EVALUATION OF AUXINIC HERBICIDES FOR BROADLEAF WEED CONTROL, TOLERANCE OF FORAGE BERMUDAGRASS HYBRIDS [*Cynodon dactylon* (L.) Pers.], AND ABSORPTION AND TRANSLOCATION IN COMMON RAGWEED [*Ambrosia artemisiifolia* L.]

A Dissertation

by

FREDERICK THOMAS MOORE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Agronomy

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ABSTRACT

Evaluation of Auxinic Herbicides for Broadleaf Weed Control, Tolerance of Forage
Bermudagrass Hybrids [*Cynodon dactylon* (L.) Pers.], and Absorption and
Translocation in Common Ragweed [*Ambrosia artemisiifolia* L.]. (May 2005)

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These studies were conducted on several central Texas agricultural producers' properties, the Stiles Farm Foundation, the Texas Agricultural Experiment Station, and the Texas A&M University campus. First, an experimental herbicide from Dow AgroSciences, GF-884, was evaluated for effectiveness in controlling three annual and three perennial weed species in production pasture lands and hay meadows. Several rates of GF-884 were examined and evaluated against three registered pasture products and one non-selective herbicide. Next, GF-884 was assessed for tolerance on two common bermudagrass hybrids (*Cynodon dactylon* (L.) Pers.) at three progressive rates with and without adjuvant. Finally, the herbicides, picloram and fluroxypyr, were applied to common ragweed (*Ambrosia artemisiifolia* L.) to characterize their individual absorption and translocation and assess any influence one might have on the other.

GF-884 applied at rates of 0.91 and 1.14 kg a.e./ha provided >85% and >75% control of the annual and perennial weed species evaluated, respectively. These same rates of GF-884 consistently provided control that was equivalent or better than that achieved with the registered products. No differences were observed among treatments when shoots from the perennial species were evaluated 12 months following treatment application. The tolerance experiments utilized GF-884 at rates twice that used to evaluate weed control efficacy. These elevated rates did not result in discernable influences on yield or forage quality for either hybrid forage grass when compared to untreated areas. The efficacy and tolerance observations suggest that GF-884 applied at the highest recommended weed control rate can effectively control several annual and perennial weed species without imparting detrimental effects to the hybrid bermudagrass being produced.

Finally, in the presence of fluroxypyr, ^{14}C picloram absorption was maintained throughout all sampling intervals. Picloram applied alone, maximized ^{14}C absorption at 6 HAT then declined significantly. At the final sampling, ^{14}C from picloram applied alone was in greater concentration in the treated leaf and the root.

Picloram significantly decreased absorption of ^{14}C fluroxypyr. Fluroxypyr alone maintained ^{14}C absorption throughout all samplings, whereas the combination maximized at 12 HAT. Initially, picloram limited ^{14}C translocation, however at 6, 12, and 24 HAT this was not evident.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

In Texas, approximately 96% of the rural lands are dedicated to four major land uses that include range and pasture (72%), dry land crops (15%), forest areas (5%), and irrigated crops (4%). Range and pasture lands comprise more than 42 million hectares with a minimum of 4 million hectares classified as improved pasture lands (Wilkins and Hays 2003). Within intensive livestock management systems, pasture improvement is an important aspect of successful grazing and hay production. Optimum production can be achieved by matching the proper forage species to specific soils, climates, and intended use. An equally important step is managing for forage health by maintaining sufficient moisture, nutrients, and optimal solar radiation (Naylor 2002). All three can be compromised by competition from undesirable plant species (weeds) that are lower in nutritive value, unpalatable, and/or toxic to ruminant and non-ruminant livestock (Stichler et al. 1998). To minimize or eliminate the effects of these detrimental plant species, extensive research has been conducted to develop control methods utilizing mechanical, biological, and herbicidal management options.

The use of herbicides to achieve efficacious control of weeds has evolved significantly over the last several decades due to the discovery of several herbicide groups with distinctive modes of action. The auxinic herbicides, one of the most widely used herbicide groups in the world, were the first selective organic herbicides to be

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This dissertation follows the style and format of Weed Technology.

developed. Their use has resulted in what some call an ‘agricultural revolution’ becoming the backbone of present-day weed science (Troyer 2001). Within this herbicide group, there are several chemical families, including the phenoxyalkanoic and pyridinecarboxylic acids, and are referred to as the phenoxy and pyridine herbicide families, respectively. These herbicides have the ability to act on susceptible broadleaf plants because of their structural resemblance to the natural plant growth hormone indole-3-acetic acid (IAA). At low doses, these herbicides act as plant growth regulators and stimulate plant cell growth. However, at high doses, they induce phytotoxic effects (Naylor 2002; Vencill 2002).

Since the 1940’s, numerous auxinic herbicides have been labeled to minimize weed competition for the benefit of crop production. The first auxinic herbicide was 2,4-D [dimethylamine salt of (2,4-dichlorophenoxy) acetic acid], a phenoxy herbicide, for use in row crops, forage, and turf production to control annual and perennial broadleaf weeds (Cates 1945; Bovey and Young 1980; Troyer 2001). When applied to foliage, the nonpolar ester forms of 2,4-D more rapidly penetrate and translocate through the symplastic pathway from areas of carbohydrate synthesis to shoot and root growing points. In the polar or salt forms, 2,4-D more readily enters plants via root absorption for transport through the xylem to the same destinations (Vencill 2002). Several physiological responses are induced in plants following treatment with 2,4-D. After entering into plant epidermal cells, the herbicide is absorbed into the symplast, migrates to the vascular system and translocates from the leaves to the stem, roots and other plant parts. Once distributed within the plant, biochemical reactions are initiated that potentially lead to abnormal cellular function and growth, ultimately leading to plant starvation (Bovey 2001). At low doses to susceptible plants, young leaves may look puckered and new leaf tips may develop as narrow extensions of the midrib. Symptoms of high dose exposure include cupping and stunting of leaf growth, brittleness, stunting and twisting of stems, and cessation of terminal leaf growth. Proliferation of malformed tissue and swelling along the stem occurs first at the tip, then the nodes, and finally along the length of the stem. The accumulation of malformed tissue results in blockage of phloem and xylem tissue. Concurrently, epinasty, bending, and splitting of the plant's stem occurs (Vencill 2002).

A pyridine-based auxin-mimicking herbicide was discovered nearly 20 years after 2,4-D. Picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid) was introduced by Dow Chemical Company with the intended use of controlling broadleaf plants, including woody species, in forages (Bovey and Scifres 1971). Picloram is translocated symplasticly and apoplasticly and is slowly degraded within susceptible plants. In the ester formulation, picloram readily penetrates foliage and roots of susceptible plants (Vencill 2002). The phytotoxic symptoms and mode of action of picloram resemble that of 2,4-D and other auxinic herbicides (Bovey 2001; Vencill 2002).

In the 1980's, fluroxypyr [((4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy) acetic acid], was developed to control annual and perennial broadleaf weeds in row crops and forages. Fluroxypyr is also a pyridine-based auxin-mimicking herbicide that enters the plant primarily through leaf penetration and less significantly by root uptake from the soil solution. Following leaf penetration, fluroxypyr translocates within the plant acropetally and basipetally, accumulating in meristematic areas where it affects cell division and cell elongation (Trozelli 1986). Fluroxypyr exhibits symptomology similar to picloram, 2,4-D and other auxinic herbicides (MacDonald et al. 1994; Vencill 2002).

Though some of these auxinic herbicides were introduced almost 60 years ago, they continue to be included in commercial applications and weed control research trials. This is primarily a result of their high efficacy for controlling numerous broadleaf weeds relatively inexpensively (Troyer 2001). Combined, these three herbicides are labeled to control over 100 different herbaceous and woody weed species (Vance Communication Corporation 2004). Also, the use rates for these herbicides equate into an average price of $15.34/ha (Zollinger 2004). Additionally, their continued use may be attributed to the associated difficulty and expense of registering new compounds. Since the 1972 amendment to the United States Federal Insecticide, Fungicide, Rodenticide Act (FIFRA), the expense of registering new products has more than tripled, from 8.3% to 25%. This dramatic increase in expenditures is directly correlated to the pesticide regulations requiring more environmental and toxicity testing along with the previously required efficacy and tolerance research (Ollinger et al., 1998). These additional tests were imposed due to concerns that chemical pesticides have the potential to contaminate ground and surface water, have harmful effects on wildlife, leave residues on agricultural products, and cause health risks to farm workers (Harper and Zilberman 1989). Critics claim that the cost of complying with these additional regulations reduces the incentive to research and develop new active ingredients needed for use as herbicides (Greene et al., 1977). Logically, it is much more cost effective to conduct further research on those labeled compounds already available because the initial expense and research required to register the product has been expended. This suggests that one trend in the pesticide industry is to reevaluate those products currently registered and identify increased herbicidal activity possibilities through reformulation or product pairing. The latter offers enhanced efficacy at potentially reduced use rates that may quite possibly result in a lower environmental impact.

Weed Control

The use of herbicides has become one of the most efficient and cost effective means to minimize weed competition (Bovey et al., 1986). Numerous compounds have been tested in countless experiments in an attempt to identify those with the ability to effectively control pernicious pasture weeds. In 1951, Elder reported that some Oklahoma pastures produced 1,121 kg/ha dry weight of perennial (western) ragweed (*Ambrosia psilostachya* DC.) annually. At the time, this species was considered the most harmful pasture weed on most of that state's 18 million grassland acres. From studies conducted by Elder (1951), it was determined that mowing was ineffective whereas applications of 2,4-D at 0.56 or 0.84 kg a.i./ha would eliminate it. Bovey et al. (1966) evaluated 2,4-D (0.56, 1.12, and 2.24 kg a.i./ha) for controlling perennial (western) ragweed. These researchers monitored regrowth of the weed three years following treatments and observed no regrowth three years following a single application of 2,4-D at 2.24 kg a.i./ha as well as no regrowth two years following two consecutive seasonal applications of 2,4-D at all three rates. Dahl et al. (1989) conducted four separate studies in 1985 and consistently found that triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid, 2,4-D, and dicamba (3,6-dichloro-o-anisic acid) + 2,4-D, were not effective in controlling western ragweed at a rate of 0.28 kg a.e./ha. Whereas, picloram, picloram + 2,4-D, and dicamba, at this same use rate, provided adequate control. Baumann and Smith (2000) observed 95% or greater control with fluroxypyr (0.14, 0.21, 0.28, and 0.56 kg a.e./ha), fluroxypyr + picloram (1:1 ratio) (0.18, 0.28, and 0.45 kg a.e./ha), picloram + 2,4-D (0.54 and 0.71 kg a.e./ha), picloram (0.14 and 0.28 kg a.e./ha), dicamba + 2,4-D (0.82 kg a.e./ha), and 2,4-D (1.12 kg a.e./ha). These same treatments were applied to both woolly croton (*Croton capitatus* Michx.) and annual marshelder (*Iva annua* L.). To achieve 90% or better woolly croton control, 0.28 kg a.e./ha of fluroxypyr + picloram, 0.71 kg a.e./ha of picloram + 2,4-D, or 1.12 kg a.e./ha of 2,4-D was required. For a similar level of annual marshelder control, fluroxypyr at 0.56 kg a.e./ha, fluroxypy + picloram at 0.28 and 0.45 kg a.e./ha, picloram + 2,4-D at 0.71 kg a.e./ha, picloram at 0.14 kg a.e./ha, and 2,4-D at 1.12 kg a.e./ha was needed. Butler and Interrante (2003a) evaluated several herbicides for the control of annual broomweed (*Amphiachyris dracunculoides* (DC.) Nutt.), western ragweed, and woolly croton. They determined that triasulfuron [3-(6-methoxy-4-methy/ L,3,5-triazin-2-yl)-1-(2-(2-chloroethoxy)phenylsulfonyl))urea] + dicamba (1:8 ratio) applied at a minimum of 0.92 kg/ha was required to achieve >90% annual broomweed control. For 87% or better western ragweed and woolly croton control, triasulfuron + dicamba (1:8

ratio) at 0.92 kg/ha, metsulfuron (methyl 2-[[[[(4-methoxy-6-methy/ L,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-benzoate) + 2,4-D + dicamba (1:23:8 ratio) at 0.56 kg a.e./ha, picloram + 2,4-D (1:4) at 0.53 kg ae / ha, or picloram + fluroxypyr (1:1) at 0.28 kg a.e./ha was required.

Western horsenettle (*Solanum dimidiatum* Raf.) and silverleaf nightshade (*Solanum elaeagnifolium* Cav.), both members of the Solanaceae family, have become major weeds in both permanent pasture and row crop production (Palmer and Miears 1978; Gorrell et al., 1981; Prostko et al., 1994; Whaley and Vangessel 2002a; Stubblefield and Sosebee 1985; Westerman and Murray 1994; Dotray and Keeling 1996). Palmer and Miears (1978) determined that picloram (0.84 kg a.e./ha) applied alone or at 0.56 kg a.e./ha + 2,4-D (1.12 kg a.e./ha) provided season-long control of western horsenettle (>80%). However, the opposite was true of dicamba (0.56 kg a.e./ha) + 2,4-D (1.68 kg a.e./ha) and 2,4-D (1.12 kg a.e./ha) applied alone providing less than 20% control. Similarly, Gorrell et al. (1981) found that picloram (0.67 and 1.23 kg a.e./ha) applied alone or in combination with 2,4-D (1.23 kg a.e./ha) significantly reduced shoot regrowth (98%). Dicamba (1.23 kg a.e./ha) and dicamba (0.34 kg v) + 2,4-D (90 kg a.e./ha) only reduced growth by 74 and 70%, respectively. Prostko et al. (1994) observed comparable results with dicamba where biomass was only reduced by 61%. In 1998, researchers found that glyphosate broadcast over the top of corn at 1.1 kg/ha provided in excess of 78% horsenettle control (Whaley and Vangessel 2002b). The same treatment applied in the fall resulted in an 88% reduction in shoot regrowth the following spring.

In another study, researchers applied treatments of picloram (1.5 and 3 kg/ha) and glyphosate (2.7 and 5.4 kg/ha) to actively growing silverleaf nightshade (Eleftherohorinos et al., 1993). The picloram treatment restricted regrowth to less than 5% and glyphosate limited regrowth from 0 to 22%. Schoenhals and Wiese (1988) found that both picloram (0.13, 0.28, and 0.56 kg a.e./ha) and glyphosate (1.68 and 3.36 kg a.e./ha) consistently provided in excess of 70% control of silverleaf nightshade in a cotton-wheat cropping rotation. Dotray and Keeling (1996) determined that glyphosate applied at the labeled rate of 1.7 kg/ha provided 97% control 12 months following application while rates of 0.8, 1.1, 1.3, and 1.5 kg a.e./ha achieved comparable control.

Bermudagrass Tolerance

The introduction of reliable herbicides has greatly facilitated forage establishment and weed management in pastures and hay meadows, improving productivity and eliminating some toxicity problems to livestock (Hoveland 2000). Some compounds that provide excellent weed control have been tested for use in forage production; however, their use has been found to be significantly injurious to forage grasses. Injury to bermudagrass can vary from negligible to severe when herbicides are applied for postemergence weed control, depending on the herbicide used and the time of application (Johnson and Burns 1985). Montgomery et al. (1999) reported Common bermudagrass injury from spring applications of imazapic {(±)-2-[4,5-dihydro-4-methyl-4- (1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid} (0.14 and 0.21 kg/ha) ranging from 27 to 37%. Others have reported more extreme growth reduction of Coastal and Common bermudagrasses (50 to 64% and 35 to 46%) from 0.21, 0.42, and 0.63 kg/ha of imazapic + 2,4-D, respectively (Etheredge et al. 2001). Johnson (1983) found that the combined treatment of 2,4-D + mecoprop {2-[(4-chloro-o-toyly) oxy] propionic acid} + dicamba in sequential applications at typical (1.1 + 0.6 + 0.1 kg a.i./ha) rates caused 40% or greater injury to four bermudagrass cultivars, when applied late summer to early fall. Reber et al. (1971) treated 16 bermudagrass cultivars with picloram (3.6 kg/ha). Approximately 2.5 months following application, all cultivars exhibited 90% or greater reduction in ground cover. One year later, only 5 of the cultivars had rebounded with greater than 50% ground cover. Similarly, Bovey et al. (1974) evaluated spray and granule applications of picloram and dicamba (0.56, 1.12, 2.24, and 4.48 kg/ha) as well as spray applications of 2,4-D (1.12 and 2.24 kg/ha) on Coastal, Common and Coastcross-1 bermudagrasses. These investigators reported that neither dicamba nor 2,4-D significantly reduced yields of the bermudagrass varieties. However, picloram (2.24 and 4.48 kg/ha) severely reduced bermudagrass growth, especially in periods of dry weather. Picloram applied at 0.56 and 1.12 kg/ha resulted in only temporary growth reductions. In a study conducted by Brooks et al. (1996), treatments of picloram + 2,4-D (0.36 and 0.71 kg a.e./ha), dicamba + 2,4-D (0.54 and 1.1 kg a.e./ha), 2,4-D (0.56 and 1.12 kg a.e./ha), picloram (0.14 kg a.e./ha), dicamba (0.28 kg a.e./ha), and glyphosate (0.56 kg a.i./ha) were applied to Tifton 85 and Jiggs bermudagrass varieties. Only the glyphosate treatment resulted in significant injury in the form of visual phytotoxicity, forage height/density, and yield reduction. Similar results were observed by Louisiana researchers (Eichhorn and Wells 1995) in which applications of 2,4-D (1.12 and 2.24 kg/ha), dicamba (0.56 kg/ha), picloram + 2,4-D (0.71 and 1.4 kg/ha) and dicamba + 2,4-D (1.12 and 2.24 kg/ha) had no inhibitory effects on Coastal bermudagrass production. Butler and Interrante (2003b) evaluated the individual treatment effects of 2,4-D (2.52 kg a.i./ha), dicamba + 2,4-D (1.63 kg a.i./ha), triasulfuron + dicamba (0.48 kg a.i./ha), picloram + 2,4-D (1.1 kg a.i./ha), clopyralid (3,6-dichloro-2-pyridinecarboxylic acid) (0.84 kg a.i./ha), triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) (1.68 kg a.i./ha), triclopyr + clopyralid (1.26 kg a.i./ha), tryclopyr + fluroxypyr (0.38 kg a.i./ha), and picloram + fluroxypyr (0.38 kg a.i./ha) on three subsequent Coastal bermudagrass harvests. They observed no significant effects from treatments of dicamba + 2,4-D, triasulfuron + dicamba, or 2,4-D. However, reductions of at least 31% in the first harvest were observed for all other treatments. These yield reductions were not evident when all three harvests were combined as season-long forage yields.

Absorption and Translocation

The performance of foliar-applied herbicides is influenced by complex interactions of spray solution properties and plant surface characteristics. The amount of herbicide absorbed by the plant dictates the total amount available for affecting processes such as translocation, metabolism, and activity at the site of action. In many cases, the majority of the applied herbicide never enters the target species (Duke 1985). With this in mind, studies on foliar absorption are imperative for the purpose of maximizing herbicide use efficiency. Sterling and Lownds (1992) investigated the foliar absorption of picloram (picloram-2,6-^{14}C) at 0.28 kg ae / ha (266 MBq/ml) by broom snakeweed (*Gutierrezia sarothrae (Pursh)* Brit. & Rusby). These researchers found that picloram accumulated rapidly, with saturation occurring between 15 min and 1 h following application. Maximum uptake was 15% of that applied. The uptake increased linearly as the external picloram concentration increased suggesting that movement of picloram across the leaf cuticle is via simple diffusion. Gorrell et al. (1988) conducted greenhouse studies on horsenettle at the early bloom stage to determine the translocation and fate of dicamba (dicamba-7-^{14}C, 0.56 kg/ha), picloram (picloram-2,6-^{14}C, 0.56 kg/ha), and triclopyr (triclopyr-2,6-^{14}C, 3.36 kg/ha) all at 108 MBq / application. All three compounds were translocated to the roots of horsenettle. Accumulation continued for at least 16 d, at which point, the roots of plants treated with dicamba and triclopyr were found to contain a higher percentage of the respective radioisotopes (3.8 and 3.6%) than those treated with picloram (3.0%). A North Dakota researcher employed leafy spurge (*Euphorbia esula* L.) to evaluate the absorption and subsequent translocation of pyridyl-ring-labeled ^{14}C-fluroxypyr (1700 Bq, 0.56 kg/ha), pyridyl-ring-labeled ^{14}C-picloram (1700 Bq, 0.56 kg/ha), and phenol-ring-labeled ^{14}C-2,4-D (1700 Bq, 1.1 kg/ha) as well as combinations of each of these with the others' commercial formulation (Lym 1992). The researcher discovered that absorption of ^{14}C-fluroxypyr was greater in vegetative plants (39%) than in flowering or post flowering plants. Total translocation to roots averaged 2% of the amount applied regardless of growth stage. Also, absorption and translocation of ^{14}C-fluroxypyr declined by 50% when applied with picloram or 2,4-

D. However, absorption and translocation of ^{14}C-picloram or ^{14}C-2,4-D was not affected by fluroxypyr.

The objectives of the following research were to (1) evaluate the efficacy of an experimental herbicide made by Dow AgroSciences for controlling annual and perennial broadleaf weeds, (2) evaluate tolerance of forage grass varieties to the experimental herbicide, and to (3) determine the influence of picloram and fluroxypyr herbicides on each other through absorption and translocation studies.

CHAPTER II

USING GF-884 TO CONTROL ANNUAL AND PERENNIAL BROADLEAF WEEDS IN BERMUDAGRASS (*Cynodon dactylon* (L.) Pers.) PASTURES

Introduction

The strategy of reducing weed competition in crops is an important component of increasing production. The production of desirable species may be increased by as much as 400% or more as a result of good weed control practices (Carlisle et al. 1980). Competition by weeds for light interception is one of the primary means for crop yield reduction. This is particularly true in situations where weed seedlings emerge at the same time or earlier than the crop emerges or breaks winter dormancy. Water and nutrient competition comprise the remaining means for reduced crop yield (Naylor 2002). Some weeds have been shown to extract twice as much nitrogen and phosphorus and three times as much potassium from the soil than corn (Carlisle et al. 1980). Weed consumption of these key life-limiting components represents wasted resources because they are no longer available for utilization by the cultivated plant (Naylor 2002). The presence of weeds can invoke additional problems beyond that of crop yield reduction. Species containing spines can make the forage unpalatable to animals. Other species that are poisonous can maintain their toxic properties following death. When these become incorporated into hay or silage, feeding animals are unable to avoid ingestion leading to stock illness or death (Carlisle et al., 1980; Troyer 2001).

Countless weed species decrease quantity and quality of forage production annually. In the 1960's, LeClerge (1965) estimated annual losses due to weed competition at 20% in rangeland of the eastern states and 13% in rangeland of the western states. When including the cost of controlling these species with forage loss, the total loss for the United States was $1 billion. Carlisle et al. in 1980 reported economic losses as a result of reduced livestock production from weed species with highly toxic compounds to have been $107 million in the 17 western states alone. In recent years, this number has escalated to more than $2 billion annually in the United States (DiTomaso 2000).

Several herbicides and herbicide combinations are labeled for use in forage crops to control noxious and invasive weed species. Many of the combinations contain 2,4-D as one of their components because of its ability to control a wide variety of species as well as its compatible and complementary relationships with other herbicides. Some of these combinations include Grazon P+D (picloram + 2,4-D), Weedmaster (dicamba + 2,4-D), and more recently, Cimmaron Max (dicamba + 2,4-D + metsulfuron). All of these combinations are labeled to control even the more problematic perennial broadleaf weeds (Vance Communication Corporation 2004). In general, these products are labeled to control similar weed species; , these lists are not identical. In a field situation where diverse weed species exists, one herbicide could significantly out perform other products and result in significantly fewer weed escapes. To eliminate these escapes, additional products could be applied; however, this method of weed management can lead to greater production expense. In an attempt to provide a more broad-spectrum level of weed control, Dow AgroSciences developed an experimental compound, GF-884[1], consisting of a new pyridine-based herbicide [aminopyralid (4-amino3,6-dichloro-2-pyridinecarboxylic acid) (0.03 kg a.e./L)] + 2,4-D (0.36 kg a.e./L). Field experiments were conducted to examine the effectiveness of the experimental compound in controlling three annual and three perennial common weed species.

All of the weed species utilized in the evaluation of GF-884 were native, warm-season broadleaf plants prevalent in Texas pasture and range lands. Prairie broomweed (*Amphiachyris dracunculoides* (DC.) Nutt.), annual marshelder (*Iva annua* L.), and woolly croton (*Croton capitatus* Michx.) are annual herbaceous weeds found in much of the same areas of Texas. Prairie broomweed is primarily located in the central third of the state. Annual marshelder and woolly croton, however, are generally found in all parts of the state except the far west. Western horsenettle (*Solanum dimidiatum* Raf.), silverleaf nightshade (*Solanum elaeagnifolium* Cav.), and western ragweed (*Ambrosia cumanensis* Kunth in H.B.K.) are all highly competitive perennial species that spread by creeping roots, root fragments, and seed (Bovey et al. 1966; Eleftherohorinos et al. 1993; Whaley and Vangessel 2002a). Silverleaf nightshade and western ragweed prosper in all areas of the state, whereas, western horsenettle populates all but Texas' eastern and western extremes (Hatch et al. 1990; Bovey and Meyer 1990).

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[1] GF-884 experimental herbicide, Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN 46268

Materials and Methods

This research was conducted in two consecutive production years, 2002 and 2003. Each field experiment consisted of nine treatments arranged in a randomized complete block design (RCBD) with three replicates utilizing plot dimensions of 3.0 by 6.1 m. All herbicide treatments were applied with a CO_2 backpack sprayer[2] equipped with 6 nozzles spaced 48.3 cm apart on a 2.9-m hand-held boom. The sprayer was calibrated to deliver 141 L/ha of spray solution emitted through TeeJet DG 8002 VS flat-fan nozzles[3] at a walking speed of 4.8 km/hr.

Herbicide treatments were applied early post-emergence (EPOST) to each of the six weed species that ranged from 15.2 to 45.7 cm in height. The experimental herbicide GF-884 (0.39 kg a.e./L), which contains aminopyralid (0.03 kg a.e./L) + 2,4-D amine (0.36 kg a.e./L), was evaluated at several rates reflected in Table 1. Additionally, several labeled herbicides were included in these studies for comparative purposes. These herbicides included 2,4-D ester (0.46 kg a.e./L), Grazon™ P+D[4] [picloram (0.065 kg a.e./L) + 2,4-D (0.24 kg a.e./L)], Weedmaster®[5] [dicamba (0.12 kg a.e./L) + 2,4-D (0.34 kg a.e./L)], and Roundup UltraMAX®[6] [glyphosate (0.44 kg a.e./L)]. All herbicide treatments were compared to untreated areas to determine levels of control. All herbicides except Roundup UltraMAX® included a non-ionic surfactant[7] at the rate

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[2] R & D Sprayers, 419 Hwy 104, Opelousas, LA 70570
[3] Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189
[4] Grazon™ P+D herbicide, Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN 46268
[5] Weedmaster® herbicide, BASF Co. Ag Products, P.O. Box 13528, Research Triangle Park, NC 27709
[6] Roundup UltraMAX® herbicide, Monsanto Co., 800 North Lindbergh Boulevard, St. Louis, MO 63167
[7] Latron AG-98, Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632

of 0.25% v/v. Each treatment utilized water as the spray carrier.

All weed control field experiments were evaluated by visual ratings, on a scale of 0 to 100%, with 0% representing no control or herbicide effect and 100% representing complete plant desiccation. Three visual ratings were conducted for each field experiment approximately 30, 60, and 90 days after treatment (DAT). For the western horsenettle, silverleaf nightshade, and western ragweed field experiments, live shoot counts were obtained from a 1- by 2-m area in each 3 by 6.1-m plot to determine if there was a change in shoot density as a result of treatment application. Counts were determined from a fixed location in each plot prior to treatment as well as 12 mo following treatment application (FTA). The change in shoot density from pre-application to 12 mo FTA was calculated using the following equation:

$$\text{pre to 12 mo following application} = \left[\frac{\text{pre application density} - \text{12 mo following application density}}{\text{pre application density}}\right] \text{x } 100\% \tag{1}$$

All data was subjected to statistical analysis performed with an ANOVA using SPSS 12.0.1 for Windows[8], where Tukey's HSD at the 5% level of significance was employed to separate treatment means. For each weed species evaluated, year by treatment interactions were detected. Therefore, all control data is presented separately for each field experiment. The data collected that reflects the change in shoot density, for both the horsenettle and silverleaf nightshade field experiments, did not result in year by

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[8] SPSS Inc. Headquarters, 233 S. Wacker Drive, 11th floor, Chicago, IL 60606

Table 1. Rates of herbicides applied to evaluate weed control efficacy.

Herbicide	Rate kg a.e./ha
GF-884[a]	0.46
GF-884	0.69
GF-884	0.91
GF-884	1.14
2,4-D Ester[b]	1.07
Picloram + 2,4-D as Grazon™ P+D[b]	0.72
Dicamba + 2,4-D as Weedmaster®[b]	1.09
Glyphosate as Roundup UltraMAX®[b]	1.70
Untreated area	-

[a] Rates examined were recommendations from Dow AgroSciences.
[b] Use rates represent the median value of labeled rates.

treatment interactions and were combined.

Field Experiments

Prairie Broomweed. The two prairie broomweed field experiments were conducted at different locations. This was unavoidable due to the substantial reduction in plant density following the first year's field experiment. The 2002 experiment was conducted near Cameron, TX, in northern Milam County (Appendix A). The 2003 experiment was conducted near Gatesville, TX, in northern Coryell County (Appendix B). Plant heights at application were 38 and 27 cm in 2002 and 2003, respectively. The plant populations for both experiments averaged 65 plants/m^2.

Annual Marshelder. Both experiments were conducted near College Station, TX, in eastern Brazos County (Appendix A and B). At the time of application, the plants were a mean height of 20 and 31 cm in 2002 and 2003, respectively. The density of plants in these experiments averaged 194 and 86 plants/m^2, respectively.

Western Horsenettle. These experiments were conducted near Meridian, TX, in central Bosque County (Appendix A and B). For both experiments, the plants averaged 38.1 and 45.7 cm with average densities of 65 and 22 plants/m^2 in 2002 and 2003, respectively, at the time of application.

Silverleaf Nightshade. The 2002 and 2003 silverleaf nightshade field experiments were conducted at the Texas Agriculture Experiment Station Farm near Snook, TX, in eastern Burleson County (Appendix A and B). The plants averaged 38 and 41 cm in height and contained 32 plants/m^2 at the time of application for 2002 and 2003, respectively.

Western Ragweed. The two field experiments were conducted at different locations, for the same reason explained in the description of the prairie broomweed field experiment locations. The 2002 experiment was conducted near Navasota, TX, in western Grimes County (Appendix A) and the 2003 experiment was near College Station, TX, in eastern Brazos County (Appendix B). At the time of application, the average plant heights were 15 and 20 cm and contained density of 172 and 86 plants/m^2 in 2002 and 2003, respectively.

Woolly Croton. Both woolly croton field experiments were conducted near College Station, TX, in eastern Brazos County (Appendix A and B). The average plant height was 34 and 25 cm at the time of application in 2002 and 2003, respectively. Plant density averaged 32/m^2 in both experimental years.

Results and Discussion

Prairie Broomweed Control

In 2002, GF-884 applied at 0.46, 0.69, and 0.91 provided equivalent control at all three rating dates (Table 2). The level of control for these rates ranged from 57 to 70% (28 DAT) and 63 to 85% (58 and 91 DAT), where effectiveness increased as rate increased. GF-884 at the rate of 1.14 kg a.e./ha achieved 78% control 28 DAT and > 95% control 58 and 91 DAT. The control provided by GF-884 at 1.14 kg a.e./ha was comparable to that of picloram + 2,4-D, dicamba + 2,4-D, and GF-884 at 0.91 kg a.e./ha. All four of these treatments provided a significantly greater level of control compared to that of 2,4-D applied alone 91 DAT. These results paralleled those observed by Scifres et al. (1971) and Boyd et al. (1983) where rates of 2,4-D (0.14, 0.28, and 0.56 kg a.e./ha) applied alone resulted in <70% control. However, when paired at 1:1 ratios with picloram (0.07, 0.14, and 0.28 kg a.e./ha) or dicamba (0.25 kg a.e./ha), control increased substantially (Scifres et al. 1971, Boyd et al. 1983).

At 30 DAT in 2003, all rates of GF-884 achieved < 62% control. Diminishing control was evident through 69 and 94 DAT, where > 54% and 48% control was achieved, respectively. At 94 DAT, the control provided by GF-884 at 1.14 kg ae / ha was not significantly different from picloram + 2,4-D, dicamba + 2,4-D, or 2,4-D ester. Glyphosate was the only treatment that maintained > 70% control through all three rating periods, both experimental years.

The reduction in control from 2002 to 2003 can be attributed to the combination of different experimental sites and environmental effects. Of the two experimental sites, the 2002 site was most consistent with the definition of arable land, fit for cultivation (Morris 1973). The 2003 site, conversely, was an upland area with a shallow soil due to a considerable amount of impenetrable subsurface rock (Appendix B). Normally, the mean annual total precipitation difference between the 2002 and 2003 sites is approximately 102 mm, or 914 and 813 mm, respectively (Hatch et al., 1990). However, the actual difference between the two sites was approximately 584 mm, where the 2002 site received 1016 mm and the 2003 site received 660 mm (Appendix C). The applications were made within the first two weeks of July, however, the environmental conditions at the time of application

Table 2. 2002 and 2003 GF-884 percent control of prairie broomweed.

		2002			2003		
Herbicide	Rate	Rating (DAT)			Rating (DAT)		
		28	58	91	30	69	94
	kg a.e./ha	----------------------------------%----------------------------------					
GF-884	0.46	57 cd[a]	63 b	63 bc	55 bc	32 c	32 de
GF-884	0.69	58 cd	68 b	68 bc	55 bc	37 bc	33 de
GF-884	0.91	70 bc	85 ab	85 ab	60 b	47 bc	42 cd
GF-884	1.14	78 b	95 a	97 a	62 b	53 b	48 bc
2,4-D Ester	1.07	47 d	63 b	55 c	47 c	32 c	52 bc
Picloram + 2,4-D	0.72	55 cd	77 ab	83 ab	58 bc	43 bc	63 b
Dicamba + 2,4-D	1.09	67 bc	80 ab	83 ab	63 b	45 bc	58 bc
Glyphosate	1.70	100 a	100 a	99 a	89 a	86 a	89 a
Untreated area	-	0 e	0 c	0 d	0 d	0 d	0 f

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

were not the same. At application, the 2002 site had received 495 mm, whereas, the 2003 site had received less than 301 mm of precipitation. This large discrepancy in precipitation coupled with the more shallow soil likely contributed to environmental related stress on the plants, making them more difficult to control. As described by Naylor (2002), plants under moisture stress generally develop smaller leaves and thicker cuticles, deposit more wax, and are generally more difficult to control than plants grown under optimum soil moisture conditions. Such changes in leaf surface characteristics can reduce uptake as well as retention. Additionally, moisture-stressed plants gradually close their stomata. This can result in a reduction of photosynthesis and phloem translocation of assimilates which subsequently reduces translocation of phloem mobile herbicides (Naylor 2002).

Annual Marshelder Control

In the 2002 field experiment, all four rates of GF-884 achieved > 94% control (Table 3) at the three consecutive ratings (34, 70, and 106 DAT). Control observed from the experimental compound was not different from that of the picloram + 2,4-D, dicamba + 2,4-D, and glyphosate, but was significantly greater than 2,4-D.

The experiment conducted in 2003 showed a reduction in control and greater differences between the GF-884 treatments (Table 3). At the 31 DAT rating, GF-884 at 0.91 and 1.14 kg a.e./ha provided a significantly greater level of control (87%) relative to the two lower rates. A similar trend was observed at both the 64 and 94 DAT rating dates. GF-884 at the 0.91 and 1.14 kg a.e./ha rates provided equivalent control to that from the picloram + 2,4-D, dicamba + 2,4-D, and glyphosate (>76%) and significantly better control than 2,4-D ester.

Table 3. 2002 and 2003 GF-884 percent control of annual marshelder.

		2002			2003		
Herbicide	Rate	Rating (DAT)			Rating (DAT)		
		34	70	106	31	63	94
	kg a.e./ha	----------------------------------%----------------------------------					
GF-884	0.46	94 ab[a]	98 a	97 a	60 d	60 d	52 d
GF-884	0.69	99 a	99 a	98 a	68 cd	70 cd	70 cd
GF-884	0.91	97 a	99 a	98 a	87 ab	87 ab	80 ab
GF-884	1.14	99 a	99 a	99 a	87 ab	87 ab	79 ab
2,4-D Ester	1.07	87 b	90 b	83 b	80 bc	72 cd	73 cd
Picloram + 2,4-D	0.72	99 a	98 a	98 a	78 bc	77 bc	76 bc
Dicamba + 2,4-D	1.09	99 a	100 a	100 a	91 ab	97 ab	97 ab
Glyphosate	1.70	100 a	100 a	100 a	100 a	99 a	99 a
Untreated area	-	0 c	0 c	0 c	0 e	0 e	0 e

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

The reduction in control from 2002 to 2003 is probably not a result of site or environmental influence, as both were much the same. The experimental sites were located within 15 m of each other and the difference in annual precipitation received was < 31 mm (Appendix D). Date of application and plant height at the time of application, though, differed by 14 days and 10 cm, respectively, between the two experimental years. The delay in the 2003 application date was due to inaccessibility of the site due to flooding. As noted previously, annual broadleaf weed species are generally more susceptible to herbicides at earlier growth stages than later (Naylor 2002). Physiologically, the increased plant height in the 2003 experiment could infer that the plants were more advanced with regard to leaf hair development and leaf cuticle thickness over that of the 2002 experiment. These two characteristics can drastically reduce herbicide retention and exposure by limiting the amount of material that absorbs into the living portion of the plant (Ashton and Crafts 1981). Logistically, the taller plants observed in 2003 could interfere with distribution of the spray material to the under story population and the soil surface. This limitation of exposure to both could result in escapes, leading to a reduction in control. An additional factor may have been at fault as well, compounding the reduction in efficacy. At the time of application, the amount of formulated GF-884 provided by Dow AgroSciences was not sufficient to treat the entire experiment. Therefore, to maintain congruence among treatments, the ratio was calculated and the compound was blended on site and dispensed to the appropriate treatment. Because this mixture was not the formulated material, an adjuvant, not listed on the experimental label, was excluded.

Western Horsenettle Control

During the 2002 field experiment, all rates of GF-884 provided 97% control or greater (Table 4) at all three rating dates (41, 78, and 115 DAT). The control achieved by the four GF-884 rates were not significantly different from that of picloram + 2,4-D, 2,4-D, or dicamba + 2,4-D.

During the 2003 field experiment, a similar trend in control, though reduced, was observed for all rates of GF-884 applied (Table 4). At 28 DAT, the four rates of GF-884 had control > 93%. However, by 57 and 92 DAT, control ranged from 82 to 89% and 74 to 86%, respectively. Additionally, by the 92 DAT rating, none of the GF-884 rates applied were significantly different from the other herbicides applied.

Shoot densities, collected 12 mo FTA, were equivalent across all treatments for both experimental years, but were all significantly less than the untreated area. However, observations 90 DAT by Gorrell et al. (1981) showed somewhat different results where differences in treatment shoot expression occurred. In their experiment, 2,4-D (1.1 kg a.e./ha), picloram + 2,4-D (0.3 + 1.1 kg a.e./ha), and dicamba + 2,4-D (0.3 + 0.8 kg a.e./ha) were not significantly different in their control, which provided consistently 80% control of western horsenettle. With regard to shoot density, the researchers observed the picloram + 2,4-D treated areas with significantly fewer shoots than those areas treated with dicamba + 2,4-D. The densities in the dicamba + 2,4-D areas were significantly less than those in the areas treated with 2,4-D ester.

A reduction in control was observed across all treatments from 2002 to 2003. The experimental sites were separated by less than 100 m and nearly identical. However, the amount of precipitation received following treatment application was considerably different.

Table 4. 2002 and 2003 GF-884 percent control and percent plant shoot reduction of Western horsenettle.

		2002			2003			2002/03
Herbicide	Rate	Rating (DAT)			Rating (DAT)			Plant Shoot Reduction
		41	78	115	28	57	92	12 mo FTA
	kg a.e./ha	----------------------%	----------------------					
GF-884	0.46	100 a[a]	100 a	99 a	93 ab	89 a	83 a	63 a
GF-884	0.69	100 a	97 a	98 a	94 ab	84 a	83 a	58 a
GF-884	0.91	100 a	97 a	98 a	98 a	82 a	74 a	53 a
GF-884	1.14	100 a	97 a	98 a	98 a	82 a	86 a	55 a
2,4-D Ester	1.07	96 a	100 a	96 a	52 c	52 b	74 a	60 a
Picloram + 2,4-D	0.72	100 a	100 a	99 a	99 a	87 a	84 a	52 a
Dicamba + 2,4-D	1.09	97 a	100 a	98 a	84 ab	73 ab	73 a	52 a
Glyphosate	1.70	88 b	88 a	84 b	81 b	78 ab	73 a	60 a
Untreated area	-	0 c	0 b	0 c	0 d	0 c	0 b	-5 b

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD ($\alpha=0.05$).

Precipitation received between the initial and final efficacy rating in 2003 was nearly twice that received during the same period in 2002 (Appendix E). This increase in precipitation provided conditions conducive to promote regrowth from the perennial portion of the plants, resulting in an overall reduction in control.

Silverleaf Nightshade Control

All applied rates of GF-884 in 2002 achieved greater than 94% control at both 31 and 81 DAT (Table 5). However, by 112 DAT, the level of control for these rates had declined to 75 to 80%. In 2003, all rates of GF-884, evaluated at 34, 63, and 99 DAT, resulted in > 89% control. At the time of the final evaluation for both years, none of the GF-884 treatments were significantly different in control from the other herbicides applied. The 12 mo FTA shoot densities were statistically equivalent for all treatments applied during both experimental years.

A substantial decrease in control was observed between the 112 and 99 DAT ratings for 2002 and 2003, respectively. The experimental sites were approximately 7 m apart and the amount of precipitation received both years was nearly identical (NOAA-NCDC 2004), however, the population of successional species was not. The 2003 experiment incurred considerably less regrowth from the perennial plants than the 2002 experiment. This is attributed to a greater amount of under story species that invoked a higher level of competition in 2003 following treatment and the subsequent removal of the silverleaf nightshade canopy. These successional species limited the ability of the perennial plant to establish new shoots.

Table 5. 2002 and 2003 GF-884 percent control and percent plant shoot reduction of silverleaf nightshade.

Herbicide	Rate	2002 Rating (DAT) 31	2002 Rating (DAT) 81	2002 Rating (DAT) 112	2003 Rating (DAT) 34	2003 Rating (DAT) 63	2003 Rating (DAT) 99	2002/03 Plant shoot Reduction 12 mo FTA
	kg a.e./ha	%						
GF-884	0.46	99 a[a]	99 a	78 a	95 ab	99 a	91 a	49 ab
GF-884	0.69	99 a	99 a	80 a	97 ab	99 a	89 a	54 a
GF-884	0.91	99 a	94 ab	75 a	99 a	99 a	94 a	60 a
GF-884	1.14	100 a	99 a	80 a	99 a	100 a	93 a	49 ab
2,4-D Ester	1.07	93 a	88 b	75 a	77 bc	88 b	95 a	27 ab
Picloram + 2,4-D	0.72	99 a	98 a	82 a	91 ab	99 a	90 a	73 a
Dicamba + 2,4-D	1.09	97 a	90 b	75 a	88 ab	90 b	94 a	49 ab
Glyphosate	1.70	96 a	93 ab	87 a	57 c	99 a	100 a	70 a
Untreated area	-	0 b	0 c	0 b	0 d	0 c	0 b	6 b

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

Western Ragweed Control

In 2002, GF-884 at rates of 0.69, 0.91, and 1.14 kg a.e./ha provided > 73% control throughout the entire season (Table 6). This level of control was not significantly different from that of dicamba + 2,4-D, or picloram + 2,4-D. In 2003, these same rates achieved control > 78% at the 32 DAT rating. By 100 DAT, all rates of GF-884 evaluated provided > 92% control. By seasons end, this level of control was equivalent to that provided by the four other herbicides applied.

The level of control observed at 104 and 100 DAT for the 2002 and 2003 experiments, respectively, was considerably different. As mentioned previous in the description of the sites, the 2002 experimental site was composed of twice the plants/m^2 as the 2003 site. The difference in plant populations was directly correlated with site conditions. The 2002 experimental site had been heavily grazed for several years prior to treatment application. This provided an optimal situation for Western ragweed to flourish without competition from forage. Conversely, the 2003 experimental site had never been grazed and therefore had a competitive stand of forage grass. The high above ground populations in the 2002 experiment suggests that a greater amount of perennial plant portions were present as well, decreasing the efficacy potential of the compound by increasing the viability of the plants. Therefore, the reduction in control in 2002 is attributed to increased weed pressure and decreased competition from values forage.

At the conclusion of the 2002 season, all materials utilized for establishing physical experimental boundaries and delineate treatments were removed. Subsequently, 12 mo FTA, treatments were indistinguishable and, therefore, shoot regrowth could not be

Table 6. 2002 and 2003 GF-884 percent control of Western ragweed.

		2002			2003		
Herbicide	Rate	Rating (DAT)			Rating (DAT)		
		29	72	104	32	63	100
	kg a.e./ha	------------------------------------%------------------------------------					
GF-884	0.46	68 c[a]	72 b	63 b	63 b	82 b	92 a
GF-884	0.69	78 ab	85 ab	73 ab	82 ab	96 ab	93 a
GF-884	0.91	88 ab	92 ab	83 ab	78 ab	93 ab	98 a
GF-884	1.14	93 a	95 a	93 a	93 a	99 a	98 a
2,4-D Ester	1.07	42 d	33 c	37 c	90 a	96 a	95 a
Picloram + 2,4-D	0.72	73 bc	83 ab	68 ab	81 ab	92 ab	92 a
Dicamba + 2,4-D	1.09	77 ab	88 ab	80 ab	94 a	99 a	97 a
Glyphosate	1.70	40 d	27 c	30 c	83 ab	95 ab	88 a
Untreated area	-	0 e	0 d	0 d	0 c	0 c	0 b

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD ($\alpha=0.05$).

measured. Also, 12 mo FTA in the 2003 experiment the forage grass had grown such that all shoot regrowth was hindered as a result of competition. Due to these circumstances, the shoot density data for both experimental years was confounded and subsequently will not be included or discussed.

Woolly Croton Control

In the 2002 field experiment, all rates of GF-884 evaluated resulted in 100% control at all three rating intervals (Table 7). Similarly in 2003, all GF-884 rates provided season-long control in excess of 96%. The control achieved by GF-884 at rates of 0.69, 0.91, and 1.14 kg a.e./ha by season's end in both field experiments was not significantly different from that provided by 2,4-D, dicamba + 2,4-D, or picloram + 2,4-D. Meyer and Bovey (1991) observed similar results for 2,4-D (1.1 kg a.e./ha), dicamba + 2,4-D (0.28 + 0.84 kg a.e./ha), and picloram (0.28, 0.56, 1.1 kg a.e./ha), with all differences being numerical.

Summary of Experiments

GF-884, at the applied rates of 0.91, and 1.14 kg a.e./ha, consistently provided >85% control of the annual weeds and >74% control of the perennial weed species evaluated, excluding the 2003 results from the prairie broomweed and annual marshelder experiments. These same rates of GF-884 achieved comparable or better control to that of the labeled herbicides. In several experiments, GF-884 significantly exceeded the control achieved with 2,4-D alone, one of the experimental herbicide's active ingredients. These findings revealed that the aminopyralid enhanced the overall performance of 2,4-D.

Table 7. 2002 and 2003 GF-884 percent control of woolly croton.

		2002			2003		
Herbicide	Rate	Rating (DAT)			Rating (DAT)		
		29	47	83	33	63	97
	kg a.e./ha	-----------------------------------%-----------------------------------					
GF-884	0.46	100 a[a]	100 a	100 a	99 ab	98 a	96 b
GF-884	0.69	100 a	100 a	100 a	99 ab	98 a	99 a
GF-884	0.91	100 a	100 a	100 a	99 ab	99 ab	99 a
GF-884	1.14	100 a	100 a	100 a	100 a	100 a	100 a
2,4-D Ester	1.07	100 a	100 a	100 a	100 a	100 a	100 a
Picloram + 2,4-D	0.72	100 a	100 a	100 a	100 a	100 a	100 a
Dicamba + 2,4-D	1.09	100 a	98 a	100 a	100 a	100 a	99 a
Glyphosate	1.70	100 a	88 b	85 b	97 b	97 a	95 b
Untreated area	-	0 b	0 c	0 c	0 c	0 c	0 c

[a] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

CHAPTER III

EVALUATING CROP TOLERANCE OF HYBRID BERMUDAGRASS (*Cynodon dactylon* (L.) Pers.) VARIETIES TO GF-884

Introduction

Grasslands in the humid southern region of the US are primarily utilized for grazing on improved pastures that were originally developed in the 1930s and 1940s. These grasslands are dominated by species introduced from other regions of the world. With the introduction of species like Kentucky 31 tall fescue (*Festuca arundinacea* Schreb.), Pensacola bahiagrass (*Paspalum notatum* Flugge), and the Common bermudagrass [*Cynodon dactylon* (L.) Pers.] progeny, hybrid bermudagrass, many of these grasslands were successfully established on eroded croplands. Hybrid bermudagrass represents one of the major forage grass species in the Southern United States, prospering from eastern Oklahoma and Texas to the Atlantic Ocean (Hitchcock 1950; Hoveland 2000).

It is believed that bermudagrass originated in tropical Africa and was introduced into the U.S. during the mid 1700’s. Once introduced, it was dispersed throughout the South where it became a valuable pasture plant (Burton and Hanna 1995). By 1807, its rapid propagation and wide distribution was noted in the southern U.S. (Mitich 1989). In 1936, Glenn Burton, a researcher in Tifton Georgia, began breeding bermudagrass. Within ten years, Coastal bermudagrass was developed through this program. It is now recognized as the first warm-season perennial grass developed with modern breeding methods (Burton 1954). Coastal bermudagrass became widely planted, even though the cultivar required the cumbersome task of vegetative propagation for dependable establishment. Today, Coastal bermudagrass is established on over 4 million hectares (ha) in the Southern US (Hill et al. 2001). The hybrid's popularity was directly linked to its superior characteristics over its parental line, common bermudagrass, by means of increased yields, extended productive season, greater disease resistance, deeper root development and more drought tolerance, and faster curing of hay (Burton and Hanna 1995).

In April 1992, the United States Department of Agriculture – Agricultural Research Service in cooperation with the University of Georgia Coastal Plain Experiment Station released a new bermudagrass hybrid, Tifton 85. It was selected from many F_1 hybrids between PI 290884 from South Africa and Tifton 68, a highly digestible, cold- susceptible hybrid released in 1983. The Tifton 85 hybrid was taller, had larger stems, broader leaves and a darker green color than other bermudagrass hybrids. It has been touted as having the potential to produce an average of 26% more dry matter with 11% more digestibility and be 10% more succulent than Coastal bermudagrass (Burton et al. 1993). Since its release, Tifton 85 has increased acceptance and popularity among hay and cattle producers in the US, Mexico and South America (Hill et al. 2001).

Bermudagrass is productive throughout the tropical and subtropical areas of the world, from latitude 45 N to 45 S. In the United States, it occurs in open ground, grasslands, fields, and waste places, from Maryland to Oklahoma, south to Florida and

Texas, and west to California. It prefers warm or hot weather, but can survive hard freezes. Bermudagrass will grow on any alkaline or acidic, moderately well-drained soil given adequate moisture and nutrients (Mitich 1989). Genus members are perennial, usually low growing, with creeping stolons or rhizomes, short blades, and several slender spike digitate at the summit of the upright culms. Bermudagrass can resemble large crabgrass (*Digitaria sanguinalis*), goosegrass (*Eleusine indica*), and dallasgrass (*Paspalum dilatatum*). However, it distinguishes itself from these through abundant stolons and a unique ring of white pubescence at the base of each leaf blade (Hitchcock 1950).

The use of herbicides for removing competitive weed species in bermudagrass pastures has become a common production practice. Chemical weed management can be advantageous providing increased forage yield and quality, when effective weed control is achieved. However, phytotoxic affect of herbicides must also be considered along with the herbicide efficacy (Butler and Interrante 2003b). With these parameters in mind, an experimental herbicide from Dow AgroSciences, GF-884, containing a new pyridine-based herbicide [aminopyralid (0.03 kg a.e./L)] + 2,4-D (0.36 kg a.e./L) was evaluated for deleterious effects on both Coastal and Tifton 85 bermudagrasses.

Materials and Methods

This research was conducted during the production seasons of 2002 and 2003. Each crop tolerance field experiment consisted of 10 treatments arranged in a randomized complete block design (RCBD) with four replicates utilizing plot dimensions of 2.4 by 6.1 m. All herbicide treatments were applied through a CO_2 backpack sprayer[9] equipped with 5 nozzles spaced 46 cm apart on a 2.3 m hand-held boom. The sprayer was calibrated to deliver 187 L/ha of spray solution through TeeJet DG 8003 VS flat-fan nozzles[10]. Herbicide treatments were applied early post-emergence (EPOST) to actively growing bermudagrass following the removal of all over-wintering aboveground biomass. The EPOST application targeted bermudagrass that was 15 to 20 cm in height to coincide with normal herbicide application timings. The herbicide examined in these experiments was GF-884, which contained a aminopyralid (0.03 kg a.e./L) plus 2,4-D (0.36 kg a.e./L), at rates of 0.91, 1.37, and 2.73 kg a.e./ha (Table 8). Each of the three GF-884 rates was applied alone, with a methylated seed oil[11] (MSO) at 1.25% volume/volume, or with a non-ionic surfactant[12] (NIS) at 0.25% volume/volume. The adjuvants were included in the treatment regime in order to assess the highest possibilities for herbicidal activity and injury. Water was utilized as the spray carrier. For comparative purposes, an untreated area was included in each of the experiments.

Bermudagrass injury from GF-884 was assessed through visual ratings just prior to each harvest. Ratings were based on a scale of 0 to 100%, with 0% representing no growth reduction or chlorosis and 100% being complete growth suppression or plant death. Since no chlorotic symptomology was observed on either variety during either experimental year, all visual rating data will refer to a reduction in growth as compared to the untreated area.

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[9] R & D Sprayers, 419 Hwy 104, Opelousas, LA 70570

[10] Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189

[11] Sun-It II, AGSCO, Inc., P.O. Box 13458, Grand Forks, ND 58208-3458

[12] Latron AG-98, Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632

Table 8. Rates of herbicide applied to evaluate bermudagrass tolerance.

Herbicide	Rate[a] kg a.e./ha	Adjuvant	Rate[a] % v/v
GF-884	0.91	-	-
GF-884	1.37	-	-
GF-884	2.73	-	-
GF-884	0.91	MSO	1.25
GF-884	1.37	MSO	1.25
GF-884	2.73	MSO	1.25
GF-884	0.91	NIS	0.25
GF-884	1.37	NIS	0.25
GF-884	2.73	NIS	0.25
Untreated area	-	-	-

[a] Rates examined were recommendations from Dow AgroSciences.

All plots were harvested twice during both experimental years. The first harvest occurred approximately 4 to 6 weeks after the EPOST applications and the second took place following a similar duration of sequential regrowth. The variability in harvest intervals was implemented to parallel the schedule of production practices. Therefore, plots were harvested just prior to adjacent forage grass production fields. All plots were harvested with a Carter® flail harvester[13], by removing a 1 by 6.1 m swath from the middle of each plot. Following each harvest, the remaining forage was cut and removed. A broadcast application of 78 kg/ha of nitrogen in the form of ammonium nitrate dry fertilizer (34-0-0) was applied over the entire experimental area to replace nitrogen removed in the harvested forage.

Once harvested, employing the methods previously mentioned, forage from each plot was weighed and a sub-sample was removed. Sub-samples were weighed, oven-dried at 65 C for 48 h, and reweighed to determine percent moisture content:

$$= \left[\frac{\text{oven dried sample weight (kg)}}{\text{fresh sample weight (kg)}}\right] \text{ x } 100\% \qquad (2)$$

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[13] Carter Manufacturing Company, Inc.; Brookston, IN

The harvest sample weight from each plot was converted to reflect kg dry matter/plot:

$$= \frac{[\text{harvest sample weight (kg) x plot area (m}^2\text{) x moisture content (\%)}]}{\text{harvest area (m}^2\text{/plot)}} \tag{3}$$

Data conversions from Equation 3 were further transformed to reflect kg of dry matter/ha:

$$= \left[\frac{\text{harvest weight (kg/plot) x ha (m}^2\text{)}}{\text{plot area (m}^2\text{)}}\right] \tag{4}$$

The data derived from Equation 4 was analyzed to determine GF-884 influence on yield. The dried sub-samples underwent further examination utilizing near infrared analysis (NIR) for the determination of crude protein (CP) and acid detergent fiber (ADF) percentages for each plot. Crude protein is calculated from the measured nitrogen content of a forage. It represents both true protein and non-protein nitrogen, which can both be utilized by livestock. Acid detergent fiber refers to the indigestible or slowly digestible fiber of a feed or forage. This limitation in utilization is typically a result of cell wall fractions made up of cellulose and lignin. The calculated value correlates to the ability of an animal to digest the feedstuff. Therefore, as ADF increases, forage digestibility usually decreases (Schroeder 1994).

All data were subjected to statistical analysis performed with an ANOVA using SPSS 12.0.1 for Windows, where Tukey's HSD at the 5% level of significance was employed to separate treatment means. For each variable evaluated, year by treatment interactions were examined. No interactions were observed, which allowed for pooling of data by variety and harvest.

Field Experiments

Coastal bermudagrass. The 2002 and 2003 crop tolerance field experiments were conducted near Lincoln, TX, in western Lee County (30 N 16’ 20” x 96 W 58’ 34”). The soil at this site was a Crockett-Wilson (51% sand, 24% silt, 25% clay) containing 1.5% organic matter and having a pH of 5.2.

Tifton 85 bermudagrass. The crop tolerance field experiments were conducted in 2002 and 2003 at the Stiles Farm Foundation near Thrall, TX, located in western Williamson County (30 N 35’ 30” x 97 W 17’ 44”) on a Burleson clay soil (25% sand, 40% silt, 35% clay) containing 1.6% organic matter and having a pH of 7.1.

Results and Discussion

Coastal Bermudagrass Tolerance

Growth reduction was observed prior to the first harvest. But, there were no significant differences among treatments (Table 9). However, GF-884 applied at 2.73 kg a.e./ha, with or without adjuvant, as well as at 0.91 and 1.37 kg a.e./ha, with NIS, caused a significant visual reduction in growth when compared to that of the untreated area. Visual ratings of growth reduction conducted prior to the second harvest resulted only in

Table 9. Coastal bermudagrass growth reduction by GF-884.

Herbicide	Rate kg a.e./ha	Adjuvant[a]	2002 and 2003 Rating 1	2002 and 2003 Rating 2
			-------------%------------	
GF-884	0.91	-	4.6 ab[b]	0.6 a
GF-884	1.37	-	4.6 ab	0.0 a
GF-884	2.73	-	13.1 a	0.0 a
GF-884	0.91	MSO	6.4 ab	0.6 a
GF-884	1.37	MSO	8.8 ab	0.6 a
GF-884	2.73	MSO	13.1 a	1.9 a
GF-884	0.91	NIS	10.0 a	1.9 a
GF-884	1.37	NIS	12.5 a	1.9 a
GF-884	2.73	NIS	12.5 a	0.6 a
Untreated area	-	-	0.0 b	0.0 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

numeric differences. The reduction in growth recorded prior to the first harvest was not an indication of a reduction in yield. All treatments achieved yields comparable to the untreated area at both harvest intervals (Table 10). Similarly, quality analyses of the harvested forage determined that there was no significant influence of GF-884 on percent crude protein or acid detergent fiber at either harvest (Appendices F and G). Similar results were observed by Bovey et al. (1974), Eichhorn and Wells (1995), and Butler and Interrante (2003b). These groups of researchers evaluated 2,4-D at rates as high as 2.52 kg/ha on Coastal bermudagrass and found no significant reduction in yield.

Tifton 85 Bermudagrass Tolerance

Numerically, visual growth reduction was caused by GF-884 when observed prior to the first cutting (Table 11). The experimental herbicide rates of 1.37 kg a.e./ha with MSO and 2.73 kg a.e./ha with NIS were the most damaging, causing significant visual injury. However, only the latter rate was significantly more influential in reducing growth over that of GF-884 applied at 0.91 kg a.e./ha alone and 1.37 kg a.e./ha with NIS as well as the untreated area. At the time of the second harvest rating, all treatments were equivalent to the untreated area. Similar to the Coastal bermudagrass experiments, the observed growth reduction at the time of the first harvest did not translate into a yield reduction at either harvest (Table 12). Additionally, there was no herbicide or rate manipulation of the forage quality. All treatments paralleled the percent crude protein and acid detergent fiber values of the forage from the untreated areas and were without significant differences (Appendices H and I). Brooks et al.

Table 10. Coastal bermudagrass yield.

Herbicide	Rate kg a.e./ha	Adjuvant[a]	2002 and 2003 Harvest 1	2002 and 2003 Harvest 2
			kg of dry matter / ha	
GF-884	0.91	-	3783.7 a[b]	3961.2 a
GF-884	1.37	-	3160.1 a	4039.3 a
GF-884	2.73	-	3295.2 a	4213.2 a
GF-884	0.91	MSO	3127.0 a	4008.6 a
GF-884	1.37	MSO	3456.0 a	4133.5 a
GF-884	2.73	MSO	2742.8 a	4036.8 a
GF-884	0.91	NIS	3231.8 a	4177.7 a
GF-884	1.37	NIS	3164.5 a	3899.6 a
GF-884	2.73	NIS	2807.0 a	4136.9 a
Untreated area	-	-	3660.4 a	4353.1 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

Table 11. Tifton 85 bermudagrass growth reduction by GF-884.

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Rating (%) 1	 2
	kg a.e./ha		------------%-----------	
GF-884	0.91	-	2.6 bc[b]	0.6 a
GF-884	1.37	-	6.3 abc	1.9 a
GF-884	2.73	-	6.8 abc	1.9 a
GF-884	0.91	MSO	4.8 abc	0.0 a
GF-884	1.37	MSO	7.5 ab	0.0 a
GF-884	2.73	MSO	6.3 abc	1.9 a
GF-884	0.91	NIS	6.9 abc	0.0 a
GF-884	1.37	NIS	4.4 bc	0.6 a
GF-884	2.73	NIS	11.9 a	1.9 a
Untreated area	-	-	0.0 c	0.0 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

Table 12. Tifton 85 bermudagrass yield.

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Harvest 1	2002 and 2003 Harvest 2
	kg a.e./ha		kg of dry matter ha	
GF-884	0.91	-	5749.0 a[b]	5171.5 a
GF-884	1.37	-	5196.0 a	4990.2 a
GF-884	2.73	-	5284.4 a	4884.3 a
GF-884	0.91	MSO	5316.1 a	5006.3 a
GF-884	1.37	MSO	5020.5 a	4553.0 a
GF-884	2.73	MSO	5474.9 a	5211.0 a
GF-884	0.91	NIS	5586.5 a	5330.3 a
GF-884	1.37	NIS	5132.0 a	5455.4 a
GF-884	2.73	NIS	4994.0 a	5385.5 a
Untreated area	-	-	5458.0 a	4930.3 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

(1996) found similar results when they applied 2,4-D at rates of 0.56 and 1.12 kg/ha to Tifton 85 bermudagrss. These individuals observed no significant injury in the form of visual phytotoxicity, forage height/density, or yield reduction.

Summary of Experiments

Applications of GF-884 to Coastal and Tifton 85 bermudagrass hybrids resulted in slight visual growth reductions prior to the first harvest. Some of these reductions were identified as significant when compared to the untreated area. However, this observed injury was not apparent in the analysis of the individual treatment yields or forage quality. This suggests that the growth reduction ratings were subjective and based on a perceived growth influence as opposed to actual reduction in production.

No discernable influence was found following applications of GF-884, with or without adjuvant, to Coastal and Tifton 85 bermudagrass hybrids with regard to yield or quality. All treatments resulted in respective values that were congruent to those derived from the untreated area.

CHAPTER IV

ABSORPTION AND TRANSLOCATION OF FLUROXYPYR AND PICLORAM IN COMMON RAGWEED [*Ambrosia artemisiifolia* L.]

Introduction

The effectiveness of a herbicide depends on uptake and herbicide movements into the symplastic system or contact with the plasmalemma surrounding the symplast. For uptake to occur, the herbicide must be absorbed into the plant and subsequently transported to the site of action in which the herbicide disrupts the metabolic process (Duke 1985). Absorption, the process by which an herbicide passes from one system into another, can occur through the root, stem, or leaf tissue (Vencill 2002).

Herbicide absorption through a plant's stem and leaf tissue is primarily the result of postemergence applications of foliar-applied herbicides. The amount of herbicide absorbed is directly influenced by the quantity that actually contacts the foliar tissue. The amount of material that reaches the surface of the plant and adheres is dependent upon leaf orientation with respect to incoming spray, density of the plant canopy, leaf pubescence, cuticle thickness, and surface tension of the spray solution. Generally speaking, once the herbicide has reached the plant surface, several events can occur before reaching the site of action. First, the herbicide may not adhere and remain on the plant surface. It can run off while still in the liquid form, be washed off by rain, or volatilize from the plant surface. Second, the herbicide may remain on the plant foliage, but dry as an amorphous deposit or crystallize after solvent evaporation. Third, the herbicide, if lipophilic, can penetrate into the plant's cuticle and remain associated with the lipoidal components, rendering the compound virtually inactive. Finally, the herbicide can be absorbed across the foliar cuticle and move into the apoplastic or symplastic system and be transported to the site of action via the xylem or phloem. These four events, according to Ashton and Crafts (1981), are not mutually exclusive and can occur in any combination.

Once absorbed, movement of the herbicide to the site of action becomes the primary physiological function involved in effectively controlling the plant (Ashton and Crafts 1981). Translocation, the movement of a herbicide in a plant, can occur over short distances (dispersed through a few cells) or (long distances via transport in the xylem or phloem) (Vencill 2002). The proportion of material absorbed and translocated relative to the amount applied can regulate an herbicide's weed control efficacy as well as its utility in particular situations.

In June 2004, Dow AgroSciences successfully labeled a product containing picloram (2.04 kg a.i./L) and fluroxypyr (1.65 kg a.i./L) under the trade name Surmount™. This herbicide has been made available for the control of annual and perennial broadleaf weeds as well as woody plants in rangeland and permanent grass pastures (Dow AgroSciences 2004a). Picloram and fluroxypyr, both pyridine-based auxinic herbicides, induce near identical responses in sensitive plants following exposure. Such responses have been observed, though, as a result of dramatically different concentrations of the two compounds within plants. In a study conducted by Lym (1992), it was determined that leafy spurge absorbed and translocated fluroxypyr at levels nearly four times that of picloram. However, picloram was consistently more toxic to this species than fluroxypyr and provided enhanced long-term control. Also, picloram consistently affects a broader array of annual and perennial broadleaf species (Shober et al. 1986). However, when applied in combination, fluroxypyr efficacy increased while absorption decreased (Lym 1992). This increased control has been attributed to decreased herbicide metabolism.

Common ragweed is a major weed in many parts of North America and is considered a noxious species by several US states (Deen et al. 1998; USDA, NRCS 2004b). In Texas, this annual warm-season broadleaf is native to most areas of the state except the far North and Western regions (Hatch et al. 1990). With the ability to grow to a height of 2.5 m, it competitively affects both row crop and pasture production. Additionally, during flowering, common ragweed produces an abundant amount of pollen, which has been identified as a significant human allergen (USDA, NRCS 2004b).

Picloram and fluroxypyr are registered as Tordon™ 22K and Vista®, respectively, and are labeled to control common ragweed (Dow AgroSciences 2000 and 2004b). The new combination, as would be expected, is labeled to achieve the same outcome (Dow AgroSciences 2004a). However, absorption and translocation of these two herbicides, alone and combined, by common ragweed has not been defined. Therefore, studies were conducted to characterize the absorption and translocation of picloram, fluroxypyr, and the combination of the two, and to determine if either herbicide influences the incorporation and movement of the other in common ragweed.

Materials and Methods

Common ragweed seeds were stratified at 2°C for approximately 9 wk on filter paper moistened with distilled water in parafilm wrapped petri dishes (Buhler and Hoffman 1999). Cone-tainer planting containers[14] were utilized to grow the common ragweed specimens. A single sheet of 11-cm diameter filter paper[15] was placed at the base of each cone-tainer to minimize soil loss. Approximately 175 g of Scotts 'Metro Mix 200'[16] was added to each cone-tainer. The soil in each cone-tainer was brought to field capacity by adding distilled water until the soil surface stabilized and water was emitted from the base of the cone. Approximately 25 stratified common ragweed seeds were dispersed on the soil surface of each cone-tainer and approximately 25 g of soil mix was added to achieve a planting depth of approximately 0.64 cm. Distilled water was added to proximate field capacity at the soil surface. All cone-tainers were housed in trays that held 20 cone-tainers and each tray was placed in a plastic tub to allow for sub-irrigation. The plants were grown in a growth chamber[17] modified to provide 50% relative humidity, 30°C air temperature, and 16 h of simulated daylight at an intensity of 415 µmol/s/m.

All cone-tainers were evaluated visually for daily moisture usage. Distilled water was added when the soil surface appeared dry. Approximately 10 days after planting (DAP), 4 g of Peters General Purpose 20-20-20 fertilizer[18] was dissolved in a L

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[14] Hummert International; Earth City, MO
[15] Fisher Scientific; Pittsburgh, PA
[16] The Scotts Company; Marysville, OH
[17] Kysor // Kalt Mfg. Co. Inc.; Goodyear, AZ
[18] The Scotts Company; Marysville, OH

of water and 45 mL of this solution was distributed to each of the planted cone-tainers. All cone-tainers were fertilized in the same manner every seventh day, until the fourth week following planting, when herbicide treatments were applied. At 14 DAP, the vegetative content of each cone-tainer was reduced so that each cone-tainer consisted of an individual plant. Concurrently, sub-irrigation was employed for all cone-tainers.

Herbicide treatments were applied to common ragweed plants at the 5- to 7-node growth stage (17.8 – 22.1 cm). Prior to treatment application, plants were evaluated and grouped to form three replicates based on similarity in height and growth stage, assigned a treatment number, and randomized. Four herbicide treatments of non-labeled material were broadcast applied in a spray chamber equipped with a single TeeJet 8002 EVS flat-fan nozzle[19] calibrated to deliver 187 L/ha of spray solution (Table 13). Treatments included broadcast applications of (1) picloram (0.24 kg a.e./L), (2) picloram (0.24 kg a.e./L) plus fluroxypyr (0.18 kg a.e./L), (3) fluroxypyr (0.18 kg a.e./L), and (4) fluroxypyr (0.18 kg a.e./L) plus picloram (0.24 kg a.e./L). Each treatment included a non-ionic surfactant[20] at the rate of 0.25% v/v. Individual herbicide treatments represented labeled rates for the control of common ragweed. The combination of the two herbicides represented the same rates of picloram and fluroxypyr. The application of non-radiolabeled herbicide ensured that absorption and translocation was representative of a normal field application (Zawierucha and Penner 2000).

Immediately following the broadcast applications, the radiolabeled herbicide was

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[19] Spraying Systems Co.; Wheaton, IL

[20] Latron AG-98, Loveland Industries, Inc., P.O. Box 1289, Greeley, CO 80632

applied to the appropriate plants. Treatments consisted of pyridyl-ring-labeled [^{14}C] picloram (60.7 Becquerels (Bq)/µL)[21] and pyridyl-ring-labeled [^{14}C] fluroxypyr (45.2 Bq/µL)[22] solutions that were spotted on the common ragweed plants based on their respective treatments. Applications were made with a 100-µL repeating pipetter calibrated to dispense 5 µL of radiolabeled herbicide solution. Treatments were applied to the adaxial side of both opposite leaves at the third node above the cotyledons (Ballard et al., 1995). Three 5 µl drops were dispensed along the midrib of each leaf resulting in approximately 1800 and 1350 Bq/plant of [^{14}C] picloram and [^{14}C] fluroxypyr, respectively.

Plants were harvested approximately 1, 6, 12 and 24 h after treatment (HAT) with the radiolabeled herbicide solution. Harvest consisted of severing and washing both treated third node leaves. The leaf wash was comprised of three rapid submersions of each leaf in 20 mL of distilled water followed by three rapid submersions in 20 mL of 1:1 methanol/water solution. The water wash was an attempt to capture the radiolabeled material that might be removed by rainfall following application. The methanol/water wash attempted to remove the material not absorbed by the leaf as well as that contained in the leaf cuticle. Further dissection of each plant consisted of gathering biomass above the third node, biomass below third node, and biomass below the soil surface. All leaf wash solutions were refrigerated (4^{o}C) and all plant parts were frozen (-17^{o}C) prior to analysis.

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[21] Picloram Technical (98.5% purity), Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN 46268

[22] Starane F Analytical (99.5% purity), Dow AgroSciences, 9330 Zionsville Road, Indianapolis, IN 46268

Table 13. Rates of herbicides applied to common ragweed.

Herbicide	Application Rate[a]	Herbicide	Radiochemical Application Rate[b]
picloram	0.22	picloram	1800
picloram + fluroxypyr	0.22 + 0.32	picloram	1800
fluroxypyr	0.32	fluroxypyr	1350
fluroxypyr + picloram	0.32 + 0.22	fluroxypyr	1350

[a] Application rates were kg a.e./ha.

[b] Radiochemical rates were Bq/plant

Two-mL aliquots of each refrigerated leaf wash solution were transferred to scintillation vials. The total volume of each vial was amended with EcoLite scintillation cocktail[23] to achieve a final volume of 20 mL. Leaf wash solutions were analyzed utilizing liquid scintillation spectrometry. Each sample vial was radioassayed using an LS 6500 Multi-purpose Scintillation Counter[24] programmed to conduct 20-minute counts of each sample vial.

All frozen plant parts were thawed, dried at 80^{o}C for at least 72 h, weighed, and finely ground. One g of each ground plant part was combusted using a biological oxidizer. The evolved CO_2 was trapped in a vial containing 10 mL of CO_2 absorber + 10 mL EcoLite scintillation cocktail (Zawierucha and Penner 2000). The oxidation solution was radioassayed utilizing liquid scintillation spectrometry, similar to that for the leaf wash samples. Percent absorption was calculated using the Norsworthy et al. (2001) equation. The combustion efficiency of the biological oxidizer was 80%. Therefore, total ^{14}C recovery was calculated as 84 and 89% for both runs of the experiment.

Plant growth, herbicide application, sample preparation and analyses occurred at the Texas A&M University campus in College Station, TX. The experiment was conducted twice with each containing three completely randomized replicates. Data were subjected to statistical analysis performed with an ANOVA using SPSS 12.0.1 for Windows, where Tukey's HSD at the 5% level of significance was employed to separate treatment means. No experiment by treatment interactions were observed for any of the

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[23] Research Products Division; Costa Mesa, CA
[24] Beckman Instruments; Fullerton, CA

variables evaluated. Therefore, data were pooled between experiments and, therefore, will be discussed by radiolabeled herbicide.

Results and Discussion

Behavior of ^{14}C Picloram

Within the first hour following application, both treatments had absorbed 33 - 39% of the applied ^{14}C herbicide (Table 14). No influence by fluroxypyr was observed on the amount of ^{14}C absorbed, unabsorbed, or partitioned into the cuticle during this time period. Radiolabeled picloram applied alone continued absorption through 6 HAT, where it achieved the greatest amount, 64%, for either treatment at any sampling interval. This amount was only numerically different from the ^{14}C absorption by the combination treatment at this sampling. However, significantly more radiolabeled material from the picloram + fluroxypyr treatment was retained in the cuticle. At 12 and 24 HAT, radiolabeled picloram applied alone showed a decline in absorption to 50 and 48%, respectively. As a result of the decreased absorption, a greater amount of ^{14}C remained unabsorbed on the leaf surface for both sampling periods compared to 6 HAT. The ^{14}C picloram from the combination treatment continued absorption through the final sampling interval, where it maximized at 61%. Absorption of ^{14}C from the picloram + fluroxypyr treatment was significantly greater at both the 12 and 24 samplings than ^{14}C from picloram applied alone. Subsequently, significantly less ^{14}C picloram from the combination treatment remained on the leaf surface at 12 and 24 HAT. Also,

Table 14. The effect of fluroxypyr on ^{14}C picloram absorption in treated leaves sampled 1, 6, 12, and 24 hours after application[a]. Data were combined over both experiments.

		Leaf Surface				Leaf Cuticle				Absorbed			
		Harvest Hour											
Treatment	Rate[b]	1	6	12	24	1	6	12	24	1	6	12	24
picloram	0.22	57	31	45	45	10	4	5	7	33	64	50	48
picloram + fluroxypyr	0.22 + 0.32	53	38	35	35	8	7	6	4	39	55	60	61
LSD (0.05)		NS	NS	4.26	10.83	NS	2.03	NS	2.37	NS	NS	5.00	12.11

[a] Data presented as percent of applied ^{14}C.

[b] Rates are kg a.e./ha.

significantly more radiolabeled picloram applied alone was sequestered in the cuticle at 24 HAT.

The ^{14}C picloram content of the treated leaf, the area above and below, and the root an hour after application was not affected when fluroxypyr was applied with picloram (Table 15). At 6 HAT, both the treated leaf and the area above contained significantly greater concentrations of ^{14}C from the combination treatment. However, the area below the treated leaf and the root contained significantly more radiolabeled material from picloram applied alone. Concentrations of ^{14}C picloram from each treatment were similar for each plant part at 12 HAT. By 24 HAT, though, significantly more radiolabeled picloram from the combination treatment had translocated out of the treated leaf than from the picloram treatment. However, significantly more ^{14}C from picloram applied alone translocated to the roots at this sampling interval. Additionally, comparable amounts of ^{14}C from both treatments partitioned into the areas above and below the third node.

Behavior of ^{14}C Fluroxypyr

Assessments made one hour after application showed no influence of picloram on the adsorption of ^{14}C fluroxypyr when compared to fluroxypyr applied alone, 55 and 65%, respectively (Table 16). This was also true with the amount of ^{14}C remaining on the leaf surface and in the cuticle. However, sampling at 6, 12, and 24 HAT revealed that a significantly greater amount of ^{14}C from fluroxypyr alone absorbed into the plant.

Table 15. The effect of fluroxypyr on ^{14}C picloram partitioning 1, 6, 12, and 24 hours after application[a]. Data were combined over both experiments.

		Treated leaf				Above treated leaf				Below treated leaf				Root			
		Harvest Hour															
Treatment	Rate[b]	1	6	12	24	1	6	12	24	1	6	12	24	1	6	12	24
picloram	0.22	56	22	29	28	11	23	33	41	31	50	35	24	0.4	4.4	3.2	6.3
picloram + fluroxypyr	0.22 + 0.32	70	37	28	17	7	35	32	46	22	26	36	35	0.2	2.8	3.6	2.6
LSD (0.05)		NS	12.3	NS	5.8	NS	7.6	NS	NS	NS	17.4	NS	NS	NS	1.5	NS	1.8

[a] Data presented as percent of absorbed ^{14}C.

[b] Rates are kg a.e./ha.

Table 16. The effect of picloram on ^{14}C fluroxypyr absorption in treated leaves sampled 1, 6, 12, and 24 hours after application[a]. Data were combined over both experiments.

		Leaf Surface				Leaf Cuticle				Absorbed			
		Harvest Hour											
Treatment	Rate[b]	1	6	12	24	1	6	12	24	1	6	12	24
fluroxypyr	0.32	16	8	7	6	19	10	8	7	65	83	84	87
fluroxypyr + picloram	0.32 + 0.22	20	11	10	11	25	15	13	13	55	74	78	76
LSD (0.05)		NS	NS	NS	NS	NS	4.10	2.35	4.56	NS	7.60	5.27	9.07

[a] Data presented as percent of applied ^{14}C.

[b] Rates are kg a.e./ha.

Also, significantly more radiolabeled material from the fluroxypyr + picloram treatment had partitioned into the leaf cuticle at these same three sampling intervals. The amount of unabsorbed material on the treated leaf was equivalent for both treatments at 6, 12, and 24 HAT.

Whole plant translocation of ^{14}C fluroxypyr was affected by picloram 1 HAT in the treated leaf and the area below (Table 17). In these portions of the plant, a significantly greater amount of radiolabeled material from the fluroxypyr treatment translocated from the treated leaf and into the area below. At the 6, 12, and 24 HAT, however, the amount of ^{14}C in each plant part from the two treatments was statistically indistinguishable.

Summary of Experiments

The presence of fluroxypyr significantly enhanced the overall absorption of ^{14}C picloram by common ragweed. Also, it increased the amount of radiolabeled material translocated from the treated leaf to the area above and below, but limited the concentration of ^{14}C in the roots. Observations also showed that picloram significantly reduced the absorption and increased the cuticle retention of ^{14}C fluroxypyr. However, once absorbed into the plant, picloram was only instrumental in limiting the translocation ^{14}C from the treated leaf to the area below within the first hour following application. At 6 HAT and beyond, it had not effect. Lym (1992) reported that the influence of fluroxypyr on ^{14}C picloram absorption was benign. He also found that ^{14}C

Table 17. The effect of picloram on ^{14}C fluroxypyr partitioning 1, 6, 12, and 24 hours after application[a]. Data were combined over both experiments.

		Treated leaf				Above treated leaf				Below treated leaf				Root			
		---Harvest Hour---															
Treatment	Rate	1	6	12	24	1	6	12	24	1	6	12	24	1	6	12	24
picloram	0.22	57	74	56	44	4	4	11	21	38	20	31	24	0.1	1.3	2.3	9.9
picloram + fluroxypyr	0.22 + 0.32	85	73	61	46	3	6	13	14	12	18	24	37	0.1	2.0	2.8	2.9
LSD (0.05)		16.6	NS	NS	NS	NS	NS	NS	NS	16.4	NS	NS	NS	NS	NS	NS	NS

[a] Data presented as percent of absorbed ^{14}C.
[b] Rates are kg a.e./ha.

fluroxypyr absorption by leafy spurge decreased as much as 50% when picloram was included in the treatment. The results of our studies resembled only the researcher's second finding. Additionally, Sterling and Lownds (1992) found that ^{14}C picloram absorption by broom snakeweed was saturated at one hour after application. Similarly, Trozelli (1986) reported that ^{14}C fluroxypyr completely penetrated and translocated in several different species within the first hour following treatment. In these experiments, we observed maximum absorption of ^{14}C picloram at 6 hours following application and ^{14}C fluroxypyr at 24 hours following application alone. When applied in combination, maximum absorption of ^{14}C picloram was delayed to 24 HAT and hastened to 12 HAT for ^{14}C fluroxypyr. Both incurred a decrease in overall absorption when applied in combination, but significance was only observed for ^{14}C fluroxypyr.

In both experiments, controlled and non-veritable conditions were employed. Varying the environmental conditions in which experiments are conducted may result in drastic alterations to the behaviors of these two herbicides applied alone and in combination to this species. Both Lym (1992) and Sterling and Lownds (1992) reported that fluroxypyr and picloram absorption is greater in plants exposed to higher relative humidity. Further research should be conducted to evaluate these potential environmental influences on the absorption and translocation characteristics of these herbicides.

CHAPTER V

SUMMARY AND CONCLUSIONS

Identifying and understanding the means at which herbicides effectively control, adversely effect, and absorb and partition in the plants they contact provides the foundation for appropriate and advantageous use. This research has discussed the efficacy of an experimental herbicide in controlling six problematic pasture weed species. It also evaluated and reported the effects of this same herbicide on the growth and nutritional value of two popular forage grasses. Finally, the absorption and translocation of two common herbicides, alone and in combination, was characterized using a common weed species.

GF-884, an experimental pasture herbicide from Dow AgroSciences, was evaluated for the control of three annual and three perennial broadleaf weed species common to Texas pasturelands. The herbicide was applied at four rates to each species as well as single rates of three labeled pasture products and one non-selective material, for comparative purposes. Season long visual evaluations were made in approximately 30 day increments following application to each species. The effects of each treatment on the persistent underground portion of each perennial species were also quantified twelve months following application. Experiments consisted of three replications over two consecutive years.

During both experimental years, GF-884, applied at rates of 0.91 and 1.14 kg a.e./ha, consistently provided equivalent or better control than the labeled herbicides.

The treatment effects to the persistent portion of the perennial species one year following application resulted in congruence among all applied treatments for western horsenettle and silverleaf nightshade.

The same experimental herbicide was applied to two hybrid bermudagrass species for the purpose of assessing tolerance. Treated areas were compared to untreated areas to determine if exposure to the herbicide had any effect on growth, yield, and qualitative properties. The material was applied at three rates with and without adjuvant. Visual ratings prior to the first harvest of each bermudagrass resulted in significant growth reduction by GF-884 at select rates and adjuvants. However, this reduction in growth was not evident in analyses following harvest. All treatments achieved comparable yields to that of the untreated area. Additionally, there was no observed influence on forage quality by any of the treatments.

The highest rate of GF-884 utilized in the hybrid bermudagrass experiments was more than twice that of the highest rate utilized in the weed control trials. As previously mentioned, GF-884 effectively and consistently controlled all six weed species evaluated at the two highest rates tested. With this said, GF-884 has the capability to effectively control weed species at levels comparable to products currently available while incurring little to no injury to cultivated bermudagrass hybrids.

Picloram and fluroxypyr, alone and in combination, were broadcast applied to common ragweed plants. Shortly after, radiolabeled picloram and fluroxypyr solutions were applied to plants to assist in determining the absorption and partitioning characteristics of each herbicide and assess the influence of one on the other. All plants were dissected into four regions, with each region undergoing individual analysis.

Fluroxypyr significantly increased overall absorption of ^{14}C picloram into common ragweed. Picloram, applied alone, maximized absorption of ^{14}C at 6 HAT, but absorption decreased significantly over the next two sampling periods. The radiolabeled material from the picloram + fluroxypyr treatment continued absorption through 24 HAT, where it reached its maximum level.

Fluroxypyr numerically increased picloram translocation in common ragweed, but significantly limited accumulation in the root. At 1 and 12 HAT, ^{14}C content from the two treatments was equivalent in the sampled plant parts. However, at 6 HAT, significantly more ^{14}C picloram from the combination treatment was contained in the treated leaf and the area above. ^{14}C from the picloram treatment, though, was in the area below the treated leaf and the root at significantly greater concentrations. At the final sampling, significantly less ^{14}C from the fluroxypyr + picloram treatment was found in the treated leaf and the root.

Picloram significantly decreased the absorption of ^{14}C fluroxypyr into common ragweed. Absorption of ^{14}C from fluroxypyr applied alone continued through 24 HAT, where it reached its maximum concentration. Absorption of radiolabeled material from the combination treatment was maximized at 12 HAT, at a significantly less amount. Absorption declined significantly at the subsequent sampling interval.

Once absorbed, picloram only imposed a short lived decrease in translocation. ^{14}C fluroxypyr translocation was decreased by picloram at the 1 HAT sampling where it restricted movement out of the treated leaf and into the area below. At the remaining samplings, all concentrations of ^{14}C from both treatments were equivalent.

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APPENDIX A

2002 SITE DESCRIPTION INFORMATION FOR WEED CONTROL EXPERIMENTS WITH GF-884

Weed Species Evaluated	Texas County	Coordinates	Soil series[a]	Soil Texture[a]	Soil pH	Soil % OM	Additional Remarks[a]
Prairie broomweed	Milam	30N 55’ 17” x 96W 59’ 42”	Sandow	Clay loam	6.7	1.1	Very deep soil; typically in flood plains
Annual marshelder	Brazos	30N 42’ 07” x 96W 11’ 08”	Navasota	Clay	5.6	1.4	Very deep soil; flood plain and tributaries
Western horsenettle	Bosque	31N 58’ 52” x 97W 46’ 35”	Frio Bosque	Silty clay	7.0	1.4	Very deep, well drained soil
Silverleaf nightshade	Burleson	30N 31’ 56” x 96W 25’ 17”	Ships-Weswood	Clay	7.8	1.4	Very deep soil; moderate sloping flood plain
Western ragweed	Grimes	30N 25’ 40” x 95W 59’ 38”	Latium-Frelsburg	Clay	8.1	1.9	Very deep, well drained soil; gentle to moderate slope
Woolly croton	Brazos	30N 43’ 02” x 96W 11’ 34”	Navasota	Clay	4.9	3.0	Very deep soil; flood plain and tributaries

[a] Information obtained from USDA-NRCS (2004a).

APPENDIX B

2003 SITE DESCRIPTION INFORMATION FOR WEED CONTROL EXPERIMENTS WITH GF-884

Weed Species Evaluated	Texas County	Coordinates	Soil series[a]	Soil Texture[a]	Soil Ph	Soil % OM	Additional Remarks[a]
Prairie broomweed	Coryell	31N 21’ 41” x 97W 52’ 45”	Nuff-Cho	Silty clay loam	7.6	5.4	Shallow, well drained soil; interbedded marl, limestone, shale
Annual marshelder	Brazos	30N 42’ 07” x 96W 11’ 08”	Navasota	Clay	5.6	1.4	Very deep soil; flood plain and tributaries
Western horsenettle	Bosque	31N 58’ 52” x 97W 46’ 35”	Frio Bosque	Silty clay	7.0	1.4	Very deep, well drained soil
Silverleaf nightshade	Burleson	30N 31’ 56” x 96W 25’ 17”	Ships-Weswood	Clay	7.8	1.4	Very deep soil; moderate sloping flood plain
Western ragweed	Brazos	30N 25’ 40” x 95W 59’ 38”	Navasota	Clay	5.4	2.5	Very deep soil; flood plain and tributaries
Woolly croton	Brazos	30N 43’ 02” x 96W 11’ 34”	Navasota	Clay	4.9	3.0	Very deep soil; flood plain and tributaries

[a] Information obtained from USDA-NRCS (2004a).

APPENDIX C

2002 AND 2003 PRECIPITATION DATA FOR PRAIRIE BROOMWEED EXPERIMENTAL SITES

Month	2002[b]	2003[b]
January	23.9	20.3
February	57.4	64.8
March	38.4	45.7
April	59.7	19.1
May	135.4	22.9
June	66.5	127.5
July	117.1	0.5
August	0.8	54.6
September	45.7	44.5
October	198.1	226.8
November	252.2	30.5
December	156	11.9
Annual total	1023.1	669

[a] Information obtained from NOAA-NCDC (2004).
[b] Data reported in mm.

APPENDIX D

2002 AND 2003 PRECIPITATION DATA FOR ANNUAL MARSHELDER EXPERIMENTAL SITES

Month	2002[b]	2003[b]
January	40.6	26.9
February	41.4	185.7
March	21.6	42.7
April	36.3	4.3
May	22.6	14.5
June	77.2	168.7
July	143.8	102.9
August	91.9	110.7
September	19.6	158.8
October	248.7	173
November	152.4	99.6
December	192.5	31
Annual total	1088.6	1118.6

[a] Information obtained from NOAA-NCDC (2004).
[b] Data reported in mm.

APPENDIX E

2002 AND 2003 PRECIPITATION DATA FOR WESTERN HORSENETTLE EXPERIMENTAL SITES

Month	2002[b]	2003[b]
January	91.4	15.7
February	43.4	97.5
March	73.9	24.4
April	71.9	68.3
May	48.5	90.7
June	33.8	214.9
July	130	22.4
August	14.2	29.2
September	59.2	114.8
October	149.1	123.2
November	13.7	39.9
December	115.3	22.4
Annual total	844.6	856.9

[a] Information obtained from NOAA-NCDC (2004).
[b] Data reported in mm.

APPENDIX F

COASTAL BERMUDAGRASS CRUDE PROTEIN

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Harvest 1	 2
	kg a.e./ha		--------------%	-----------
GF-884	0.91	-	12.3 a[b]	11.5 a
GF-884	1.37	-	12.6 a	11.4 a
GF-884	2.73	-	14.0 a	12.6 a
GF-884	0.91	MSO	13.6 a	11.5 a
GF-884	1.37	MSO	12.1 a	11.8 a
GF-884	2.73	MSO	13.5 a	11.8 a
GF-884	0.91	NIS	12.7 a	11.8 a
GF-884	1.37	NIS	13.5 a	11.7 a
GF-884	2.73	NIS	13.3 a	11.6 a
Untreated area	-	-	13.4 a	12.2 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD ($\alpha=0.05$).

APPENDIX G

COASTAL BERMUDAGRASS ACID DETERGENT FIBER

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Harvest 1	2002 and 2003 Harvest 2
	kg a.e./ha		-------------%	-----------
GF-884	0.91	-	37.3 a[b]	37.0 a
GF-884	1.37	-	37.9 a	37.8 a
GF-884	2.73	-	36.9 a	36.6 a
GF-884	0.91	MSO	36.9 a	37.6 a
GF-884	1.37	MSO	37.4 a	36.9 a
GF-884	2.73	MSO	37.6 a	36.8 a
GF-884	0.91	NIS	37.9 a	37.9 a
GF-884	1.37	NIS	37.0 a	37.0 a
GF-884	2.73	NIS	37.5 a	37.5 a
Untreated area	-	-	36.3 a	37.7 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

APPENDIX H

TIFTON 85 BERMUDAGRASS CRUDE PROTEIN

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Harvest 1	 2
	kg a.e./ha		-------------%-----------	
GF-884	0.91	-	8.4 a[b]	9.8 a
GF-884	1.37	-	8.8 a	9.3 a
GF-884	2.73	-	9.6 a	9.4 a
GF-884	0.91	MSO	8.3 a	9.0 a
GF-884	1.37	MSO	8.8 a	9.3 a
GF-884	2.73	MSO	8.7 a	9.0 a
GF-884	0.91	NIS	8.5 a	9.1 a
GF-884	1.37	NIS	8.9 a	9.2 a
GF-884	2.73	NIS	8.6 a	9.3 a
Untreated area	-	-	8.3 a	8.7 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

APPENDIX I

TIFTON 85 BERMUDAGRASS ACID DETERGENT FIBER

Herbicide	Rate	Adjuvant[a]	2002 and 2003 Harvest 1	2002 and 2003 Harvest 2
	kg a.e./ha		-------------%	-----------
GF-884	0.91	-	40.4 a[b]	42.9 a
GF-884	1.37	-	40.0 a	43.4 a
GF-884	2.73	-	40.5 a	43.3 a
GF-884	0.91	MSO	40.2 a	44.1 a
GF-884	1.37	MSO	40.3 a	43.9 a
GF-884	2.73	MSO	40.1 a	44.5 a
GF-884	0.91	NIS	40.3 a	44.2 a
GF-884	1.37	NIS	40.4 a	44.6 a
GF-884	2.73	NIS	40.6 a	43.8 a
Untreated area	-	-	40.6 a	45.3 a

[a] MSO = methylated seed oil @ 1.25% v/v; NIS = non-ionic surfactant @ 0.25% v/v.

[b] Means within a column followed by the same letter are not significantly different according to Tukey's HSD (α=0.05).

VITA

Frederick (Fred) Thomas Moore, son of Pamela Rau Moore and Thomas Sutton Moore, was born in Wichita, KS, on August 21, 1972. Fred grew up in McAllen, TX, under the cherished influence of his grandparents. Through their insight and encouragement he became interested in agriculture. He graduated from McAllen High School in May of 1990 and began his collegiate studies at the University of Texas, Pan American in Edinburg, TX. A year later, in 1991, he transferred to Texas A&M University (TAMU) in College Station, TX. In May of 1994 he received a Bachelor of Science Degree in Agronomy. Following graduation, he moved to the Panhandle of Texas where he worked as an agronomist for three years providing producers with agronomic advice. In 1996, he moved to Texhoma, OK, where he worked for Seaboard Farms, Inc. as an Organic Nutrient Manager. Following his brief stint in the swine industry, he began working on a Master of Agriculture Degree in Agricultural Systems Management at TAMU in College Station, TX, in 1998. Fred completed the degree requirements for a Master of Agriculture and graduated in December of 1999. He then began employment with Texas Cooperative Extension as an extension assistant, and later an extension associate, conducting herbicide efficacy and tolerance experiments on row crop, pasture land, and turf grass. Concurrently, Fred worked toward a Doctor of Philosophy in weed science from TAMU. He completed the Ph.D. requirements while working as the Cooperative Extension / U.S. EPA Region 6 Liaison in Dallas, TX. Fred graduated in May of 2005. His permanent address is 1566 Bradford Trace, Allen, TX, 75002.