawn becomes unsightly within two to seven days when the ray flowers are replaced with relatively large plumes to aid in wind distribution of the dandelion achene (73). A dandelion left uncontrolled in a growth regulated turf lowers the turf quality and results in the need for mowing, defeating the purpose of the growth retardant.

Although dandelion is a prevalent weed it is also easily controlled. Control of 90 to 100% is often achieved with commonly used turf broadleaf herbicides containing at least one of the following herbicides; 2,4-D [(2,4-dichlorophenoxy)acetic acid], dicamba (3,6-dichloro-o-anisic acid) and triclopyr [((3,5,6-trichloro-2-pyridinyl) oxy)acetic acid] (8, 9, 65). Herbicides that result in the greatest control of dandelion are systemic in nature. A systemic herbicide is needed to achieve complete control of the above ground portion and tap root of the dandelion. Triclopyr is classified as a pyridine and is an auxin type herbicide used for the control of a wide range of annual and deep rooted perennial broadleaf plants (3, 5, 9, 64). Triclopyr is absorbed rapidly by the roots and foliage and is readily translocated throughout the plant via both xylem and phloem tissue (3, 5, 31, 59, 64). Triclopyr is thought to exert a toxic action at multiple sites within the plant via one or more mechanisms and the most herbicide sensitive of these sites can differ among plant species, similar to the mode of action of the phenoxy herbicides (3, 5, 31, 59).

The combination of a turf growth retardant with a broadleaf herbicide would be convenient because of their application timings. Herbicides for use in turf afford the greatest control of broadleaf weeds when the weeds are actively growing (3). The optimum times to control the majority of broadleaf weeds are in the spring and fall when the temperature and moisture are optimum for growth (8, 76). The optimum time for the use of a turf growth retardant is spring, due to the benefits of i) controlling turf growth during rainy periods in the spring when frequent mowing is necessary, but difficult to accomplish, ii) reducing mowing during a time of high labor requirements, allowing the labor force to be redirected, iii) growth retardants having been found to be more effective when used in spring than fall due to seedhead suppression and length of regulation activity,

iv) a fall treatment causing growth inhibition to persist into the period of turf dormancy, and v) suppressing turf growth in spring when a greater amount of foliar growth is occurring compared to a smaller growth peak in the fall for cool season turf (9, 19, 22, 35, 37, 50, 68).

The incorporation of a broad spectrum herbicide with a growth retardant gives turf managers a valuable method of solving vegetation management problems with one application (26, 35, 48). Foote and Himmelman (26) suggested the incorporation of a broad spectrum herbicide with a growth retardant to avoid a ragged appearance of the turf due to growth of broadleaf weeds. Eliminating the broadleaf weeds may also have the beneficial effect of reducing competition for available nutrients, moisture and light required for aesthetically desirable turfgrass (72). Stich et al. (72) assessed the effects and compatibility of mefluidide in combination with several broadleaf herbicides. They found that all combinations significantly reduced weeds and had no adverse effect on the appearance of the turf other than the discoloration caused by mefluidide. Test results of grass and weed yield showed that most treatments significantly reduced clipping weights. This provided evidence that growth retardants in combination with broadleaf herbicides effectively suppress vegetative growth and eliminate weeds resulting in fewer cuttings while also enhancing the appearance of the turf (30). Link et al. (45) reported in 1981 that an usual practice along Virginia highways has been to use MH in combination with 2,4-D or dicamba to reduce turf growth and achieve good weed control. Murray and Klingman (53) found no significant weed problem to develop when evaluating combinations of growth regulators, nitrogen levels and herbicides on turf. Morre' and Tautvydas (51), using a combination of mefluidide plus chlorsulfuron as a growth retardant, a detergent to enhance penetration and 2,4-D to provide control of broadleaf weeds, achieved full-season vegetation management of bluegrass-tall fescue mixtures along roadsides. They found a single spray application made in spring required no additional herbicide applications that year. Other than the reports mentioned above, little research has been done with tank mixes of a growth retardant plus a herbicide to develop a turf management program resulting in a high quality, low maintenance turf.

A combination of chemicals in a tank mix is advantageous because the number of chemical applications is reduced, in turn reducing cost of fuel, labor and time (25, 34, 64). A majority of turf management programs include a spring application of herbicide(s), either granular or liquid. Incorporation of a turf growth retardant into this treatment significantly reduces the cost of turf maintenance when chemical mowing is compared to mechanical mowing. However, several important considerations must be taken into account when chemicals are tank mixed (25, 34, 51, 72, 64). The reason for herbicide combinations is usually to surpass the separate effects of the components, or to see if a material applied for another purpose, with a herbicide, enhances or detracts from the effect of a herbicide (52). The latter reason is of concern here. Tank mixes must first be researched and tried on a small scale due to the potential for physical incompatibility and the potential for altered plant responses, particularly when the solution is applied to the foliage, such as in turf (52, 64). Combination effects of herbicides which result in altered plant responses are categorized into three effects; additive, antagonistic and synergistic (2, 13, 25, 34, 52, 55, 64). When the chemical combination results in a plant response predicted from the activity achieved with each chemical applied individually the effect is described as additive (2, 13, 25, 34, 75). The second two effects are categorized as interactions, and indicate that the combined effects of the chemicals are not additive (13, 25, 34, 75). If the activity achieved from a combination of two or more herbicides results in an observed response greater than the predicted response, the interaction is termed synergistic (2, 25, 34, 64). If the observed response is less than the predicted response, the interaction is termed antagonistic.

Interactions are analyzed by several methods. Colby (13) developed one of the earliest methods, used by plant scientists for detection of synergisms and antagonisms. However, this method was widely criticized due to a lack of sensitivity in detecting interactions (25, 34, 75). Hatzios (34) later developed a means to detect significance of synergisms and antagonisms, using an analysis of variance (ANOVA) method. Recently this method of detecting significance of synergisms and antagonisms has been further developed by Flint et al. (25). Data are transformed to logarithms, to decrease problems associated with heterogeneity of variance, and significance of antagonisms and synergisms is detected by a t-test and P-value (25). Data must be initially analyzed for variance to determine the presence of a significant herbicide interaction (25, 41, 46). If the interaction exists, characterization of those interactions is conducted.

An example of an interaction between herbicidal chemicals was used by Colby (13). Early research by Jagschitz and Skogley (38) included tank mixing of dicamba, mecoprop and 2,4-D for control of dandelion in turf. Depending on the rate of each herbicide used in the combination the effect on dandelion control was synergistic or antagonistic (13). These studies have lead to an important, often used turf herbicide, Trimec®[2]. Antagonisms and synergisms are common between herbicides (34). The severity and reason for the interactions depend on several factors and the joint response in most cases is poorly understood (34).

One reason for an interaction could be the result of changes in the amount of herbicide reaching the site of action, either by a change in uptake due to the nature of the chemical itself or its chemical form (34. 60, 72). Richardson (60) reviewed absorption and translocation of 2,4-D and found that the formulation of the phenoxy has a marked effect on its penetration and translocation. Experiments on penetration of 2,4-D in the ester, amine and salt forms demonstrated that absorption of organic materials into the leaves is correlated inversely with polarity. The pH of a herbicide solution influences absorption in the same way. Szabo and Bucholtz (74) showed that penetration of 2,4-D was higher at pH 3.5 than pH 5.5. When the molecules

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[2] Trimec Classic. PBI/Gordon Corporation, Kansas City, MO 64101.

are undissociated, and thus relatively non-polar, uptake is favored (60). Therefore, if the pH of the solution or the properties of the herbicide or growth regulator change, due to a mixture of the two chemicals, a result of increased or decreased cuticular penetration may be observed. A synergistic effect on uptake usually results in increased broadleaf weed control, but may also increase the potential of turfgrass injury.

Examples of this type of interaction have already been documented. Davis et al. (15) showed picloram (4-amino-3,5,6-trichloropicolinic acid), in the same family as triclopyr, to reduce the uptake of 2,4,5-T [(2,4,5-trichlorophenoxy)acetic acid] in mesquite plants although the uptake of picloram was enhanced by the presence of 2,4,5-T. Richardson (60) reported that 2,4-D plus dicamba combinations are synergistic when applied to leafy spurge. In the first 4 hours of the experiment, uptake of dicamba was stimulated by 2,4-D; however, in the final 4-16 hours of the experiment 2,4-D uptake was stimulated by dicamba. Other researchers found that the absorption of 2,4-D was not affected by picloram but the uptake of picloram was reduced by 2,4-D in field bindweed (1, 49).

The interference of one chemical with another may also result in a change in the pattern of one or both of the chemical's penetration, translocation or biotransformation in plants (34). Translocation, like absorption, is also partially dependent on pH of the herbicide solution (32, 60). Greenham (32) reported that more 2,4-D is translocated to the roots when applied at 10.2 x 10^{-3}M than at 3.4 x 10^{-3}M at pH 8.5, while at pH 4 there were no significant differences in translocation between the two concentrations. The direct effect of herbicide formulation on translocation is also documented by Norris & Freed (56) who showed that more 2,4-D was translocated to the roots when applied as an acid than as an ester or amine, and more 2,4,5-T was translocated to the roots when applied as an ester rather than as an acid or amine.

Interactions between chemicals affecting translocation have already been reported by several research groups (1, 15, 16, 24). Davis et al. (16) showed that 2,4,5-T translocation in mesquite is decreased when picloram is added although picloram translocation is enhanced in the presence of 2,4,5-T. Richardson (60) has found that dicamba increases the amount of 2,4-D translocated in leafy spurge (Euphorbia esula L.) although translocation of dicamba is reduced by the presence of 2,4-D. The interaction between picloram and 2,4-D in field bindweed (Convolvulus arvensis L.) was examined by Agbakoba and Goodin (1). They found that picloram increased the amount of 2,4-D translocated to nontreated parts of the plant, while 2,4-D had no effect on overall picloram translocation.

A herbicide may also influence the toxicity of another herbicide by interacting at the site of the biochemical or physiological action within the plant cells (34). This type of interaction is possible with ACP 2100 and imazaquin. Both chemicals are in a new class of herbicides, the imidazolinones (47). The mode of action of several imidazolinones has been researched and they have been found to inhibit the enzyme acetohydroxyacid synthase (69, 70, 71). If both herbicides within a combination act at the same site, an antagonism may occur due to the competition for that site; however, both herbicides may inhibit the same enzyme at different sites, depending on the plant species, resulting in additive, antagonistic or synergistic control of the vegetation. Sulfonylurea herbicides also inhibit acetohydroxyacid synthase. Research by Riley and Shaw (61) showed a synergism between chlorimuron (2-[[[[4-chloro-6-methoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid), a sulfonylurea, and imazapyr {(±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridinecarboxylic acid}, an imidazolinone, for pitted morningglory (*Ipomoea lacunosa* L.) control. The combination of imazapyr plus imazaquin was synergistic for Johnsongrass (*Sorgum halepense* (L.) Pers.) control; however, an antagonistic response was observed for control of sicklepod. Therefore, it is difficult to predict the type of interaction to expect with the combination of ACP 2100 plus imazaquin on Kentucky bluegrass or dandelion.

Due to the different response of species to herbicide combinations Hatzios and Penner (34) suggest that interactions of two or more agrochemicals be evaluated only on one plant species at a time. Also, within a species, genotype variation often occurs and there is a possibility that two or more chemicals may interact differently between genotypes within a species. Numerous researchers assessing the effects of growth retardants on turf have found a difference in turf growth suppression activity between varieties of turfgrass (11, 58, 82, 83, 87).

Objectives. The main objective of this research was to explore the development of a vegetation management program utilizing a tank mix of PGR plus broadleaf herbicide for fine turf. The objectives for each stage of research were:

Field

1) To evaluate the activity and compatibility of ACP 2100, imazaquin and triclopyr in all possible combinations for turf growth regulation and control of common dandelion.
2) To compare the effect of the chemicals alone and in combination on three kentucky bluegrasses to detect if varietal differences occur.

Greenhouse

1) To characterize the interactions between ACP 2100 and imazaquin and between ACP 2100 and triclopyr for growth suppression of 'Plush' Kentucky bluegrass.
2) To characterize the interaction between triclopyr and ACP 2100 and between triclopyr and imazaquin on the control of common dandelion.

Laboratory

1) To determine if there is a change in uptake, translocation or metabolism of triclopyr when it is applied alone compared to when it is in combination with ACP 2100.

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CHAPTER II

EFFECT OF ACP 2100, IMAZAQUIN AND TRICLOPYR ON THREE KENTUCKY BLUEGRASS TURF TYPES

Abstract. Field experiments were conducted to evaluate all possible combinations of three rates of ACP 2100 and two rates each of imazaquin and triclopyr on three kentucky bluegrass cultivars, 'Plush', '190', and a 'Glade-Plush-Ram' blend. The combined high rates of ACP 2100 and imazaquin resulted in unacceptable turf quality due to the extent of turf injury. Combined low rates of ACP 2100 and imazaquin resulted in equal growth regulation to either herbicide alone or in combination at the high rates, with less turf injury. Triclopyr at 276 g ha^{-1} plus ACP 2100 at 96 g ha^{-1} resulted in reduced turf injury for the 'Plush' and 'Glade-Plush-Ram' bluegrass compared to ACP 2100 alone. Three-way interactions between chemicals seldom occurred, however, turf quality was influenced by all three chemicals for the 'Plush' variety, with triclopyr reducing turf injury caused by imazaquin and ACP 2100. The broadleaf weed evaluated was common dandelion, with imazaquin at 276 g ha^{-1} affording 22% control; however, no additional control of dandelion was achieved with imazaquin plus triclopyr compared to triclopyr alone. ACP 2100 had no effect on dandelion control.

Nomenclature: Kentucky bluegrass, *Poa pratensis* L. #[1] POAPR; common dandelion, *Taraxacum officinale* Weber in Wigger # TAROF; imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid; triclopyr, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid.

Additional index words. Plant growth regulator, PGR, chemical mowing.

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[1] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

INTRODUCTION

ACP 2100, a member of the imidazolinone family (exact chemical structure not released), has been shown to suppress turf growth with little discoloration or phytotoxicity to 'Rebel' tall fescue and 'Plush' Kentucky bluegrass (2, 12, 13). However, poor weed control has been achieved with ACP 2100 at growth regulation use rates (2, 13). Before ACP 2100 can be developed as a vegetation management tool for high quality turf, research is needed for incorporation of a broadleaf herbicide into the turf growth retardant treatment.

Turf growth regulation of a roadside turf, heavily infested with broadleaf weeds, resulted in an uneven, poor quality turf due to continued growth of weeds (4, 8, 9, 11). Foote and Himmelman (4) suggested the incorporation of a broad spectrum herbicide with a growth retardant to help provide a uniform appearance of the turf through control of broadleaf weeds. Stich et al. (11) assessed the effects and compatibility of a turf growth regulator with several broadleaf herbicides and found all combinations significantly reduced weeds without adverse effects to the appearance of the roadside turf. The combination of a PGR with a broadleaf herbicide would be convenient because the optimum time to apply both chemicals is in the spring. A tank mix would reduce labor and time expenses for chemical application and mowing. This suggests that a high quality, fine turf may be maintained with chemical mowing if a broadleaf herbicide is incorporated into the turf growth retardant treatment. The incorporation of a broad spectrum herbicide with a growth retardant would give turf managers a valuable tool for solving vegetation management problems with one herbicide application (4).

Due to the aesthetic value of fine turf; however, a chemical interaction resulting in turf injury or decreased weed control could not be tolerated. Two herbicides that may result in acceptable vegetation control when in combination with ACP 2100 are imazaquin and triclopyr. Imazaquin is a broad spectrum herbicide in soybeans (Glycine max (L.) Merr.) and is used for the control of sedges (Cyperus sp.), wild onion (Allium canadense L.) and wild garlic (Allium vineale L.) in warm season turf (5, 6, 14). However, imazaquin has been found to injure cool season turf such as Kentucky bluegrass (12, 13). With lower rates of imazaquin weed control decreases, indicating the possibility of an associated decrease in turf injury (5, 14). Imazaquin has the potential to result in added turf growth retardant activity and afford some weed control when combined with ACP

2100. Triclopyr is used for control of a wide range of broadleaf species alone and in combination with 2,4-D [(2,4-dichloro-phenoxy)acetic acid] and affords little activity on turf species at recommended use rates (1, 3). Addition of triclopyr to ACP 2100 has the potential to afford the needed weed control without resulting in turf injury. Combinations of imazaquin, triclopyr and ACP 2100 may result in an additive, synergistic or antagonistic effect on growth regulation and broadleaf weed control.

The objective of this study was to evaluate the activity and compatibility of ACP 2100, imazaquin and triclopyr for turf growth regulation and control of common dandelion, a prevalent broadleaf weed found in fine turf.

MATERIALS AND METHODS

Field experiments were conducted at the Virginia Tech Turf Research Center in Blacksburg, VA during 1987 and 1988 on two Kentucky bluegrass varieties, 'Plush' and '190', and one Kentucky bluegrass blend, 'Glade-Plush-Ram' (blend) in a 10-25-10 ratio. The soil type for all plot areas was a Groseclose silt loam (Clayey, mixed, mesic Typic Hapludult) with a pH of 6.0 and 3.2% organic matter. Areas were fertilized with 10-10-10 at 49 kg N ha^{-1} in March, 1987 and in October, 1987 and February, 1988 for 1987 and 1988 plot areas, respectively. Plot size in each study was 1.8 by 2.4 m.

Treatments were applied on May 10, 1987, after 100% green-up, four days after the initial 6 cm mowing with turf in the boot stage. In 1988, treatments were applied on April 17, after 100% green-up and two weeks prior to the boot stage. Chemicals were applied with a CO_2 pressurized sprayer in 280 L ha^{-1} water spray volume and 0.25% v/v nonionic surfactant[2] at 210 kPa with 8003 flat fan tips[3]. Plots were trim mowed to 6 cm five days after application.

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[2] X-77. Chevron Chem. Co., San Francisco, CA 94119. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

[3] TeeJet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

In 1987 plots were irrigated as needed because only 5.3, 3.7 and 7.9 cm of rain fell during May, June and July, respectively. Irrigation was not needed in 1988 because 9.6, 4.3 and 8.1 cm of rain fell during April, May and June, respectively. Chemicals used alone and in combination were ACP 2100 at 48, 96 and 144 g ha^{-1}, and imazaquin and triclopyr amine each at 138 and 276 g ha^{-1}. Only 48 and 96 g ha^{-1} of ACP 2100 were used on the '190' variety due to limited space.

Percent turf injury and quality (on a scale of 0 to 9 with 6 indicating acceptable and 9 indicating excellent turf quality) (9) were rated once every two weeks. Turf height was measured weekly and when turf height reached 10 cm, an individual plot was mowed to 6 cm. The number of days before the first mowing (length of plant growth regulation), and the total number of mowings per eight weeks after treatment were recorded. The seedhead data recorded was height and count m^{-2}. Common dandelion counts were taken at zero, four and eight weeks after treatment.

All studies utilized a randomized complete block design with four replications in the 'Plush' and 3-way blend Kentucky bluegrass and three replications in the '190' Kentucky bluegrass. Data were analyzed using a factorial analysis of variance and significance was determined by partitioning the effects of treatments into main effects and interactions (7). Multiple comparison tests were performed using the least significant difference (LSD) multiple range test when interactions occurred and the Waller Duncan k-ratio t-test when main effects were significant.

RESULTS and DISCUSSION

Data were not combined by year or turf type due to unlike error mean squares as determined by a homogeneity of variance test. Results in 1987 differed from 1988 because of differences in rainfall and the time of application. Data from turf types were not combined due to differences in varietal sensitivity to chemicals.

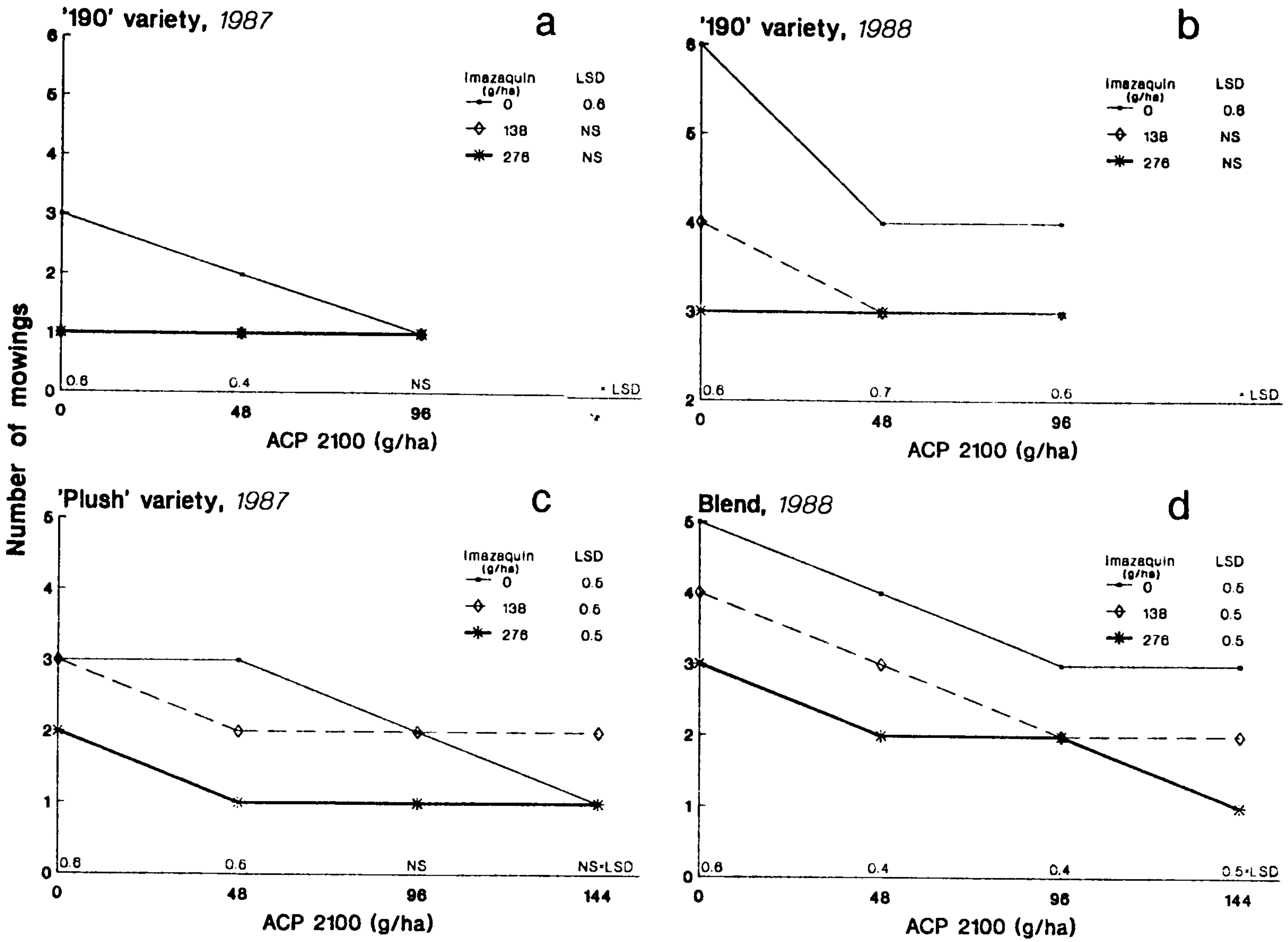
Number of mowings. For the total number of mowings needed during the eight weeks following treatment, all Kentucky bluegrass turf types showed a significant interaction between ACP 2100 and imazaquin, except the 'Glade-Plush-Ram' blend in 1987 and the 'Plush' variety in 1988. Of the latter two plot areas, mowing need significantly decreased as the rate of ACP 2100 and imazaquin increased (Table 1). There was no difference in mowing need, however, with ACP 2100 at 96 g ha^{-1} compared to 144 g ha^{-1}. Interactions between ACP 2100 and imazaquin were most evident in the '190' bluegrass, in that mowing need was not decreased by the addition of ACP 2100 at 48 or 96 g ha^{-1} to treatments containing imazaquin compared to treatments containing no ACP 2100 (Figure 1a and b). At the zero rate of imazaquin, addition of ACP 2100 resulted in a decrease in mowing need. For the 'Plush' variety, addition of ACP 2100 at 48 g ha^{-1}

Table 1. Turf growth regulation parameters following the eight weeks after treatment of Kentucky bluegrass, as affected by ACP 2100, imazaquin and triclopyr, reported as the mean of imazaquin plus triclopyr, ACP 2100 plus triclopyr, and ACP 2100 plus imazaquin, respectively.[a]

Rate	Mowing need		Length of PGR activity		Injury				Quality		
(g/ha)			- (days) -		------ (%) ------						
Herbicide	ACP 2100										
Variety	Blend	Plush	Plush	190	190	Plush	Plush		190	190	Blend
Year	'87	'88	'88	'88	'88	'88	'87		'88	'88	'87
Week					(4)	(4)	(6)		(4)	(6)	(6)
0	2.8 a	3.5 a	20 d	24 b	12 b	2 c	4 c		5.6 a	6.0 a	5.6 a
48	2.1 b	3.2 b	24 c	30 a	17 b	11 b	6 bc		5.4 a	5.3 b	5.7 ab
96	1.7 c	2.6 c	28 b	32 a	26 a	13 b	9 b		4.6 b	4.4 c	5.1 ab
144	1.5 c	2.4 c	30 a	--	--	19 a	15 a		---	---	4.9 b
Herbicide	Imazaquin										
Variety	Blend	Plush	Plush	190	190	Blend	Plush	Plush		190	Blend
Year	'87	'88	'88	'88	'88	'88	'88	'87		'88	'88
Week					(4)	(4)	(4)	(6)		(6)	(4)
0	2.6 a	3.4 a	16 c	18 c	5 c	7 c	8 c	4 c		6.1 a	6.9 a
138	1.9 b	2.9 b	27 b	32 b	14 b	16 b	9 b	9 b		5.4 b	6.7 a
276	1.6 c	2.3 c	32 a	36 a	36 a	33 a	17 a	13 a		4.3 c	5.0 b
Herbicide	Triclopyr										
Variety						190			190	Blend	Blend
Year						'88			'88	'87	'87
Week						(4)			(4)	(4)	(8)
0						22 a			4.7 b	4.5 b	4.7 b
138						22 a			5.0 b	4.8 ab	5.5 b
276						11 b			5.8 a	5.0 a	6.2 a

[a] Means within a column followed by the same letter are not significantly different at the 0.05 level as determined by Waller Duncan K-ratio t-test.

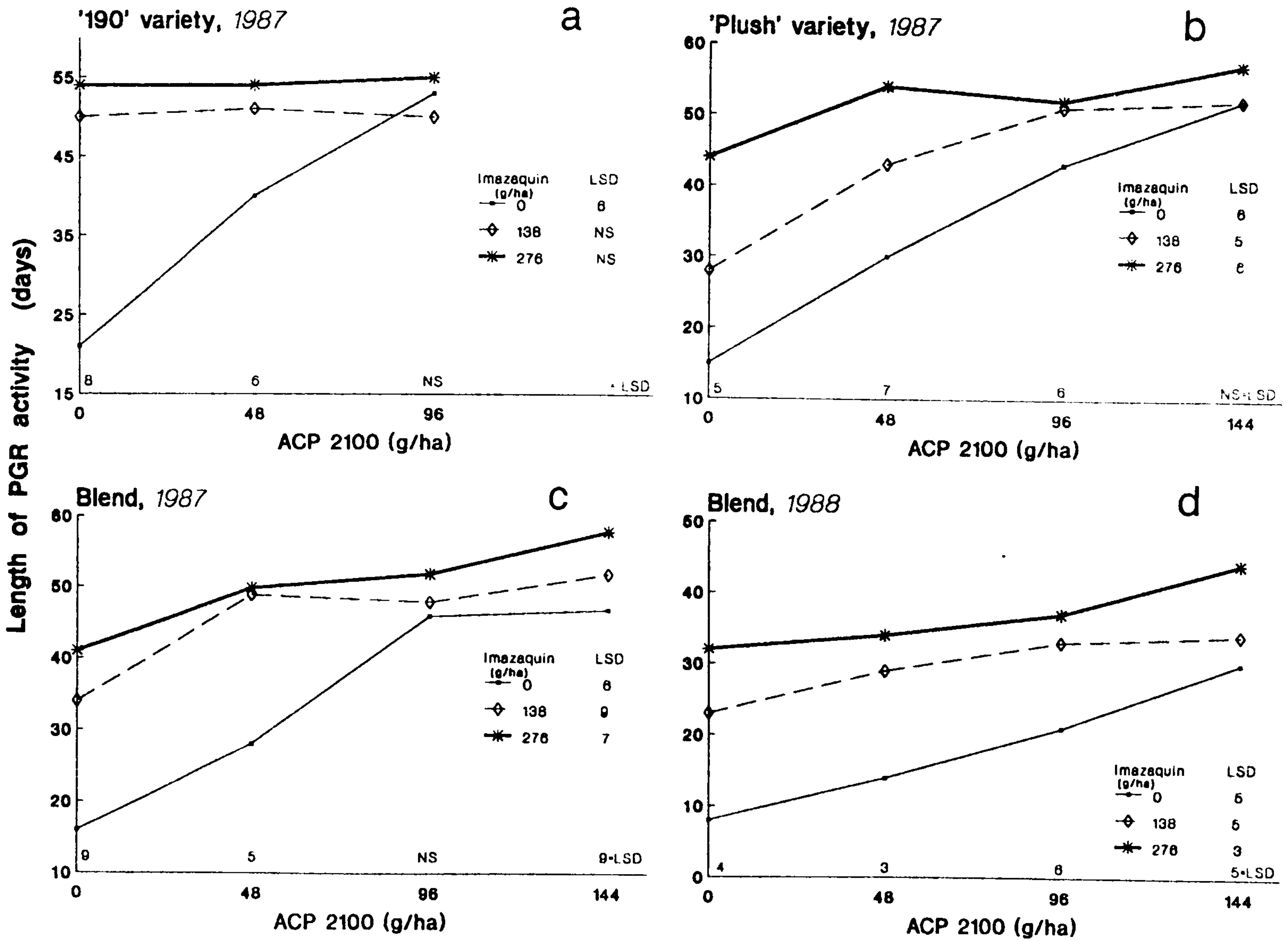
Figure 1. The number of mowings needed during the eight weeks following treatment of three Kentucky bluegrass cultivars, as affected by the combination of ACP 2100 and imazaquin, graphed as the mean across all rates of triclopyr. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100, respectively, at the 5% level.


Number of mowings
'190' variety, 1987
a
Imazaquin (g/ha)
LSD
0
0.6
138
NS
276
NS
0.6
0.4
NS
- LSD
0
48
96
ACP 2100 (g/ha)
'190' variety, 1988
b
Imazaquin (g/ha)
LSD
0
0.8
138
NS
276
NS
0.6
0.7
0.6
- LSD
0
48
96
ACP 2100 (g/ha)
'Plush' variety, 1987
c
Imazaquin (g/ha)
LSD
0
0.5
138
0.6
276
0.5
0.6
0.6
NS
NS-LSD
0
48
96
144
ACP 2100 (g/ha)
Blend, 1988
d
Imazaquin (g/ha)
LSD
0
0.6
138
0.5
276
0.5
0.6
0.4
0.4
0.5-LSD
0
48
96
144
ACP 2100 (g/ha)

to treatments containing imazaquin significantly decreased the mowing need compared to the mean of either herbicide alone and in combination with triclopyr (Figure 1c). At 96 and 144 g ha^{-1} of ACP 2100 plus imazaquin, no decrease in mowing need was observed compared to treatments containing only ACP 2100 at the two high rates. The 'Glade-Plush-Ram' blend showed a similar trend to the 'Plush' variety, however, a significant decrease in mowing need was also afforded with the combination of ACP 2100 plus imazaquin at 96 plus 138, 96 plus 276 and 144 plus 276 g ha^{-1} compared to treatments with only one of the above chemicals (Figure 1d). There was no significant difference between combinations containing ACP 2100 at 144 g ha^{-1} plus imazaquin at 138 g ha^{-1} and the combined mean of treatments containing ACP 2100 at the zero rate of imazaquin.

Length of turf growth regulation. The length of turf growth suppression was influenced by ACP 2100 and imazaquin for the 'Plush' and '190' variety in 1988 (Table 1). As the rates of ACP 2100 and imazaquin increased, there was a significant increase in the length of turf growth retardation. However, for the '190' variety in 1988, ACP 2100 afforded no difference in the length of turf growth suppression between the 0 and 48 g ha^{-1} rate. All other turf areas showed an interaction between ACP 2100 and imazaquin (Figure 2). For

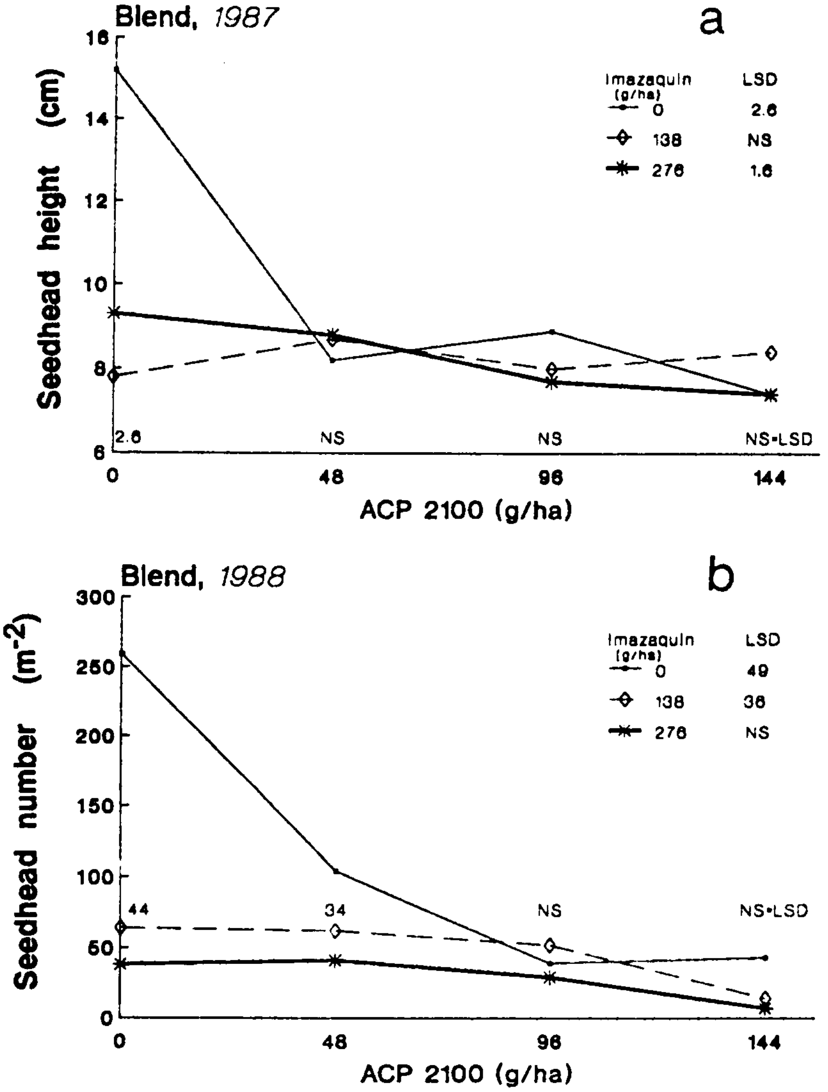
Figure 2. The length of turf growth regulation following treatment of Kentucky bluegrass as affected by the combination of ACP 2100 and imazaquin, graphed as the mean across all rates of triclopyr. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100, respectively, at the 5% level.


'190' variety, 1987
a
Length of PGR activity (days)
55
45
35
25
15
0
48
96
ACP 2100 (g/ha)
Imazaquin (g/ha)
LSD
0 6
138 NS
276 NS
8
6
NS
• LSD
'Plush' variety, 1987
b
60
50
40
30
20
10
0
48
96
144
ACP 2100 (g/ha)
Imazaquin (g/ha)
LSD
0 8
138 5
276 8
5
7
6
NS=LSD
Blend, 1987
c
60
50
40
30
20
10
0
48
96
144
ACP 2100 (g/ha)
Imazaquin (g/ha)
LSD
0 6
138 9
276 7
9
5
NS
9=LSD
Blend, 1988
d
50
40
30
20
10
0
0
48
96
144
ACP 2100 (g/ha)
Imazaquin (g/ha)
LSD
0 5
138 5
276 3
4
3
8
5=LSD

the '190' variety, as with mowing need, the length of turf growth suppression was not increased by the addition of ACP 2100 (Figure 2a). An increase in the rate of ACP 2100 without imazaquin in the combination, however, did increase the length of turf growth suppression. For the blend and 'Plush' bluegrass, in 1987, treatments that contained either ACP 2100 or imazaquin showed a significant increase in the length of turf growth suppression activity with an increase in rate (Figure 2b and c). There was no increase in turf growth suppression when the rate of imazaquin was increased from 0 to 276 g ha^{-1} and the rate of ACP 2100 was held constant at 96 or 144 g ha^{-1}, for the blend and 'Plush', respectively. Length of plant growth regulation for the bluegrass blend, in 1988, showed a significant difference between the zero and 276 g ha^{-1} rates of imazaquin at all rates of ACP 2100 (Figure 2d).

For turf growth retardant activity, there was a difference between varieties in response to imazaquin and combinations of imazaquin plus ACP 2100. The 'Glade-Plush-Ram' blend, in 1988, under excellent growing conditions, showed the greatest response to increasing rates of ACP 2100 and imazaquin in combination and the '190' variety showed the least response to a change in the rate of imazaquin. Therefore, to achieve the least number of mowings with the smallest amount of chemical would depend on the turf variety. Triclopyr afforded no turf growth suppression. **Seedhead control.** Seedhead height and number differed in 1987 and 1988 due to the time of application. Treatments in 1987 were applied when the turf was in the boot stage, resulting in the majority of seedheads emerging with no difference between treatments (data not shown). The difference in seedhead height between treatments, however, was significant (Figure 3a and Appendix figure 1a and b). In 1988, treatments were applied approximately two weeks before seedhead emergence. This resulted in prevention of a percentage of seedheads from emerging, depending on the amount of plant growth regulation activity afforded by the treatment (Figure 3b and Appendix figure 1c and d). For the seedheads that emerged, in 1988, seedhead height was measured and there was no difference between treatments (data not shown). For all turf types a similar interaction occurred between ACP 2100 and imazaquin for seedhead height and number in 1987 and 1988, respectively. Seedhead height and number were taken before the nontreated check was mowed. For seedhead height, all rates of ACP 2100 and imazaquin afforded good height suppression as compared to the non-treated or triclopyr treated turfgrass. Due to the extent of height suppression achieved with the low rate of either

Figure 3. Seedhead height and seedhead number for 'Glade-Push-Ram' Kentucky bluegrass, as affected by the combination of ACP 2100 and imazaquin, graphed as the mean across all rates of triclopyr. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100, respectively, at the 5% level.

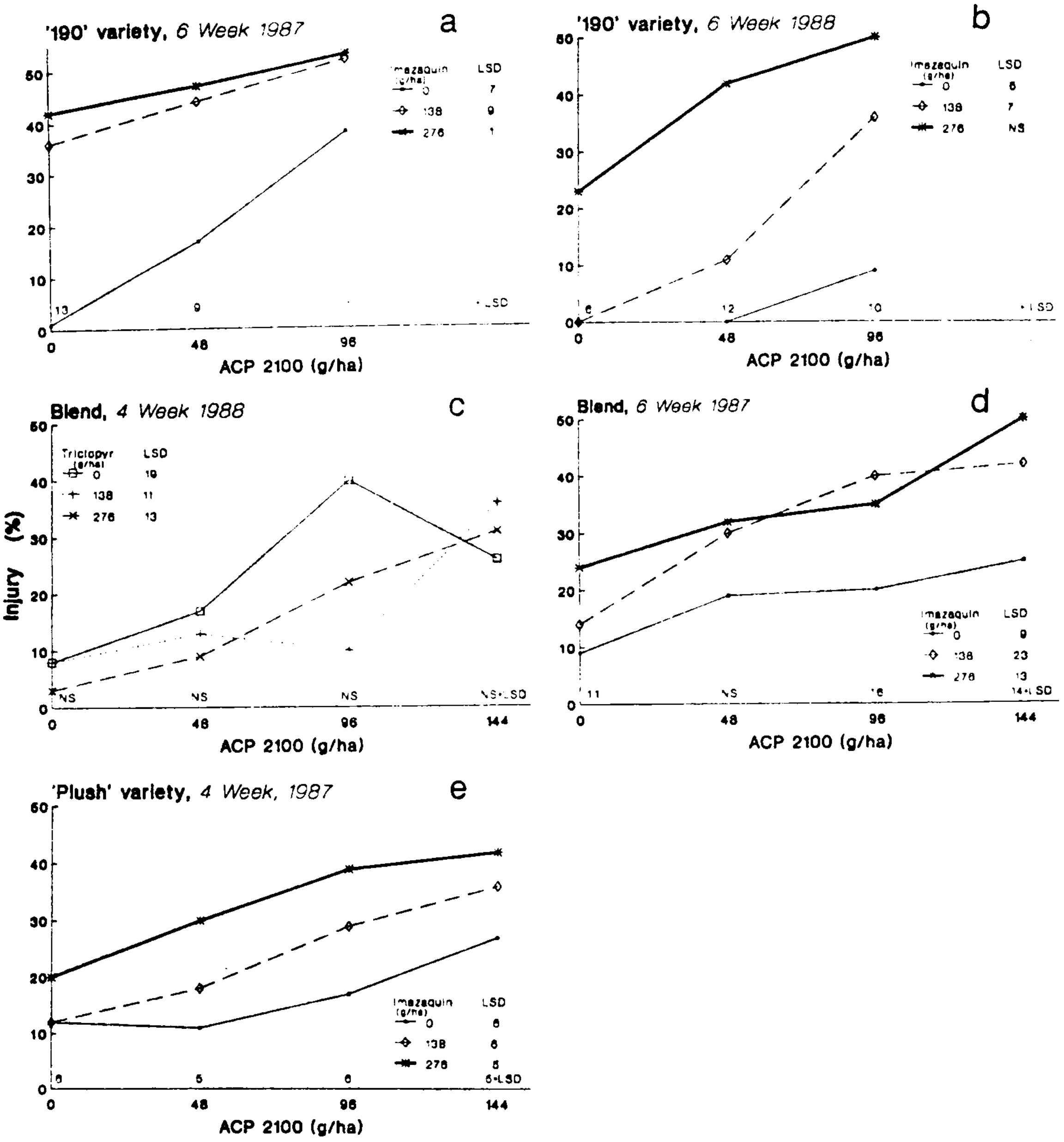

Blend, 1987
a
Seedhead height (cm)
16
14
12
10
8
6
Imazaquin (g/ha)
LSD
0
2.6
138
NS
276
1.6
2.6
NS
NS
NS=LSD
0
48
96
144
ACP 2100 (g/ha)
Blend, 1988
b
Seedhead number (m-2)
300
250
200
150
100
50
0
Imazaquin (g/ha)
LSD
0
49
138
36
276
NS
44
34
NS
NS=LSD
0
48
96
144
ACP 2100 (g/ha)

ACP 2100 or imazaquin, increasing the rate, or combining the two herbicides, did not result in significantly greater height suppression. Seedhead number showed a rate response to ACP 2100 between the rates of 0, 48 and 96 g ha^{-1} and no rate response to imazaquin for all three varieties. Combinations of ACP 2100 plus imazaquin did not further decrease the number of emerged seedheads.

Injury. For all turf types, at four weeks in 1988, an increase in the rate of imazaquin resulted in an increase in turf injury (Table 1). The '190' and 'Plush' varieties also showed an increase in injury with an increase in the rate of ACP 2100. These same two trends occurred in the 'Plush' variety at six weeks in 1987. However, the percent injury in the 'Plush' variety was always lower than in the '190' or blend bluegrass.

The injury ratings at four and six weeks, in 1987, and six and eight weeks, in 1988, for the '190' variety showed the same interaction between ACP 2100 and imazaquin (Figure 4a and b, Appendix figure 2a and b). At four and six weeks in 1987, as the rate of ACP 2100 increased, injury increased and there was no significant difference between the two rates of imazaquin (Figure 4a). For the six and eight week ratings in 1988, however, imazaquin at 276 g ha^{-1} resulted in significantly greater injury than the 138 g ha^{-1} rate

Figure 4. Percent injury of Kentucky bluegrass, as affected by the combination of ACP 2100 and imazaquin, or triclopyr, graphed as the mean across all rates of triclopyr or imazaquin, respectively. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100, respectively, at the 5% level.


'190' variety, 6 Week 1987
a
Imazaquin (g/ha)
LSD
0 7
138 9
276 1
13
9
LSD
'190' variety, 6 Week 1988
b
Imazaquin (g/ha)
LSD
0 6
138 7
276 NS
6
12
10
LSD
Blend, 4 Week 1988
c
Triclopyr (g/ha)
LSD
0 19
138 11
276 13
NS
NS
NS
NS=LSD
Blend, 6 Week 1987
d
Imazaquin (g/ha)
LSD
0 9
138 23
276 13
11
NS
16
14=LSD
'Plush' variety, 4 Week, 1987
e
Imazaquin (g/ha)
LSD
0 6
138 6
276 5
6
5
6
6=LSD
Injury (%)
0
10
20
30
40
50
ACP 2100 (g/ha)
0
48
96
144

(Figure 4b). For both years the addition of imazaquin to ACP 2100 further increased injury over that resulting from imazaquin alone. At eight weeks for the '190' variety, in 1987, there was no longer an ACP 2100/imazaquin interaction and injury was negligible (Appendix table 1). At six and eight weeks in 1987 and 1988, respectively, injury of the blend was influenced by a similar interaction between imazaquin and ACP 2100 although injury in 1987 was 30% greater than injury in 1988 (Figure 4d, Appendix figure 2d). Both interactions showed that treatments containing imazaquin plus ACP 2100 at 144 g ha^{-1} caused significantly greater injury than all other treatments. There was little to no decrease in percent injury from six to eight weeks in 1988, however, in 1987 injury at eight weeks had decreased enough to result in no significant difference between treatments (data not shown). The interaction for the 'Plush' variety between imazaquin and ACP 2100 at four weeks in 1987 showed that as the rate of both imazaquin and ACP 2100 increased, injury significantly increased; however, there was no significant difference in turf injury caused by ACP 2100 at 96 and 144 g ha^{-1} when the rate of imazaquin remained at 276 g ha^{-1} (Figure 4e).

For the '190' variety, the high rate of triclopyr decreased injury caused by ACP 2100 and imazaquin compared to treatments containing the zero and low rate of triclopyr (Table 1). Both the 'Plush' variety and the blend showed an interaction between triclopyr and ACP 2100 at four weeks in 1987 and 1988, respectively (Figure 4c, Appendix figure 2c). With triclopyr in the tank mix there was no difference in injury between the 48 and 96 g ha^{-1} rate of ACP 2100. Without triclopyr, however, 96 g ha^{-1} of ACP 2100 resulted in greater turf injury than 48 g ha^{-1} of ACP 2100. This suggests that addition of triclopyr to ACP 2100 at 96 g ha^{-1} can reduce injury to equal the injury occurring at the low rate of ACP 2100. At six weeks, overall injury increased and was no longer influenced by the rate of triclopyr.

Injury of the blend bluegrass at four and six weeks in 1987 and 1988, respectively, showed a three-way interaction between chemicals. For the four week injury, at the high rate of triclopyr, there was no increase in injury as either the rate of imazaquin or ACP 2100 increased (Table 2). At six weeks, the only treatments to result in unacceptable turf injury contained ACP 2100 at 144 g ha^{-1} and imazaquin at 276 g ha^{-1}, with injury between 36 and 53% (Appendix table 2).

Percent turf injury was consistently high for the combinations of imazaquin plus ACP 2100 at 96 and 144 g ha^{-1}. Early injury caused by 96 g ha^{-1} of ACP 2100 and the

Table 2. Four week injury of the 'Glade-Plush-Ram' blend of Kentucky bluegrass and eight week quality of 'Plush' Kentucky bluegrass as affected by combinations of ACP 2100, imazaquin and triclopyr.[a]

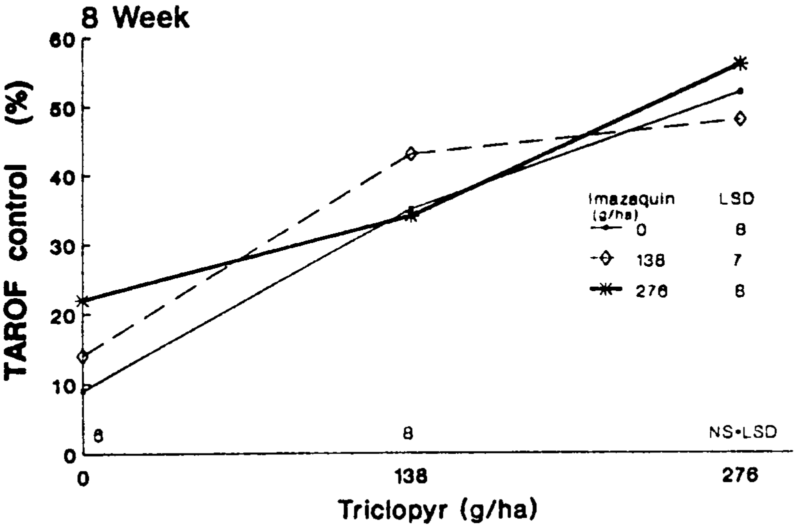
		Injury				Quality			
		Triclopyr g/ha							
ACP 2100	Imazaquin	0	138	276	LSD	0	138	276	LSD
(g/ha)	(g/ha)	---	(%)	---					
0	0	15	30	15	NS	4.5	7.2	6.0	1.1
	138	28	35	28	NS	5.5	5.0	5.5	NS
	276	32	30	35	NS	5.0	6.0	6.0	NS
	LSD	14	NS	16		NS	1.2	NS	
48	0	35	18	28	4	5.0	6.0	5.5	1.8
	138	32	42	48	9	5.0	6.5	6.0	NS
	276	45	48	45	NS	6.0	5.8	5.8	NS
	LSD	NS	8	11		0.8	NS	NS	
96	0	20	38	38	NS	4.8	5.5	6.5	1.3
	138	42	35	50	13	5.0	5.2	6.0	NS
	276	48	42	50	NS	5.2	6.5	5.8	1.1
	LSD	14	NS	9		NS	0.9	NS	
144	0	35	35	38	NS	4.7	4.7	6.0	NS
	138	45	48	45	NS	5.2	5.5	6.2	NS
	276	48	50	48	NS	5.0	5.8	5.5	NS
	LSD	11	NS	4		NS	0.9	NS	
LSD	0	19	16	9		NS	0.9	NS	
	138	10	11	15		NS	1.4	NS	
	276	11	9	5		0.7	NS	NS	

[a] LSD at the P = 0.05 level for percent injury comparison.

high rates of ACP 2100 plus imazaquin were decreased with addition of triclopyr at 276 g ha^{-1} to the tank mix. For all turf types, turf injury did not occur until four weeks. At eight weeks, the 'Plush' variety had overcome all phytotoxic affects rated as injury; however, the '190' variety and the 'Glade-Plush-Ram' blend still showed unacceptable phytotoxicity in the range of 30 to 50% injury.

Common dandelion control. Only 1987 common dandelion control is presented due to uneven dandelion populations in 1988. Dandelion control was pooled across the three turf varieties. Triclopyr at 550 g ha^{-1} will result in excellent control of common dandelion (3), therefore, triclopyr was applied in this study at the 1/4X and 1/2X rate in order to detect increases in dandelion control from combinations of triclopyr and ACP 2100 and/or imazaquin. ACP 2100 did not contribute to the control of common dandelion; however, there was a significant interaction between triclopyr and imazaquin (Figure 5). Each herbicide, at the zero rate of the other, resulted in an increase in dandelion control with an increase in rate. Although imazaquin alone afforded 22% control of dandelion, a combination of imazaquin plus triclopyr did not result in greater control than triclopyr alone. In fact, addition of imazaquin to triclopyr at 276 plus 138 g ha^{-1}, respectively, resulted in less dandelion

Figure 5. The percent control of common dandelion (TAROF) as affected by the combination of triclopyr and imazaquin, graphed as a mean across all rates of ACP 2100. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of triclopyr, respectively, at the 5% level.


8 Week
TAROF control (%)
0
10
20
30
40
50
60
Triclopyr (g/ha)
0
138
276
Imazaquin (g/ha)
LSD
0
8
138
7
276
8
8
8
NS•LSD

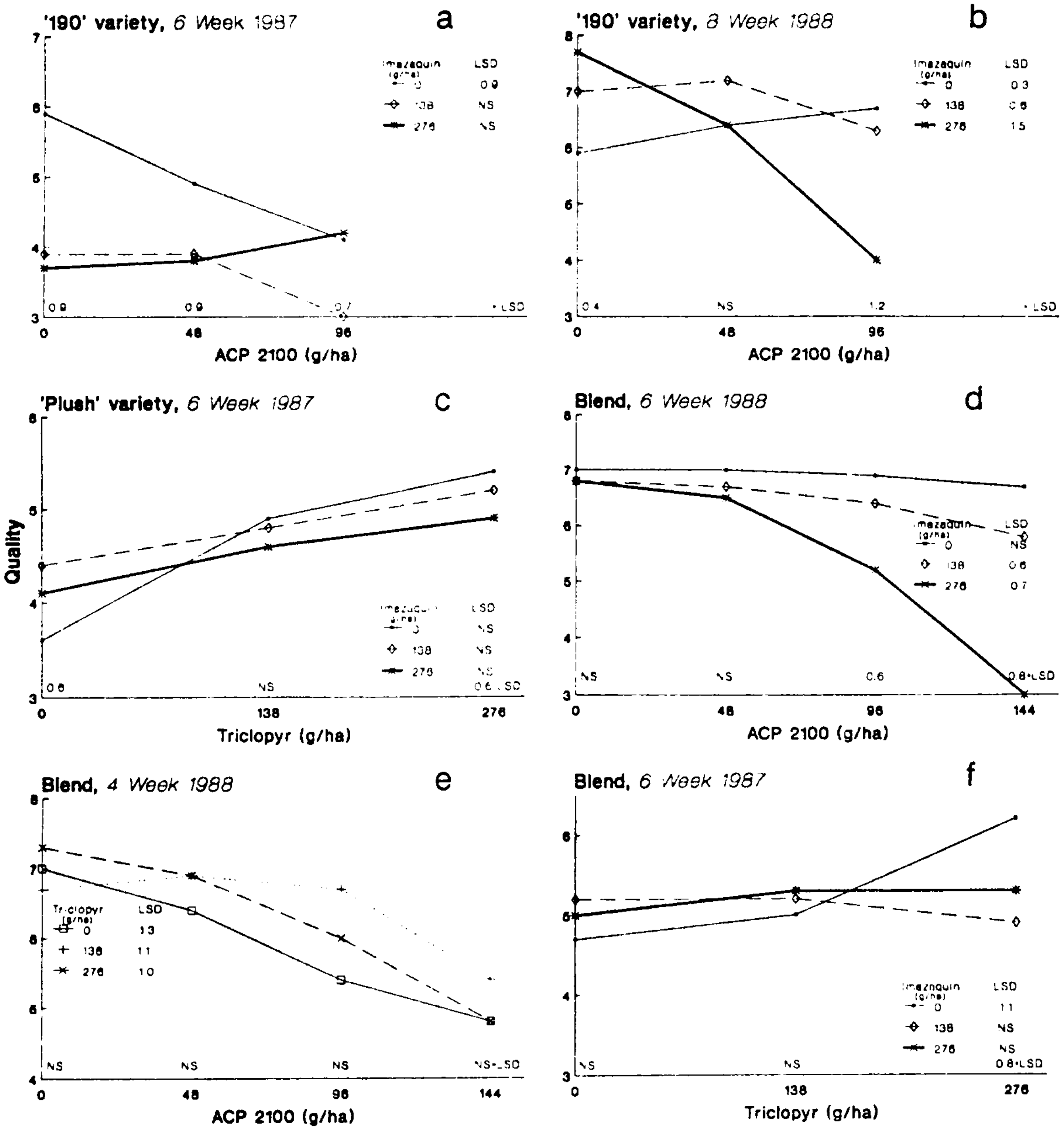
control than 138 g ha^{-1} each of imazaquin plus triclopyr. These results indicate that imazaquin added to triclopyr is not beneficial because it results in control less than or equal to triclopyr alone.

Quality. Quality was an overall rating, determined visually (Appendix figure 3). High quality ratings reflect good turf color and uniformity of height, high turf density, low turf phytotoxicity, no presence of seedheads and good dandelion control. At two weeks, quality was excellent for all treatments across all turf varieties (data not shown). At four and six weeks, in 1988, the '190' variety was influenced most by ACP 2100 and imazaquin (Table 1). As the rate of ACP 2100 or imazaquin increased, there was a decrease in quality to below acceptable due to turf injury. This same trend occurred in the blend with imazaquin and ACP 2100 at four weeks in 1988 and at six weeks in 1987, respectively. In the '190' variety in 1988 and the blend in 1987, triclopyr influenced quality in that treatments containing triclopyr at 276 g ha^{-1} had significantly higher quality than plots with 138 g ha^{-1} or no triclopyr in the treatment. The increase in quality may be due to a decrease in turf injury caused by ACP 2100 along with greater weed control. At four and six weeks in 1987 there was a significant interaction between ACP 2100 and imazaquin

(Figure 6a, Appendix figure 4a). All treatments containing imazaquin and/or ACP 2100 resulted in quality below acceptable due to the degree of turf injury. At eight weeks, in 1987, there was little difference in quality between treatments and turf injury resulted in quality ratings less than 6. (Appendix table 1). At eight weeks in 1988 the interaction between ACP 2100 and imazaquin for quality showed that when no ACP 2100 was in the treatment, an increase in the rate of imazaquin resulted in an increase in turf quality due to a desirable dark green color of the turf with no thinning (Figure 6b). At 96 g ha^{-1} of ACP 2100, the rate of 276 g ha^{-1} of imazaquin resulted in a significant decrease in quality as compared to the 0 and 138 g ha^{-1} rate of imazaquin.

At four and six weeks in 1988, all quality was above acceptable for the 'Plush' variety (Appendix figure 4c and d). In 1987 all quality ratings were excellent for the 'Plush' variety at four weeks (data not shown). Six week quality ratings indicated an interaction between triclopyr and imazaquin (Figure 6c). At the zero level of triclopyr, treatments containing imazaquin at 138 g ha^{-1} afforded greater quality than treatments with no imazaquin in the treatment. However, at 276 g ha^{-1} of triclopyr, quality was greatest for treatments not containing imazaquin. At eight

Figure 6. Quality of Kentucky bluegrass as affected by the combination of ACP 2100 and imazaquin, triclopyr and imazaquin, and the combination of triclopyr and ACP 2100, graphed as the mean across all rates of triclopyr, ACP 2100 and imazaquin, respectively. Least significant differences (LSD's) listed across the bottom of the graph and in the legend indicate differences between and within the rates of imazaquin, respectively, at the 5% level.


'190' variety, 6 Week 1987
a
Imazaquin (g/ha) LSD
0 0.9
138 NS
276 NS
0.9 0.9 0.7 LSD
ACP 2100 (g/ha)
'190' variety, 8 Week 1988
b
Imazaquin (g/ha) LSD
0 0.3
138 0.6
276 1.5
0.4 NS 1.2 LSD
ACP 2100 (g/ha)
'Plush' variety, 6 Week 1987
c
Quality
Imazaquin (g/ha) LSD
0 NS
138 NS
276 NS
0.6 NS 0.6 LSD
Triclopyr (g/ha)
Blend, 6 Week 1988
d
Imazaquin (g/ha) LSD
0 NS
138 0.6
276 0.7
NS NS 0.6 0.8 LSD
ACP 2100 (g/ha)
Blend, 4 Week 1988
e
Triclopyr (g/ha) LSD
0 1.3
138 1.1
276 1.0
NS NS NS NS LSD
ACP 2100 (g/ha)
Blend, 6 Week 1987
f
Imazaquin (g/ha) LSD
0 1.1
138 NS
276 NS
NS NS 0.8 LSD
Triclopyr (g/ha)

weeks in 1987 a three way interaction occurred for quality (Table 2). At the zero rate of imazaquin quality increased as triclopyr increased for the 0, 48 and 96 g ha^{-1} rate of ACP 2100. At the 138 g ha^{-1} rate of triclopyr and the zero rate of imazaquin, quality decreased with an increase in ACP 2100; however, at the 276 g ha^{-1} rate of imazaquin, there was no difference between rates of ACP 2100. There was no significant difference in quality at the high rate of triclopyr as the rate increased for either imazaquin or ACP 2100.

At six weeks in 1987, there was also an interaction between imazaquin and triclopyr with all treatments across the 0 and 138 g ha^{-1} rate of triclopyr and both rates of imazaquin affording equal quality (Figure 6f). However, the combinations containing triclopyr at 276 g ha^{-1} and no imazaquin resulted in quality significantly greater than the above treatments. In 1988, at four weeks, there was an interaction for quality between triclopyr and ACP 2100 for the 'Glade-Plush-Ram' blend (Figure 6e), with the effect of triclopyr on quality due to a decrease in turf injury. There was no significant difference in quality between rates of ACP 2100 at 96 and 144 g ha^{-1} when triclopyr was at 0 and 138 g ha^{-1} in the combination. At 276 g ha^{-1} of triclopyr, however, 96 g ha^{-1} of ACP 2100 aachieved greater quality due to less phytotoxicity compared to the 144 g ha^{-1} rate. Ratings at six and eight weeks, in 1988, were similar and showed the same interaction between ACP 2100 and imazaquin (Figure 6d, Appendix figure 4b). The bluegrass blend treated with combinations of imazaquin plus the 0 or low rate of ACP 2100 or combinations containing ACP 2100 and no imazaquin had excellent quality. As the rates of both imazaquin and ACP 2100 increased turf quality decreased.

There was a definite varietal difference in response to all three chemicals. For the 'Glade-Plush-Ram' blend and 'Plush' variety, triclopyr decreased injury caused by ACP 2100. For the '190' variety only, there was no response to an increase in imazaquin rate or addition of ACP 2100 to imazaquin. The chemicals that most commonly interacted were ACP 2100 and imazaquin. A combination of the low rate of each chemical resulted in equal growth regulation activity with less turf injury compared to the high rate of either chemical alone. High rates of ACP 2100 and imazaquin in combination resulted in unacceptable turf injury. Since the low rate of imazaquin and ACP 2100, in combination, resulted in equal turf growth suppression, no dandelion control, and greater turf injury compared to ACP 2100 at 96 or 144 g ha^{-1} alone, the combination would not be beneficial. The greatest compatibility existed between ACP 2100 and triclopyr due to the lack of interference between chemicals for broadleaf weed control and growth regulation. Further, triclopyr decreased turf injury caused by ACP 2100, compared to ACP 2100 alone.

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CHAPTER III

INTERACTIONS OF ACP 2100, IMAZAQUIN AND TRICLOPYR ON TURF AND COMMON DANDELION

Abstract. Greenhouse studies were developed to characterize possible two-way interactions between ACP 2100, imazaquin and triclopyr for growth regulation of 'Plush' Kentucky bluegrass and control of common dandelion. A synergism occurred between imazaquin and ACP 2100, at the low rates, for turf growth regulation. The combination of triclopyr plus ACP 2100 showed an antagonism, with triclopyr reducing bluegrass injury caused by ACP 2100 with no decrease in growth regulatory activity. Interactions between imazaquin and triclopyr resulted in less dandelion control than expected for specific rate combinations. Dandelion fresh weight data indicated that ACP 2100 aided triclopyr in control of dandelion; however, the synergism only occurred at low rates of triclopyr and dandelion control was unacceptable. Nomenclature: imazaquin, 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid; triclopyr, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid; ACP 2100 (an imidazolinone, exact chemistry not released); Kentucky bluegrass, *Poa pratensis*

L. #[1] POAPR; common dandelion, Taraxacum officinale Weber in Wiggers # TAROF.

Additional index words. plant growth regulator.

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[1] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

INTRODUCTION

Turf growth regulators, due to their ability to inhibit foliar vertical growth without resulting in death of the plant, are not well suited as broadleaf herbicides (8). A few herbicides, such as metsulfuron (2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl] benzoic acid) and chlorsulfuron (2-chloro-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]-carbonyl]benzenesulfonamide), are turf growth regulators, but weed control is reduced when used at growth retardant rates compared to field use rates (11, 12). There may be a 5 to 10 fold difference, or a narrow concentration range, between the chemical rate that would provide retardation of turfgrass growth and cause severe turf injury compared to the rate that would control weeds (8). To maintain an acceptable appearance of the turf in an urban environment, two requirements of a program utilizing a turf growth regulator are i) to uniformly control the turf height and maintain acceptable color and ii) to control plants which grow or flower above the height of the suppressed turf (4, 6, 11, 18). To accomplish these requirements the combination of a broad spectrum herbicide with a turf growth regulator has been suggested (6, 11, 18) and studied by several researchers (8, 11, 12, 13, 15).

Previous research using a growth retardant plus a broadleaf herbicide, to achieve a uniform turf height by controlling both weeds and regulating the growth of turf, indicated no interaction between chemicals in the combination (6, 13, 15). Tests of mefluidide (N-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino]phenyl] acetamide) plus 2,4-D [(2,4-dichlorophenoxy)acetic acid] and 2,4-D combinations provided evidence that control of weeds and vegetative and seedhead growth of turf were effectively obtained, resulting in an enhanced appearance of the turf. Foote and Himmelman (6) reported that the addition of 2,4-D to maleic hydrazide (1,2-dihydro-3,6-pyridazinedione) was essential to enhance turf quality and appearance. Morre' and Tautvydas (12) reported an antagonism between mefluidide and 2,4-D amine in suppression of tall fescue (Festuca arundinacea Schreb.) seedheads. Addition of a surfactant to the combination of mefluidide and 2,4-D resulted in greater seedhead suppression. Data also indicated that the antagonism between mefluidide and 2,4-D amine was lessened with the use of a high rate, 2.24 kg ha^{-1}, of 2,4-D (12). Therefore, an antagonism or synergism between a broadleaf herbicide and turfgrass growth regulator may occur and should be researched when a combination is otherwise feasible.

A new growth regulator, ACP 2100, has shown promise for use in intensively managed turf, however, this chemical provides little to no broadleaf weed activity (16, 17). Addition of a broadleaf herbicide to ACP 2100 has the potential to increase or decrease growth retardant activity. Imazaquin is a broad spectrum herbicide in soybeans [*Glycine max* (L.) Merr.] and is used for control of *Cyperus* sp. and *Allium* sp. in warm season turf (1, 9). Research showed that imazaquin on Kentucky bluegrass resulted in some injury and turf growth regulation (16, 17). Triclopyr, a broadleaf herbicide, is used in turf, however, injury may occur when triclopyr is used at excessive rates (2). Before these compounds may be used in combination research must be conducted to determine the effect, if any, of one chemical on the other. Using a Multiplicative Survival Model, three types of chemical effects are possible (7). An additive effect would indicate that the cooperative action of the two chemicals is such that the observed response of the test organism to their joint application is equal to the response predicted by the above model. A synergistic effect would indicate the cooperative action of the two chemicals is such that the observed response is greater than the response predicted by the model. An antagonistic effect would indicate the cooperative action of the two chemicals is such that the observed response is less than the response predicted by the model. Triclopyr or imazaquin, in combination with ACP 2100, may result in a synergistic or antagonistic change of broadleaf weed activity or turf growth regulation (7). If an interaction occurs between these chemicals, the amount of herbicide or growth regulator required in the combination may need to be adjusted to achieve a high quality, growth regulated turf with broadleaf weed control.

Greenhouse studies were developed to characterize possible interactions between ACP 2100 and imazaquin and between ACP 2100 and triclopyr for growth regulation of 'Plush' Kentucky bluegrass. Greenhouse studies for common dandelion control were developed to identify possible interactions between triclopyr and ACP 2100 and between triclopyr and imazaquin.

MATERIALS AND METHODS

Bluegrass study. 'Plush' Kentucky bluegrass cores, 10 cm in diameter and trimmed to a depth of 7 cm, were pulled September 1 and October 2, 1987 from the Virginia Tech Turf Research Center. The area selected had a Groseclose silt loam (Clayey, mixed, mesic Typic Hapludult) with a pH of 6.0 and 3.2% organic matter. Cores were immediately potted into 15 cm plastic pots with a 3:2 v/v steam sterilized field soil, sand mix. The field soil was a Groseclose loam (Clayey, mixed, mesic Typic Hapludults) with a pH of 5.8 and 3.1% organic matter. Cores were watered as needed without wetting the foliage to avoid disease and fungal growth. The turfgrass was allowed to adjust to greenhouse conditions for four weeks before treatment and was mowed weekly to 6 cm. Four days after the final mowing, treatments were applied on October 2 and November 3, 1987 for the first and second experiments, respectively. Turf was mowed to 6 cm seven days after treatment.

Chemicals applied were ACP 2100 at 0, 12, 24, 36 and 48 g ha^{-1} alone and in combination with imazaquin at 0, 17, 34, 52, and 69 g ha^{-1}. ACP 2100 was also applied at 0, 24, 48, 72 and 96 g ha^{-1} alone and in combination with triclopyr amine at 0, 140, 280, 420 and 560 g ha^{-1}. Treatments were broadcast applied in 280 L/ha of water and 0.25% v/v nonionic surfactant[2] at 210 kPa using a CO_2 sprayer and 8003 flat fan tips[3]. Data were taken weekly for eight weeks consisted of turf height, percent injury and quality (on a scale of 1 to 9 where 6 represents acceptable quality and 9 represents excellent quality) (14). Above ground biomass was harvested at six and eight weeks after treatment for the first and second experiment run, respectively. Turfgrass was clipped 1 cm above the soil, weighed, dried at 60 C for 72 hours and weighed again to determine fresh and dry weight of above ground biomass.

Each of two runs was arranged in a randomized complete block design with 3 replications. Turfgrass cores were separated into blocks by visual estimates of turf density.

Dandelion study. Plants were grown in the greenhouse with a day/night temperature of 21/29°C. Common dandelion seeds were spread on the soil surface of 20 by 30 cm metal flats layered with 6 cm of sterilized field soil (Groseclose loam [Clayey, mixed, mesic Typic Hapludults] pH of 5.8 and 3.1% organic matter) and 3 cm of a 3:1:1 potting mix of peat moss, vermiculite and perlite. Seeds were covered with a

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[2] X-77. Chevron Chem. Co., San Francisco, CA 94119. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

[3] TeeJet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

thin layer of potting mix and flats were placed on a plastic lined bench and watered from the bottom. Common dandelion seeds were planted on September 4, 1987 and January 12, 1988. Seeds germinated at a rate of 50% on September 9 and January 18. Five days after germination flats were removed from the plastic bench to be watered over the top as needed. When seedlings reached the two to three leaf stage with fibrous roots, groups of 10 to 15 seedlings were transplanted into 10 cm plastic pots with a 3:1 field soil to sand mix. Two months after germination dandelions were in the six to eight leaf stage with fibrous roots and total contents of 10 cm pots were transplanted to 15 cm plastic pots with a 3:1 field soil to sand mix, thinned to 5 dandelions per pot and fertilized once every other week with 0.12 g N, 0.026 g P and 0.10 g K per pot. Tap roots formed within one month after the final transplant. Dandelions, for the first run, were at 35% bloom March 25 and were treated March 27, 1988. Dandelions for the second run were at 35% bloom August 5 and treated August 8, 1988.

Treatments were applied to the dandelions as described earlier for the turfgrass. Chemicals applied were triclopyr at 34, 69, 103 and 138 g ha^{-1} alone and in combination with imazaquin at 34, 69, 103 and 138 g $ha-^{1}$ and ACP 2100 at 12, 24, 36 and 48 g ha^{-1}. Data were taken weekly for four weeks as plant count, rosette diameter, and percent injury, rated visually. Above ground biomass was harvested at four weeks, weighed, dried at 60°C for 72 hours and weighed again to determine fresh and dry weights.

Each experiment was arranged in a randomized complete block design with 3 replications. Plants were visually separated into blocks by rosette diameter.

Data analysis. All data were subjected to analysis of variance. Data with significant differences between treatments were analyzed as a factorial and significance was determined by partitioning the effects of treatments into main effects and interactions (5, 7). A statistical treatment of Colby's method was used when appropriate to characterize interactions (5). Data are presented with an expected value calculated by Colby's method (3). Where no interaction was found main effect treatment means were separated by an LSD when appropriate.

RESULTS AND DISCUSSION

Bluegrass studies. Results from both greenhouse studies on 'Plush' Kentucky bluegrass with ACP 2100 and imazaquin showed several significant interactions for the parameters height and quality. Data for each study was analyzed and presented separately due to unlike error mean square values as calculated from a homogeneity of variance test. It was not until four and six weeks after application, for the first and second greenhouse studies, respectively, that turf height differed between treatments other than the nonmowed, nontreated check. At six weeks ACP 2100 at 36 and 48 g ha^{-1} and imazaquin at 52 and 69 g ha^{-1} continued to suppress growth of the turf alone and in combination (Table 1). Combinations of ACP 2100 at 12 g ha^{-1} plus imazaquin at 17 and 34 g ha^{-1} resulted in significantly more growth regulation activity than expected. This synergism indicates that combined low rates of ACP 2100 and imazaquin provided greater growth regulation activity than either chemical alone and resulted in equal growth suppression to the high rate of either chemical alone and in combination. The activity from ACP 2100 at 24 g ha^{-1} plus imazaquin at 17 and 34 g ha^{-1}, and ACP 2100 at 12 g ha^{-1} plus imazaquin at 52 and 69 g ha^{-1} was additive with the expected height

Table 1. Combined effects of ACP 2100 and imazaquin on Kentucky bluegrass height.[a]

Imazaquin	6 Week height (Run 1)						8 Week height (Run 2)					
	ACP 2100 (g/ha)											
	0	12	24	36	48	LSD	0	12	24	36	48	LSD
(g/ha)	(cm)						(cm)					
0	22.7	20.3	11.3	6.7	7.0	4.7	19.7	13.0	7.3	7.0	6.0	2.4
17	18.3	10.3** (16.4)	6.0 (9.1)	6.3	6.7	2.9	10.7	6.7 (7.1)	6.0	7.0	6.7	2.7
34	17.0	7.7** (15.2)	7.3 (8.5)	6.0	6.0	4.1	9.7	6.0 (6.4)	6.0	6.0	6.0	2.4
52	8.3	7.3 (7.4)	6.7	6.7	6.0	2.2	6.3	6.7	6.3	6.0	6.0	0.6
69	8.0	6.3 (7.2)	6.0	6.3	6.3	2.0	6.0	6.0	6.0	6.0	6.0	NS
LSD	4.3	4.6	2.8	NS	0.6	0.6	2.9	2.2	0.7	0.8	0.5	

[a] Mean height values are from 3 replications. Numbers in parenthesis are the estimate, with a positive difference of the predicted minus the actual value indicating synergism. Significance at the 1% level of probability are indicated as (**), as determined by a statistical treatment of Colby's Method (5). Least significicant difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

statistically equal to the observed height.

A longer period of growth regulation in the second greenhouse run was possibly due to shorter day length resulting in slower recovery of turf growth from the activity of the growth retardant. At six weeks turf treated with ACP 2100 alone at 12 g ha^{-1} was the first turf to overcome the growth regulator effect. The significant interaction that occurred from week four to seven was due to the slow growth of the turf treated with low rates of ACP 2100 and imazaquin, compared to the excellent growth regulation achieved with all herbicide combinations and the high rates of each herbicide alone (Appendix table 4 and 5). Due to the slow growth of the turf in the second study, data were taken through eight weeks. At eight weeks ACP 2100 at 24, 36 and 48 g ha^{-1} and imazaquin at 52 and 69 g ha^{-1} alone and in combination continued to afford excellent growth regulation of the turf (Table 1). Unlike the first study, combinations of ACP 2100 at 12 g ha^{-1} plus imazaquin at 17 and 34 g ha^{-1} afforded growth regulation statistically equal to the expected growth regulation. A synergism between ACP 2100 and imazaquin may not have occurred in the second study due to the activity of each chemical alone still affording some growth regulation of the turf.

Quality ratings took into account turf height, uniformity of turf height, turf injury and visual density of the turf. At two and three weeks after application there was little to no injury in either study and no treatment caused thinning of the turf compared to the nontreated check. Height and uniformity of height, therefore, were the major influence on turf quality. For the first study, interactions found with quality ratings paralleled those found with height ratings at four and five weeks with quality ratings in the acceptable range (Appendix table 8). At six weeks, for the first run, greater quality than expected was achieved with imazaquin plus ACP 2100 at 17 plus 12, 17 plus 24, and 34 plus 12 g ha^{-1} (Table 2). This synergism is the result of the above treatments maintaining turf at an acceptable height, with uniform growth and no visual turf injury, while turf treated with either chemical alone at the above rates had a ragged, unacceptable appearance. At six weeks all other treatments achieved quality in the acceptable range. For the second greenhouse study, all treatments afforded acceptable quality through eight weeks except the nontreated control and the low rate of both ACP 2100 and imazaquin with quality ratings of 3 to 4, due to turf height (Appendix table 8 and 9). At eight weeks no interaction occurred between treatments. Quality was only significantly influenced by imazaquin with all

Table 2. Combined effects of ACP 2100 and imazaquin on Kentucky bluegrass quality.[a]

	6 Week quality (Run 1)						8 Week quality (Run 2)					
Imazaquin	ACP 2100 (g/ha)											
(g/ha)	0	12	24	36	48	LSD	0	12	24	36	48	Mean
0	3.0	3.0	4.3	8.0	7.0	1.1	3.0	4.3	6.3	6.0	6.3	4.6
17	3.0	5.3^{**} (3.0)	7.3^{**} (4.3)	6.7 (8.0)	7.0 (7.0)	0.8	4.0	6.3	6.3	7.0	6.3	6.0
34	3.7	6.3^{*} (3.7)	7.7 (5.3)	6.0	5.3	2.7	4.7	5.7	7.3	6.7	6.0	6.6
52	5.3	7.0	7.3	6.7	7.0	2.0	5.0	7.0	5.7	7.3	5.0	6.6
69	5.7	7.3	7.3	6.0	7.7	NS	6.3	6.7	7.3	6.0	6.3	6.0
LSD	1.0	1.9	1.6	NS	NS							1.0

[a] Mean quality values are from 3 replications. Numbers in parenthesis are the estimate, with a negative difference of the predicted minus the actual value indicating synergisim. Significance at the 1% and 5% level of probability are indicated as ** and *, respectively, as determined by a statistical treatment of Colby's Method (5). Least significant difference (LSD) listed across the bottom and along the side of the table, indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

rates affording acceptable quality, and significantly lower quality achieved with the zero rate of imazaquin.

There was no turf injury for either study at two weeks (data not shown) and injury occurring during the following weeks was negligible. There was a significant interaction between ACP 2100 and imazaquin; however, a statistical Colby's method was not used to interpret the data because the ratings were not in the range of the I_{50} value (3, 5, 7). With injury ratings in the negligible range, 0 to 10%, the concern of ACP 2100 and imazaquin, in combination, lowering the quality of the turf was disregarded. Had the study been conducted in the I_{50} injury range, data from height and quality would not have been in the I_{50} range.

No significant difference in dry weight was found for either the first or second study (Data not shown). Results of the second study indicated only imazaquin to influence Kentucky bluegrass fresh weight (Table 3), as was also indicated by quality ratings. There was a significant decline in fresh weight from those treatments not containing imazaquin to those treatments containing imazaquin at 52 and 69 g ha^{-1}. Lower fresh weights for the 52 and 69 g ha^{-1} rate of imazaquin compared to the nontreated control were due to shorter turf. Had the rate of imazaquin influenced turf thinning it would have been detected by a significant

Table 3. Combined effects of ACP 2100 and imazaquin on fresh weight of above ground Kentucky bluegrass biomass.[a]

Imazaquin	Fresh weight (Run 1)						Fresh weight (Run 2)					
	ACP 2100 (g/ha)											
	0	12	24	36	48	LSD	0	12	24	36	48	Mean
(g/ha)	(g)						(g)					
0	9.0	10.0	6.8	4.7	4.6	3.0	11.5	5.0	4.8	5.3	4.5	6.2
17	8.9	5.1 (9.9)	3.9* (6.7)	5.3 (4.6)	4.7 (4.5)	1.7	4.5	4.6	4.8	5.5	5.6	5.0
34	8.6	5.3 (9.5)	4.0 (6.5)	4.2 (4.5)	3.5 (4.4)	3.1	5.8	4.1	5.1	5.7	5.5	5.2
52	6.2	5.6 (6.9)	5.0 (4.7)	4.2 (3.2)	4.0 (3.2)	1.5	4.2	4.3	4.9	5.7	3.8	4.6
69	5.2	5.4 (5.8)	4.7 (3.9)	3.7 (2.7)	4.5* (2.6)	1.7	3.7	4.4	5.5	5.3	4.3	4.6
LSD	3.6	1.8	2.1	1.6	NS							1.3

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[a] Mean fresh weight values are from 3 replications. Numbers in parenthesis are the estimate, with a positive difference indicating synergisim and a negative difference indicating antagonism as calculated from the predicted minus the actual value. Significance at the 5% level of probability are indicated as a *, as determined by a statistical treatment of Colby's Method (5). Least significant difference (LSD) listed across the bottom and along the side of the table, indicate difference within and between the rate of ACP 2100, respectively, at the 5% level. There was no difference within ACP 2100 rates for the 8 week quality rating.

difference in quality and fresh weight between the high and low rate of imazaquin. The first study showed a significant interaction for fresh weight between ACP 2100 and imazaquin (Table 3). All treatments were additive except ACP 2100 plus imazaquin at 24 plus 17 g ha^{-1} and 48 plus 69 g ha^{-1} which were synergistic and antagonistic, respectively. The synergism at the low rate supports height and quality data in that the combination of ACP 2100 and imazaquin, at low rates, achieved greater growth regulation than expected. The antagonism supports height and quality data in that the combination of ACP 2100 at 48 g ha^{-1} plus imazaquin at 69 g ha^{-1} resulted in good growth suppression without causing adverse affects to the turf, such as turf thinning. This information is valuable for indicating a margin of safety for this herbicide combination.

Data from the two 'Plush' Kentucky bluegrass greenhouse studies were combined. Results from these studies indicated no interaction between the chemicals ACP 2100 and triclopyr for the parameters height and quality. Height and quality were significantly influenced by the rate of ACP 2100 with no effect from triclopyr (Appendix table 10 and 12). The only interactions that occurred between ACP 2100 and triclopyr were for the parameter of injury at the four and six week rating (Table 4). At four weeks triclopyr plus ACP

Table 4. Combined effects of ACP 2100 and triclopyr on Kentucky bluegrass injury.[a]

Triclopyr	4 Week injury						ACP 2100 (g/ha)	6 Week injury				
	0	24	48	72	96	LSD	0	24	48	72	96	LSD
(g/ha)			(%)						(%)			
0	0	20	30	30	37	3	0	27	27	34	34	1
140	5	33 (24)	29 (34)	33 (34)	40 (40)	3	5	23** (30)	21 (30)	40 (37)	40 (37)	3
280	5	20 (24)	25 (34)	38** (34)	51** (40)	2	7	18** (32)	27** (32)	36 (39)	40 (39)	2
420	15	22 (32)	30 (40)	40 (40)	47 (46)	1	8	21** (33)	20** (33)	34** (39)	40 (39)	4
560	27	27 (42)	33 (49)	45 (49)	49 (54)	3	20	26** (42)	21** (42)	34** (47)	40 (47)	5
LSD	2	2	3	2	1		2	2	4	1	0	

[a] Mean percent injury values are from combined runs of 3 replications. Numbers in parenthesis are the estimate, with a positive difference indicating antagonism and a negative difference indicating synergism as calculated from the predicted minus the actual value. Significance at the 1% and 5% level of probability are indicated as ** and *, respectively, as determined by a statistical treatment of Colby's Method. Least significant difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

2100 at 280 plus 72 and 280 plus 96 g ha^{-1} resulted in significantly greater injury than expected. At six weeks combinations containing triclopyr at 420 and 560 g ha^{-1} plus ACP 2100 at 24, 48 and 72 g ha^{-1} and triclopyr plus ACP 2100 at 140 plus 24, 280 plus 24 and 280 plus 48 g ha^{-1} were antagonistic. The final six week injury rating indicated that the addition of triclopyr to ACP 2100 reduced phytotoxic effects of the growth retardant without affecting turf quality or height regulation.

No significant difference was found between treatments for the parameter of dry weight (Data not shown). As with height and quality ratings, fresh weight was unaffected by triclopyr resulting in no interaction with ACP 2100 (Data not shown).

In conclusion there was no adverse affect to the turf with either triclopyr or imazaquin in combination with ACP 2100 as compared to ACP 2100 alone. The synergism between the low rates of imazaquin and ACP 2100, that occurred in the first greenhouse study, indicated an advantage in using this combination due to low cost and reduced chemical rates. The combination of triclopyr plus ACP 2100 showed a strong advantage over ACP 2100 alone due to the antagonism of triclopyr resulting in reduced turf injury caused by ACP 2100, without a decrease in growth regulation activity.

Dandelion studies. Data from the two triclopyr plus ACP 2100 common dandelion studies were combined due to like error mean square values. No significant difference was found between treatments for the parameters of rosette diameter or the number of plants per pot (Data not shown). The parameters of injury, fresh and dry weight, however, showed a significant difference between treatments. Both fresh and dry weight data showed a significant interaction between triclopyr and ACP 2100. Only fresh weight data will be presented because desiccant tissue was included in the above ground biomass, therefore, dry weight data narrowed the margin of difference between treatments (Table 5). Triclopyr at the low rate plus ACP 2100 at 12, 24 and 48 g ha^{-1} resulted in a synergism, indicating greater dandelion control than expected. The combination of triclopyr plus ACP 2100 at 69 and 36 g ha^{-1} also resulted in less dandelion fresh weight than expected. Therefore, at low rates of triclopyr, ACP 2100 aids in decreasing above ground dandelion biomass.

Injury ratings did not show an interaction between triclopyr and ACP 2100. At two and three weeks after treatment ACP 2100 significantly influenced dandelion injury in that dandelions treated with ACP 2100 at 24, 36 and 48 g ha^{-1} had greater injury than the dandelions not treated with

Table 5. Combined effects of triclopyr and ACP 2100 on fresh weight of above ground common dandelion biomass.[a]

Triclopyr	Fresh weight ACP 2100 (g/ha) 0	12	24	36	48	LSD
(g/ha)	(g)					
0	13.1	12.9	11.9	12.5	11.8	NS
34	12.6	9.7** (12.4)	8.2** (11.4)	11.2 (12.0)	9.5* (11.3)	2.0
69	11.8	10.8 (11.6)	11.6 (10.7)	7.2** (11.2)	9.6 (10.6)	0.9
103	10.1	10.2 (9.9)	9.9 (9.2)	10.0 (9.6)	11.1 (9.1)	2.2
138	11.6	10.2 (11.4)	11.0 (10.5)	10.5 (11.1)	12.4 (10.4)	1.6
LSD	1.6	1.0	1.6	1.9	2.0	

[a] Mean fresh weight values are from combined runs of 3 replications each. Numbers in parenthesis are the estimate, with a positive difference indicating synergism. Significance at the 1% and 5% level of probability are indicated as ** and *, respectively, as determined by a statistical treatment of Colby's Method (5). Least significance difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

ACP 2100 (Appendix table 13). The rate of triclopyr influenced injury ratings during all four weeks. Four weeks after treatment triclopyr at 138 g ha^{-1} afforded the greatest dandelion injury of 44%, with no significant difference between the three lower rates (Table 6). Treatments not containing triclopyr only afforded 20% injury to common dandelion.

Dandelion control with triclopyr plus imazaquin only showed significant differences between treatments for the parameter injury, with no significant interactions between herbicides (Table 6). At two weeks after treatment, only triclopyr significantly influenced dandelion injury (Appendix table 14). Dandelions treated with triclopyr, except at the low rate, had significantly greater injury than the nontreated control and plants treated with imazaquin alone. Dandelions treated with triclopyr at 103 and 137 g ha^{-1} showed the greatest injury of 24 and 28%, respectively. At one and three weeks, both triclopyr and imazaquin influenced injury ratings (Appendix table 14). Plants not treated with imazaquin were only significantly different from plants treated with imazaquin at 103 and 138 g ha^{-1} for the first and third week ratings, respectively. Injury at the four week rating showed a significant interaction between triclopyr and imazaquin (Table 6).

Table 6. Combined effects of triclopyr and imazaquin and the combination effect of triclopyr and ACP 2100 on common dandelion injury.[a]

	Injury											
	4 Week						4 Week					
Triclopyr	ACP 2100 (g/ha)						Imazaquin (g/ha)					
	0	12	24	36	48	Mean	0	34	69	103	138	LSD
(g/ha)						(%)						
0	3	20	15	28	32	20	0	28	20	23	27	7
34	42	20	40	33	42	35	8	28 (34)	35 (26)	38 (29)	37 (33)	21
69	15	32	35	37	47	32	15	42 (39)	23 (32)	40^{**} (34)	43 (38)	28
103	27	37	40	38	42	34	30	37 (50)	50 (44)	38 (46)	40^{**} (49)	15
138	50	45	30	37	38	44	37	37^{**} (55)	47 (50)	20 (51)	30^{**} (54)	15
LSD						6	13	14	19	27	21	

[a] Mean injury values are from combined runs of 3 replications each. Numbers in parenthesis are the estimate, with a positive difference indicating antagonism and a negative difference indicating synergism as calculated from the predicted minus the actual value. Significance at the 1% and 5% level of probability are indicated as **, as determined by a statistical treatment of Colby's Method (5). Least significant difference indicate difference for rows and columns at the 5% level.

Triclopyr plus imazaquin at 103 plus 138, 138 plus 34, and 138 plus 138 g ha^{-1} resulted in antagonism of dandelion injury, while triclopyr at 69 g ha^{-1} plus imazaquin at 103 g ha^{-1} resulted in a synergism. The significant antagonism that occurred between triclopyr and imazaquin was noted in field studies where triclopyr at 138 g ha^{-1} plus imazaquin at 138 g ha^{-1} resulted in greater dandelion control than 138 plus 276 g ha^{-1}, respectively.

In conclusion, these studies show that no advantage exists for combining imazaquin with triclopyr for the control of common dandelion. Fresh weight data indicate that ACP 2100 does aid triclopyr in control of dandelion at low rates of triclopyr, and an increase in the rate of ACP 2100 did not result in a synergism with a higher rate of triclopyr, therefore, with both ACP 2100 and triclopyr at field use rates, no interaction should occur between chemicals.

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CHAPTER IV

UPTAKE, TRANSLOCATION AND FATE OF TRICLOPYR IN COMMON DANDELION (*TARAXACUM OFFICINALE*) AS AFFECTED BY ACP 2100

Abstract. Radiolabeled triclopyr[2,6-^{14}C] was applied to common dandelion, alone and in combination with the experimental growth regulator, ACP 2100, to determine if uptake, translocation or fate of triclopyr was affected. The initial uptake of triclopyr was slower when it was combined with ACP 2100 compared to triclopyr alone. However, by 48 hours greater uptake of triclopyr occurred when combined with ACP 2100. Autoradiography and oxidation studies showed no difference in triclopyr translocation at 2 hours after treatment, between triclopyr alone and triclopyr combined with ACP 2100. At 24 and 48 hours, however, ACP 2100 enhanced triclopyr translocation to the roots, crown and middle aged leaves of the dandelion. The metabolism of triclopyr in dandelion was not influenced by ACP 2100. The enhanced uptake and translocation of triclopyr by ACP 2100 showed that a favorable interaction occurred between the two compounds on common dandelion. Nomenclature: Common dandelion, *Taraxacum officinale* Weber in Wigger #[1] TAROF;

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[1] Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street,

triclopyr, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid; ACP 2100, chemistry not released.

Additional index words. Broadleaf weed control, foliar application.

Champaign, IL 61820.

INTRODUCTION

Common dandelion is a deep rooted herbaceous broadleaf perennial that is a major problem in turf. For complete control of this weed it is essential to control the tap root. Several herbicides afford acceptable control of dandelion, and at the proper rate triclopyr has achieved 90 to 100% control (4, 11). Triclopyr is absorbed rapidly by both the roots and foliage and is classified as a systemic, auxin type herbicide (2, 8, 16, 18). As with other auxin type herbicides, triclopyr is thought to exert its herbicidal effect at multiple sites within a plant via one or more mechanisms (8, 18).

A situation in which dandelion control is important is in a growth regulated turf (7, 13, 20). A chemical with potential for growth regulation of fine turf is ACP 2100 (3, 21, 22). However, a major drawback is the lack of weed control afforded by ACP 2100 (3, 21, 22). Eliminating dandelions has the beneficial effect of reducing competition for nutrients, moisture and light, and improves the aesthetic value of the turf (20). Dandelions left uncontrolled in a suppressed turfgrass cause an uneven, ragged appearance of the turf due to unsightly coarse leaves, flower stalks, flowers and pappus above the canopy.

Without chemical control of the dandelion, mechanical control, such as mowing, would be needed, defeating the purpose of a turf growth regulator.

A tank mix combination of triclopyr plus a plant growth regulator could be advantageous, since it reduces the number of chemical applications and the associated costs in fuel, labor and time (9, 13, 18). However, several important considerations must be taken into account when chemicals are tank mixed (9, 14, 18, 20). Tank mixes must first be researched and tried on a small scale due to the potential for altered plant responses, particularly when the combination is applied to the turf foliage (15). An altered plant response may be due to a change in the amount of herbicide reaching the site of action, caused by a change in uptake, translocation or chemistry of the herbicide due to the effect of an added chemical (1, 9, 17, 20). Agbakoba and Goodin (1) found that picloram uptake was affected by 2,4-D in field bindweed (Convolvulus arvensis L.) and 2,4-D translocation was increased to nontreated parts of the plant by picloram. Richardson (17) reported that dicamba uptake was stimulated by 2,4-D in the first four hours after treatment of leafy spurge (Euphorbia esula L.) and vice-versa during the next 4 to 16 hours. Dicamba caused an increase in 2,4-D translocation, and the presence of 2,4-D reduced translocation of dicamba (17). The uptake and translocation of triclopyr in common dandelion may be affected by the plant growth regulator ACP 2100. Change in the uptake, translocation or fate of triclopyr, caused by ACP 2100, may explain a deviation from the expected dandelion control with this herbicide combination.

The objective of this research was to determine if uptake, translocation or fate of triclopyr were altered in common dandelion by the presence of ACP 2100.

MATERIALS AND METHODS

Growth of Dandelions. Plants were grown in the greenhouse with a day/night temperature of 21/29°C. Common dandelion seeds were spread on the soil surface of 20 by 30 cm metal flats layered with 6 cm of sterilized Groseclose loam soil (Clayey, mixed, mesic Typic Hapludults), pH of 5.8 and 3.1% O.M., and 3 cm of a 3:1:1 potting mix of peat moss, vermiculite and perlite. Seeds were covered with a thin layer of potting mix and flats were placed on a plastic lined bench and watered from the bottom. Common dandelion seeds were planted on January 12, 1988. Seeds germinated at a rate of 50% on January 18. Five days after germination flats were placed on a greenhouse bench and watered over the top as needed. When seedlings had fibrous roots and reached the two to three leaf stage groups of 10 to 15 seedlings were transplanted into 10 cm plastic pots with a 3:1 field soil to sand mix. Two months after germination dandelions with fibrous roots were in the six to eight leaf stage and the total contents of 10 cm pots were transplanted to 15 cm plastic pots with a 3:1 soil to sand mix, thinned to 5 dandelions per pot and fertilized once every other week with 0.12 g N, 0.026 g P and 0.10 g K per pot. Tap roots formed within one month after the final transplanting. Plants were allowed to continue growing for eight months. Flowering occurred in spring and fall.

On December 5 and January 19 (for uptake and translocation studies), and on January 19 and 30 (for metabolism studies), for the first and second runs, respectively, plants were visually selected for uniform shoot growth. Selected plants were unpotted, soil carefully rinsed from the roots, and placed in one liter of half strength Hoagland's nutrient solution (10). During the experimental time greenhouse temperature was maintained at $21^oC \pm 3$ with a 10-h photoperiod. The average high for photosynthetic photon flux density was 230 $uE \cdot m^{-2} \cdot s^{-1}$. The relative humidity was an average of 40% ± 5. Dandelions were blocked on the basis of rosette diameter and tap root formation and arranged in a randomized complete block with two replications. After one week plants were treated.

Uptake and translocation. Treatments consisted of a control, triclopyr amine alone at 138 g ha^{-1} and in combination with ACP 2100 at 60 and 120 g ha^{-1}. Herbicides were broadcast applied in 280 L ha^{-1} distilled water and 0.25% v/v nonionic surfactant[2] at 210 kPa using a CO_2

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[2] X-77. Chevron Chem. Co., San Francisco, CA 94119. Principal functioning agents are alkylarylpolyoxyethylene glycols, free fatty acids, and isopropanol.

sprayer and 8003 flat fan tips[3]. Plants receiving treatments containing unlabeled triclopyr were immediately treated with 0.13 uCi of triclopyr-2,6-^{14}C dissolved in triethylamine at a 1:1 molar concentration plus 0.1% v/v nonionic surfactant[2]. Solutions of ^{14}C-triclopyr were 98% pure with a specific activity of 11.24 mCi/mmole. The method used for applying the ^{14}C-triclopyr to the dandelion leaves is according to methodology previously described (5, 6, 8). A 7 mm disk punched from a Whatman No. 1 filter paper was immersed in isotope solution and placed on the adaxial surface, 2 cm from the leaf base, of the fourth fully expanded leaf from the center of the rosette of an intact plant. On the average 13 ul of solution was applied per filter paper disk. Leaves were exposed to the solution for 2, 24 and 48 hours. After exposure, each treated leaf was excised, and the plants were harvested. At harvest plants were sectioned into the following parts: treated leaf spot, leaf above and below treated spot, three youngest leaves, middle leaves, three to four oldest leaves, crown and roots. The treated disk was removed and placed in a scintillation vial containing 10 ml of scintillation

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[3] TeeJet 8003 tips. Spraying Systems Co., Wheaton, IL 60287.

cocktail[4]. The treated area of the leaf was rinsed in 10 ml of distilled water and a 0.5 ml aliquot was placed in 10 ml of scintillation cocktail. The total ^{14}C-triclopyr applied minus the count from the harvested disk and leaf wash constituted the total percent uptake. Each section was excised and immediately frozen on dry ice. Whole plant sections, except for roots, were combusted in a biological material oxidizer[5]. Tap root systems were thinly sliced and a 0.6 g representative sample was used for combustion. The evolved $^{14}CO_2$ was trapped in a liquid scintillation cocktail[6] containing a CO_2 absorber[7]. All scintillation cocktails were assayed by liquid scintillation spectrometry[8].

Plants from one replication were sectioned as described previously, ~~and~~ placed between two pieces of lithograph paper, dried at 60°C for 48 hours and pressed for 18 hours.

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[4] Scinti Verse E. Fisher Scientific Co. Chemical Manufacturing Division. Fairlawn, NJ 07410.

[5] Packard Tricarb sample oxidizer, Packard Instruments Co. Inc. Downer Grove, IL 60515.

[6] Permaflour V, Packard Instrument Co. Inc. Downer Grove, IL 60515.

[7] Carbo-sorb carbon dioxide absorber for scintillation counting, Packard Instrument Co. Inc. Downer Grove IL 60515.

[8] Beckman LS-255 Liquid Scintillation counter, Beckman Instruments, Inc., Columbia, MD 21045.

Prepared plants were exposed to X-ray Film[9] for 28 days.

Metabolism. Treatments consisted of a control, a 1 ml solution containing a 1:0 ratio of cold triclopyr amine to ACP 2100 plus 1 uCi of labeled triclopyr plus 0.25% v/v nonionic surfactant, and a 1 ml solution containing a 1:0.8 ratio of cold triclopyr amine to ACP 2100 plus 1 uCi of labeled triclopyr plus 0.25% v/v nonionic surfactant. Chemicals were combined in and applied with an atomizer to each plant of two runs with three replications. At 48 hours dandelions were harvested and sectioned into leaves, crown and roots, frozen and subsequently extracted[10] by a method described previously (8) (Appendix figure 6). Plant sections were ground in liquid nitrogen, placed in a foil covered beaker, and samples were heated to 130°C in methanolic sodium hydroxide. The mixture was cooled, shaken and filtered through Whatman No. 0.5 filter paper using a Buchner funnel with four consecutive rinses of methanol. An aliquot of the solution was diluted with distilled water and acidified with hydrochloric acid. Diethyl ether and hexane

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[9] Kodak Diagnostic X-ray Film X-OMAT. Eastman Kodak Co., Rochester, NY 14650.

[10] McKellar, R. L. 1977. Determination of triclopyr, ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid); 3,5,6-trichloro-2-pyridinol and 2-methoxy-3,5,6-trichloropyridine in grass by gas chromatography. ACR 77.4. Unpublished. Dow Chemical Co., Midland, Michigan 48674.

(30:70 v/v) were used to partition the sample in the presence of sodium chloride. The sample was shaken, centrifuged and the organic phase was decanted. Diethyl ether was added again, shaken, centrifuged and the organic phase was again decanted and added to the previously decanted liquid. The diethyl ether - hexane phase was partitioned with sodium bicarbonate, shaken, centrifuged and the organic phase was discarded. Before discarding of any sodium bicarbonate or diethyl ether - hexane phase extracts a 1 ml aliquot was placed in 10 ml of scintillation cocktail and tested for radioactivity. Concentrated hydrochloric acid, methanol and sodium chloride were added to the sodium bicarbonate phase and again partitioned with diethyl ether - hexane and the above process repeated. The final sodium bicarbonate phase contained the triclopyr and was once more acidified and partitioned. The organic phase was decanted and evaporated to 1 ml. Recovery was 90 to 95%. Extracts from leaves, roots and crown, for both triclopyr alone and in combination with ACP 2100, were spotted on a 0.25 mm silica gel TLC plate. The spots from untreated plant material were spiked with 10 nCi of reference triclopyr. The mobile phase used was a 8:1:1 v/v mixture of isopropanol, ammonium hydroxide and water. TLC plates were covered with X-ray film and placed in folders for 36 days.

After development of the film, TLC plates were scraped every 1 cm, from the origin to the front of each source. Each section was added to scintillation cocktail and further tested for radioactivity in order to calculate R_f values of metabolites.

RESULTS AND DISCUSSION

Absorption. The amount of ^{14}C material remaining on the 7 mm number 1 Whatman disk at harvest was not significantly different between treatment and was not influenced by the number of hours the disk remained on the dandelion leaf (Table 1). The amount of ^{14}C material rinsed from the treated leaf area was significantly influenced by treatment and harvest time (Table 1). For all treatments the greatest amount of ^{14}C material was washed from the leaf surface at two hours. At 48 hours, less than 10% of the applied ^{14}C material was rinsed from the leaf surface. This indicates that absorbtion of the triclopyr from the leaf surface occurred throughout the 48 hours although transfer of ^{14}C material from the disk to the leaf surface did not differ from 2 to 48 hours. At two hours, the least amount of ^{14}C-triclopyr was washed from the dandelion leaf treated with triclopyr alone. Therefore, at two hours, greater absorbtion of triclopyr occurred when ACP 2100 was not present since there was no difference between treatments in the amount of ^{14}C-triclopyr remaining on the treatment disks. At 24 hours after treatment there was no difference between treatments and at 48 hours dandelions treated with triclopyr plus the high rate of ACP 2100 had the least

Table 1. Percent of applied ^{14}C remaining on the disk, washed from the leaf surface and taken up by common dandelion at 2, 24 and 48 hours after application of 0.13 uCi of ^{14}C-triclopyr amine, with and without ACP 2100.

		Time after application[a]		
Chemical	Rate	2 h	24 h	48 h
	(g/ha)	------ (% of applied) ------		
		Disk		
Triclopyr	138	49 aA	59 aA	55 aA
Triclopyr ACP 2100	138 60	59 aA	62 aA	47 aA
Triclopyr ACP 2100	138 120	51 aA	58 aA	57 aA
		Leaf Wash		
Triclopyr	138	12 cA	11 aB	6 bC
Triclopyr ACP 2100	138 60	15 bA	11 aB	9 aC
Triclopyr ACP 2100	138 120	18 aA	10 aB	5 cC
		Uptake		
Triclopyr	138	39 aA	34 aA	38 bA
Triclopyr + ACP 2100	138 + 60	26 cB	28 aB	44 aA
Triclopyr + ACP 2100	138 + 120	31 bB	30 aB	39 bA

[a] Means within a row and column followed by the same capital and small letter, respectively, are not significantly different at the 5% level according to a Waller/Duncan K-ratio t-test.

amount of ^{14}C material washed from the leaf surface. Uptake was affected by both time and treatment (Table 1). For triclopyr alone, there was no significant difference in uptake from 2 to 48 hours. However, when ACP 2100 was present an average of one and a half times more ^{14}C-triclopyr was absorbed at 48 hours compared to 2 and 24 hours. At two hours, uptake was greatest with triclopyr alone, as noted above, followed by triclopyr plus the high then low rate of ACP 2100. At 24 hours, there was no significant difference in uptake between treatments. At 48 hours, 44% of ^{14}C-triclopyr was absorbed when triclopyr plus the low rate of ACP 2100 was applied. Triclopyr alone and in combination with the high rate of ACP 2100 resulted in less uptake than the above treatment as indicated by leaf wash and calculated uptake data. These data indicate that ACP 2100 slowed initial uptake of triclopyr, but the low rate resulted in greater uptake by 48 hours.

Translocation. Enhanced translocation of triclopyr by ACP 2100 was indicated by ^{14}C distribution data (Table 2). As with uptake, translocation was also significantly affected by time and treatment. The total ^{14}C material accounted for was an average of 87% of the amount calculated to be taken-up by the plant. For all treatments, at two hours, greater than 96% of the absorbed triclopyr remained in the treated

Table 2. Distribution of absorbed ^{14}C in common dandelion at 2, 24 and 48 hours after application of ^{14}C-triclopyr with and without ACP 2100.

Tissue fraction	Chemical	Rate	^{14}C Recovered[a]		
			2 h	24 h	48 h
		(g/ha)		(%)	
treated leaf spot	triclopyr	138	29.7 cB	42.3 aA	36.1 aAB
	+ ACP 2100	+ 60	32.8 aA	28.7 bB	16.5 bC
	+ ACP 2100	+ 120	30.8 bA	21.4 bB	19.3 bC
leaf above & below treated spot	triclopyr	138	69.4 aA	31.5 aB	35.4 aB
	+ ACP 2100	+ 60	66.1 bA	30.8 aB	17.1 bC
	+ ACP 2100	+ 120	65.3 bA	28.3 bB	18.1 bC
young leaves	triclopyr	138	0.1 aA	19.2 aA	20.8 bA
	+ ACP 2100	+ 60	0.1 aC	24.3 aB	34.0 aA
	+ ACP 2100	+ 120	0.1 aC	17.6 aB	32.1 aA
middle leaves	triclopyr	138	0.1 bB	1.1 bA	0.5 bAB
	+ ACP 2100	+ 60	0.4 aB	0.4 cB	7.7 aA
	+ ACP 2100	+ 120	0.2 bB	1.9 aB	9.0 aA
old leaves	triclopyr	138	0.1 aA	0.0 aA	0.1 aA
	+ ACP 2100	+ 60	0.1 aA	0.7 aA	0.2 aA
	+ ACP 2100	+ 120	0.7 aA	0.1 aA	0.1 aA
crown	triclopyr	138	0.3 bB	4.8 cA	5.7 cA
	+ ACP 2100	+ 60	0.4 bB	12.4 bA	16.9 aA
	+ ACP 2100	+ 120	2.6 aB	19.3 aA	12.9 bA
roots	triclopyr	138	0.3 aB	1.1 bA	1.4 bA
	+ ACP 2100	+ 60	0.1 aB	2.7 bB	7.5 aA
	+ ACP 2100	+ 120	0.3 aB	11.4 aA	8.5 aA

[a] Means of three replications. Numbers within a tissue fraction, within rows or columns, followed by the same capital or small letter, respectively, are not different at the 5% level according to a Waller Duncan K-ratio t-test.

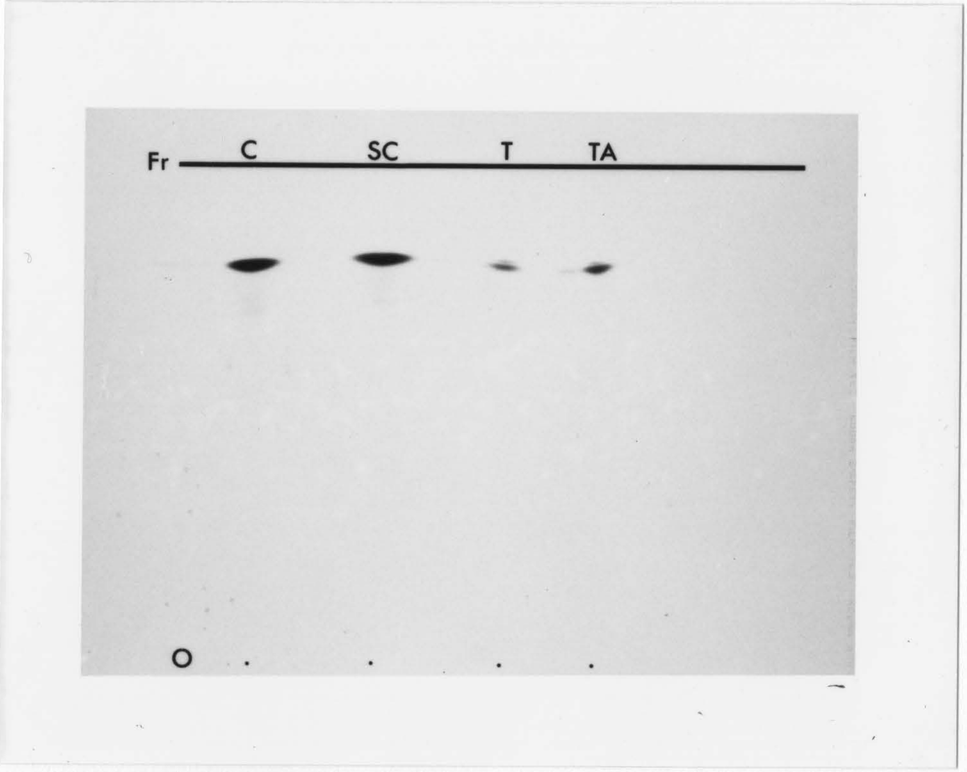
leaf. At 24 hours, 36% of the ^{14}C-triclopyr had translocated to the crown and young leaves of the dandelions treated with the combination of triclopyr and ACP 2100, compared to only 24% in the triclopyr alone treated plants. Significantly more ^{14}C-triclopyr translocated to the roots of plants treated with triclopyr plus ACP 2100 at 120 g ha^{-1} compared to triclopyr alone or in combination with 60 g ha^{-1} of ACP 2100. At 48 hours, there was no difference between treatments containing ACP 2100, except that a greater percentage of the triclopyr remained in the crown of dandelions treated with the low rate of ACP 2100 compared to the high rate. There was no difference in translocation between the 24 and 48 hour harvest for dandelions treated with triclopyr alone. Those treated with combinations containing ACP 2100, however, showed continued translocation to the middle leaves and the low rate resulted in continued translocation to the root. Values less than 1% are not accurate estimates of the ^{14}C material located in a plant section. With this in mind, no treatments resulted in translocation of ^{14}C-triclopyr to the oldest leaves. The presence of ACP 2100 resulted in approximately 20 to 25% more translocation of triclopyr out of the treated leaf, causing 35 to 38% more translocation to the middle leaves, crown and plant roots. Results from autoradiography support the above data (Appendix figure 7). Both imidazolinones and pyridines are known to translocate through the xylem and phloem and accumulate in the meristematic tissue (1, 2, 8, 19). To better understand the change in the rate of translocation of ^{14}C-triclopyr when in combination with ACP 2100, the translocation pattern and speed of ACP 2100 would have to be known. If 10% of applied ACP 2100 translocates to the root within 48 hours after treatment it is possible that this may influence triclopyr translocation. It is also possible that ACP 2100 may increase translocation of all materials within dandelion.

In order for an herbicide to be effective in controlling a deep rooted perennial, such as dandelion, translocation to the root is essential. ACP 2100 increased the translocation of triclopyr to the dandelion root, suggesting increased control of dandelion in the presence of ACP 2100 compared to triclopyr alone.

Metabolism. In the leaf, crown and roots, triclopyr was metabolized very little during the 48 hours after treatment. Autoradiographys of the TLC plates used for the analysis of extracts from the three dandelion sections were similar (Figure 1, Appendix figure 8). Further analysis of the TLC plates, through scraping and counting each section, supported the results of autoradiographys that no metabolites were present (data not shown). However the extraction procedure used was specific for the recovery of triclopyr and not for any of the possible metabolites, such as conjugates. Similar results were previously found with horsenettle showing slow metabolism of triclopyr over a period of 16 days (8). For all extracts there was no difference between the ^{14}C-material extracted from plants treated with triclopyr alone compared to those treated with triclopyr plus ACP 2100. In addition no radioactivity was found in the sodium bicarbonate or diethyl ether - hexane extractions (data not shown). This evidence further supports the concept that little to no metabolism of the ^{14}C-triclopyr occurred in dandelions treated with or without ACP 2100.

The enhanced translocation of triclopyr by ACP 2100, appears to be the best explanation for the favorable interaction of the two compounds on common dandelion. However, this interaction may result in less dandelion control in the field due to the slower initial uptake of triclopyr in the presence of ACP 2100, compared to triclopyr alone during adverse weather conditions, resulting in less herbicide reaching the site of action. The increased translocation of the absorbed material to the tap root may result in expected or greater than expected dandelion

Figure 1. Autoradiography of common dandelion foliage, extract 48 hours after foliar application of ^{14}C-triclopyr, with and without ACP 2100: C = control (triclopyr reference), SC = spiked extract control, T = extract from plant treated with triclopyr, TA = extract from plant treated with triclopyr + ACP 2100. Origin (O) is at bottom; solvent front (Fr) is 15 cm above.


Fr
C
SC
T
TA
O

control with more triclopyr reaching the sites of action in the presence of ACP 2100.

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CHAPTER V

SUMMARY AND CONCLUSIONS

The incorporation of a broad spectrum herbicide with a growth retardant would give turf managers a valuable method for solving vegetation management problems with one application (2, 4, 5). A combination of chemicals in a tank mix may be advantageous by reducing the number of chemical applications, in turn reducing costs of fuel, labor and time (1, 3, 7). However, a tank mix must first be researched and tried on a small scale due to the potential for altered plant responses, particularly when the solution is applied to the turf foliage (6, 7). The results from several tank mixes containing ACP 2100, a plant growth regulator, triclopyr, a broadleaf herbicide, and/or imazaquin, a broad spectrum herbicide, give the information needed to achieve acceptable bluegrass growth regulation and dandelion control.

Studies showed that there was no advantage for the combination of imazaquin plus triclopyr and/or ACP 2100 compared to triclopyr plus ACP 2100. In the field, imazaquin controlled only 22% of the common dandelion and afforded no additional control when in combination with triclopyr. Greenhouse data further emphasized the imazaquin/triclopyr incompatibility with an antagonism of dandelion control occurring at several rates. Although a synergism for turf growth regulation occurred between imazaquin and ACP 2100, the combination was not beneficial for turf management due to the resulting injury on several bluegrass varieties. A combination of the low rates of imazaquin and ACP 2100 resulted in equal plant growth regulation to ACP 2100 alone at 96 and 144 g ha^{-1}. However, no dandelion control and unacceptable turf injury were also encountered, resulting in unacceptable quality. The effect of imazaquin was largely dependent on the turf variety, with '190' bluegrass unable to tolerate use rates. No further work was done with imazaquin in combination with ACP 2100 or triclopyr due to the impracticality of the combination.

The combination of ACP 2100 and triclopyr showed promise for use in a vegetation management program utilizing chemical mowing and broadleaf weed control. This combination resulted in no interaction between the two chemicals for growth regulation or weed control in the field. Addition of triclopyr to ACP 2100, however, resulted in decreased turf injury compared to ACP 2100 alone. In the greenhouse this interaction was shown to be antagonistic, with less turf injury than expected and no effect on turf height suppression as regulated by ACP 2100. Further greenhouse and laboratory studies also indicated a beneficial interaction between ACP 2100 and triclopyr for dandelion control. Fresh weight data from dandelion greenhouse studies showed a synergistic effect from ACP 2100 with low rates of triclopyr, resulting in less above ground dandelion biomass than expected. The above interaction, however, only occurred at low rates of triclopyr and no evidence of an interaction between triclopyr and ACP 2100 was observed in the field. Laboratory results confirmed that there was a synergistic effect of ACP 2100 on triclopyr. Translocation of triclopyr to the crown, roots and middle leaves of dandelion was improved in the presence of ACP 2100. Uptake of triclopyr was initially decreased by ACP 2100, however, after 48 hours uptake increased one and a half times compared to triclopyr alone. Although ACP 2100 influenced uptake and translocation of triclopyr, it did not alter the chemical fate of triclopyr in dandelion.

In conclusion the tank mix of ACP 2100 at 96 or 144 g ha^{-1} plus triclopyr at field use rates appeared to be a practical vegetation management program. The activity achieved with the combination of ACP 2100 and triclopyr showed that there is a vegetation management program that may result in a high quality bluegrass turf at low cost.

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Appendix Table 1. Turf growth regulation parameters of three Kentucky bluegrasses, as affected by ACP 2100, imazaquin and triclopyr, reported as the mean of imazaquin plus triclopyr and ACP 2100 plus triclopyr, and ACP 2100 plus imazaquin, respectively.[a]

Herbicide		Injury		Quality	
(g/ha)		---- (%) ----			
	Variety	190	Plush	190	Blend
	Year	'87	'88	'97	'87
	Week	4	6	8	6
ACP 2100	0	5 b	0 c	6.0 a	5.0 b
	48	4 b	0 b	5.7 ab	4.8 ab
	96	14 a	2 b	5.4 b	4.8 ab
	144	--	4 a	---	4.6 a
	Variety	190	Plush	190	
	Year	'87	'88	'88	
	Week	8	6	6	
Imazaquin	0	3 c	0 b	6.5 a	
	138	8 b	1 b	5.2 b	
	276	12 a	3 a	3.8 c	

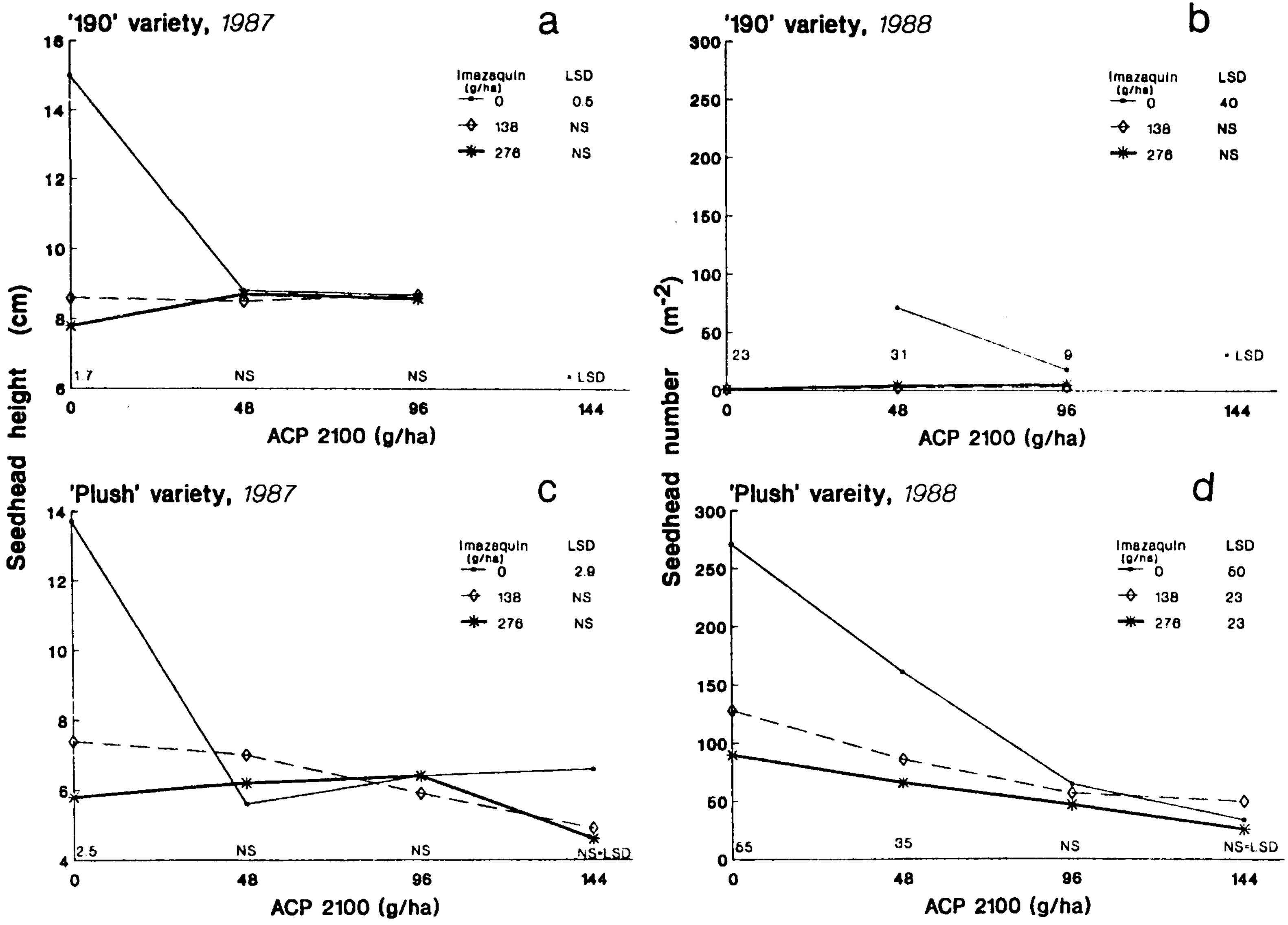
[a] Means within a column followed by the same letter are not significantly different at the 0.05 level as determined by Waller Duncan K-ratio t-test.

Appendix Table 2. Percent injury of the 'Glade-Plush-Ram' blend of Kentucky bluegrass as affected by ACP 2100, imazaquin and triclopyr.[a]

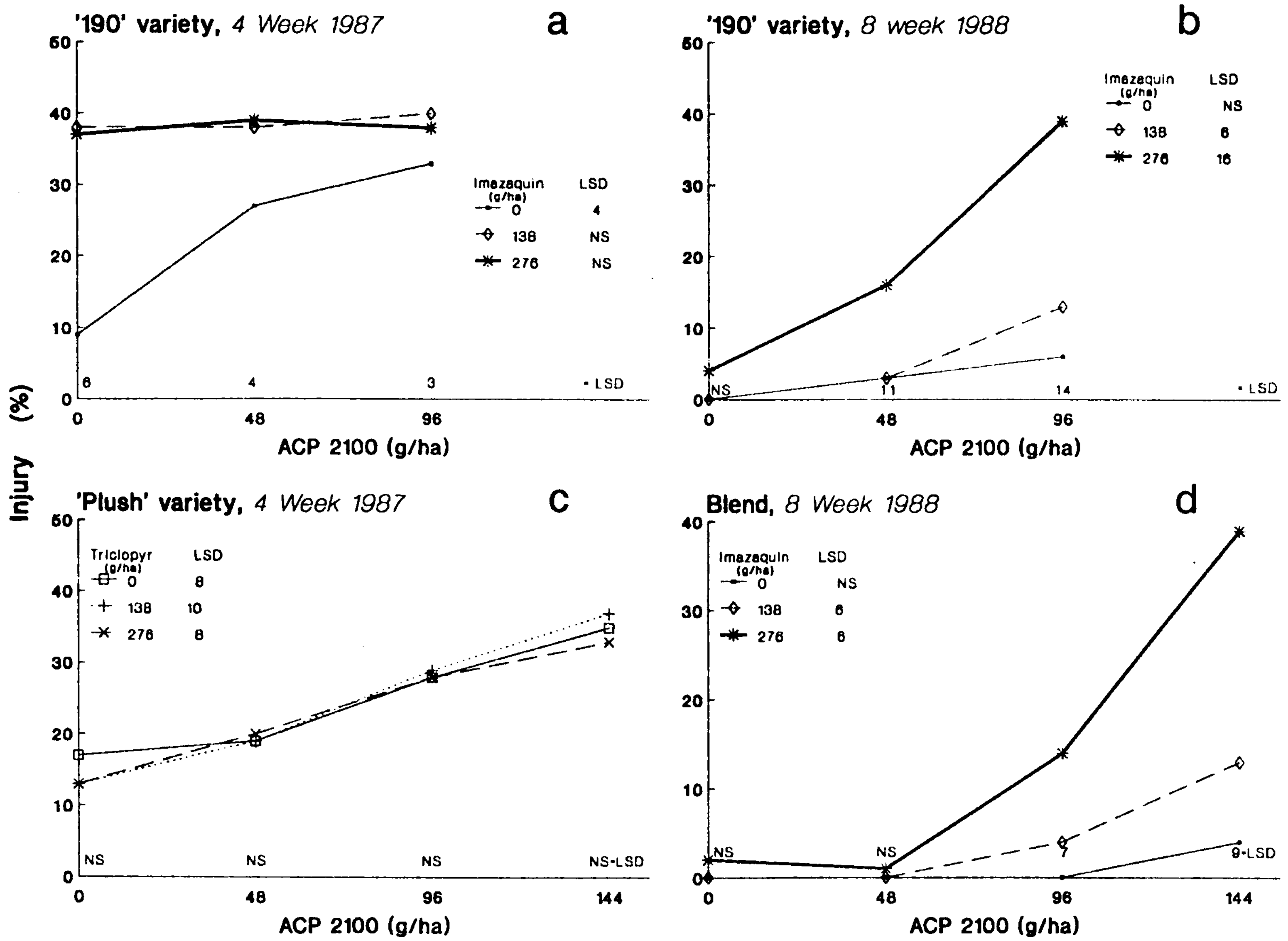
		6 Week injury			
		Triclopyr g/ha			
ACP 2100	Imazaquin	0	138	276	LSD
(g/ha)	(g/ha)	-----	(%)	-----	
	0	0	0	0	NS
0	138	0	0	0	NS
	276	0	0	0	NS
	LSD	NS	NS	NS	
	0	0	0	0	NS
48	138	3	0	0	NS
	276	0	3	3	NS
	LSD	NS	NS	NS	
	0	0	0	0	NS
96	138	0	3	6	NS
	276	23	3	13	13
	LSD	7	NS	NS	
	0	3	6	7	NS
144	138	7	13	23	NS
	276	36	43	53	NS
	LSD	17	22	15	
	0	NS	NS	NS	
LSD	138	NS	NS	13	
	276	9	10	20	

[a] LSD at the $P = 0.05$ level for percent injury comparison.

Appendix Figure 1. Seedhead height and seedhead number for two Kentucky bluegrass varieties, as affected by combinations of ACP 2100 and imazaquin, graphed as the mean across the rate of triclopyr. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100 at the 5% level.


'190' variety, 1987
a
Imazaquin (g/ha)
LSD
0
0.5
138
NS
276
NS
1.7
NS
NS
• LSD
16
14
12
10
8
6
0
48
96
144
ACP 2100 (g/ha)
Seedhead height (cm)
'190' variety, 1988
b
Imazaquin (g/ha)
LSD
0
40
138
NS
276
NS
23
31
9
• LSD
300
250
200
150
100
50
0
0
48
96
144
ACP 2100 (g/ha)
Seedhead number (m-2)
'Plush' variety, 1987
C
Imazaquin (g/ha)
LSD
0
2.9
138
NS
276
NS
2.5
NS
NS
NS=LSD
14
12
10
8
6
4
0
48
96
144
ACP 2100 (g/ha)
'Plush' vareity, 1988
d
Imazaquin (g/ha)
LSD
0
60
138
23
276
23
65
35
NS
NS=LSD
300
250
200
150
100
50
0
0
48
96
144
ACP 2100 (g/ha)

Appendix Figure 2. Percent injury of three Kentucky bluegrasses, as affected by combination of ACP 2100 and imazaquin or triclopyr, graphed as the mean across the rate of triclopyr or imazaquin, respectively. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of ACP 2100, respectively, at the 5% level.


'190' variety, 4 Week 1987
a
Imazaquin (g/ha) LSD
0 4
138 NS
276 NS
6
4
3
• LSD
'190' variety, 8 week 1988
b
Imazaquin (g/ha) LSD
0 NS
138 6
276 16
NS
11
14
• LSD
Injury (%)
'Plush' variety, 4 Week 1987
c
Triclopyr (g/ha) LSD
0 8
138 10
276 8
NS
NS
NS
NS•LSD
Blend, 8 Week 1988
d
Imazaquin (g/ha) LSD
0 NS
138 6
276 6
NS
NS
7
9•LSD
0
10
20
30
40
50
0
48
96
144
ACP 2100 (g/ha)

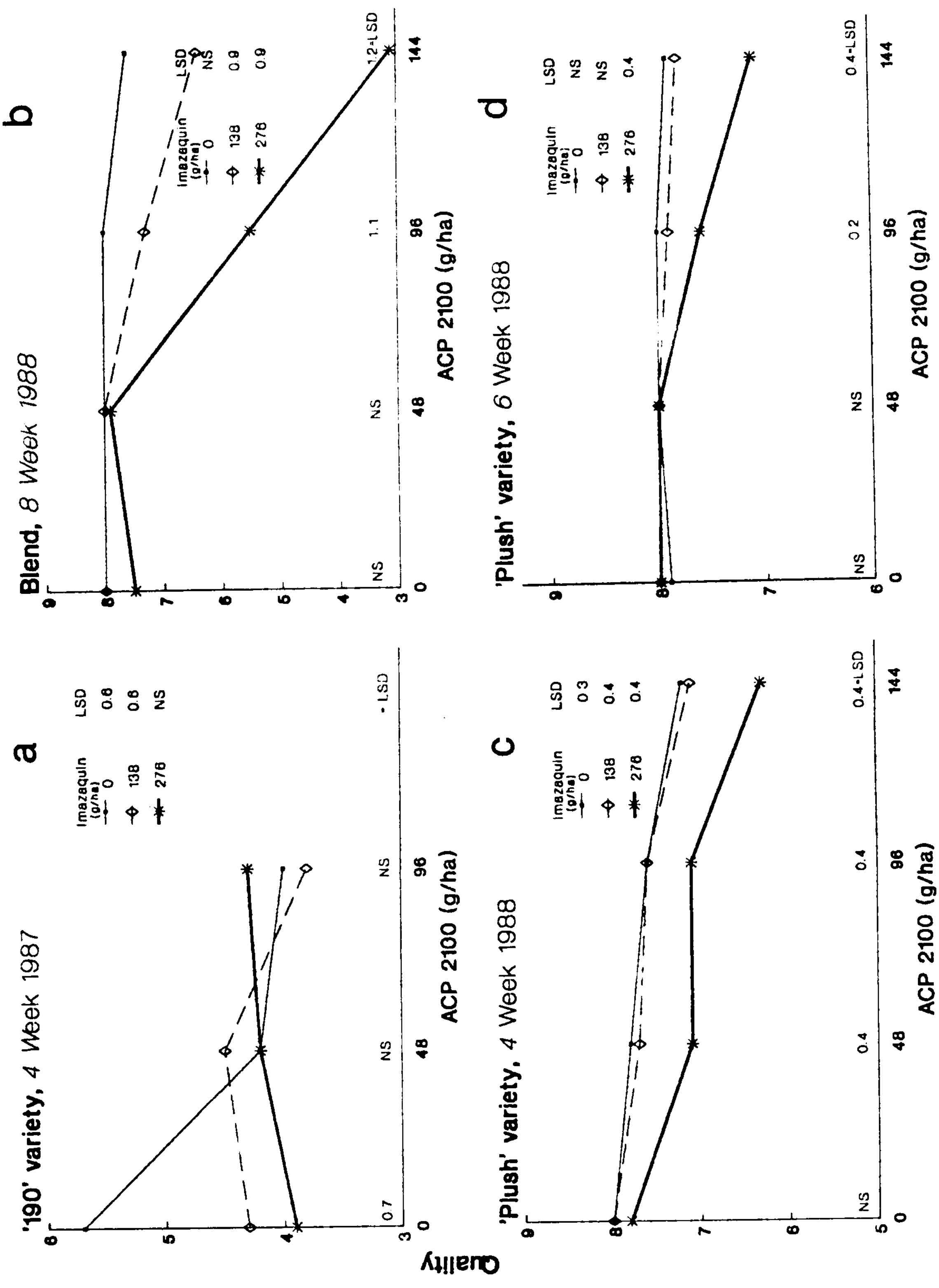
Appendix Figure 3. Illustration of quality and distinct differences between treatments for the 'Plush' (a), '190' (b), and 'Glade-Plush-Ram' (c) Kentucky bluegrass turf types.

a

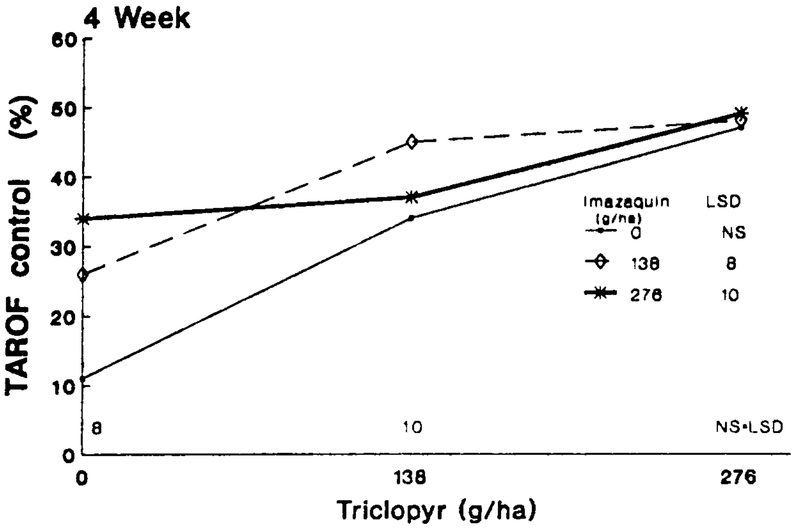
b

c

Appendix Figure 4. Quality of three Kentucky bluegrasses as affected by the combinatio of ACP 2100 and imazaquin, triclopyr and imazaquin, and the combination of triclopyr and ACP 2100, graphed as the mean across the rate of triclopyr, ACP 2100 and imazaquin, respectively. Least significant differences (LSD's) listed across the bottom of the graph and in the legend indicate differences between and within the rates of imazaquin, respectively, at the 5% level.


'190' variety, 4 Week 1987
a
Blend, 8 Week 1988
b
'Plush' variety, 4 Week 1988
c
'Plush' variety, 6 Week 1988
d
Quality
ACP 2100 (g/ha)
Imazaquin (g/ha)
0
138
276
LSD
0.8
0.8
NS
NS
0.9
0.9
0.3
0.4
0.4
NS
NS
0.4
0.7
NS
NS
NS
NS
1.1
1.2=LSD
0.4
0.4
0.4=LSD
NS
NS
0.2
0.4=LSD
- LSD
0
48
96
144
3
4
5
6
7
8
9

Appendix Figure 5. The percent control of common dandelion (TAROF) as affected by the combination of triclopyr and imazaquin, graphed as a mean across the rate of ACP 2100. Least significant differences (LSD) listed across the bottom of the graph and in the legend indicate differences within and between the rates of triclopyr, respectively, at the 5% level.


4 Week
TAROF control (%)
60
50
40
30
20
10
0
Imazaquin (g/ha)
LSD
0
NS
138
8
276
10
8
10
NS=LSD
0
138
276
Triclopyr (g/ha)

Appendix Table 3. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass height at two and three weeks.[a]

Imazaquin	2 Week height						3 Week height					
	ACP 2100 (g/ha)											
rate	0	12	24	36	48	LSD	0	12	24	36	48	LSD
(g/ha)	(cm)						(cm)					
	Run 1											
0	11.7	7.0	6.0	6.7	6.0	0.7	14.0	7.0	6.0	6.0	6.0	0.8
17	7.0	6.0	6.0	6.0	6.0	0.8	8.0	6.0	6.0	6.0	6.0	0.8
34	6.0	6.0	6.0	6.0	6.0	NS	6.3	6.0	6.0	6.0	6.0	NS
52	6.7	6.0	6.3	6.3	6.0	0.7	7.7	6.0	6.0	6.0	6.0	0.4
69	6.0	6.0	6.0	6.0	6.0	NS	6.3	6.0	6.0	6.0	6.0	NS
LSD	1.2	0.0	NS	0.6	NS		0.9	0.0	NS	NS	NS	
	Run 2											
0	13.0	6.0	6.0	6.0	6.0	0.4	14.7	6.7	6.3	6.0	6.0	0.5
17	6.0	6.0	6.0	6.0	6.0	NS	6.3	6.0	6.0	6.0	6.0	0.2
34	6.0	6.0	6.0	6.0	6.0	NS	6.0	6.0	6.0	6.0	6.0	NS
52	6.0	6.0	6.0	6.0	6.0	NS	6.0	6.0	6.0	6.0	6.0	NS
69	6.0	6.0	6.0	6.0	6.0	NS	6.0	6.0	6.0	6.0	6.0	NS
LSD	0.4	NS	NS	NS	NS		0.3	0.2	0.2	NS	NS	

[a] Means height values are from 3 replications. Least significant difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, resectively, at the 5% level.

Appendix Table 4. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass height at four and five weeks.[a]

Herbicide rate	4 week height						5 week height					
	ACP 2100 (g/ha)											
	0	12	24	36	48	LSD	0	12	24	36	48	LSD
(g/ha)	(cm)						(cm)					
Imazaquin	(Run 1)											
0	13.7	13.7	6.7	6.0	6.0	4.2	18.3	17.0	7.7	6.7	6.3	2.3
17	13.0	6.7**	6.0	6.0	6.0	1.9	16.0	7.7**	6.3	6.0	6.7	1.3
		(13.0)						(14.9)				
34	10.3	6.3**	6.0	6.0	6.0	0.7	14.3	7.3**	6.7	6.0	6.0	2.6
		(10.3)						(13.3)				
52	7.0	6.0	6.0	6.0	6.0	0.7	7.7	6.0	6.3	6.3	6.0	1.9
69	7.3	6.0	6.0	6.0	6.0	0.8	6.0	6.7	6.3	6.0	6.0	1.1
LSD	6.3	1.3	NS	NS	NS		2.4	1.9	NS	0.6	0.6	
	(Run 2)											
0	17.3	8.0	6.3	6.0	6.0	0.8	19.3	9.7	6.7	6.7	6.0	1.6
17	7.0	6.0	6.0	6.0	6.0	0.8	7.3	6.0	6.0	6.0	6.0	1.1
34	6.7	6.0	6.0	6.0	6.0	0.5	7.7	6.0	6.0	6.0	6.0	1.3
52	6.0	6.0	6.0	6.0	6.0	NS	6.0	6.0	6.0	6.0	6.0	NS
69	6.0	6.0	6.0	6.0	6.0	NS	6.0	6.0	6.0	6.0	6.0	NS
LSD	0.9	0.0	0.2	NS	NS		1.4	1.4	0.5	0.5	NS	

[a] Mean height values are from 3 replications. Numbers in parenthesis are the estimate, with a positive difference indicating synergism, Significance at the 1% level of probability is indicated as (**) as determined by a statistical treatment of Colby's Method. Least significant difference (LSD) listed across the bottom and along the side of the table, indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

Appendix Table 5. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass height, for the second run, at six and seven weeks.[a]

Imazaquin	6 Week height						7 Week height					
	ACP 2100 (g/ha)											
rate	0	12	24	36	48	LSD	0	12	24	36	48	LSD
(g/ha)	(cm)						(cm)					
0	19.3	11.7	6.7	6.7	6.0	2.3	18.7	11.7	6.7	7.0	6.3	2.7
17	8.3	6.0	6.0	6.0	6.0	1.9	10.3	7.3 (6.4)	6.0	7.0	6.3	2.5
34	8.3	6.0	6.0	6.3	6.0	1.6	8.7	6.0	6.3	6.0	6.3	1.9
52	6.3	6.0	6.0	6.0	6.0	0.2	6.7	6.0	6.0	6.0	6.0	0.5
69	6.0	6.0	6.0	6.0	6.3	0.2	6.0	6.0	6.0	6.0	6.0	NS
LSD	1.9	2.2	0.5	0.6	0.2		2.2	2.8	0.6	0.8	NS	

[a] Mean height values are from 3 replications. Numbers in parenthesis are the estimate, with a positive difference indicating synergism. Least significant difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

Appendix Table 6. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass injury, for the first run of the greenhouse experiment.[a]

Imazaquin Rate	4 Week injury ACP 2100 (g/ha)					
	0	12	24	36	48	LSD
(g/ha)	(%)					
0	7	10	0	0	0	4
17	10	0	0	0	0	0
34	3	0	0	0	0	NS
52	0	0	0	0	0	NS
69	0	0	0	0	0	NS
LSD	6	0	NS	NS	NS	
	6 Week injury					
0	10	10	3	0	0	4
17	10	3	0	0	0	4
34	10	0	0	0	0	0
52	0	0	0	0	0	NS
69	0	0	0	0	0	NS
LSD	0	4	4	NS	NS	

[a] Injury values are from 3 replications. Least significant difference (LSD) listed across the bottom and side indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

Appendix Table 7. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass injury, for the second run of the greenhouse experiment.[a]

	4 Week injury					
Imazaquin	ACP 2100 (g/ha)					
Rate	0	12	24	36	48	Mean
(g/ha)	(%)					
0	0	0	0	0	0	0
17	0	0	0	3	3	1
34	0	0	3	3	10	3
52	0	0	7	3	7	3
69	0	0	3	7	0	2
Mean	0	0	2	3	4	
	COLUMN MEAN LSD = 3			ROW MEAN LSD = 3		
	6 Week injury					
0	0	0	0	0	0	
17	7	0	3	0	0	
34	0	3	0	0	0	
52	10	0	7	0	7	
69	3	0	0	0	0	
Total LSD = NS						
	8 Week injury					
0	3	3	0	7	7	4
17	23	7	10	7	10	11
34	7	13	7	3	10	8
52	17	7	13	7	20	13
69	13	7	3	13	7	9
LSD						8

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[a] Injury values are from 3 replications. Least significant difference (LSD) indicates difference between means at the 5% level.

Appendix Table 8. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass quality.[a]

Imazaquin	4 Week quality						5 Week quality					
	ACP 2100 (g/ha)											
rate	0	12	24	36	48	LSD	0	12	24	36	48	LSD
(g/ha)	Run 1											
0	5.0	4.0	8.3	9.0	9.0	3.2	3.0	3.0	7.0	7.7	7.7	1.5
17	3.7	9.0	9.0	9.0	9.0	0.9	3.3	7.0	8.0	7.7	7.7	0.9
		(3.0)	(6.1)	(6.7)	(6.7)			(3.3)	(7.7)	(8.5)	(8.5)	
34	4.7	8.7	9.0	9.0	9.0	1.4	3.7	7.3	7.0	7.0	6.7	1.8
		(3.8)	(7.8)	(8.5)	(8.5)			(3.7)	(8.6)	(9.5)	(9.5)	
52	8.0	9.0	9.0	9.0	9.0	NS	6.0	7.7	8.0	7.3	7.0	1.4
69	8.0	9.0	9.0	9.0	9.0	NS	6.3	7.3	7.3	6.3	7.7	1.1
LSD	4.2	1.0	NS	NS	NS		0.9	1.3	NS	1.3	NS	
	Run 2											
0	3.0	6.3	7.3	7.7	7.7	1.3	3.0	5.3	7.7	7.3	7.7	1.8
17	7.3	8.0	8.0	8.0	8.0	NS	6.0	8.0	8.0	7.7	8.0	0.9
34	7.3	7.7	7.7	8.0	7.7	NS	6.7	7.7	7.7	8.0	7.0	NS
52	8.0	8.0	7.7	8.0	7.0	NS	7.7	8.0	7.0	8.0	6.3	NS
69	8.0	8.0	8.0	7.3	8.0	NS	8.0	8.0	7.3	6.7	8.0	0.9
LSD	1.1	0.6	NS	NS	NS		1.2	1.9	NS	0.6	1.5	

[a] Numbers in parenthesis are the estimate, with a (-) difference indicating a synergism. Signifance at the 1% and 5% level of probability is indicated as ** and *, respectively, as determined by a statistical treatment of Colby's Method (5). LSD's listed across the bottom and along the side indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

Appendix Table 9. Combination effect of ACP 2100 and imazaquin on Kentucky bluegrass quality, for the second run of the greenhouse experiment.[a]

Imazaquin	6 Week quality					
	ACP 2100 (g/ha)					
Rate (g/ha)	0	12	24	36	48	LSD
0	3.0	4.0	6.3	7.0	7.3	2.5
17	4.7	7.3	7.0	7.7	7.7	2.0
34	6.0	8.0	7.3	8.0	7.3	1.6
52	7.3	8.0	7.0	8.0	6.3	NS
69	7.3	6.7	8.0	7.0	8.0	0.9
LSD1.9	1.5	NS	0.9	1.4		

[a] Mean quality values are from 3 replications. Least significant difference (LSD) listed across the bottom and along the side of the table indicate difference within and between the rates of ACP 2100, respectively, at the 5% level.

Appendix Table 10. Combination effect of ACP 2100 and triclopyr on Kentucky bluegrass foliar height.[a]

Triclopyr Rate	2 Week height ACP 2100 (g/ha) 0	12	24	36	48	LSD
(g/ha)			(cm)			
0	9.7	6.0	6.0	6.0	6.0	
140	10.3	6.0	6.0	6.0	6.0	
280	11.3	6.0	6.0	6.0	6.0	
420	10.3	6.0	6.0	6.0	6.0	
560	10.7	6.3	6.0	6.0	6.0	
Mean	10.5	6.1	6.0	6.0	6.0	0.5
			4 Week height			
0	12.7	6.2	6.0	6.0	6.0	
140	12.3	6.3	6.0	6.0	6.0	
280	16.3	6.2	6.0	6.0	6.0	
420	13.7	6.3	6.0	6.0	6.0	
560	12.7	6.7	6.0	6.0	6.0	
Mean	12.1	6.2	6.0	6.0	6.0	0.8
			6 Week height			
0	13.3	7.2	7.0	6.0	6.0	
140	15.0	6.7	6.7	6.0	6.0	
280	16.7	7.4	6.3	6.0	6.0	
420	18.7	7.8	6.3	6.0	6.0	
560	12.7	9.4	6.7	6.0	6.0	
Mean	14.9	8.5	6.4	6.0	6.0	1.9

[a] Height values are from 2 runs of 3 replications each. Least significant difference (LSD) indicate difference between means at the 5% level.

Appendix Table 11. Combination effect of ACP 2100 and triclopyr on Kentucky bluegrass injury.[a]

Triclopyr Rate	2 Week injury ACP 2100 (g/ha) 0	12	24	36	48	LSD
(g/ha)	(%)					
0	0	0	7	7	10	
140	0	0	7	10	13	
280	0	0	7	7	10	
420	0	3	7	7	13	
560	0	0	0	10	10	
Mean	0	0	7	8	11	3

[a] Injury values are from 2 runs of 3 replications each. Least significant difference (LSD) indicate difference between means at the 5% level.

Appendix Table 12. Combination effect of ACP 2100 and triclopyr on Kentucky bluegrass quality.[a]

Triclopyr	2 Week quality					
	ACP 2100 (g/ha)					
Rate (g/ha)	0	12	24	36	48	LSD
0	4.0	8.0	8.0	8.0	8.0	
140	4.3	8.0	8.0	8.0	8.0	
280	4.0	8.0	8.0	8.0	8.0	
420	3.7	8.0	8.0	8.0	8.0	
560	3.0	8.0	8.0	8.0	8.0	
Mean	3.9	8.0	8.0	8.0	8.0	0.4
	4 Week quality					
0	2.7	8.0	7.1	7.0	7.0	
140	4.3	7.7	6.7	7.0	6.5	
280	4.0	8.0	7.1	7.0	5.5	
420	2.7	7.3	7.0	6.7	5.7	
560	3.0	8.0	7.3	6.0	5.5	
Mean	3.0	7.7	7.2	6.7	6.0	0.6
	6 Week quality					
0	3.0	5.0	6.7	7.0	7.0	
140	3.6	5.5	5.4	7.0	6.5	
280	2.7	5.5	6.0	7.0	6.7	
420	2.7	6.0	6.0	7.0	7.0	
560	2.0	5.1	6.1	7.2	6.3	
Mean	2.8	5.5	6.2	7.0	6.5	0.7

[a] Quality values are from 2 runs of 3 replications each. Least significant difference (LSD) indicates difference between means at the 5% level.

Appendix Table 13. Combination effect of triclopyr and ACP 2100 on common dandelion injury.[a]

Triclopyr rate	Injury											
	1 Week						2 Week					
	ACP 2100 (g/ha)											
	0	12	24	36	48	Mean	0	12	24	36	48	Mean
(g/ha)	(%)											
0	0	8	8	7	10	7	0	7	7	10	12	7
34	8	13	25	27	32	17	7	12	30	28	38	17
69	22	20	22	28	37	23	17	22	33	42	47	30
103	28	18	27	27	23	28	27	23	37	20	40	31
138	30	25	20	28	28	30	38	22	33	40	38	40
Mean							18	23	30	26	29	

ROW MEAN LSD = 3 COLUMN MEAN LSD = 7 ROW MEAN LSD = 4

Triclopyr rate	3 Week					
(g/ha)	0	12	24	36	48	Mean
0	0	5	10	13	13	8
34	5	10	27	27	27	16
69	12	20	28	32	40	24
103	25	22	30	28	30	28
138	34	25	25	27	35	33
Mean	15	19	26	25	25	

COLUMN MEAN LSD = 5 ROW MEAN LSD = 4

---

[a] Mean injury values are from combined runs of 3 replications each.

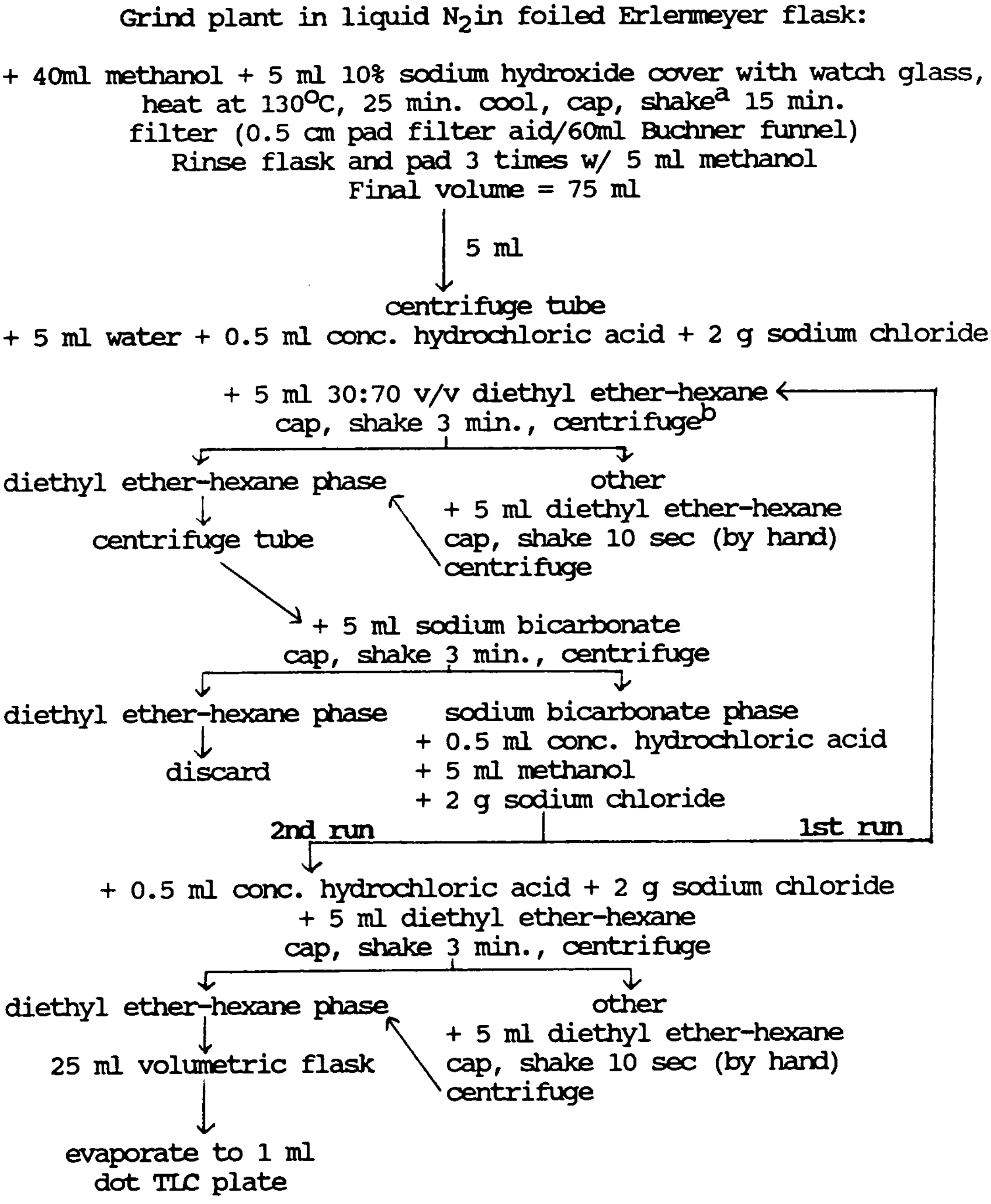
Appendix Table 14. Combination effect triclopyr and imazaquin on common dandelion injury.[a]

	Injury											
	1 Week						2 Week					
Triclopyr rate	Imazaquin (g/ha)											
	0	34	69	103	138	Mean	0	34	69	103	138	Mean
(g/ha)	(%)											
0	0	20	12	15	18	13	2	12	5	7	15	8
34	12	22	25	32	28	17	3	13	15	32	28	12
69	20	15	20	23	23	21	13	15	20	22	18	18
103	28	18	17	28	33	26	24	17	18	25	27	24
138	33	18	22	18	30	30	40	12	22	17	27	28
Mean	19	19	21	22	25							
	COLUMN MEAN LSD = 6			ROW MEAN LSD = 5						ROW MEAN LSD = 6		
	3 Week											
0	0	14	5	12	8	8						
34	7	15	20	27	30	15						
69	12	14	14	17	28	19						
103	23	23	30	25	35	22						
138	33	17	22	18	27	31						
Mean	15	21	15	25	18							
	COLUMN MEAN LSD = 8			ROW MEAN LSD = 6								

---

[a] Mean injury values are from combined runs of 3 replications each.

EXTRACTION PROCEEDURE



Grind plant in liquid N_2in foiled Erlenmeyer flask:

+ 40ml methanol + 5 ml 10% sodium hydroxide cover with watch glass,
heat at 130°C, 25 min. cool, cap, shake[a] 15 min.
filter (0.5 cm pad filter aid/60ml Buchner funnel)
Rinse flask and pad 3 times w/ 5 ml methanol
Final volume = 75 ml

5 ml

centrifuge tube
+ 5 ml water + 0.5 ml conc. hydrochloric acid + 2 g sodium chloride

+ 5 ml 30:70 v/v diethyl ether-hexane
cap, shake 3 min., centrifuge[b]

diethyl ether-hexane phase
centrifuge tube

other
+ 5 ml diethyl ether-hexane
cap, shake 10 sec (by hand)
centrifuge

+ 5 ml sodium bicarbonate
cap, shake 3 min., centrifuge

diethyl ether-hexane phase
discard

sodium bicarbonate phase
+ 0.5 ml conc. hydrochloric acid
+ 5 ml methanol
+ 2 g sodium chloride

2nd run

1st run

+ 0.5 ml conc. hydrochloric acid + 2 g sodium chloride
+ 5 ml diethyl ether-hexane
cap, shake 3 min., centrifuge

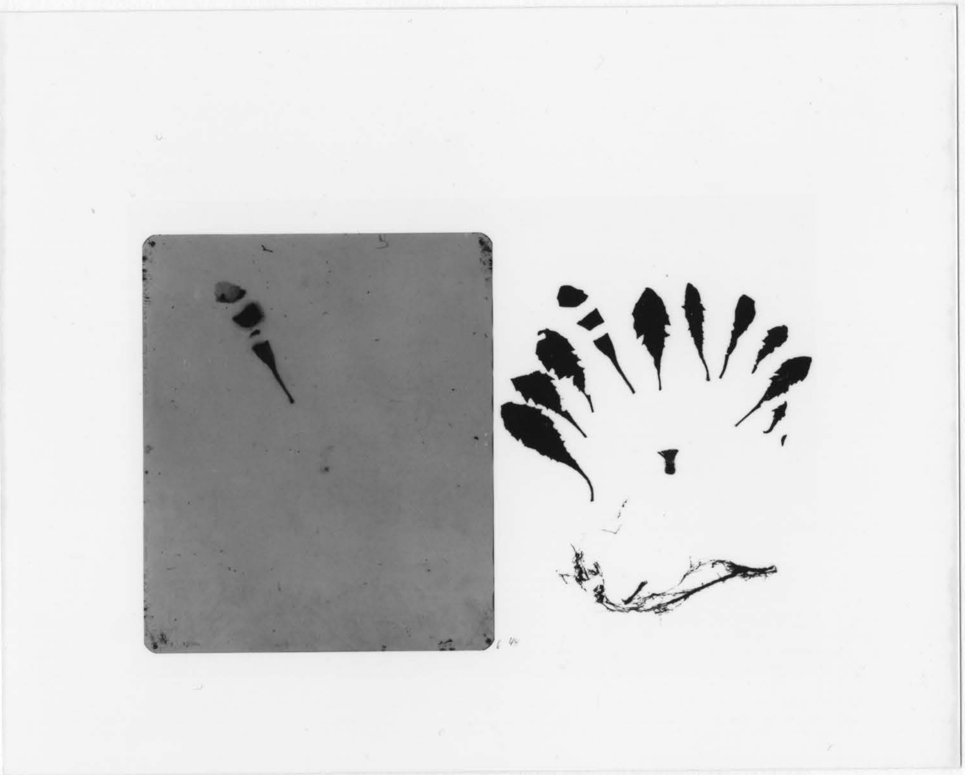
diethyl ether-hexane phase
25 ml volumetric flask
evaporate to 1 ml
dot TLC plate

other
+ 5 ml diethyl ether-hexane
cap, shake 10 sec (by hand)
centrifuge

Appendix Figure 6. Proceedure for extraction of triclopyr from plant tissue. [a]Shake at 280 excrusions/min. [b]Centrifuge at 3000 rpm for 1 min. McKellar, R.L. 1977. Determination of triclopyr, ([(3,5,6-trichloro-2-pyridinyl0oxy]acetic acid); 3,5,6-tricloropyridine in glass by gas chromatography. ACR 77.4. Unpublished. Dow Chemical Co., Midland, Michigan 48674

Appendix Figure 7. Autoradiography (left) of dandelion (right) at 2 and 24 hours after treatment with 0.13 uCi ^{14}C-triclopyr, with and without ACP 2100. a = representative of 2 h after treatment, b = representative of triclopyr alone 24 and 48 h after treatment, c = representative of triclopyr plus ACP 2100 at 60 g ha^{-1} 24 and 48 h after treatment, d = representative of triclopyr plus ACP 2100 at 120 g ha^{-1} 24 and 48 h after treatment.

a

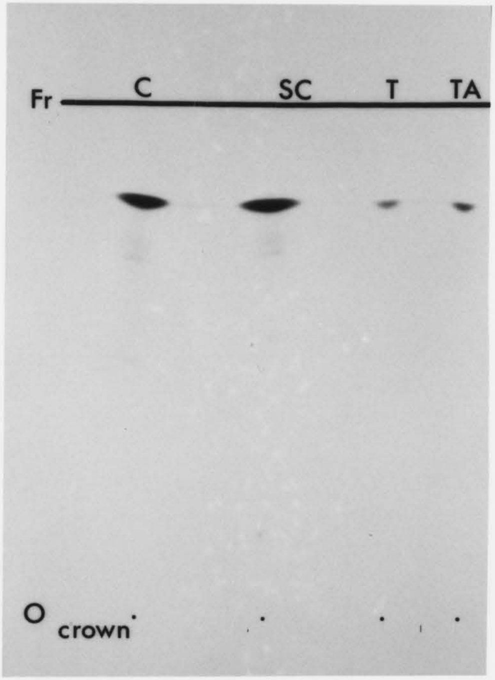


b

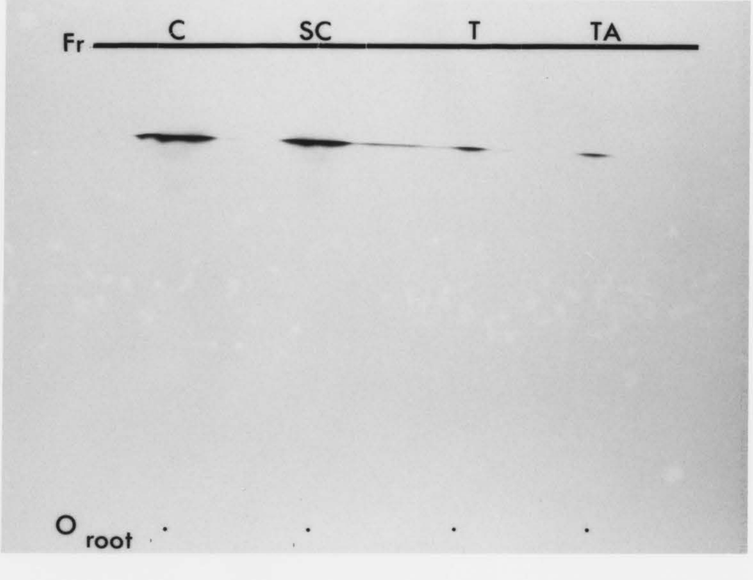
c

d

Appendix Figure 8. Autoradiography of common dandelion crown and root extracts 48 h after foliar application of ^{14}C-triclopyr, with and without ACP 2100: C = control (triclopyr reference), SC = spiked extract control , T = extract from plan treated with triclopyr, TA = extract from plant treated with triclopyr + ACP 2100. Origin (O) is at bottom; solvent front (Fr) is 15 cm above.



a



b

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