Evaluation of best management practices for bermudagrass (*Cynodon* spp.) control in zoysiagrass (*Zoysia* spp.) turf

by

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Abstract

Zoysiagrasses (*Zoysia* spp.) are a popular choice as turfgrasses in the transition zone of the United States. When managing zoysiagrass, one of the most problematic weeds to control is bermudagrass [*Cynodon dactylon* (L.) Pers.]. Bermudagrass is typically more competitive and faster growing than any zoysiagrass cultivars currently available, thus contamination is a major problem. Currently, there are few options for turfgrass managers who wish to effectively control bermudagrass in zoysiagrass. Research conducted at Auburn University focused on efficacy of bermudagrass control during turfgrass renovation and selective control in established turfgrass systems.

Fairway conversion studies were initiated in May of 2008 and 2009 on an established Tifway bermudagrass stand. Treatments included: glyphosate, EPTC, dazomet, siduron, glyphosate plus ETPC, glyphosate plus dazomet, EPTC plus siduron, and dazomet plus siduron. Results indicate that dazomet plus glyphosate or siduron and EPTC plus glyphosate or siduron were equally effective at controlling Tifway bermudagrass, yielding ≤12% bermudagrass cover 15 weeks after zoysiagrass establishment. Comparing EPTC- and dazomet-alone, EPTC yielded significantly less bermudagrass cover (32%) than dazomet (71%).

Field studies were conducted to determine the influence of nitrogen and trinexapac-ethyl on zoysiagrass competiveness with bermudagrass. Trinexapac-ethyl alone was the only treatment to result in decreased Tifway spread throughout the study, relative to the nontreated. In contrast, all rates of nitrogen applied alone resulted in statistically equivalent common bermudagrass spread as trinexapac-ethyl applied alone. In general, nitrogen fertilizer applied with trinexapac-ethyl reduced the efficacy of bermudagrass suppression.

Field experiments were conducted to evaluate new aryloxyphenoxypropionate herbicides for the selective control of Tifway bermudagrass in zoysiagrass. Treatments included: clodinafop, triclopyr, clodinafop plus triclopyr, fenoxaprop, fenoxaprop plus triclopyr, metamifop, and metamifop plus triclopyr. Three sequential applications were made at 21-d intervals. Results indicate the addition of triclopyr to clodinafop, fenoxaprop, and metamifop increased bermudagrass control and reduced injury to zoysiagrass.

Additive competition experiments were conducted to determine the competitive effects of smooth crabgrass and goosegrass on Zenith zoysiagrass establishment. Zoysiagrass development was reduced at all seeding densities by both weed species 8 weeks after seeding. At the highest neighbor density, goosegrass inhibited zoysiagrass tillering entirely, whereas >20% of zoysiagrass plants developed tillers when grown with smooth crabgrass. Overall, zoysiagrass drymatter yield was reduced from 38 to 99% with increasing weed density. Regression analysis indicated that goosegrass caused greater yield loss per weed unit and maximum yield loss compared to smooth crabgrass.

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List of Abbreviations

ACCase	Acetyl-CoA carboxylase
AL	Alabama
ANOVA	Analysis of variance
AOPP	Aryloxyphenoxypropionate
C	Celsius
CL	Confidence limit
cm	Centimeter
cv	Cultivar
d	Days
DAS	Days after seeding
EIV	Errors in variables
EPA	Environmental Protection Agency
F	Fahrenheit
ft	Feet
GA	Gibberellic acid
ha	Hectare
JPEG	Joint photographic experts group
kg	Kilogram
kPa	Kilopascal

L	Liter
LSD	Least significant difference
m	Meter
mm	Millimeter
N	Nitrogen
NIS	Nonionic surfactant
PLS	Pure live seed
PGR	Plant growth retardant
POST	Postemergence
PRE	Preemergence
r	Replicate
TE	Trinexapac-ethyl
USGA	United States Golf Association
v/v	Volume to volume
WAE	Weeks after establishment
WAIT	Weeks after initial treatment
WAS	Weeks after seeding
WAT	Weeks after treatment
wk	Week
WPE	Weeks prior to establishment
yr	Year

I. Literature Review

Bermudagrass' aggressive growth habit, extensive rhizome and stolon system, and tolerance to adverse environmental and management conditions make it a desirable turfgrass. However, these same traits make bermudagrass one of the most difficult to control weeds in agronomic crops, ornamental beds, pastures, and turfgrasses in the southeastern United States (Dowler 1999; Ferrell et al. 2005; Webster 2000). A mixture of different grass species in the same area often leads to a poor turfgrass stand due to differences in color, texture, and growth habit (Johnson 1987; Johnson and Carrow 1995). Bermudagrass, especially, presents a problem in zoysiagrass due to the limited availability of selective herbicides that do not excessively injure zoysiagrass (Dernoeden 1989; Johnson 1987,1992). Bermudagrass and zoysiagrass share similar herbicide tolerances because of their physiological similarities as C_4 warm-season grasses (Johnson 1987). Non-selective herbicides are impractical as they lead to the death of both bermudagrass and the desired species. Furthermore, complete bermudagrass eradication requires up to three applications of glyphosate [*N*-(phosphonomethyl)glycine] at 2.2 kg ae ha^{-1} and spot spraying in the second year (Johnson 1988). Alternatively, researchers have evaluated various postemergent (POST) herbicides for their efficacy of selective bermudagrass control (Johnson 1992; Johnson and Carrow 1989; McCarty 1996; McElroy and Breeden 2006).

Bermudagrass. Bermudagrass (*Cynodon* spp.) is a perennial warm-season species whose center of origin is Eastern Africa to the East Indies (Beard 1973). Bermudagrasses form a vigorous, uniform turf and are extensively used throughout the southern United States for a variety of turfgrass applications. The majority of *Cynodon* spp. have both rhizomes and stolons, excellent heat and drought tolerance, good wear tolerance, and excellent recuperative ability (Beard 1973; Turgeon 2005). In general, the two limiting factors to the use of bermudagrass are poor shade tolerance and lack of winter hardiness (Bunnell et al. 2005; Christians 2004; McBee and Holt 1966). Areas subject to reduced light, under trees or adjacent to other light barriers, results in a thin, less dense turfgrass stand. Bermudagrass has a low tolerance to cold temperatures, often entering dormancy when soil temperatures reach 50°F (10°C) (Christians 2004). Bermudagrass is quite susceptible to 'winter-kill' when grown in areas of the upper transition zone of the United States where winter temperatures drop below 10°F (-12°C) (McCarty 2005). Bermudagrass is also susceptible to many diseases that are common to the hot humid days and cool nights of the transition zone (McCarty 2005).

Management. Bermudagrass requires a medium to high intensity of management depending on cultivar and specific use. Mowing heights range from as low as 0.125 in. (0.32 cm) for ultradwarf greens applications up to 2.0 in. (5.0 cm) when used as home lawns or utility turf applications (Turgeon 2005). The recommended nitrogen (N) fertility for bermudagrass is 4 to 8 lb 1000 ft^{-2} yr^{-1} (195 to 781 kg ha^{-1} yr^{-1}) (Beard 1973; Carrow et al. 1987). To achieve optimal turf quality, management practices should include frequent (daily) mowing with a sharp, reel-type mower. Irrigation should be performed as needed to sustain color and growth. Due to its vigorous growth habit and high fertility requirement, bermudagrass is prone to thatch accumulation, which may be alleviated by cultural practices including topdressing, core aerification, or vertical mowing (Carrow et al. 1987).

Zoysiagrass. Zoysiagrasses (*Zoysia* spp.) are warm-season grass species native to the hot, humid southeastern region of Asia including China, Korea, and Japan. Zoysiagrass is a spreading perennial that exhibits both rhizomes and stolons. In the United States, zoysiagrasses are primarily used in the warm humid southeast and cooler transition regions. As a whole, zoysiagrasses are slow growing, relatively tolerant to heat and shade, winter hardy, and require a medium intensity of management (Beard 1973; Bunnell et al. 2005; McCarty 2005). Dormancy usually occurs with the advent of 50 to 55°F (10 to 13°C) temperatures, at which time the turf turns a golden brown color.

Management. Zoysiagrass requires a medium intensity of management to maintain optimal quality. Mowing heights of 0.5 to 1.0 inch (1.25 to 2.5 cm) are adequate for most conditions. Due to the high silica content of the shoots, mowing should be performed with a well-adjusted, reel-type mower to achieve optimal quality. Nitrogen fertility recommendation for zoysiagrass is 1.5 to 3.0 lb 1000 ft^{-2} yr^{-1} (73 to 146 kg ha^{-1} yr^{-1}). Irrigation should be performed as needed to sustain color and growth. When maintained under intense culture and high mowing height, thatch accumulation will occur (McCarty 2005). Periodic vertical mowing is recommended to reduce thatch accumulation and potential scalping problems (Beard 1973; Turgeon 2005).

Establishment. Zoysiagrasses are primarily established by vegetative propagation, either by sprigs, plugs, or sod (Patton et al. 2004a). Due to sterility and to insure trueness to type, most hybrid zoysiagrasses currently available are established vegetatively (Beard 1973; Engelke et al. 2002). At present, the only zoysiagrass cultivars that can be established by seed are *Z. japonica* species. These zoysiagrass species typically are coarser textured, more cold tolerant, but less dense than hybrid zoysiagrass (McCarty 2005). However, new seeded zoysiagrass cultivars that exhibit improved turf quality characteristics are now available and are up to \$30,000 ha^{-1} less expensive to establish depending on seeding rate, establishment rate, and cultivar (Morris 2006; Patton et al. 2004a; Zuk and Fry 2005).

Cultural Means to Hasten Zoysiagrass Establishment. The main disadvantage of zoysiagrass is the slow establishment rate (Busey and Myers 1979). Rapid establishment is desired when establishing turf vegetatively or by seed. Several cultural practices such as seeding rate, fertilization, and weed control have been evaluated for their significance on zoysiagrass establishment. Patton et al. (2004b) concluded that increasing seeding rate of 'Zenith' zoysiagrass (*Zoysia japonica* Steud.) from 1.0 to 2.0 lb 1000 ft^{-2} (49 to 98 kg ha^{-1}) only produced minimal increase (3 to 11%) zoysiagrass coverage. An additional study showed that 42 d after seeding (DAS), there was no enhancement in zoysiagrass cover by seeding greater than 2.0 lb 1000 ft^{-2} (98 kg ha^{-1}). Furthermore, by 56 DAS, all zoysiagrass seeding rates greater than 0.5 lb 1000 ft^{-2} (24 kg ha^{-1}) produced similar tiller densities (Patton et al. 2004b).

Fry and Dernoeden (1987) reported that increasing N rates up to 196 kg ha^{-1} yr^{-1} produced only 5% increase in 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) plug coverage. Carroll et al. (1996) observed no significant influence on Meyer zoysiagrass sprig establishment with monthly applications of 49 kg N ha^{-1} the first yr, but did report a 5% increase in cover when compared to areas not receiving supplemental N the second yr. Similarly, Richardson and Boyd (2001) reported minimal increase in cover (5 to 10%) 120 d after planting (DAP) of Meyer zoysiagrass sprigs when increasing N rates from 24 to 49 kg ha^{-1}. Patton et al. (2004a) found that increasing monthly N fertilization from 49 to 98 kg ha^{-1} did not increase Zenith zoysiagrass establishment by seed.

Weed Control During Zoysiagrass Establishment. A primary factor to successfully establishing any turfgrass is implementing procedures to reduce weed competition. Weeds compete with new plantings for light, nutrients, moisture, and space (McCarty 2005). Summer annual grassy weeds such as crabgrass (*Digitaria* spp.) and goosegrass [*Eleusine indica* (L.) Gaertn.] germinate in late spring to early summer at the same time that is recommended for zoysiagrass establishment in the southeastern United States (Beard 1973; Patton et al. 2004a). Additionally, zoysiagrass is relatively slow to establish vegetatively or by seed (Busey and Myers 1979). Therefore, weed control is essential for optimal establishment of zoysiagrass since competition with summer annual weeds will significantly reduce establishment rates (Carroll et al. 1996; Dernoeden 1989). Many studies have evaluated preemergent (PRE) and POST herbicides for their efficacy of weed control and safety in newly established zoysiagrass.

Fenoxaprop [(2R)-2-[4-[(6-chloro-2-benzoxyazolyl)oxy]phenoxy]propanoic acid] applied alone and in combination with several PRE herbicides was evaluated for annual grass control in Meyer zoysiagrass plugs and in common Korean zoysiagrass (*Z. japonica* Steud.) seedlings (Dernoeden 1989). Fenoxaprop (0.10 kg ai ha^{-1}) applied in mixtures with prodiamine [2,4-dinitro-N^3,N^3-dipropyl-6-(trifluoromethyl)-1,3-benzenediamine] (0.56 kg ai ha^{-1}), quinclorac [3,7-dichloro-8-quinolinecarboxylic acid] (1.1 kg ai ha^{-1}), or pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] (1.7 kg ai ha^{-1}) controlled smooth crabgrass [*Digitaria ischaemum* (Schreb. ex Schweigg.) Schreb. ex Muhl.] (>93%) and yielded 76 to 90% Meyer zoysiagrass cover versus 25% cover in untreated plots. Fenoxaprop applied to 2- to 3-leaf zoysiagrass seedlings was extremely injurious at rates as low as 0.09 kg ha^{-1}. However, all rates of fenoxaprop effectively controlled tillered goosegrass. In another study, fenoxaprop applied to 2- to 5-tiller zoysiagrass seedlings caused some phytotoxity, but plots recovered by 8 wks after treatment (WAT) (Dernoeden 1989). Maximum zoysiagrass cover (60%) was observed in plots treated with fenoxaprop (0.07 kg ha^{-1}) due to effective smooth crabgrass control (95%) (Dernoeden 1989).

Fry et al. (1986) reported oxadiazon [3-[2,4-dichloro-5-(1-methylethoxy)phenyl]-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one] applied at a rate of 3.4 kg ai ha^{-1}, fenoxaprop at 0.2 kg ha^{-1}, and siduron [*N*-(2-methylcyclohexyl)-*N'*-phenylurea] at 6.7 and 13.4 kg ai ha^{-1} effectively controlled smooth crabgrass and did not cause injury to Meyer zoysiagrass plugs. Furthermore, the researches reported these treatments increased stolon production and establishment of Meyer zoysiagrass from plugs in the presence of severe competition from smooth crabgrass.

Carroll et al. (1996) reported that oxadiazon treatments applied PRE to crabgrass germination at 3.4 kg ha^{-1} resulted in 5 to 6 times more zoysiagrass cover than nontreated areas in the first yr of Meyer sprig establishment. Quinclorac applied at 0.84 kg ha^{-1} to 2- to 3-leaf crabgrass was highly effective yielding 98% zoysiagrass cover after 1 yr. Dithiopyr [*S,S'*-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbothioate] applied PRE at 0.56 kg ai ha^{-1} and fenoxaprop applied POST at 0.2 kg ha^{-1} also effectively controlled crabgrass and increased zoysiagrass cover. However, dithiopyr treated plants had up to 39% less rooting mass than nontreated plants. Patton et al. (2004a) reported dithiopyr applied 0.56 kg ha^{-1} PRE or at establishment reduced seeded Zenith zoysiagrass establishment up to 50%.

The effect of glyphosate treatments to existing turf and POST herbicides were evaluated on renovating perennial ryegrass (*Lolium perenne* L.) fairways with Zenith zoysiagrass (Patton et al. 2004b). Despite increasing zoysiagrass seeding rate to 3.0 lb 1000 ft^{-2} (146 kg ha^{-1}), a maximum of 2% cover was achieved when glyphosate was not applied prior to seeding. Similarly, Zuk and Fry (2005) reported a significant difference in Zenith zoysiagrass cover in untreated (1% cover) and glyphosate treated (84% cover) perennial ryegrass stands. Treatments with MSMA [monosodium methylarsonate] applied at 2.4 kg ai ha^{-1} 14 + 28 or 14 + 28 + 42 d after emergence effectively controlled annual grassy weeds yielding 97% mean zoysiagrass cover (Patton et al. 2004b).

Compared to other turfgrasses, zoysiagrasses exhibit a very slow growth rate. While the attribute of slow growth is advantageous from a maintenance aspect, it is a major disadvantage in the scope of establishment, recuperative potential, and competitiveness (McCarty 2005). In the transition zone, Meyer zoysiagrass requires up to 2 yr for complete establishment from vegetative sprigs (Fry and Dernoeden 1987). This lengthy period of establishment is often unacceptable in golf course applications or when immediate cover is desired. Furthermore, this is problematic when used in areas of intense play such as tee boxes or fairways where rapid recovery is desired to maintain aesthetics and playability (Karcher et al. 2005). The low recuperative ability of zoysiagrass often leads to thinning turf which in turn leaves it susceptible to infestation by weeds and other species.

Bermudagrass Control. Bryson and Wills (1985) determined the susceptibility of bermudagrass biotypes collected from Mississippi and Tennessee to several POST herbicides. They observed an average of 94% control 13 WAT over all bermudagrass biotypes using haloxyfop [2-[4-[[3-chloro-5-(trifluromethyl)-2-pyridinyl] oxy] phenoxy] propanoic acid] applied at 0.56 kg ai ha^{-1}. Fenoxaprop applied at 0.28 kg ha^{-1} yielded maximum control (48%) 2 WAT, with a reduction in control to 16% at 13 WAT. Fenoxaprop applied at a higher rate (0.6 kg ha^{-1}) yielded 55% control 4 WAT, but control rapidly declined to 19% at 13 WAT. Fluazifop [(±) –2–[4 –[[5 – (trifluoromethyl) – 2 – pyridinyl] oxy] phenoxy] propanoic acid] applied at 0.28 kg ai ha^{-1} maintained 47% control at 13 WAT. For all herbicides, differences in control among biotypes were greater with lower rates of each herbicide (Bryson and Wills 1985).

Johnson (1987) evaluated fluazifop and sethoxydim [2 – [1-(ethoxyimino)butyl]-5-[2-(ethylthio) propyl]–3–hydroxy–2–cyclohexen – 1 – one] on monocultures of 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy], 'Emerald' zoysiagrass [*Zoysia japonica* Steud. × *Z. matrella* (L.) Merr. var. *tenuifolia*], centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.], and tall fescue (*Festuca arundinacea* Schreb.). Three applications of fluazifop at 0.20 kg ha^{-1} provided >99% control of Tifway bermudagrass. Sethoxydim required up to six applications at a minimum rate of 0.34 kg ai ha^{-1} over a 2-yr period to effectively control bermudagrass. Fluazifop applied at 0.20 kg ha^{-1} caused severe injury (55%) to Emerald zoysiagrass at 4 WAT. Sethoxydim caused slight injury to zoysiagrass when applied at 0.22 kg ha^{-1}, but 13% of bermudagrass regrew after 2-yr of this treatment (Johnson 1987).

Fenoxaprop applied to a mixed stand of common bermudagrass and Emerald zoysiagrass at 0.20 kg ha^{-1} in four applications reduced bermudagrass cover to 3% (Johnson 1992). Zoysiagrass turf quality was reduced immediately after each treatment but recovery was acceptable by 3 WAT. Dernoeden (1989) found that fenoxaprop applied at 0.20 kg ha^{-1} in three applications controlled common bermudagrass 91% in a perennial ryegrass fairway. Similarly, Cudney et al. (1997) reported fenoxaprop applied at 0.21 kg ha^{-1} in four applications reduced common bermudagrass cover to 8%. Fluazifop applied at 0.10 kg ha^{-1} in four applications for 2 consecutive yr controlled bermudagrass similar to treatment with fenoxaprop (Johnson 1992). However, fluazifop severely reduced turf quality (78%) and required up to 5 wks for full recovery. Johnson (1992) concluded that a transition from a mixed stand of turfgrass to a zoysiagrass monoculture required multiple applications of fenoxaprop or fluazifop for at least 2-yr regardless of herbicide choice.

Fenoxaprop (0.2 kg ha^{-1}) tank-mixed with ethofumesate [2-ethoxy-2,3-dihydro-3,3-dimethyl-5-benzofuranyl methanesulfonate] (1.7 kg ai ha^{-1}) suppressed common bermudagrass 98% by late August with five monthly applications beginning in April

(Johnson and Carrow 1995). Control was significantly greater when fenoxaprop was tank-mixed with ethofumesate than when fenoxaprop was applied alone (66%). Similar applications to Tifway bermudagrass resulted in 30% suppression by September. Optimum bermudagrass suppression was observed when fenoxaprop plus ethofumesate (0.2 + 1.7 kg ha^{-1}) was applied initially in early spring soon after green up, followed by four applications at monthly intervals (Johnson and Carrow 1995).

McCarty (1996) reported that ethofumesate applied at 3.4 kg ha^{-1} controlled common bermudagrass 80% without significantly injuring St. Augustinegrass [*Stenotaphurum secundatum* (Walter) Kuntze]. Ethofumesate tank-mixed with flurprimidol [α-(1-methylethyl)-α-[4-(trifluoromethoxy)phenyl]-5-pyrimidinemethanol] (0.8 kg ai ha^{-1}) reduced St. Augustinegrass quality, while ethofumesate tank-mixed with siduron (6.6 kg ha^{-1}) controlled bermudagrass poorly (66%). Johnson and Duncan (2000) noted that ethofumesate tank-mixed with flurprimidol (1.7 + 0.8 kg ha^{-1}) severely injured three searshore paspalum (*Paspalum vaginatum* Sw.) cultivars 44 to 65%. Three applications of ethofumesate tank-mixed with atrazine (4.5 kg ai ha^{-1}) controlled bermudagrass >95% while maintaining St. Augustinegrass quality. From additional timing and rate studies, McCarty (1996) concluded that applications in November or February contributed little to bermudagrass control and that single applications only provided acceptable control for an abbreviated period of time (<6 wks).

Cudney et al. (1997) reported that fenoxaprop tank mixed with triclopyr (0.21 + 0.56 kg ae ha^{-1}) reduced common bermudagrass cover to 6% after four sequential applications. The same rate of triclopyr applied alone reduced bermudagrass cover to 31%, while fenoxaprop applied alone reduced bermudagrass cover to 8%. In supplementary greenhouse studies, they concluded that tank-mixing triclopyr (1.12 kg ha^{-1}) with fenoxaprop (0.42 kg ha^{-1}) effectively reduced plant injury when applied POST to 1- and 2-leaf perennial ryegrass and tall fescue plants (Cudney et al. 1997). McElroy and Breeden (2006) reported similar results applying combination treatments of fenoxaprop (0.13 kg ha^{-1}), fluazifop (0.10 kg ha^{-1}), and triclopyr (1.12 kg ha^{-1}) to Meyer zoysiagrass. Triclopyr applied alone injured zoysiagrass 1 to 10% after three sequential applications. When applied alone, fenoxaprop injured zoysiagrass 18 to 38%, but tank-mixed with triclopyr, injury was reduced to <5%. Similarly, fluazifop alone injured zoysiagrass 9 to 23%, but injury was reduced to <5% when tank-mixed with triclopyr.

Interactions Between Plant Populations. Each species in a community has its own range of resources and conditions in which it can live and survive. Interactions within a community are complex as they may benefit, harm, or have no effect on the species involved (Booth et al. 2003). In agricultural systems, the negative effect of weeds on crop yield and quality is of utmost importance. The relationship where two or more individuals (e.g. weed vs. crop) make simultaneous demands that exceed limited resources is known as competition. Beard (1973) defined competition as any condition in which the supply of light, water, nutrients, etc., is less than that required for the growth of each individual plant. Much of what is known about the competitive ability of plant species is learned from a comparison of their relative competitiveness with one another in varying environments. Competition may occur between individuals of the same species (intraspecific) or different species (interspecific). Additionally, competition may be divided into above and below ground because plants use different structures to compete for different resources (Booth et al. 2003). As a result, quantifying and interpreting plant competition has been problematic for agronomists and ecologists.

The competitive ability of any organism consists of two distinct aspects: competitive effect and response (Goldberg and Fleetwood 1987; Goldberg and Werner 1983). The competitive effect of an organism is the ability to reduce the performance of another organism whereas the competitive response is the ability to continue to perform well in the presence of competitors. Goldberg and Landa (1991) found significant differences in competitive effect per-plant among seven species in a 5 wk greenhouse experiment. They reported that neighbor species with larger seed mass and larger maximum potential mass had stronger per-plant competitive effects, while neighbor species with higher maximum relative growth rates had stronger per-gram competitive effects. In contrast, target species with lower maximum relative growth rates were better response competitors (Goldberg and Landa 1991).

The most basic ecological principle of competition is that a plant that gains an initial advantage concomitantly increases its competitive advantage (Beard 1973). Weigelt et al. (2002) found that biomass advantage over a competitor (achieved by earlier germination) was significant for successful seedling establishment. Turfgrass communities are often composed of one or many plant species of which possess significant differences in growth habit, root system, and growth requirements (Danneberger 1997). Beard (1973) identified several factors that influence the competitive ability of individual plants in a given environment. These factors include: vertical shoot growth rate, leaf area, form, growth habit, rooting depth, and nutrient uptake ability (Blackshaw and Brandt 2008; Blackshaw et al. 2003; Roush and

Radosevich 1985). The importance of these factors on a plant's competitive ability varies, depending on the turfgrass species present and intensity of culture. In addition to individual plant characteristics, the outcome of competition is often affected by the environment, plant density, and time scale (Booth et al. 2003; Goldberg and Landa 1991).

Blackshaw et al. (2003) evaluated the differential response of weed species to added N fertilizer. They noted that the weed species tested varied greatly in their level of response to soil N levels. More importantly, they reported that many agricultural weeds showed greater response in shoot and root biomass to increasing levels of soil N, compared with crops such as wheat and canola. Similarly, Blackshaw and Brandt (2008) recognized that altered soil N levels may influence crop-weed competitive interactions. They considered yield of weed and crop species grown in mixtures and monoculutres to quantify weed aggressivity index (AI) values. Using these weed AI values, they were able to rank diverse weed species competitiveness with wheat at increasing soil N levels. From their results, Blackshaw and Brandt (2008) concluded that fertilizer management strategies could be employed to favor crop growth over weeds, especially when weeds known to be highly responsive to soil N levels are present.

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II. Conversion of bermudagrass stands to zoysiagrass turf using cultural and chemical methods

Abstract

Field experiments were conducted to evaluate the efficacy of herbicides and soil sterilants for the fairway conversion of Tifway bermudagrass to Zorro zoysiagrass. Treatments included glyphosate (4.48 kg ae ha^{-1}), EPTC (7.84 kg ai ha^{-1}), dazomet (338 kg ai ha^{-1}), siduron (13.4 kg ai ha^{-1}), glyphosate plus ETPC (4.48 + 7.84 kg ha^{-1}), glyphosate plus dazomet (4.48 + 338 kg ha^{-1}), EPTC plus siduron (7.84 + 13.4 kg ha^{-1}), and dazomet plus siduron (338 + 13.4 kg ha^{-1}). Glyphosate treatments were applied 5 wks prior to establishment (WPE), dazomet and EPTC treatments were applied 3 WPE, and siduron was applied at establishment. Dazomet and EPTC treatments were incorporated to a depth of 10 to 15 cm with a rotary tiller and rolled with a weighted roller to reduce losses from volatilization after application. Zorro zoysiagrass was established in June 2008 and 2009 using a mixture of rhizomes and stolons at a rate of 10 bushels 1000 ft^{-2}. Results from field studies were consistent between 2008 and 2009. Results indicate that glyphosate + dazomet, glyphosate + EPTC, dazomet + siduron, and EPTC + siduron were equally effective at controlling Tifway bermudagrass. EPTC and dazomet controlled bermudagrass more effectively when integrated with glyphosate or siduron. There were no significant differences in bermudagrass cover between the EPTC combinations with glyphosate or siduron and dazomet applied with glyphosate or siduron. Comparing EPTC- and dazomet-alone, EPTC yielded significantly less

bermudagrass cover (32%) than dazomet (71%). At present, research is limited on using EPTC for controlling perennial grasses in turfgrass systems. Data from these studies demonstrate the potential use of EPTC as a preplant soil herbicide to control hybrid bermudagrass during turfgrass renovation.

Introduction

Zoysiagrasses (*Zoysia* spp.) are warm-season grasses primarily used in the warm southeast and cooler transition regions of the United States. Due to its slow lateral growth and minimal cultural management requirement, zoysiagrass is a desirable turfgrass for use in home lawns, commercial, and golf course applications (McCarty 2005). Zoysiagrasses exhibit excellent traffic tolerance due to the high lignin and silica content within their leaves. Most improved zoysiagrasses must be established using vegetative propagation (e.g. sod, sprigs, or stolons), but seeded zoysiagrasses (*Zoysia japonica* Steud.) with improved turf quality are now available (Morris 2006; Patton et al. 2004a, 2004b). Once established, zoysiagrass forms a dense turf stand that is a natural deterrent to invading weed populations. Compared to bermudagrass, zoysiagrass exhibits a slower growth-rate, superior shade tolerance, excellent winter hardiness, and requires a lower intensity of management (Bunnell et al. 2005; McCarty 2005).

Bermudagrasses (*Cynodon* spp.) are used widely as turfgrasses throughout the warm climatic regions of the United States. Bermudagrass forms a vigorous turf stand that exhibits excellent recuperative ability and is tolerant to a wide range of environmental and management conditions; therefore, bermudagrass easily contaminates other turf species (Brede 1992; Webster 2000). However, bermudagrass is less adapted to the cooler transition regions of the United States due to its lack of winter hardiness and shade tolerance (Bunnell et al. 2005; Christians 2004; McBee and Holt 1966). Furthermore, bermudagrass is susceptible to 'winter-kill' when grown in areas of the upper transition zone where temperatures frequently drop below -12°C (McCarty 2005).

Turf renovation is increasingly popular where homeowners or turf managers wish to convert from bermudagrass to more desirable zoysiagrass (Foy 2001). This is a difficult task since the same attributes that make bermudagrass a popular turfgrass also make it a difficult-to-control perennial weed during a turfgrass renovation (Ferrell et al. 2005; Webster 2000). A successful turfgrass renovation necessitates the existing grass species be effectively controlled to permit the establishment of a monoculture.

Traditionally, nonselective herbicides have been utilized to kill the existing turf and subsequently replant the desired species; however, successful control is not always achieved (Boyd 1991; Johnson 1976, 1988). In studies conducted by Johnson (1988), 38 to 62% regrowth of four bermudagrass cultivars (Tifway, Tifgreen, Tifdwarf, and Ormond) was observed 1 yr after when treated twice with glyphosate at 2.2 kg ae ha^{-1} and 1 to 2% when treated three times.

Thiocarbamate herbicides, first synthesized in 1954, have been utilized to control perennial grasses, including bermudagrass, in a variety of agronomic crops (Csinos et al. 2000; Dawson 1981; Gray 1975; Harvey et al. 1987). These herbicides are highly volatile which necessitates their incorporation immediately after application (Ashton and Crafts 1981). Thiocarbamates are absorbed via the root or shoot and subsequently inhibit fatty acid and lipid biosynthesis in susceptible grass and broadleaf species (Fuerst 1987). In grasses, the developing leaves beneath the coleoptile and apical intercalary meristems are the primary sites affected (Dawson 1963; Gray and Joo 1978). EPTC is a thiocarbamate herbicide once widely used in corn (*Zea mays* L.) infested with perennial grasses. Several researchers have reported decreased efficacy of EPTC when applied in successive years (Harvey 1985; Harvey et al. 1987; Rahman and James 1983). The aliphatic structure of EPTC renders it susceptible to rapid microbial degradation under field conditions. From field and greenhouse studies, Rahman and James (1983) demonstrated that decreased weed control with EPTC on soils previously treated with EPTC was likely from increased microbial activity. In turfgrass renovation, this would not be a significant problem, as a single application of EPTC would be made to an area of land prior to perennial turfgrass establishment.

Due to the inconsistent control observed using nonselective herbicides, fumigation prior to turf establishment is often required. Methyl bromide has been the predominant broad-spectrum soil fumigant used to eliminate weeds and aid in turfgrass renovation. However, methyl bromide has been identified as an ozone-depleting substance and will ultimately lose registration (Unruh 1998; U. S. Environmental Protection Agency 2010). Dazomet is a granular soil fumigant currently being used in a variety of agricultural sectors to control fungi, nematodes, bacteria, and weed seeds (Fritsch and Huber 1995). Studies conducted by Unruh et al. (2002) found that dazomet (392 kg ai ha^{-1}) did not provide consistent control of coastal bermudagrass [*Cynodon dactylon* (L.) Pers.] and purple nutsedge (*Cyperus rotundus* L.) at two Florida locations (Jay and Arcadia, FL). Unruh et al. (2002) reported that inconsistent coastal bermudagrass control using dazomet might be attributed to the failure to incorporate this material uniformly within the soil profile.

Regrowth of undesirable bermudagrass is a major problem in turfgrass renovation, especially when converting to a different grass species. Severe contamination often leads to a poor turfgrass stand due to differences in color, texture, and growth-habit (Johnson and Carrow 1995). Applications of nonselective herbicides have not proven to effectively control bermudagrass without repeat applications the following year (Boyd 1991; Johnson 1988). Although EPTC is an older thiocarbamate chemistry, there is a potential for its use in controlling perennial grasses prior to turfgrass renovations. At present, research is limited on the efficacy of EPTC and dazomet for the control of hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] prior to turfgrass renovation. The objective of this research was to evaluate integrated practices for the fairway conversion of 'Tifway' bermudagrass to 'Zorro' zoysiagrass.

Materials and Methods

Field studies were conducted in 2008 and 2009 at the Auburn University Turfgrass Research Unit in Auburn, AL to evaluate practices for the fairway conversion of Tifway bermudagrass to Zorro zoysiagrass. Soil was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic Typic Kanhapludult), pH 6.0. The experimental design was a randomized complete block (r = 4) with a plot size of 1.5 x 3 m.

The conversion study was initiated on 9 May 2008 and 8 May 2009. Herbicide treatments were applied in 280 L H_2O ha^{-1} with a CO_2 pressurized boom sprayer at 125 kPa of pressure. Dazomet treatments were applied with a 0.9 m drop spreader. Treatments included glyphosate[1] (4.48 kg ha^{-1}); EPTC[2] (7.84 kg ai ha^{-1}); dazomet[3] (388 kg ha^{-1}); siduron[4] (13.4 kg ai ha^{-1}); glyphosate plus ETPC (4.48 + 7.84 kg ha^{-1}); glyphosate plus dazomet (4.48 + 338 kg ha^{-1}); EPTC plus siduron (7.84 + 13.4 kg ha^{-1}); dazomet plus siduron (388 + 13.4 kg ha^{-1}); and a nontreated control (Table 1). Due to an application error in 2008, dazomet was applied at 222 kg ha^{-1}. Existing Tifway bermudagrass sod was removed on 20 May 2008 and 19 May 2009 before application of dazomet and EPTC. All areas were tilled and rolled prior to application of treatments. Dazomet and EPTC treatments were incorporated to a depth of 10 to 15 cm with a rotary tiller and rolled with a weighted roller to reduce losses from volatilization after application. Additionally, irrigation was applied daily to provide 1.3 cm of water for 7 d after application. 'Zorro' zoysiagrass [*Zoysia matrella* (L.) Merr.] was established on 12 June 2008 and 11 June 2009 using a mixture of rhizomes and stolons at a rate of 10 bushels 1000 ft^{-2}. Sprigs were rolled with a cultipacker in two directions to ensure adequate sprig-to-soil contact. Irrigation was applied eight times daily for the first 4 wk after establishment to provide 3 mm of water in each cycle. Beginning 10 July 2008, irrigation was applied only to prevent zoysiagrass wilting. Turf was mowed at a 3.8 cm height three times a week using a rotary mower.

Prior to sprigging, 16-28-0 (N-P-K) fertilizer was applied to deliver N at 49 kg ha^{-1} on 12 June 2008 and 11 June 2009. Urea (46-0-0) was applied to the entire study to provide N at 24.5 kg ha^{-1} on 24 July; 7 August; 20 August; and 4 September 2008. Tank mixtures of 2,4-D[5] (1.0 kg ae ha^{-1}), dicamba (1.12 kg ae ha^{-1}), and halosulfuron-methyl[6] (0.07 kg ai ha^{-1}) were applied to all plots to control broadleaf and grassy weeds on 11 July and 1 August 2008. Additionally, a single application of quinclorac[7] at 0.84 kg ai ha^{-1} was made on 11 August 2008.

Data Collection and Analysis. The following data was collected each year of the study: (i) percentage ground cover via line transect counts; (ii) visual percent zoysiagrass cover and bermudagrass contamination (data not shown). At 5, 10, and 15 weeks after establishment (WAE), percentage ground cover was determined in each plot by placing a dowel rod (122 cm) randomly across the plot twice. The dowel rod had twenty-five evenly spaced marks. The presence of any part of a zoysiagrass or bermudagrass plant under an intersection of an increment was recorded as a *hit*. The number of hits for each count was converted to percentage ground cover on a plot mean basis.

Percentage ground cover data were analyzed using mixed models methodology as implemented in SAS® PROC GLIMMIX[8]. The behavior of residuals was assessed using graphical means provided through the "StudentPanel" option of the procedure. The arcsine squareroot transformation resulted in homogenous variances among treatment groups (Bartlett 1947). Year, treatment, and weeks after establishment and their interactions were considered fixed effects. The random effects included in the model were Block (Year), Treatment x Block(Year) interaction, and WAE x Block(Year). Because of non-independence among observations taken on each mainplot we did some R-side modeling using the AICC criterion to pick the best-fitting residual structure, a first-order autoregressive model. Least square treatment means were separated utilizing 95% confidence intervals. Pairwise contrasts were utilized to determine differences between: Dazomet vs. EPTC; EPTC vs. EPTC + glyphosate or siduron; EPTC + glyphosate vs. EPTC + siduron; dazomet vs. dazomet + glyphosate or siduron; dazomet + glyphosate vs. dazomet + siduron; and EPTC + glyphosate/siduron vs. dazomet +

glyphosate/siduron. The Type I error rate for the P-values is 0.05/6 = 0.0083 to account for the inflation of Type I error since six contrasts were performed.

Errors-in-variables (EIV) regression was used to compare bermudagrass and zoysiagrass estimates between visual percent cover and line-transect methods. This regression method is appropriate when there is variation for the regressor variable in addition to the variation present in the dependent variable (Good and Hardin 2006). Estimates were obtained using SAS® PROC NLP by minimizing the following quantity:

$$Distance = \frac{[Y-(b_0+b_1*X)]^2}{1+b_1^2},$$

where Y are the observed visual estimates, X refers to the line intercept method values, b_0 is the intercept from regression analysis, and b_1 is the slope estimate.

Results and Discussion

Bermudagrass Coverage. The glyphosate, dazomet, EPTC, and siduron combination treatments yielded significantly less bermudagrass cover compared to the individual treatments at 10 and 15 WAE (Table 2). At 5 WAE, dazomet-alone resulted in greater bermudagrass cover (19%) compared to the glyphosate + dazomet or dazomet + siduron combination treatments (5%). EPTC-alone resulted in equivalent bermudagrass cover (6%) as the glyphosate + EPTC or EPTC + siduron combination treatments, each yielding 4% groundcover. Siduron-alone resulted in the highest bermudagrass cover (30%) among all treatments.

Dazomet-alone yielded 43% bermudagrass cover 10 WAE compared to 26% cover observed from EPTC-alone. Integrating glyphosate or siduron with EPTC resulted in less than half (11 and 5%, respectively) bermudagrass cover compared to EPTC-alone (26%). Similarly, the addition of glyphosate or siduron to dazomet resulted in 4 and 5% bermudagrass cover in contrast to 43% using dazomet-alone. The glyphosate + dazomet, glyphosate + EPTC, dazomet + siduron, and EPTC + siduron treatments all resulted in statistically equivalent bermudagrass cover 10 WAE.

Similar trends in bermudagrass cover were observed at the final rating (15 WAE). Bermudagrass cover from the combination treatments was significantly lower (≤12%) compared to the individual treatments applied alone. EPTC and dazomet controlled bermudagrass more effectively when integrated with glyphosate or siduron. Pairwise contrasts revealed there were no significant differences in bermudagrass cover between the EPTC combinations with glyphosate or siduron and dazomet applied with glyphosate or siduron (Table 2). Comparing EPTC- and dazomet-alone, EPTC yielded significantly less bermudagrass cover (32%) than dazomet (71%). Dazomet, glyphosate, and siduron applied alone were ineffective in controlling bermudagrass, yielding >70% cover 15 WAE.

EIV regression between visual cover and line transect counts showed that the two assessment methods were significantly different at 5 and 10 WAE (Figures 1 to 4). In 2008, EIV regression of 5 WAE data yielded a y-intercept estimate (b_0) of 9.2 with slope estimate (b_1) of 0.88 (Figure 1). However, analysis of 2009 data yielded a y-intercept estimate (b_0) of -4.2 with slope (b_1) of 1.03 (Figure 2). Analysis of 15 WAE data showed decreased error between these two cover assessment methods (Figures 5 and 6). 2008 and 2009 data yielded y-intercept estimates (b_0) of 3.5 and 0.6, respectively, with statistically equivalent slope estimates (b_1) of 0.94 and 0.95. Discrepancies between visual cover and line transect counts is likely due to the experience required and subjective nature of visual estimates. EIV regression estimates of these parameters would ideally be $b_0 = 0$ and $b_1 = 1$. Overall, positive y-intercept estimates indicate the tendency for visual assessment to overestimate turf cover compared to line transect counts in these studies. Based on our experience, line transect counts are more time consuming, but are less subjective in nature and typically require less experience. Analysis of 2009 data illustrate that rating experience and turfgrass knowledge yield similar results of turf cover regardless of method chosen.

Zoysiagrass Coverage. Zoysiagrass cover was greater in treatments that yielded lower bermudagrass cover at all three rating dates (Tables 2 and 3). Over the duration of the study, zoysiagrass cover never exceeded 10% in the nontreated control. The glyphosate + dazomet treatment yielded the greatest zoysiagrass cover (65%) 5 WAE, but this was significant only when compared to the individual siduron and glyphosate treatments. EPTC- and dazomet-alone yielded equivalent zoysiagrass cover (53%) 5 WAE. Integrating glyphosate or siduron with dazomet or EPTC did not significantly increase zoysiagrass cover.

At 10 WAE, the glyphosate + dazomet, dazomet + siduron, and EPTC + siduron treatments yielded significantly greater zoysiagrass cover compared to the individual treatments. EPTC-alone yielded similar zoysiagrass cover (67%) to the EPTC + glyphosate treatment (76%); however, EPTC-alone resulted in less zoysiagrass cover than the EPTC + siduron combination treatment (85%). Dazomet-alone yielded significantly less zoysiagrass cover (48%) than EPTC-alone (67%) due to the lack of bermudagrass control (Table 3).

The four combination treatments yielded significantly greater zoysiagrass cover (>86%) than dazomet, EPTC, glyphosate, and siduron applied alone 15 WAE (Table 3). In particular, zoysiagrass cover was greater when EPTC or dazomet was integrated with glyphosate or siduron. No differences in zoysiagrass cover were observed among combinations with glyphosate compared to combinations with siduron as revealed by contrasts (Table 3). Similar to the observation 10 WAE, dazomet-alone yielded significantly less zoysiagrass cover (31%) than EPTC applied alone (65%) at the final rating. Zoysiagrass cover decreased from 10 to 15 WAE in the individual dazomet, EPTC, glyphosate, and siduron treatments. Decreased zoysiagrass cover in these treatments is primarily due to the lack of bermudagrass control.

EIV regression of zoysiagrass cover data revealed similar results as bermudagrass cover data. At all three rating dates, visual assessment yielded higher zoysiagrass cover than line transect counts except for 10 WAE in 2009 (Figure 10). Data from the 5 WAE rating in 2008 produced the greatest discrepancy between methods (Figure 7). EIV regression analysis of these data yielded a y-intercept estimate (b_0) of 12.1 with slope estimate (b_1) of 0.65. Difference between assessment methods is largely due to lack of rating experience and difficulty in identifying turf species in immature growth stage. Regression analysis of 15 WAE zoysiagrass cover data yielded y-intercept estimates (b_0) of 2.7 and 6.6 with slope estimates (b_1) of 0.91 and 0.92 for 2008 and 2009, respectively (Figure 11 and 12). Similar to bermudagrass cover, visual assessment typically overestimated zoysiagrass cover compared to line transect method.

Overall, an inverse relationship was observed between zoysiagrass and bermudagrass groundcover in these studies (Tables 2 and 3). Integrating glyphosate or siduron with dazomet or EPTC provided adequate bermudagrass control and permitted acceptable establishment of zoysiagrass. Conversely, the individual dazomet, EPTC, glyphosate, and siduron treatments provided poor bermudagrass control and resulted in poor zoysiagrass establishment (Johnson 1988). These treatments, with the addition of the nontreated control, exemplify the robust nature of bermudagrass and demonstrate the need for adequate control of an existing bermudagrass stand when reestablishing zoysiagrass. Bermudagrass control ratings reported in this study using dazomet-alone are similar to a previous report by Unruh et al. (2002). By 15 WAT, Unruh et al. (2002) reported less than 45% coastal bermudagrass control using dazomet (392 kg ha^{-1}) or dazomet + chloropicrin (392 + 168 kg ha^{-1}).

These data indicate that combination treatments of glyphosate + dazomet, glyphosate + EPTC, dazomet + siduron, and EPTC + siduron may be effective in controlling hybrid bermudagrass prior to turfgrass renovations. In these studies, dazomet and EPTC combination treatments were equally effective for bermudagrass control. Dazomet is relatively expensive ($11 kg^{-1}) and its efficacy of perennial grass control has been reported to vary over years and locations (Unruh et al. 2002). Additionally, dazomet's formulation as a fine powder (granule) necessitates even distribution within the soil profile and adequate soil moisture to achieve consistent weed control. EPTC's relatively low cost and ease of application make it desirable compared to dazomet. At present, research is limited on using EPTC for controlling perennial grasses in turfgrass systems. Data from these studies demonstrate the potential use of EPTC as a preplant incorporated herbicide to control hybrid bermudagrass during turfgrass renovation.

Sources of Materials

[1]RoundUp Pro® herbicide, Monsanto Company, St. Louis, MO 63167.

[2]Eptam® 7-E herbicide, Gowan Company, Yuma, AZ 85366-5569.

[3]Basamid® G Soil sterilant, Certis USA LLC, Columbia, MD 21046.

[4]Tupersan® herbicide, Gowan Company, Yuma, AZ 85366-5569.

[5]Agri Star® 2,4-D LV6 low volatile herbicide, Albaugh, Inc., Ankeny, IA 50021.

[6]Manage® herbicide, Gowan Company, Yuma, AZ 85366-5569.

[7]Drive® 75 DF herbicide, BASF Corporation, Research Triangle Park, NC 27709.

[8]SAS® Statistical Software v. 9.1, SAS Institute, Inc. Cary, NC 27513-2414.

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Table 1: Treatments and application timings used for bermudagrass to zoysiagrass conversion study, where sprigs and stolons of cv. Zorro [*Zoysia matrella* (L.) Merr] were established on 12 June 2008 and 11 June 2009.

Treatment	Rate	Timing	Dates applied
	kg ha^{-1}		
EPTC	7.8	3 WPE	22 May 2008; 22 May 2009
Dazomet	388	3 WPE	22 May 2008; 22 May 2009
Glyphosate	4.5	5 WPE = weeks prior to establishment	9 May 2008; 8 May 2009
Siduron	13.4	EST = at establishment	12 June 2008; 11 June 2009
Glyphosate + EPTC	4.5 + 7.8	5 WPE + 3 WPE	9 May 2008 + 22 May 2008; 8 May 2009 + 22 May 2009
EPTC + Siduron	7.8 + 13.4	3 WPE + At EST	22 May 2008 + 12 June 2008; 22 May 2009 + 11 June 2009
Glyphosate + Dazomet	4.5 + 388	5 WPE + 3 WPE	9 May 2008 + 22 May 2008; 8 May 2009 + 22 May 2009
Dazomet + Siduron	388 + 13.4	3 WPE + At EST	22 May 2008 + 12 June 2008; 22 May 2009 + 11 June 2009
Nontreated control	—	—	—

Table 2: Estimates of percentage ground cover obtained from the line intercept method, 95% confidence limits, and P-values from contrasts among treatments for Tifway bermudagrass 5, 10, and 15 weeks after establishment (WAE). Treatment means represent averages over the two experimental years and were backtransformed from the arcsine scale on which the statistical analysis was performed. The critical P-value was adjusted from 0.05 to 0.05/6 = 0.0083 to account for the inflation of Type I error since six contrasts were performed.

	Tifway bermudagrass					
	5 WAE		10 WAE		15 WAE	
Treatment	Estimate	95% CL	Estimate	95% CL	Estimate	95% CL
	% Cover					
Nontreated	90	[82, 95]	100	[97,100]	100	[98, 99]
EPTC	6	[2, 13]	26	[19, 35]	32	[23, 43]
Dazomet	19	[11, 28]	43	[34, 52]	71	[61, 80]
Glyphosate	15	[8, 23]	43	[33, 52]	73	[63, 82]
Siduron	30	[20, 40]	66	[57, 74]	87	[79, 93]
Glyphosate + EPTC	4	[1, 9]	11	[5, 17]	12	[6, 20]
EPTC + Siduron	4	[1, 10]	5	[2, 10]	9	[4, 15]
Glyphosate + Dazomet	5	[2, 11]	4	[1, 9]	6	[2, 12]
Dazomet + Siduron	5	[1, 11]	5	[2, 9]	5	[1, 10]
Contrasts	*P* value					
Dazomet vs. EPTC	0.010		0.010		**<0.001**	
EPTC vs. Dazomet when combined with glyphosate or siduron	0.583		0.166		0.081	
Adding glyphosate or siduron to EPTC	0.411		**<0.001**		**<0.001**	
Glyphosate vs. siduron when combined with EPTC	0.944		0.106		0.407	
Adding glyphosate or siduron to dazomet	**0.002**		**<0.001**		**<0.001**	
Glyphosate vs. siduron when combined with dazomet	0.954		0.856		0.723	

Table 3: Estimates of percentage ground cover obtained from the line intercept method, 95% confidence limits, and P-values from contrasts among treatments for Zorro zoysiagrass 5, 10, and 15 weeks after establishment (WAE). Treatment means represent averages over the two experimental years and were backtransformed from the arcsine scale on which the statistical analysis was performed. The critical P-value was adjusted from 0.05 to 0.05/6 = 0.0083 to account for the inflation of Type I error since six contrasts were performed

	Zorro zoysiagrass					
	5 WAE		10 WAE		15 WAE	
Treatment	Estimate	95% CL	Estimate	95% CL	Estimate	95% CL
	% Cover					
Nontreated	10	[5, 16]	0	[0, 1]	0	[1, 2]
EPTC	53	[44, 62]	67	[59, 76]	65	[54, 75]
Dazomet	53	[44, 61]	48	[39, 57]	31	[22, 42]
Glyphosate	45	[36, 54]	45	[36, 54]	27	[18, 37]
Siduron	40	[31, 48]	23	[16, 31]	13	[7, 22]
Glyphosate + EPTC	55	[46, 63]	76	[68, 84]	86	[77, 93]
EPTC + Siduron	57	[48, 65]	85	[78, 91]	90	[82, 96]
Glyphosate + Dazomet	65	[56, 73]	89	[83, 94]	93	[86, 97]
Dazomet + Siduron	58	[49, 67]	85	[78, 91]	94	[88, 98]
Contrasts	*P* value					
Dazomet vs. EPTC	0.972		**0.003**		**<0.001**	
EPTC vs. Dazomet when combined with glyphosate or siduron	0.161		0.058		0.080	
Adding glyphosate or siduron to EPTC	0.608		**0.008**		**<0.001**	
Glyphosate vs. siduron when combined with EPTC	0.752		0.089		0.429	
Adding glyphosate or siduron to dazomet	0.092		**<0.001**		**<0.001**	
Glyphosate vs. siduron when combined with dazomet	0.265		0.317		0.429	

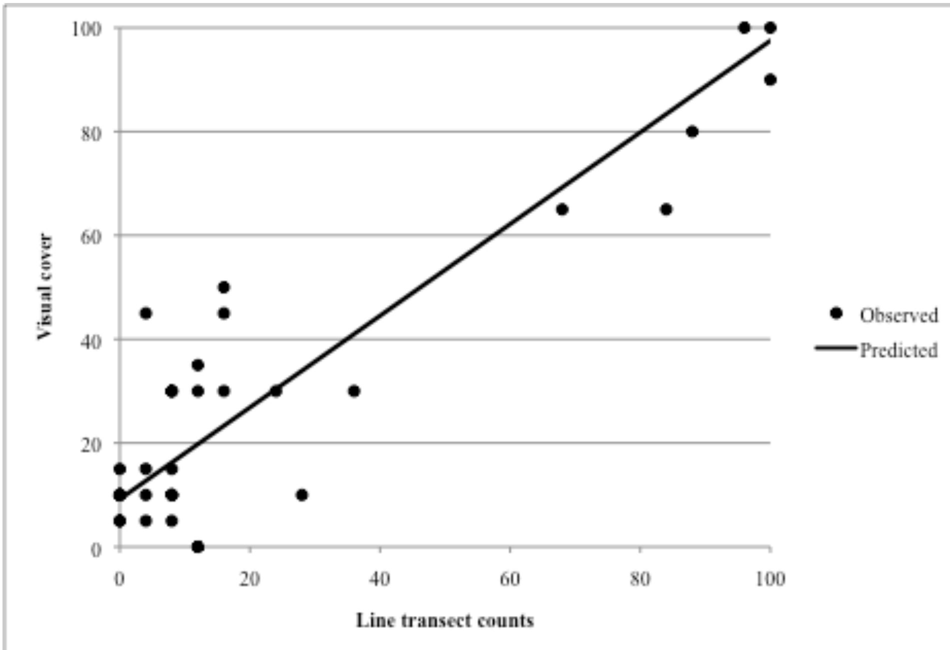

Figure 1: EIV regression of Tifway bermudagrass cover (2008) assessed visually and using line transect counts 5 weeks after zoysiagrass establishment.

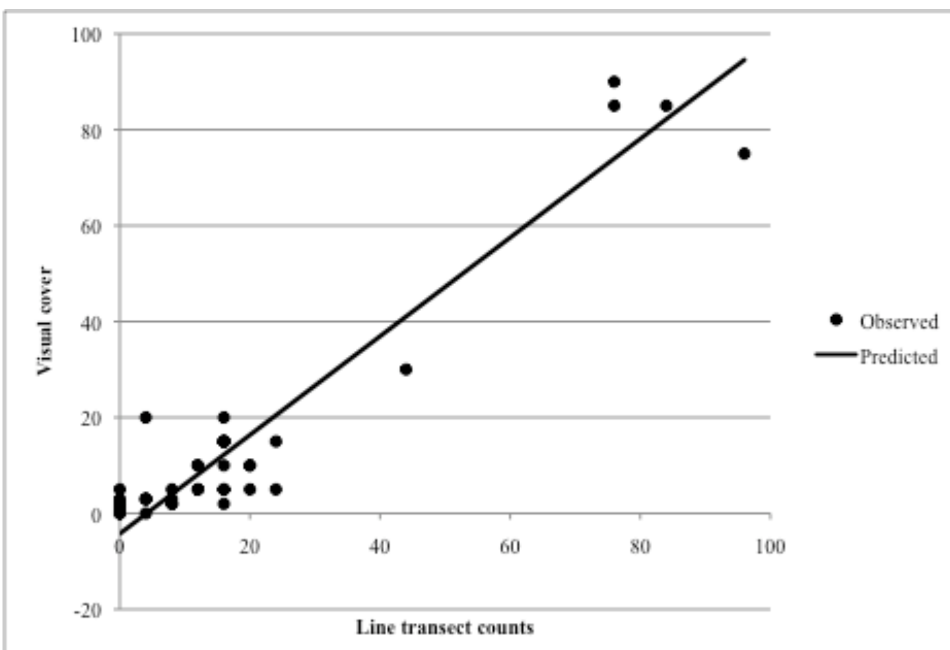

Figure 2: EIV regression of Tifway bermudagrass cover (2009) assessed visually and using line transect counts 5 weeks after zoysiagrass establishment.

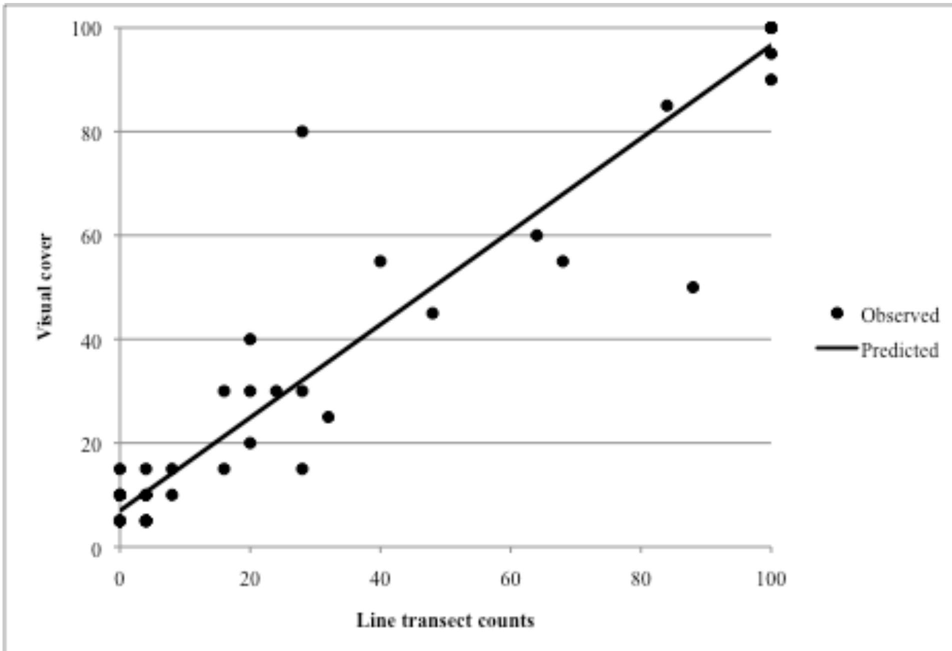

Figure 3: EIV regression of Tifway bermudagrass cover (2008) assessed visually and using line transect counts 10 weeks after zoysiagrass establishment.

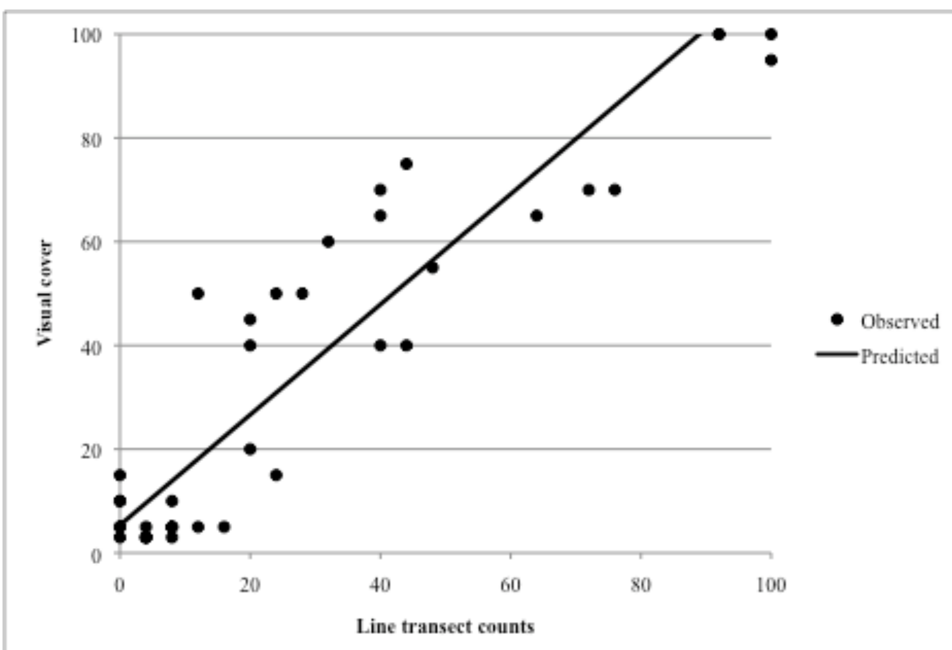

Figure 4: EIV regression of Tifway bermudagrass cover (2009) assessed visually and using line transect counts 10 weeks after zoysiagrass establishment

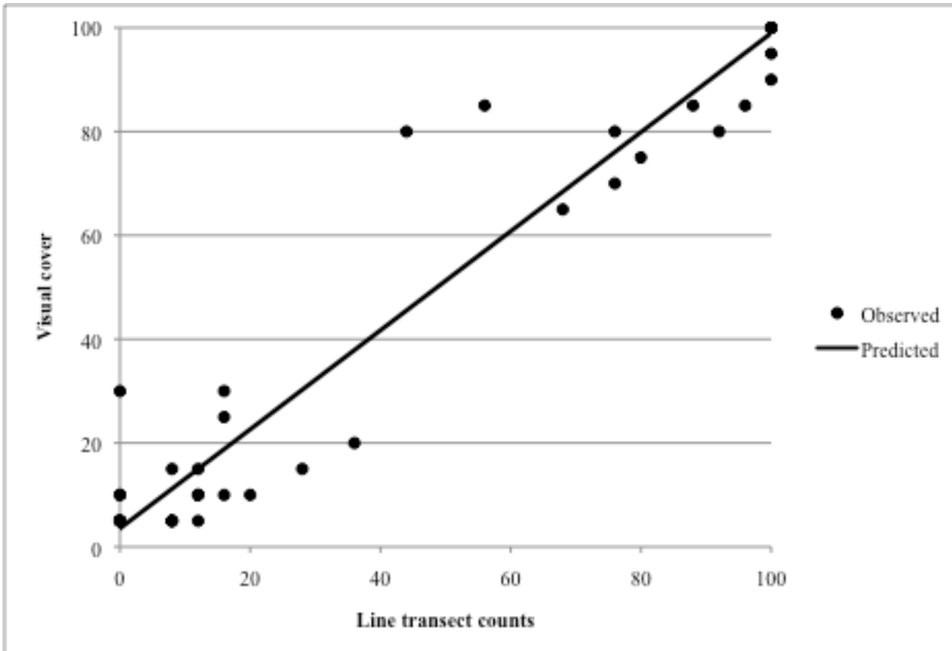

Figure 5: EIV regression of Tifway bermudagrass cover (2008) assessed visually and using line transect counts 15 weeks after zoysiagrass establishment.

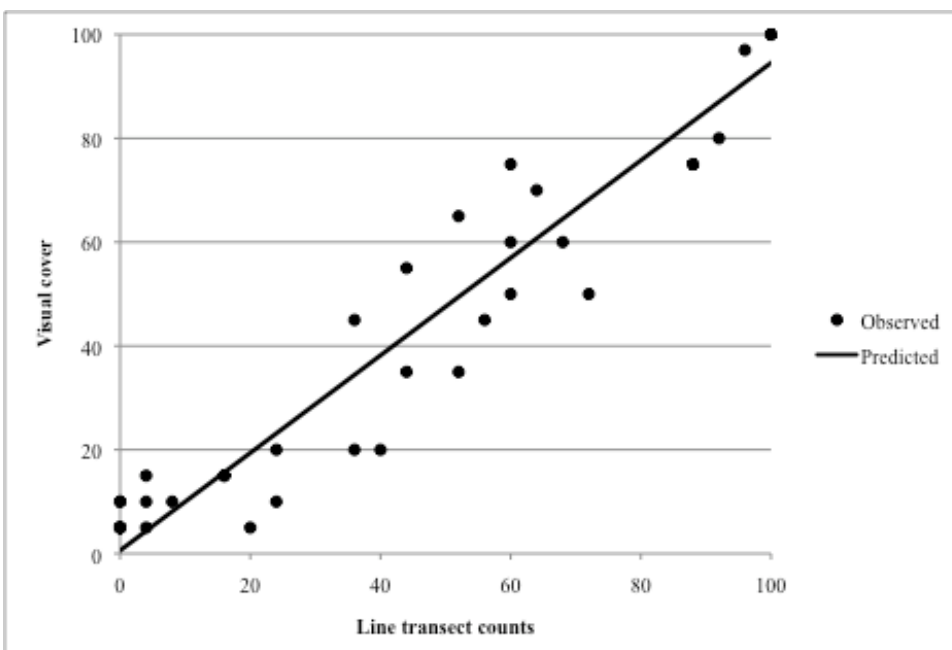

Figure 6: EIV regression of Tifway bermudagrass cover (2009) assessed visually and using line transect counts 15 weeks after zoysiagrass establishment.

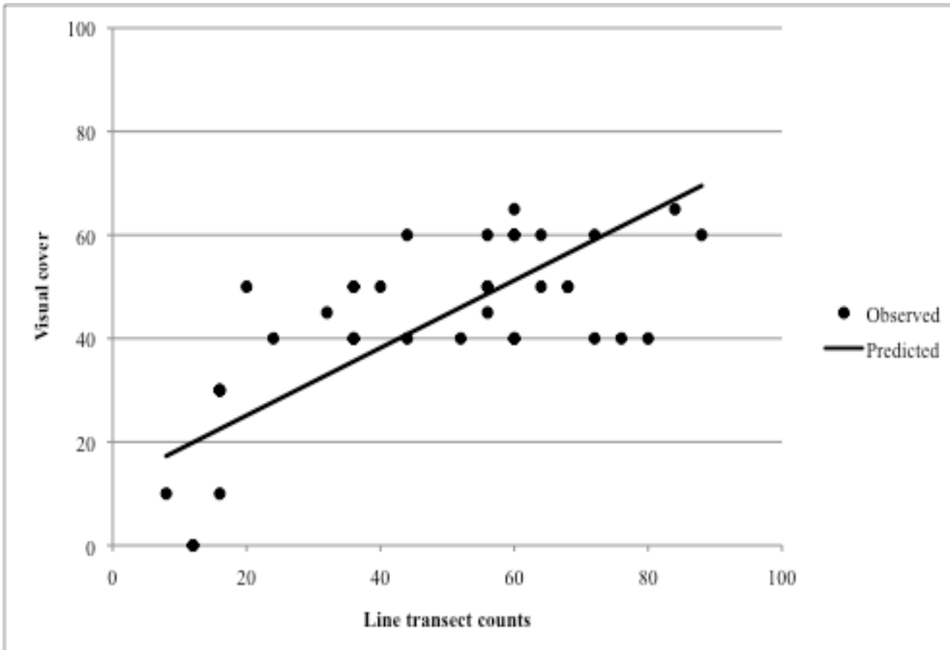

Figure 7: EIV regression of Zorro zoysiagrass cover (2008) assessed visually and using line transect counts 5 weeks after zoysiagrass establishment.

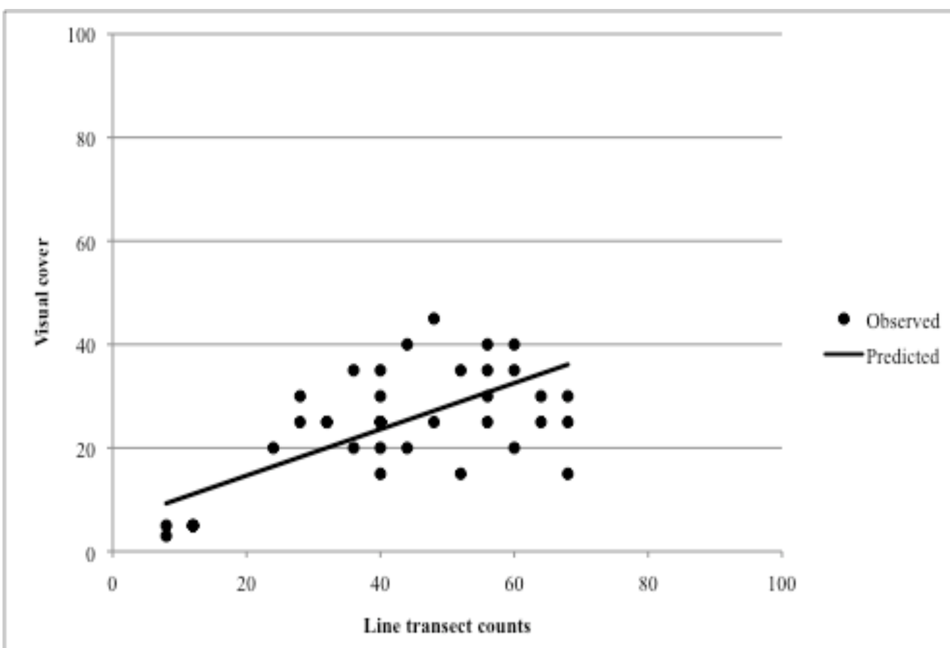

Figure 8: EIV regression of Zorro zoysiagrass cover (2009) assessed visually and using line transect counts 5 weeks after zoysiagrass establishment.

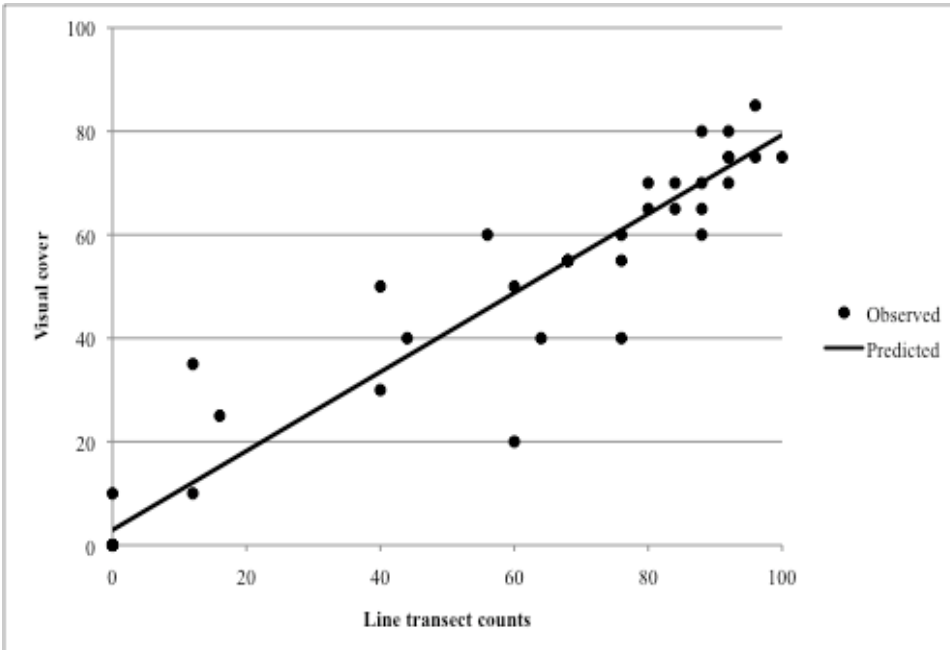

Figure 9: EIV regression of Zorro zoysiagrass cover (2008) assessed visually and using line transect counts 10 weeks after zoysiagrass establishment.

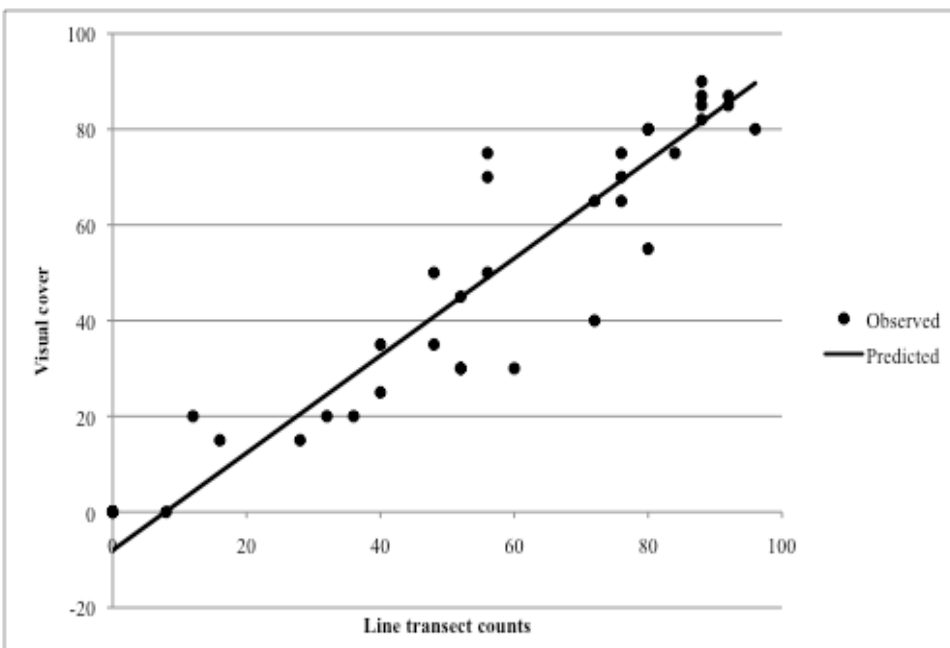

Figure 10: EIV regression of Zorro zoysiagrass cover (2009) assessed visually and using line transect counts 10 weeks after zoysiagrass establishment.

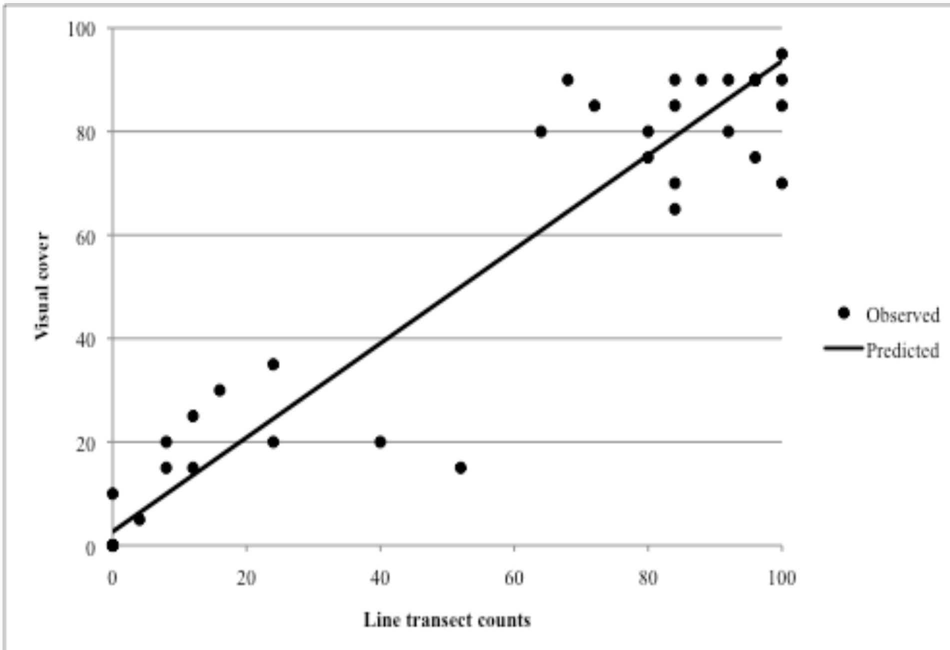

Figure 11: EIV regression of Zorro zoysiagrass cover (2008) assessed visually and using line transect counts 15 weeks after zoysiagrass establishment.

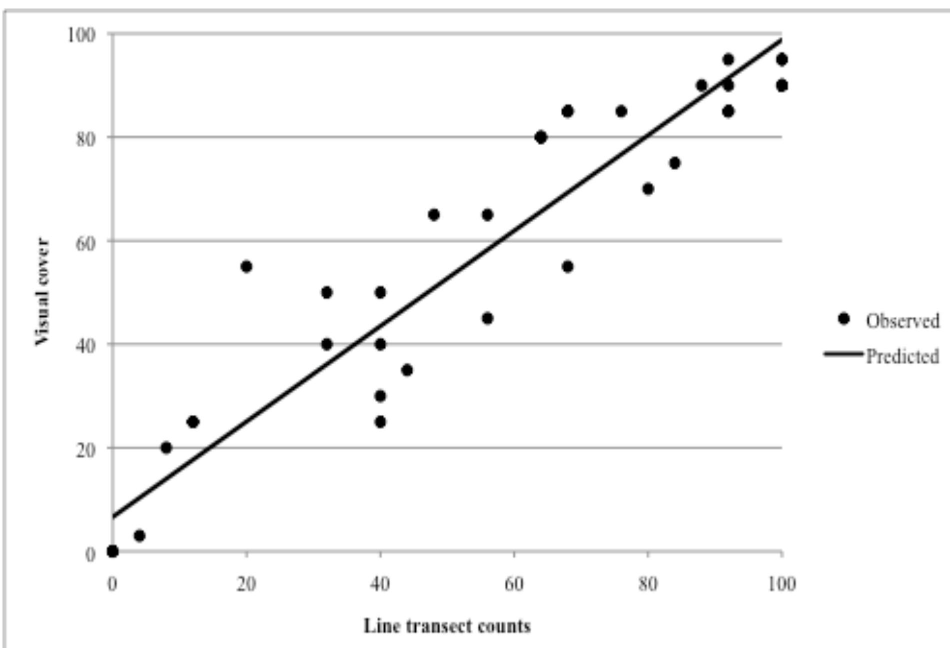

Figure 12: EIV regression of Zorro zoysiagrass cover (2009) assessed visually and using line transect counts 15 weeks after zoysiagrass establishment.

III. Evaluation of various cultural practices on zoysiagrass competitiveness with bermudagrass

Abstract

Field experiments were conducted to evaluate the effect of nitrogen fertilizer applied alone and in combination with the plant growth retardant, trinexapac-ethyl (TE), on zoysiagrass competitiveness with two bermudagrass cultivars. Treatments included: TE at 0.05 kg ai ha^{-1}; TE + Urea at 12.3, 24.5 and 49 kg N ha^{-1}; Urea alone at 12.3, 24.5, and 49 kg N ha^{-1}; and a nontreated control. Treatments were applied at 3 wk intervals for a total of three applications per yr. Maximum diameter bermudagrass spread measurements were taken 4, 8, and 12 weeks after initial treatment (WAIT). Additionally, zoysiagrass color was visually assessed on a 1-9 scale, with 9 representing ideal dark green, fine-textured turf, 6 representing minimally acceptable turf, and 1 representing dead turf. Tifway and common bermudagrass differed in response to experimental treatments. Trinexapac-ethyl alone was the only treatment to result in decreased Tifway spread throughout the study, relative to the nontreated. Tifway bermudagrass spread was greatest from the 49 kg N ha^{-1} and TE plus 49 kg N ha^{-1} treatments (4.1 and 4.3 cm, respectively) 12 WAIT. All nitrogen rates evaluated in this study reduced the ability of TE to suppress Tifway bermudagrass spread in zoysiagrass. All nitrogen rates applied alone resulted in statistically equivalent common bermudagrass spread as TE applied alone. Trinexapac-ethyl plus 49 kg N ha^{-1} resulted in the greatest common bermudagrass spread 12 WAIT, equivalent only to TE plus 12.3 kg N ha^{-1}.

Applying TE plus nitrogen (12.3 or 49 kg ha^{-1}) resulted in significantly greater common bermudagrass spread (3.9 and 6.2 cm, respectively) than all rates of nitrogen or TE applied alone. Zorro zoysiagrass color was most ideal (dark green) for the 49 kg N ha^{-1} and TE plus 49 kg N ha^{-1} treatments throughout the study. All treatments, other than the nontreated, produced acceptable zoysiagrass turf color (≥6). Results of these studies indicate that nitrogen fertilizer applied with trinexapac-ethyl may reduce the efficacy of bermudagrass suppression.

Introduction

A mixed stand of zoysiagrass (*Zoysia* spp.) and bermudagrass (*Cynodon* spp.) produces a poor turfgrass stand due to differences in color, texture, and growth habit (Johnson and Carrow 1995). In general, zoysiagrasses are slow growing, relatively tolerant to heat and shade, and exhibit a unique green color during the summer months (Bunnell et al. 2005; McCarty 2005). Bermudagrass is particularly invasive in zoysiagrass because of its aggressive growth rate and rhizomatous-stoloniferous habit (McCarty 2005). Research on herbicidal control of bermudagrass in zoysiagrass has produced varying results due to the similar herbicide tolerance of these two grasses, often causing severe injury to zoysiagrass and allowing suppressed bermudagrass to regrow (Dernoeden 1989; Johnson 1987, 1992a; McElroy and Breeden 2006). Furthermore, multiple applications over a 2 yr period may be required for complete eradication.

An alternative method of managing bermudagrass contamination in zoysiagrass is through the use of cultural practices. Fertilization and mowing are two of the most common cultural practices used in managing turfgrass. Improved turfgrass stands often develop if cultural practices favor the growth of one species over another. Brede (1992) reported tall fescue (*Festuca arundinacea* Schreb.) mowed at 5.7 cm and fertilized with 49 kg N ha^{-1} yr^{-1} resisted common bermudagrass invasion better compared to a 1.9 cm mowing height and 244 kg N ha^{-1} yr^{-1}. Similarly, Hoyle et al. (2009) reported significantly less bermudagrass cover in tall fescue turf mowed at 7.6 and 10.2 cm than when mowed at 2.5 or 5.1 cm. Others have reported a similar relationship between weed infestation and cultural management practices (Dernoeden et al. 1993; Gray and Call 1993; Henry et al. 2007; Hoyle et al. 2008; Lowe 1998). In studies where a significant effect has been detected within the mowing heights evaluated, lower mowing height is largely associated with greater weed density in turfgrasses. In golf course applications, industry standards often dictate mowing heights of fairways, tees, and greens and may not be altered. Therefore, the use of plant growth retardants (PGRs) and manipulation of nitrogen rate may be beneficial to improve turfgrass stands.

Plant growth retardants are commonly used on golf course fairways and greens to reduce mowing frequency and suppress seedhead production (Ervin et al. 2002; Johnson 1992b, 1993, 1994; Johnson and Murphy 1996; Richardson 2002). Flurprimidol and paclobutrazol applied in two sequential applications have been shown to reduce 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] clipping weight up to 83% and plant height 72% (Johnson 1990, 1992b; Johnson and Duncan 2000; Lowe and Whitwell 1999). Johnson and Carrow (1989) reported significantly less stolons on Tifway and Tifgreen bermudagrass plugs when treated with two applications of flurprimidol at 0.8 kg ai ha^{-1}. However, there was no difference in stolon number between treated and untreated common bermudagrass [*C. dactylon* (L.) Pers.] plugs

(Johnson and Carrow 1989). Additionally, PGR use prior to overseeding has been shown to reduce bermudagrass growth competition, allowing a smoother transition to the overseeded grass (McCarty and Weinbrecht 1996).

Trinexapac-ethyl (TE) is a PGR that effectively reduces gibberellic acid (GA) biosynthesis and subsequent shoot cell elongation (Ervin et al. 2002; Qian and Engelke 1999; Rademacher 2000). Johnson (1992a) reported that TE applied at 0.2 kg ai ha^{-1} suppressed vegetative growth of common bermudagrass for 3 weeks and Tifway bermudagrass up to 8 weeks. Furthermore, Johnson (1992a) reported a second application of TE 3 weeks after initial application extended suppression for 4 weeks. Similarly, Fagerness and Yelverton (2000) reported three sequential applications of TE at 0.071 kg ha^{-1} suppressed Tifway growth for 10 weeks after initial treatment (WAIT).

Nitrogen requirement of bermudagrass and zoysiagrass differ markedly. In highly managed turfgrass systems, such as golf courses, bermudagrass requires up to 390 kg N ha^{-1} yr^{-1} while zoysiagrass requires significantly less nitrogen (146 kg ha^{-1} yr^{-1}) (McCarty 2005). Nitrogen applications have not been shown to reduce the efficacy of PGRs or herbicides on bermudagrass suppression (Johnson 1988; Rogers et al. 1987). Little information is available on the use of PGRs and nitrogen to decrease bermudagrass spread in zoysiagrass. Therefore, field studies were conducted to evaluate the influence of sequential applications of trinexapac-ethyl and nitrogen on the competitiveness of zoysiagrass with bermudagrass.

Materials and Methods

Field studies were conducted in 2008 and 2009 at the Auburn University Turfgrass Research Unit in Auburn, AL. Soil was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic Typic Kanhapludult), pH 6.0. The experimental design was a split-plot design (r = 3) with treatment as the main plot factor and bermudagrass cultivar as the subplot factor. Experimental plots measured 1.5 x 1.5 meters.

Studies were initiated in April 2008 and 2009. Glyphosate (2.24 kg ae ha^{-1}) was applied to the entire research area 4 weeks prior to mechanically removing bermudagrass sod. A second application of glyphosate was applied to kill any bermudagrass regrowth 2 weeks before zoysiagrass establishment. Prior to planting zoysiagrass sod, 16-28-0 (N-P-K) fertilizer was applied to deliver N at 49 kg ha^{-1} on 12 June 2008 and 11 June 2009. No further nitrogen applications were made aside from the experimental treatments. 'Zorro' zoysiagrass [*Zoysia matrella* (L.) Merr] sod was established on 12 June 2008 and 11 June 2009. A weighted roller was used to ensure adequate root-to-soil contact and to smooth the surface to prevent mower scalping. Irrigation was applied eight times daily for the first 4 weeks after establishment to provide 3 mm of water in each cycle. Beginning 10 July 2008 and 13 July 2009, irrigation was applied only to prevent zoysiagrass wilting. The entire area was topdressed with 0.5 ft^3 sand 1000 ft^{-2} 3 weeks after planting to encourage establishment and fill any voids between sod. Turf was mowed three times per week at 1.8 cm cutting height with clippings returned to the surface.

A standard USGA (United States Golf Association) cup cutter was used to transplant two Tifway bermudagrass and two common bermudagrass plugs into each plot on 24 July 2008 and 20 July 2009. Each plug was 10.8 cm in diameter and 10.2 cm deep. Bermudagrass plugs were harvested from established turf areas at the Auburn University Turfgrass Research Unit. Plugs were planted approximately 0.7 m from the corner of each 1.5 x 1.5 m plot to allow lateral growth of individual plugs without encroachment on adjacent bermudagrass plugs. Common and Tifway bermudagrass plugs were randomly assigned to one of four possible positions within each plot.

Treatments were initiated on 31 July 2008 and 6 August 2009. Experimental treatments were applied at 3 week intervals for a total of three applications per year. Trinexapac-ethyl[1] treatments were applied in 280 L H_2O ha^{-1} with a CO_2 pressurized boom sprayer. Nitrogen treatments were applied using uncoated granular urea (46-0-0). Treatments included: TE at 0.05 kg ha^{-1}; TE + Urea at 12.3, 24.5 and 49 kg N ha^{-1}; Urea alone at 12.3, 24.5, and 49 kg N ha^{-1}; and a nontreated control (Table 4).

Data Collection and Analysis. Maximum diameter bermudagrass spread measurements were taken 4, 8, and 12 WAIT. Diameter spread of each plug was taken as the average measurement in two directions Diameter spread data were expressed relative to the nontreated for analysis. Additionally, zoysiagrass color was visually assessed 4, 8, and 12 WAIT on a 1-9 scale, with 9 representing ideal dark green, fine-textured turf, 6 representing minimally acceptable turf, and 1 representing dead turf.

Bermudagrass diameter spread and zoysiagrass color data were analyzed using SAS® PROC GLM[2]. Fisher's protected least-significant difference ($P = 0.05$) is provided as a general means of comparison among treatments, and pairwise contrasts were used when making preplanned comparisons according to initial experimental objectives.

Alpha levels were adjusted to account for the inflation of Type I error using 0.05/*n*, where *n* is the number of contrasts performed.

Results and Discussion

Treatment by species interaction was significant (P <0.001) for bermudagrass diameter spread and did not allow for pooling; therefore data is presented separately by species. Experimental year and treatment by WAIT interaction was not significant for zoysiagrass color; therefore data was pooled across experimental years and rating dates.

Tifway bermudagrass. Tifway bermudagrass diameter spread was greater 8 and 12 WAIT with increasing nitrogen rates compared to common bermudagrass (Tables 5 and 6). Trinexapac-ethyl applied alone resulted in the smallest Tifway spread at all rating dates. The addition of nitrogen (12.3, 24.5, or 49 kg ha^{-1}) to TE significantly increased Tifway spread at all rating dates except for 4 WAIT with the 12.3 kg ha^{-1} nitrogen rate. Contrasts revealed that Tifway spread was not significantly different at any rating date when nitrogen was applied with TE compared to nitrogen applied alone.

Trinexapac-ethyl alone resulted in decreased Tifway bermudagrass spread compared to the nontreated 4 WAIT. The addition of nitrogen (24.5 and 49 kg ha^{-1}) to TE significantly increased Tifway spread compared to TE alone, but did not increase spread at the lowest nitrogen rate of 12.3 kg ha^{-1}. The TE plus 49 kg N ha^{-1} treatment resulted in greater Tifway spread (2.5 cm) than either TE plus 12.3 or 24.5 kg N ha^{-1}, but was not significantly different than 49 kg N ha^{-1} applied alone.

Tifway bermudagrass diameter spread increased consistently with increasing nitrogen rates applied alone 8 WAIT (Table 5). All rates of nitrogen applied with TE resulted in significantly greater Tifway spread compared to TE applied alone. Trinexapac-ethyl plus 24.5 or 49 kg N ha^{-1} resulted in greater Tifway spread than TE plus 12.3 kg N ha^{-1}, but was not significantly different from nitrogen (24.5 or 49 kg ha^{-1}) applied alone.

Tifway bermudagrass spread was greatest from the 49 kg N ha^{-1} and TE plus 49 kg N ha^{-1} treatments (4.1 and 4.3 cm, respectively) 12 WAIT. Trinexapac-ethyl alone was the only treatment to result in decreased Tifway spread throughout the study, relative to the nontreated. All nitrogen rates evaluated in this study reduced the ability of TE to suppress Tifway bermudagrass spread in zoysiagrass. This is contrary to previous reports by Rogers et al. (1987) and Johnson (1988) where bermudagrass suppression is similar between flurprimidol and flurprimidol applied with 25 and 50 kg N ha^{-1}. This might be due to differences between trinexapac-ethyl and flurprimidol or that Johnson (1988) recorded Tifway bermudagrass vegetative height rather than diameter spread as recorded in this study. Trinexapac-ethyl and flurprimidol are both classified as Type II PGRs that inhibit GA biosynthesis; however they differ in activity within the GA biosynthesis pathway and absorption into the plant (Rademacher 2000; Totten et al. 2006). Flurprimidol interrupts GA biosynthesis early in the pathway via the cytochrome p450 monoonxygenase enzyme and is predominately root absorbed (Rademacher 2000). In contrast, trinexapac-ethyl interrupts GA biosynthesis late in the pathway via the 3β-hydroxylase enzyme and is foliar absorbed (Rademacher 2000).

Common bermudagrass. Common bermudagrass spread did not increase with nitrogen rate at any rating date (Table 6). Similar to the results observed on Tifway bermudagrass, the addition of nitrogen to TE, particularly 49 kg ha^{-1}, reduced the efficacy of TE to suppress common bermudagrass spread in zoysiagrass.

Common bermudagrass spread was statistically equivalent among all treatments 4 WAIT, except for TE plus 49 kg N ha^{-1}, which resulted in the greatest spread (3.9 cm) relative to the nontreated control. Nitrogen (12.3 and 24.5 kg ha^{-1}) applied with TE did not reduce TE's ability to suppress common bermudagrass spread 4 WAIT. Contrasts revealed that common bermudagrass spread was significantly different only when the highest rate of nitrogen (49 kg ha^{-1}) was applied with TE compared to nitrogen (49 kg ha^{-1}) applied alone.

Eight weeks after the initial application, all nitrogen rates applied alone resulted in decreased or minimal (<1 cm) common bermudagrass spread relative to the nontreated. Treatment with TE plus 12.3 or 49 kg N ha^{-1} resulted in significantly greater common bermudagrass spread compared to nitrogen applications alone; however, this relationship was not observed for the 24.5 kg ha^{-1} nitrogen rate (Table 6). Applying nitrogen at 49 kg ha^{-1} with TE significantly increased common bermudagrass spread compared to TE applied alone (0.4 to 4.7cm).

Trinexapac-ethyl plus 49 kg N ha^{-1} resulted in the greatest common bermudagrass spread 12 WAIT, equivalent only to TE plus 12.3 kg N ha^{-1} (Table 6). All nitrogen rates applied alone resulted in statistically equivalent bermudagrass spread as TE applied alone. However, applying TE plus nitrogen (12.3 or 49 kg ha^{-1}) resulted in significantly greater common bermudagrass spread (3.9 and 6.2 cm, respectively) than all rates of nitrogen or TE applied alone (≤1.2 cm).

Zoysiagrass Color. Zorro zoysiagrass color was most ideal (dark green) for the 49 kg N ha^{-1} and TE plus 49 kg N ha^{-1} treatments throughout the study (Table 7). All treatments, other than the nontreated, produced acceptable zoysiagrass turf color (≥6). Trinexapac-ethyl applied alone produced darker green turf compared to the nontreated. This is similar to previous reports by Qian and Engelke (1999) and Ervin et al. (2002) where monthly applications of TE at 0.05 kg ha^{-1} to 'Diamond' zoysiagrass [*Zoysia matrella* (L.) Merr] and 'Meyer' zoysiagrass (*Z. japonica* Steud.) improved turf quality (color and density) compared to the nontreated. All rates of nitrogen applied alone and with TE improved turf color compared to TE alone. Trinexapac-ethyl applied with nitrogen (12.3 or 49 kg ha^{-1}) did not improve turf color compared to these nitrogen rates applied alone. Zoysiagrass color was slightly darker when 24.5 kg N ha^{-1} was applied with TE (8.3) than when nitrogen (24.5 kg ha^{-1}) was applied alone (8.1).

Management and Research Implications. Data from these studies indicate the application of nitrogen reduces the ability of TE to suppress Tifway and common bermudagrass spread in zoysiagrass. Suppression of lateral growth differed between Tifway and common bermudagrass, as indicated by a previous report by Johnson and Duncan (2000), where sequential ethofumesate plus flurprimidol treatments suppressed Tifway bermudagrass greater than common bermudagrass. Overall, TE applied alone consistently reduced Tifway bermudagrass spread compared to the nontreated. A secondary benefit to applying TE to a mixed stand of Tifway bermudagrass and zoysiagrass is improved zoysiagrass color (Table 7). Therefore, reducing nitrogen fertilizer inputs and subsequently applying a plant growth retardant, such as TE, may serve to increase the competitiveness of zoysiagrass with Tifway bermudagrass and improve turf color.

Common bermudagrass did not respond to increasing nitrogen rates in these studies. However, applying nitrogen with trinexapac-ethyl enhanced common bermudagrass spread in zoysiagrass. Even though zoysiagrass color improved with increasing nitrogen rates applied with TE, these treatments were not conducive to suppressing common bermudagrass spread in zoysiagrass. Therefore, turf managers may choose to make sequential applications of a PGR or apply nitrogen separately to encourage zoysiagrass growth.

Future research evaluating different zoysiagrass varieties, especially those with growth rates similar to bermudagrass (e.g. *Zoysia japoncia* Steud.), may make nitrogen management and PGR usage a viable option for suppression of bermudagrass in zoysiagrass (Karcher et al. 2005). Additionally, conducting field studies with zoysiagrass planted within bermudagrass may provide valuable information about competition between these two grass species.

Sources of Materials

[1]Primo MAXX® Plant Growth Regulator, Syngenta Crop Protection, Inc., Greensboro, NC 27409.

[2]SAS® Statistical Software v. 9.1, SAS Institute, Inc. Cary, NC 27513-2414.

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Table 4: Treatments and application timings used to evaluate the effect of nitrogen and the plant growth retardant, trinexapac-ethyl, on zoysiagrass competitiveness with common and Tifway bermudagrass.[a]

Treatment	Trade Name/Product	Rate	Yearly N Applied	Application Description
		kg ha^{-1}	kg ha^{-1}	
Trinexapac-ethyl	Primo Maxx	0.05	---	Every 3 Weeks
Trinexapac-ethyl + Nitrogen	Primo Maxx + Urea[b]	0.05 + 12.3	37	Every 3 Weeks
Trinexapac-ethyl + Nitrogen	Primo Maxx + Urea	0.05 + 24.5	73.5	Every 3 Weeks
Trinexapac-ethyl + Nitrogen	Primo Maxx + Urea	0.05 + 49	147	Every 3 Weeks
Nitrogen	Urea	12.3	37	Every 3 Weeks
Nitrogen	Urea	24.5	73.5	Every 3 Weeks
Nitrogen	Urea	49	147	Every 3 Weeks
Nontreated	---	---	---	---

[a] Common and Tifway bermudagrass plugs were planted 24 July 2008 and 20 July 2009.
[b] Urea utilized was uncoated with standard analysis (46-0-0).

Table 5: Mean Tifway bermudagrass spread (cm) 4, 8, and 12 weeks after initial treatment (WAIT). Diameter spread data are shown relative to the nontreated control. Data were pooled over experimental years. Pairwise contrasts were conducted as shown at a significance level of 0.05.[a]

	Tifway bermudagrass[b]					
Treatment	4 WAIT		8 WAIT		12 WAIT	
	Diameter spread (cm)					
12.3 kg N ha^{-1}	0.9	bc	2.2	ab	2.4	b
24.5 kg N ha^{-1}	1.4	bc	2.6	a	2.3	b
49 kg N ha^{-1}	1.7	ab	3.1	a	4.1	a
TE alone	-0.1	d	-0.3	c	-0.5	c
TE + 12.3 kg N ha^{-1}	0.5	cd	1.1	b	1.4	b
TE + 24.5 kg N ha^{-1}	1.4	bc	2.5	a	2.6	b
TE + 49 kg N ha^{-1}	2.5	a	2.4	a	4.3	a
LSD (0.05)	0.9		1.2		1.3	
Contrasts	*P*-value					
12.3 kg N ha^{-1} vs. TE + N	0.468		0.145		0.321	
24.5 kg N ha^{-1} vs. TE + N	0.844		0.781		0.760	
49 kg N ha^{-1} vs. TE + N	0.117		0.297		0.776	
TE vs TE + N	0.002		0.003		0.003	

[a]The Type I error rate for the P-values is 0.05/4 = 0.0125 to account for the inflation of Type I error since four contrasts were performed.

[b]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 6: Mean common bermudagrass spread (cm) 4, 8, and 12 weeks after initial treatment (WAIT). Diameter spread data are shown relative to the nontreated control. Data were pooled over experimental years. Pairwise contrasts were conducted as shown at a significance level of 0.05.[a]

Treatment	Common bermudagrass[b] 4 WAIT		8 WAIT		12 WAIT	
	Diameter spread (cm)					
12.3 kg N ha^{-1}	0.7	b	-0.1	c	0.0	c
24.5 kg N ha^{-1}	2.3	ab	0.8	bc	1.1	c
49 kg N ha^{-1}	1.7	b	-0.8	c	0.1	c
TE alone	1.2	b	0.4	bc	0.8	c
TE + 12.3 kg N ha^{-1}	2.0	b	1.9	b	4.0	ab
TE + 24.5 kg N ha^{-1}	1.6	b	0.9	bc	1.7	bc
TE + 49 kg N ha^{-1}	3.9	a	4.7	a	6.1	a
LSD (0.05)	1.6		1.7		2.4	
Contrasts	*P*-value					
12.3 kg N ha^{-1} vs. TE + N	0.297		0.233		0.029	
24.5 kg N ha^{-1} vs. TE + N	0.524		0.927		0.728	
49 kg N ha^{-1} vs. TE + N	0.091		0.008		0.004	
TE vs TE + N	0.208		0.138		0.030	

[a]The Type I error rate for the P-values is 0.05/4 = 0.0125 to account for the inflation of Type I error since four contrasts were performed.
[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).

Table 7: Visual color response of Zorro zoysiagrass to increasing nitrogen rates applied alone and with trinexapac-ethyl (TE).

Treatment	Zorro zoysiagrass[ab] — Turf Color (1-9 scale) —	
49 kg N ha^{-1}	9	a
TE + 49 kg N ha^{-1}	8.9	a
TE + 24.5 kg N ha^{-1}	8.3	b
24.5 kg N ha^{-1}	8.1	c
TE + 12.3 kg N ha^{-1}	7.2	d
12.3 kg N ha^{-1}	7	d
TE alone	6.7	e
Nontreated	5.8	f
LSD (0.05)	0.25	

[a]Means within a column followed by the same letter are not significantly different according to Fisher's Protected LSD (P = 0.05).
[b]Means represent averages pooled across experimental years and rating dates.

IV. Evaluation of new aryloxyphenoxypropionate herbicides for selective control of bermudagrass in zoysiagrass turf

Abstract

Field experiments were conducted in 2008 and 2009 to evaluate aryloxyphenoxypropionate (AOPP) herbicides for Tifway bermudagrass control in Zorro zoysiagrass. Treatments included clodinafop (0.07 kg ai ha^{-1}); triclopyr (1.12 kg ae ha^{-1}); clodinafop plus triclopyr (0.07 + 1.12 kg ha^{-1}); fenoxaprop (0.10 kg ai ha^{-1}); fenoxaprop plus triclopyr (0.10 + 1.12 kg ha^{-1}); metamifop (0.40 kg ai ha^{-1}); and metamifop plus triclopyr (0.40 + 1.12 kg ha^{-1}). Clodinafop, fenoxaprop, and metamifop applied in combination with triclopyr controlled bermudagrass ≥89% when rated 3 weeks after the final application. The addition of triclopyr to clodinafop, fenoxaprop, and metamifop increased bermudagrass control and significantly reduced injury to zoysiagrass. Clodinafop and fenoxaprop alone caused unacceptable injury to zoysiagrass, 42 and 33%, respectively. Metamifop alone was safe to apply three applications to zoysiagrass, but only controlled bermudagrass 36%.

Introduction

Zoysiagrass (*Zoysia* spp.) is a popular warm-season turfgrass in the transitional and southeast regions of the United States. Its relatively low fertility requirement, slow growth rate, high density, and tolerance to shaded areas make zoysiagrass beneficial for turfgrass use (McCarty 2005). When managing zoysiagrass, one of the most problematic weeds to control is bermudagrass (*Cynodon* spp.). Bermudagrass contamination is a concern due to its aggressive growth-habit, extensive rhizome and stolon system, and tolerance to adverse environmental and management conditions (Johnson 1992). Bermudagrass contaminated areas typically produce a poor turfgrass stand because of differences in color, texture, and growth habit (Johnson and Carrow 1995).

Bermudagrass and zoysiagrass share similar herbicide tolerances due to their physiological similarities as C_4 warm-season grasses (Johnson 1987). As a result, there is a limited availability of selective herbicides that do not excessively injure zoysiagrass (Dernoeden 1989; Johnson 1992). Traditional nonselective herbicide applications are impractical as they result in the death of the weed and the desired species. The efficacy of nonselective herbicides for bermudagrass control has also been reported to vary because of bermudagrass' ability to regrow from underground rhizomes (Boyd 1991; Johnson 1988).

Postemergent graminicides, namely the aryloxyphenoxypropionates (AOPP) and cyclohexanediones, have been the primary herbicides evaluated for selective control of bermudagrass in other turfgrass species. In sensitive species, these herbicides inhibit the acetyl-CoA carboxylase (ACCase) enzyme, which is a catalyst in fatty acid synthesis (Walker et al. 1988). Inhibition of fatty acid synthesis subsequently blocks the production of phospholipids used in building new membranes required for cell growth (Devine et al. 1993). While dicotyledonous plants are naturally resistant to these herbicides because of an insensitive ACCase enzyme, graminaceous plants vary in their relative sensitivities (Stoltenberg et al.1989).

Multiple studies have utilized POST graminicides at a variety of rates and applications in an effort to selectively control bermudagrass in zoysiagrass. Three applications of fluazifop at 0.20 kg ai ha^{-1} provided ≥99% control of 'Tifway' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy], but caused severe injury (55%) to 'Emerald' zoysiagrass [*Zoysia japonica* Steud. × *Z. matrella* (L.) Merr. var. *tenuifolia*] 4 wk after application (Johnson 1987). Fenoxaprop applied to a mixed stand of common bermudagrass and Emerald zoysiagrass at 0.20 kg ai ha^{-1} in four applications reduced bermudagrass cover to 3% (Johnson 1992). Zoysiagrass turf quality was reduced immediately after each treatment but recovery was acceptable by 3 weeks after treatmnent (WAT) (Johnson 1992). Cudney et al. (1997) reported fenoxaprop applied at 0.20 kg ha^{-1} in four applications reduced common bermudagrass cover to 8%. Similarly, Dernoeden (1989) reported that four monthly applications of fenoxaprop suppressed bermudagrass 97 to 99%, but yellowing of common Korean zoysiagrass (*Zoysia japonica* Steud.) occurred.

Triclopyr, a synthetic auxin herbicide, has traditionally been used for the control of annual broadleaf weeds and woody species in pastures and rights-of-way (Gorrell et al. 1981; Jacoby and Meadors 1983; Senseman 2007). However, triclopyr has been shown to cause significant injury to some warm-season grasses, including bermudagrass (Bell et al. 2000). Several studies have attempted to explain the reason for differential tolerance to triclopyr among similar species (Gorrell et al. 1988; Lewer and Owen 1990). Gorrell et al. (1988) attributed differential selectivity of triclopyr to metabolism. Using horsenettle (*Solanum carolinense* L.), a difficult to control herbaceous perennial, the researchers demonstrated that only 3.8% of ^{14}C-triclopyr was translocated to roots after

16 d (Gorrell et al. 1988). Similarly, Lewer and Owen (1990) found that a greater percentage of triclopyr was retained in a treated leaf of wheat (*Triticum aestivum* L.), in comparison to barley, which translocated more and is less tolerant to triclopyr.

Another aspect of the synthetic auxin herbicides is their interaction with AOPP herbicides. Many have reported decreased activity of diclofop when combined with the auxin herbicides 2,4-D and MCPA (Fletcher and Drexler 1980; Hill et al. 1980; Olson and Nalewaja 1981; Taylor et al. 1983; Todd and Stobbe 1980). Todd and Stobbe (1980) determined that the addition of 2,4-D amine to diclofop reduced the translocation of diclofop to the site of action in meristematic tissue; thus, control of wild oat (*Avena fatua* L.) was reduced. More recently, Scherder et al. (2005) reported that triclopyr applied at 0.28 kg ae ha^{-1} before application of cyhalofop (1, 3, or 5 d) or tank-mixed with cyhalofop severely reduced control of broadleaf signalgrass [*Brachiaria platyphylla* (Griseb.) Nash.] and barnyardgrass [*Echinocloa crus-galli* (L.) Beauv.]. However, control of these two grasses was not reduced when triclopyr was applied after an application of cyhalofop. In greenhouse studies, Cudney et al. (1997) demonstrated that tank-mixing fenoxaprop with triclopyr (0.42 + 1.12 kg ha^{-1}) effectively reduced plant injury to perennial ryegrass (*Lolium perenne* L.) and tall fescue plants (*Festuca arundinacea* Schreb.). Additionally, they found that tank mixtures of fenoxaprop and triclopyr effectively controlled common bermudagrass after four sequential applications (Cudney et al. 1997). McElroy and Breeden (2006) observed reduced injury to zoysiagrass when triclopyr was mixed with fenoxaprop or fluazifop. However, the researchers did not observe this safening effect when utilizing fluroxypyr, a pyridine herbicide with a similar chemistry to triclopyr.

Favorable results have been observed using fenoxaprop and fluazifop in combination with triclopyr for bermudagrass control in zoysiagrass (Lewis 2009; McElroy and Breeden 2006). Research was conducted to evaluate clodinafop and metamifop, herbicides not currently registered for use in turfgrass, applied alone and in combination with triclopyr for their safety on zoysiagrass and efficacy of bermudagrass control.

Materials and Methods

Field experiments were conducted in 2008 and 2009 to evaluate AOPP herbicides for bermudagrass control in zoysiagrass turf. Both experiments were conducted at the Auburn University Turfgrass Research Unit in Auburn, AL. Soil was a Marvyn sandy loam (fine-loamy, kaolinitic, thermic Typic Kanhapludult), pH of 6.0. Plot units measured 2.9 m^2 and were arranged in a randomized complete block design. Plot units were arranged such that each was half Tifway bermudagrass and half 'Zorro' zoysiagrass [*Zoysia matrella* (L.) Merr].

Prior to the initiation of treatments each year, glyphosate was applied at 2.24 kg ae ha^{-1} on 16 April 2008 and 16 April 2009 to kill unwanted bermudagrass. Bermudagrass sod was removed on 16 May 2008 and 19 May 2009. Zorro zoysiagrass sod was planted on 12 June 2008 and 11 June 2009. Treatments were initiated on 25 July 2008 and 24 July 2009 and were repeated at 21 d intervals, with a total of three applications per year. Herbicide treatments were applied in 280 L H_2O ha^{-1} with a CO_2 pressurized boom sprayer. Treatments included clodinafop[1] (0.07 kg ai ha^{-1}); triclopyr[2] (1.12 kg ha^{-1}); clodinafop plus triclopyr (0.07 + 1.12 kg ha^{-1}); fenoxaprop[3] (0.10 kg ha^{-1});

fenoxaprop plus triclopyr (0.10 + 1.12 kg ha^{-1}); metamifop (0.40 kg ai ha^{-1}); metamifop plus triclopyr (0.40 + 1.12 kg ha^{-1}); and a nontreated control. All treatments were applied with 0.25% v/v nonionic surfactant[4] (NIS).

16-28-0 (N-P-K) starter fertilizer was applied to deliver N at 49 kg ha^{-1} on 12 June 2008 prior to planting zoysiagrass sod. Urea (46-0-0) was applied to the entire study to provide N at 24.5 kg ha^{-1} on 24 July; 7 August; 20 August; and 4 September 2008. Fertilizer was applied in an identical manner in 2009. Halosulfuron-methyl was applied at 0.07 kg ai ha^{-1} on 9 July and 11 August 2008 to control *Kyllinga* spp. For preemergence control of winter annual weeds, oxadiazon was applied at 4.0 kg ai ha^{-1} on 17 September 2008.

Data Collection and Analysis. Data were collected on zoysiagrass injury, bermudagrass control, and percent green cover. Zoysiagrass injury and bermudagrass control were visually rated weekly utilizing a 0-100% scale (0% = no visible turfgrass injury/control; 100% = complete turfgrass death). For discussion purposes, injury >20% and bermudagrass control < 80% was deemed unacceptable.

Digital images were taken 14 d after each application utilizing a portable light box (61 cm L x 51 cm W x 56 cm H) equipped with a digital camera[5] (Ikemura 2003). White balance (Tone) was calibrated under light box conditions using a standard 18% photographic gray card. Camera settings included a shutter speed of 1/30 s, ISO 100, and an aperture of F2.8. The collected images were saved in the JPEG (joint photographic experts group, .jpg) format, and an image size of 640 by 480 pixels. Digital images were analyzed individually by SigmaScan software[6] for percent green cover according to published methods (Richardson et al. 2001). The color threshold feature in the software was used to identify a specific range of green color tones. Since bermudagrass and zoysiagrass differ in color, hue and saturation ranges used for analysis differed among species. Preliminary work with images indicated that a hue range from 42 to 100 and a saturation range from 15 to 100 would selectively identify green tissue in bermudagrass images while a hue range from 50 to 100 and a saturation range of 20 to 100 were used for zoysiagrass images.

Data for zoysiagrass injury, bermudagrass control, and percent green cover were subjected to analysis of variance using SAS® PROC MIXED[7]. Years, replicates (nested within year), and interactions containing either of these effects were considered random effects; treatment and weeks after treatment (WAT) were considered a fixed effect. Considering year as an environment or random effect permits inferences about treatments to be made over a range of environments (Carmer et al. 1989; Hager et al. 2003). Least-square means were used for mean separation at $P \leq 0.05$. There was no significant year or year by treatment interaction for zoysiagrass injury, bermudagrass control, or percent green cover for zoysiagrass; therefore, data were pooled across years.

Results and Discussion

Zoysiagrass Injury. When rated 2 weeks after the initial treatment (WAIT), clodinafop applied alone injured zoysiagrass 24%, the highest among treatments (Table 8). Fenoxaprop and metamifop applied alone caused minimal injury, 19 and 9%, respectively. Triclopyr caused no visual injury to zoysiagrass at all rating dates.

Applying triclopyr with clodinafop, fenoxaprop, and metamifop effectively reduced zoysiagrass injury to 1 to 3%.

Clodinafop applied alone injured zoysiagrass 35%, compared to no visual injury when tank-mixed with triclopyr 5 WAIT (Table 8). Similarly, triclopyr reduced herbicide injury from fenoxaprop and metamifop. Even though fenoxaprop and metamifop caused minimal injury to zoysiagrass, 20% and 22% respectively, visual injury was significantly less, 3 and 1% respectively, when tank-mixed with triclopyr.

Three weeks after the final application, clodinafop and fenoxaprop applied alone caused unacceptable zoysiagrass injury, 42 and 33%, respectively. Among the three AOPP herbicides used in this study, only metamifop was safe to apply three applications at 21 d intervals to zoysiagrass. Tank-mixing triclopyr with clodinafop, fenoxaprop, or metamifop with triclopyr effectively reduced herbicide injury on zoysiagrass. These results are similar to previous reports by McElroy and Breeden (2006) and Lewis (2009) who reported reduced zoysiagrass injury by applying AOPP herbicides in combination with triclopyr.

The observed safety of applying AOPP herbicides in combination with triclopyr to zoysiagrass may be due to the antagonistic effect of these herbicides. Several researchers have reported reduced activity of AOPP herbicides on target species when applied with synthetic auxin herbicides such as 2,4-D, MCPA, and triclopyr (Deschamps et al. 1990; Mueller et al. 1989; Scherder et al. 2005; Todd and Stobbe 1980). Using ^{14}C-diclofop, Todd and Stobbe (1980) determined that 2,4-D amine significantly reduced the translocation of the phytotoxic free acid, diclofop, within the phloem to its site of action in meristematic tissues; thus rendering diclofop ineffective against the target species. In contrast, Scherder et al. (2005) reported no effect on foliar absorption or translocation of cyhalofop when applied with triclopyr to two annual grasses, broadleaf signalgrass and barnyardgrass. However, the researchers noted that translocation of cyhalofop in general was minimal (0.51 to 2.24%) 72 hours after exposure compared with reports of other AOPP herbicides (Culpepper et al. 1999; Rossi et al. 1993). Therefore, increased safety to zoysiagrass observed in these studies may be due to decreased translocation of the AOPP herbicides when applied in combination with triclopyr.

Bermudagrass Control. The three AOPP herbicides applied alone controlled bermudagrass poorly (22 to 32%) when rated 2 WAIT (Table 9). Triclopyr applied alone controlled bermudagrass (42%) greater than clodinafop, fenoxaprop, and metamifop. Bell et al. (2000) reported similar 'Midlawn' bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] control when applying triclopyr at 3.8 kg ha^{-1}. Adding triclopyr to clodinafop, fenoxaprop, and metamifop increased bermudagrass control. Two week after the second application, bermudagrass control using clodinafop, fenoxaprop, or metamifop remained poor (<50%). However, tank-mixing these herbicides with triclopyr increased bermudagrass control to 85 to 90%.

Clodinafop, fenoxaprop, and metamifop tank-mixed with triclopyr controlled bermudagrass ≥89% when rated 3 weeks after the final application. Clodinafop applied alone controlled bermudagrass 65% compared to 89% when tank-mixed with triclopyr. An even greater synergistic response was observed when tank-mixing triclopyr with fenoxaprop and metamifop. Fenoxaprop and metamifop applied alone controlled bermudagrass poorly, 32 and 36%, compared to 92 and 93% control when tank-mixed with triclopyr. McElroy and Breeden (2006) reported a similar response using fenoxaprop in combination with triclopyr for common bermudagrass (*Cynodon dactylon*).

Triclopyr applied alone significantly injured bermudagrass in these studies. In contrast to the decreased injury of AOPP herbicides applied to zoysiagrass, the addition of triclopyr to these herbicides significantly increased bermudagrass control. Increased bermudagrass control may be attributed in part to greater absorption and translocation of triclopyr in bermudagrass compared to zoysiagrass (Robertson and Kirkwood 1970). Gorrell et al. (1988) attributed differential selectivity of triclopyr among similar species to metabolism. Studies using wheat and barley have demonstrated that retention of triclopyr within a leaf (lack of translocation) increased a species tolerance to triclopyr (Lewer and Owen 1990). Applying this reasoning, adequate translocation of triclopyr in bermudagrass would render it effective. Furthermore, rapid translocation would likely permit the translocation of any herbicides applied in combination with triclopyr, e.g. aryloxyphenoxypropionates. From greenhouse studies using ^{14}C-cyhalofop, Scherder et al. (2005) determined that triclopyr applied before cyhalofop (1 or 3 d) or tank-mixed with cyhalofop resulted in similar foliar absorption and translocation within barnyardgrass compared to cyhalofop alone. Thorough translocation of these herbicides effectively incorporates two modes of action within the plant, resulting in increased control. Therefore, the distinction between the antagonism and additive effects of triclopyr applied with AOPP herbicides may lie in the degree of translocation of these materials within the plant.

Zoysiagrass Green Cover. Zoysiagrass cover data (Table 10) are inversely related with visual zoysiagrass injury data (Table 8). Fenoxaprop and clodinafop were the only two treatments to significantly decrease zoysiagrass green cover 2 WAIT. Metamifop, triclopyr, and AOPP + triclopyr treatments all maintained >90% zoysiagrass green cover. Triclopyr applied alone maintained ≥92% zoysiagrass cover throughout the entire study.

Fenoxaprop and clodinafop decreased zoysiagrass cover to 75 and 73% when rated 2 weeks after the second application. However, fenoxaprop and clodinafop tank-mixed with triclopyr both maintained >93% zoysiagrass cover. Metamifop applied alone decreased zoysiagrass cover slightly to 88% when rated 2 weeks after the second application, but this was not significantly different than metamifop applied in combination with triclopyr (93%).

Clodinafop, fenoxaprop, and metamifop applied in combination with triclopyr all maintained ≥95% zoysiagrass cover when rated 2 weeks after the final application. Clodinafop applied alone decreased zoysiagrass cover to 66%, the greatest among all treatments in this study. Fenoxaprop applied alone reduced zoysiagrass cover to 70%. Dernoeden (1989) reported a similar reduction in Meyer zoysiagrass cover following the application of fenoxaprop at 0.10 kg ha^{-1}. Metamifop applied alone caused the least reduction in zoysiagrass cover among the AOPP herbicides evaluated in this study.

Bermudagrass Green Cover. Bermudagrass cover estimates (Table 11) were on average 15% lower than reflected in the visual bermudagrass control ratings (Vanha-Majamaa et al. 2000) (Table 9). Two weeks after the initial treatment, fenoxaprop applied alone yielded the greatest bermudagrass cover, 69%. This correlates with a visual bermudagrass control rating of 22%. Metamifop and clodinafop each reduced bermudagrass cover to 53%. Triclopyr alone reduced bermudagrass cover to 30%. Applying fenoxaprop, clodinafop, and metamifop in combination with triclopyr all resulted in a greater reduction of bermudagrass cover (<30%) compared to the individual treatments.

Two weeks after the second application, greater reduction in bermudagrass cover was observed among all treatments (Table 11). Only triclopyr applied alone reduced bermudagrass cover to less than 30%. All AOPP + triclopyr treatments reduced bermudagrass cover to less than 5% after the second application. Two weeks after the final application, fenoxaprop applied alone resulted in the greatest bermudagrass cover, 44%. However, tank-mixing fenoxaprop with triclopyr significantly reduced bermudagrass cover (3%) compared to fenoxaprop alone. Similarly, metamifop and clodinafop applied in combination with triclopyr reduced bermudagrass cover to 3 and 5%, while these herbicides applied alone reduced cover to 32 and 19%, respectively. Triclopyr alone was the only treatment to yield increased bermudagrass cover between the second and third applications. This trend was also observed in the visual bermudagrass control ratings (Table 9).

These data indicate that three sequential applications of clodinafop, fenoxaprop, and metamifop tank-mixed with triclopyr are safe to apply to Zorro zoysiagrass and provide acceptable control of Tifway bermudagrass. Of the AOPP herbicides evaluated in this study, only fenoxaprop is currently labeled for use on turfgrasses. Clodinafop provided the greatest bermudagrass control (65%) when rated 3 weeks after the final application, but caused severe injury (42%) to zoysiagrass. Conversely, metamifop alone caused transient yellowing of zoysiagrass and provided poor bermudagrass control (36%). The addition of triclopyr to each of these AOPP herbicides effectively increased bermudagrass control and reduced injury to zoysiagrass.

Research has been previously conducted evaluating AOPP herbicides for control of bermudagrass in zoysiagrass (Dernoeden 1989; Johnson 1987, 1992; Lewis 2009; McElroy and Breeden 2006). The majority of selective control methods have been ineffective due to the similar herbicide tolerance of bermudagrass and zoysiagrass. This research is the first study to be conducted evaluating clodinafop and metamifop for the selective control of bermudagrass in zoysiagrass. The results of this research may be integrated into a bermudagrass management program. Where zoysiagrass is contaminated with bermudagrass, fenoxaprop, clodinafop, and metamifop applied in combination with triclopyr could be used in sequential applications for selective bermudagrass control. Although significant control of bermduagrass was achieved in each year of these studies, retreatment in ensuing years would likely be required to control bermudagrass regrowth.

Sources of Materials

[1]Discover® NG herbicide, Syngenta Crop Protection, Inc., Greensboro, NC 27409.

[2]Turflon® Ester herbicide, Dow AgroSciences LLC, Indianapolis, IN 46268.

[3]Acclaim® Extra herbicide, Bayer Environmental Science, Research Triangle Park, NC 27709.

[4]Induce® adjuvant, Helena Company, Collierville, TN 38017.

[5]PowerShot® G9 digital camera, Canon USA, Inc., Lake Success, NY 11042.

[6]SigmaScan® Pro, v. 5.0. Systat Software Inc., Chicago, IL 60606.

[7]SAS® Statistical Software v. 9.1, Statistical Analysis Systems, SAS Institute, Inc. Cary, NC 27513-2414.

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Table 8: Visual zoysiagrass injury 2, 5, 9, and 15 weeks after initial application of clodinafop, fenoxaprop, and metamifop applied alone and in combination with triclopyr.

		Injury[b]			
Herbicide[a]	Rate	2 WAIT[c]	5 WAIT	9 WAIT	15 WAIT
	kg ha^{-1}	%			
Clodinafop	0.07	24 a	35 a	42 a	10 a
Fenoxaprop	0.10	19 b	20 b	33 b	5 b
Metamifop	0.40	9 c	23 b	20 c	8 ab
Metamifop + Triclopyr	0.40 + 1.12	3 d	3 de	0 d	0 c
Fenoxaprop + Triclopyr	0.10 + 1.12	1 d	1 e	0 d	0 c
Clodinafop + Triclopyr	0.07 + 1.12	1 d	0 e	0 d	0 c
Triclopyr	1.12	0 d	0 e	0 d	0 c

[a]All herbicide treatments were applied with 0.25% v/v nonionic surfactant (NIS). Product: Induce, contains 90% alkylarylpolyoxylkane ethers, free fatty acids, and dimethylpolysiloxane; Helena Chemical Company, 225 Schilling Blvd., Suite 300, Collierville, TN 38017.

[b]Means followed by the same letter were not significantly different according to the *t*-test on difference of least square means at P = 0.05.

[c]Abbreviations: WAIT, weeks after initial treatment.

Table 9: Visual bermudagrass control 2, 5, 9, and 15 weeks after initial application of clodinafop, fenoxaprop, and metamifop applied alone and in combination with triclopyr.

		Control[b]			
Herbicide[a]	Rate	2 WAIT[c]	5 WAIT	9 WAIT	15 WAIT
	kg ha^{-1}	%			
Metamifop + Triclopyr	0.40 + 1.12	73 a	90 a	93 a	70 a
Fenoxaprop + Triclopyr	0.10 + 1.12	58 b	85 b	92 a	61 b
Clodinafop + Triclopyr	0.07 + 1.12	49 c	85 b	89 a	63 b
Triclopyr	1.12	42 d	69 c	58 c	45 c
Clodinafop	0.07	32 e	46 d	65 b	38 d
Metamifop	0.4	23 f	33 e	36 d	13 e
Fenoxaprop	0.10	22 f	31 e	32 d	9 e

[a]All herbicide treatments were applied with 0.25% v/v NIS.

[b]Means followed by the same letter were not significantly different according to the *t*-test on difference of least square means at P = 0.05.

[c]Abbreviations: WAIT, weeks after initial treatment; NIS, nonionic surfactant.

Table 10: Zosyiagrass green cover 2, 5, and 8 weeks after initial application of clodinafop, fenoxaprop, and metamifop applied alone and in combination with triclopyr.

Herbicide[c]	Rate	Green cover[ab] 2 WAIT[d]		5 WAIT		8 WAIT	
	kg ha^{-1}	%					
Triclopyr	1.12	92	a	93	ab	95	a
Fenoxaprop + Triclopyr	0.10 + 1.12	91	a	93	ab	95	a
Clodinafop + Triclopyr	0.07 + 1.12	91	a	96	a	96	a
Metamifop	0.40	91	a	88	b	88	b
Metamifop + Triclopyr	0.4 + 1.12	90	a	93	ab	95	a
Fenoxaprop	0.10	83	b	75	c	70	c
Clodinafop	0.07	80	b	73	d	66	d

[a]Percent green cover quantified using digital image analysis in SigmaScan Pro v. 5.0.
[b]Means followed by the same letter were not significantly different according to the *t*-test on difference of least square means at P = 0.05.
[c]All herbicide treatments were applied with 0.25% v/v NIS.
[d]Abbreviations: WAIT, weeks after initial treatment; NIS, nonionic surfactant.

Table 11: Bermudagrass green cover 2, 5, and 8 weeks after initial application of clodinafop, fenoxaprop, and metamifop applied alone and in combination with triclopyr.

Herbicide[c]	Rate	Green cover[ab] 2 WAIT[d]		5 WAIT		8 WAIT	
	kg ha^{-1}	%					
Fenoxaprop	0.10	69	a	53	a	44	a
Metamifop	0.40	53	b	42	b	32	b
Clodinafop	0.07	53	b	30	c	19	c
Triclopyr	1.12	30	c	9	d	18	c
Fenoxaprop + Triclopyr	0.10 + 1.12	30	c	4	e	3	d
Clodinafop + Triclopyr	0.07 + 1.12	28	c	4	e	5	d
Metamifop + Triclopyr	0.40 + 1.12	15	d	3	e	3	d

[a]Percent green cover quantified using digital image analysis in SigmaScan Pro v. 5.0.
[b]Means followed by the same letter were not significantly different according to the *t*-test on difference of least square means at P = 0.05.
[c]All herbicide treatments were applied with 0.25% v/v NIS.
[d]Abbreviations: WAIT, weeks after initial treatment; NIS, nonionic surfactant.

V. Competitive effects of various weed species on seeded zoysiagrass establishment

Abstract

Weed competition during seeded establishment often inhibits turfgrass development, thus producing a poor turfgrass stand. The result of turfgrass-weed competition may be affected by management practices, weed density, and weed species present. Currently, little is known about how specific weed species compete with turfgrasses during early developmental stages. Additive competition experiments were conducted in 2008 and 2009 to determine the competitive effects of smooth crabgrass and goosegrass on Zenith zoysiagrass establishment. Zoysiagrass seeding rate was held constant at 49 kg ha^{-1} pure live seed (PLS) while weeds (neighbor species) per unit area increased. Treatments included: zoysiagrass-alone (monoculture) and zoysiagrass plus 61, 185, 395, 674, or 898 neighbor plants (PLS) per experimental unit (0.13 m^2 greenhouse flats). Experimental data indicate that neighbor density and neighbor by density interaction were significant for all developmental stages evaluated in this study. Zoysiagrass development was reduced at all seeding densities by both weed species 8 weeks after seeding (WAS). At the highest neighbor density (898 PLS per experimental unit), zoysiagrass populations were comprised entirely of non-tillering plants (100% leaf stage) when grown with goosegrass, whereas >20% of zoysiagrass plants developed tillers when grown with smooth crabgrass. A similar relationship was observed between neighbor density and zoysiagrass drymatter yield data. Overall, zoysiagrass drymatter

yield was reduced from 38 to 99% with increasing weed density. Hyperbolic equation parameter estimates indicate that goosegrass caused greater yield loss per weed unit and greater maximum yield loss compared to smooth crabgrass.

Introduction

In agricultural and turfgrass systems, the negative effect of weeds on crop yield and aesthetics is of utmost importance. Weeds compete with new plantings for light, nutrients, moisture, and space (McCarty 2005). Summer annual grassy weeds such as crabgrass (*Digitaria* spp.) and goosegrass [*Eleusine indica* (L.) Gaertn.] germinate in late spring to early summer at the same time that is recommended for the establishment of warm-season grasses such as zoysiagrass in the southeastern United States (Beard 1973; Patton et al. 2004a). Rapid establishment of a turfgrass is desirable to reduce weed colonization, reduce potential erosion problems, and minimize disruption of play. Unfortunately, zoysiagrass is relatively slow to establish vegetatively or by seed (Busey and Myers 1979; Karcher et al. 2005). Literature indicates that cultural practices such as seeding rate and nitrogen fertilization have minimal impact on zoysiagrass establishment rates (Carroll et al. 1996; Fry and Dernoeden 1987; Patton et al. 2004a, 2004b; Richardson and Boyd 2001). Since competition with summer annual weeds is known to reduce establishment, weed control is essential for optimal establishment of zoysiagrass (Carroll et al. 1996; Dernoeden 1989).

Plant-plant interactions experienced by individuals in heterospecific communities are complex. Much of what is known about the competitive ability of plant species is learned from a comparison of their relative competitiveness with one another in varying environments (Gardner 1942; Weigelt et al. 2002). Competition may occur between individuals of the same species (intraspecific) or different species (interspecific). Additionally, competition may be divided into above- and below-ground since plants use different structures to compete for different resources (Newbery and Newman 1978; Booth et al. 2003). As a result of this complexity, quantifying and interpreting plant-plant interactions has been problematic for agronomists and ecologists.

The result of crop-weed competition may be affected by management practices, duration of competition, weed species present, and weed density (Connolly et al. 1990). In crop production systems, numerous studies have evaluated the effect of individual weed species on crop yield (Beckett et al. 1988; Bell 1995; Knake and Slife 1962; Staniforth 1957; Swinton et al. 1994; VanDevender et al. 1997). Many indices have been developed that rate the competitiveness (the ability to reduce crop yield) of weed species (Weigelt and Jolliffe 2003). Furthermore, the model of an economic threshold has been well-defined in agricultural crops as a function of weed density, cost of treatment, yield loss caused by each weed unit, and efficacy of treatment (Smith 1988; Stauber et al. 1991). In contrast to agricultural crops, managed turfgrasses are typically rated using visual assessment (color, quality, and texture) and therefore there is no true yield component that is reduced by the presence of weeds (Bell et al. 2000; Horst et al. 1984). As a result, competition indices ranking various weed species have not been developed for turfgrass systems.

Little is known about how weed species compete with turfgrasses during early developmental stages. Understanding how specific weed species compete with turfgrasses during establishment will contribute to our overall knowledge of turfgrass growth and ecology. Therefore, competition experiments were conducted to determine the competitive effects of smooth crabgrass [*Digitaria ischaemum* (Schreb. ex Schweig) Schreb. ex Muhl.] and goosegrass on 'Zenith' zoysiagrass (*Zoysia japonica* Steud.) establishment.

Materials and Methods

Competition studies were initated in winter 2008 and 2009 at the Auburn University Weed Science greenhouse in Auburn, AL. The experiment was an additive design with three replications per experimental run (Cousens 1991; Radosevich 1988). Experimental units were 0.13 m^2 greenhouse flats. A Wickham sandy-loam (fine- loamy, siliceous, subactive, thermic Typic Hapludult), pH 6.1 was steam sterilized and subsequently mixed with Pro-mix[1] at 5:1 (soil:Pro-mix) to restore soil structure and water holding capacity. Zenith zoysiagrass[2] seeding rate was constant at 49 kg ha^{-1} pure live seed (PLS) while weeds (neighbor species) per unit area increased. Neighbor seeding rate was based on seed weight and germination percentage. Smooth crabgrass[3] seed was obtained from Estel Farm and Seeds while goosegrass seed was collected from local populations. Treatments included: zoysiagrass-alone (monoculture) and zoysiagrass plus 61, 185, 395, 674, or 898 neighbor plants (PLS) per experimental unit. These densities represent plant counts from preliminary studies using neighbor seeding rates of 4.9 to 49 kg ha^{-1}. Due to poor goosegrass germination in the second year, only one experimental run was conducted using goosegrass in these studies.

Greenhouse flats were fertilized with a commercial fertilizer[4] 24-8-16 (N-P-K) every 2 weeks and were maintained at a vegetative height of 3.2 cm using hand-held grass shears throughout each study.

Data Collection and Analysis. Data collected from each experiment included: (i) Plant counts and developmental stage measurements at 2, 4, 6, and 8 WAS from two 104 cm^2 samples per flat, and (ii) dry weights of above-ground tissue harvested 8 WAS. Three categories of zoysiagrass development stage were organized: 'Leaf' stage represented by one to three leaf plants (no tillers present); 'Tiller 1' represented by one to four tiller plants; and 'Tiller 2' represented by five to eight tiller plants. A tiller was defined as the initial plant plus any aerial shoots emerging from axillary buds or a shoot emerging from stolons (McCarty 2005). Developmental stage counts were converted to percent of total zoysiagrass population using the following formula:

$$\%\ \text{in growth stage} = \left(\frac{\#\ \text{of plants in stage A}}{P_{total}}\right) \times 100 \qquad [1]$$

where stage A = Leaf, Tiller 1, or Tiller 2, and P_{total} = total number of zoysiagrass plants in one 104 cm^2 sample.

Above-ground zoysiagrass plant tissue was harvested from one 104 cm^2 sample per experimental unit 8 WAS. Plant material was placed into a forced air dryer for 72 hours at 60°C before weighing. Zoysiagrass dry weight measurements were converted to percent yield loss using the formula:

$$Y_L = (1 - Y_i / Y_{WF}) \times 100 \qquad [2]$$

where Y_L is percent yield loss, Y_i is yield of a plot, and Y_{WF} is the average yield of a weed free plot within each rep.

The relationship of weed density to crop yield has been described using a rectangular hyperbola model (Cousens 1985). This model contains several biologically meaningful parameters that allow the researcher to account for the effect of weeds at low and high densities and subsequently use parameter estimates to rank the competitiveness of different weed species (Cousens 1985). Zoysiagrass drymatter yield loss data were fit to the rectangular hyperbola model implemented in SAS® PROC NLIN[5]. The rectangular hyperbola model is:

$$\mathrm{Y_L} = Id / (1 + Id / A) \quad [3]$$

where $\mathrm{Y_L}$ is percent yield loss, *I* is percent yield loss per unit weed density as *d* approaches zero, *d* is weed density, and *A* is percent yield loss as *d* approaches infinity.

Data were subjected to ANOVA to determine the effect of neighbor species, density, and neighbor by density interaction. The behavior of residuals was assessed using graphical means provided through the "StudentPanel" option as implemented in SAS® PROC GLIMMIX. Because zoysiagrass plants did not attain mature developmental stages (Tiller 1 and Tiller 2) until 6 WAS, data discussed herein were taken 8 WAS.

Results and Discussion

Neighbor species (crabgrass or goosegrass) was significant for Tiller 1 and Tiller 2 development stage, but was not significant to total zoysiagrass plant count. Neighbor seeding density and neighbor by density interaction was significant for all developmental stages (Table 12). Intercept and density effect estimates modeling interference on zoysiagrass development are presented in Table 13.

Zoysiagrass Development. Zoysiagrass development was reduced at all seeding densities by both weed species (Figures 13 and 14). Zoysiagrass development was similar among the monoculture and the lowest neighbor density of 61 PLS per experimental unit. However, percentage of zoysiagrass population in the Leaf stage (no tillers present) progressively increased with increasing neighbor density. Under competition with smooth crabgrass or goosegrass (395 PLS per experimental unit), zoysiagrass populations were comprised of approximately 60% Leaf stage in comparison to <10% leaf stage in zoysiagrass monocultures. This is similar to an early report by Gardner (1942) where tillering of six grass species was reduced in mixed species plots compared to single species plots. Although neighbor species itself was not significant (P = 0.149) to percent of zoysiagrass plants in Leaf stage, significant neighbor by density interaction (P = 0.015) was evident, particularly at the highest neighbor density of 898 PLS per experimental unit. At this neighbor density, zoysiagrass populations were comprised entirely of non-tillering plants when grown with goosegrass (Figure 14), whereas >20% of zoysiagrass plants developed tillers when grown with smooth crabgrass (Figure 13).

An inverse relationship was observed between Leaf stage and Tiller 1 zoysiagrass development in these studies. Therefore, as Leaf stage became the predominant developmental stage, percentage of zoysiagrass plants in Tiller 1 stage decreased. Analogous to Leaf stage plant counts, percent zoysiagrass plants in Tiller 1 developmental stage was similar among the monoculture and neighbor seeding densities of 61 and 185 PLS per experimental unit. This may indicate a competitive level at which zoysiagrass development is not inhibited. Neighbor species, density, and neighbor by density interaction effects were significant to Tiller 1 development (Table 12). Comparing the two neighbor species across all densities evaluated, zoysiagrass grown with smooth crabgrass resulted in a greater percentage of Tiller 1 plants than when grown with goosegrass. In particular, smooth crabgrass permitted >20% Tiller 1 development at the highest neighbor density, whereas goosegrass eliminated this developmental stage entirely (Figure 14).

Tiller 2 developmental stage was not a major constituent of zoysiagrass populations in these studies. This is most likely due to the slow growth rate and establishment of zoysiagrass species, indicating that greater than 8 weeks is required to determine the effect of weed species on mature growth stages such as Tiller 2. In spite of the limitation of these studies, Tiller 2 zoysiagrass development was significantly reduced from all levels of neighbor density ($P < 0.001$). Zoysiagrass grown with smooth crabgrass did not exceed 10% Tiller 2 development at the lowest neighbor density of 61 PLS per experimental unit. In contrast, zoysiagrass populations grown with goosegrass at this same density were comprised of approximately 25% Tiller 2 plants. This difference in Tiller 2 development may be correlated with the prevalence of Tiller 1 stage plants in the smooth crabgrass trials. In particular, Tiller 1 stage plants comprised >90% of zoysiagrass populations in smooth crabgrass trials (61 PLS per experimental unit) in contrast to <60% with goosegrass as the neighbor species. Alternatively, differences in Tiller 2 development may be due to the classification system used in these studies. Tiller 1 and Tiller 2 are artificial groupings that represent a range of developmental stages that were meant to serve as a descriptive measure of population composition.

Zoysiagrass Drymatter Yield. Neighbor density was highly significant ($P<0.001$) to zoysiagrass drymatter yield in all trials conducted. Zoysiagrass yield loss increased with weed density (Figure 15). Parameter estimates for the hyperbolic equation (Equation 3) are shown in Table 14.

Within the hyperbolic equation, parameter *I* represents percent yield loss per weed unit as density approaches zero. This parameter estimates the initial slope of the hyperbolic curve and thus provides a useful estimate of per unit yield loss to weeds when weed densities are low (Cousens 1985). The slope estimate (*I*) for zoysiagrass yield loss with goosegrass was much steeper than the estimate for smooth crabgrass (Table 14). The steeper slope estimate with goosegrass indicates that goosegrass interfered more with zoysiagrass development than smooth crabgrass in these studies. Overall, both weed species evaluated significantly reduced zoysiagrass yield, even at low densities. Based on estimates of yield loss per weed unit, one can conclude that seeded zoysiagrass (*Zoysia japonica*) is not competitive with these two annual weeds.

Parameter *A* in the rectangular hyperbola model represents the upper asymptote, thus estimates the maximum yield loss at high weed density. Zoysiagrass drymatter yield was reduced from 38 to 99% with increasing weed densities (Figure 15). Significant yield reduction at the high neighbor densities is directly related to zoysiagrass development, where percentage of tillering plants decreased with increasing weed density (Figures 13 and 14). In particular, zoysiagrass drymatter yield was reduced approximately 40% by both weed species at the lowest neighbor density (61 PLS per experimental unit). Using estimates of *A* to compare weed species, goosegrass has the potential to cause greater zoysiagrass yield loss (99%) than smooth crabgrass (84%).

Research Implications. Results from these studies indicate that weed species and density do not affect number of germinating seedlings, but that these factors do significantly impact maturation and drymatter yield of seeded zoysiagrass 8 WAS. When grown with high weed densities, the majority of plants comprising zoysiagrass populations did not reach the tiller stage, thus reducing stand density and overall quality. Drymatter yield data followed a similar trend and were fit using a rectangular hyperbola model to determine yield loss as a function of weed density. This model has been previously used successfully to determine yield loss in many agricultural crops (Bell 1995; Blackshaw 1991; O'Donovan 1991; Weaver 1991), but has not been applied to turfgrass science. Hyperbolic equation parameters (*I* and *A*) allow for comparison of weed species based on per unit yield loss and maximum yield loss. In these studies, zoysiagrass yield loss (per weed unit and maximum loss) was greater for goosegrass compared to smooth crabgrass (Table 14).

Studies discussed within this manuscript are preliminary in nature. Environmental conditions (temperature, light, water, fertility) were all assumed to be ideal for zoysiagrass growth and thus weed species and density were the only experimental factors. Environmental conditions within a field would likely alter the effects of weed species on zoysiagrass establishment (Connolly et al. 1990). Based on our observations, studies should be conducted over a longer time scale (>8 weeks) to determine the competitive effect on mature growth stages. Future studies in turfgrass ecology may utilize this model to determine competitive effects of various weed species on turfgrass establishment under field conditions.

Sources of Materials

[1]Pro-Mix TA® growing medium, Premier Horticulture Inc., Quakertown, PA 18951.

[2]Zenith zoysiagrass®, Patten Seed Company, Lakeland, GA 31635-0217.

[3]Smooth crabgrass, Estel Farm and Seeds, Ardmore, OK 73401-9157.

[4]Miracle-Gro® fertilizer, The Scotts Company LLC, Marysville, OH 43041.

[5]SAS® Statistical Software v. 9.1, Statistical Analysis Systems, SAS Institute, Inc. Cary, NC 27513-2414.

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Table 12: Analysis of variance for fixed effects of total number of zoysiagrass plants, percent of plants in Leaf, Tiller 1, and Tiller 2 stage 8 weeks after seeding with smooth crabgrass or goosegrass.[a]

Effect	Zoysia total[b]	Leaf	Tiller 1	Tiller 2
	———	P-value	———	
Neighbor	0.313	0.149	<0.001	0.002
Density	<0.001	<0.001	<0.001	<0.001
Neighbor x Density	0.541	0.015	0.085	<0.001

[a]Developmental stages represent zoysiagrass plants with no tillers (Leaf), one to four tillers (Tiller 1) or five to eight tillers (Tiller 2).
[b]Zoysia total represent number of zoysiagrass plants in one 104 cm^2 sample.

Table 13: Intercept and density effect estimates with standard errors for smooth crabgrass and goosegrass interference on zoysiagrass development 8 weeks after seeding.

	Intercept	Linear	Quadratic[a]	Cubic	R^2
Smooth crabgrass					
Leaf	0.5 ± 4.7	0.25 ± 0.09	− 3.7 ± 1.7	0.002 ± 0.001	0.75
Tiller 1	83.9 ± 6.2	− 0.12 ± 0.08	0.8 ± 2.3	− 0.003 ± 0.002	0.63
Tiller 2	13.9 ± 3.1	− 0.09 ± 0.04	1.8 ± 1.1	− 0.001 ± 0.001	0.20
Goosegrass					
Leaf	3.3 ± 7.4	0.14 ± 0.09	0.4 ± 2.7	− 0.003 ± 0.002	0.89
Tiller 1	46. 1 ± 7.2	0.17 ± 0.09	− 6.0 ± 2.6	0.004 ± 0.002	0.71
Tiller 2	50.6 ± 6.8	− 0.31 ± 0.08	5.6 ± 2.4	− 0.003 ± 0.002	0.92

[a]Quadratic and cubic density estimates multiplied by a factor of 10^4 for presentation.

Table 14: Estimated values of rectangular hyperbola model parameters with standard errors for zoysiagrass yield as a function of neighbor density.

Neighbor species	Maximum yield loss (A)	Slope (I)	R^{2a}
	——— % ———		
Smooth crabgrass	84.1 ± 6.5	1.36 ± 0.5	0.92
Goosegrass	99.3 ± 4.0	2.02 ± 0.4	0.98

[a]Nonlinear model R^2 approximated using the formula:
1-SS(Residual) / SS($Total_{Corrected}$)

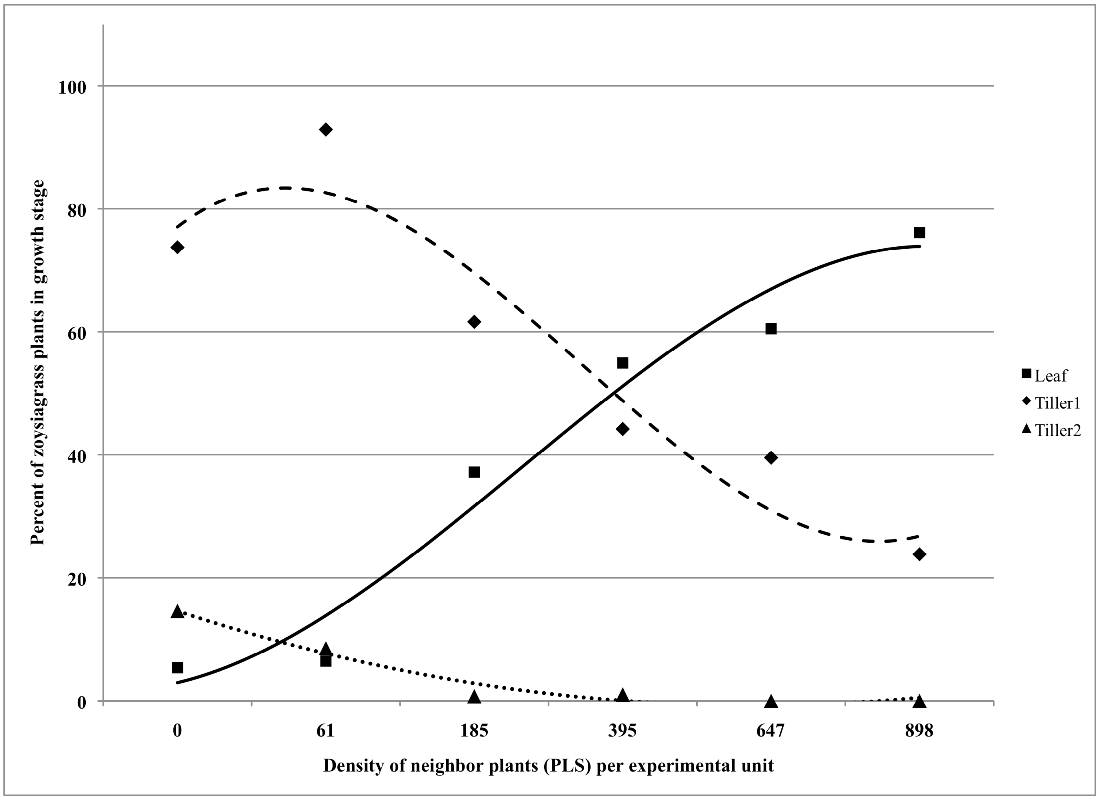

Figure 13: Zenith zoysiagrass developmental response to increasing smooth crabgrass density 8 weeks after seeding. Symbols are least square means, lines are fitted values. Intercept and density effect regression estimates presented in Table 13.

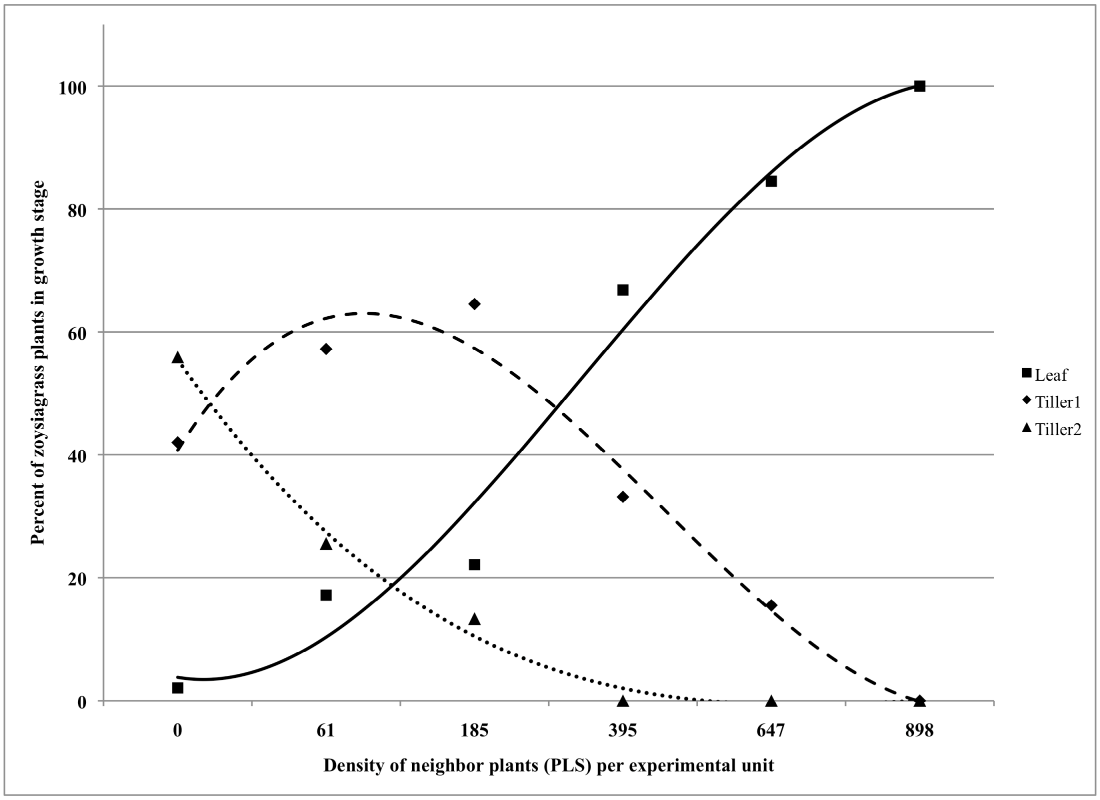

Figure 14: Zenith zoysiagrass developmental response to increasing goosegrass density 8 weeks after seeding. Symbols are least square means, lines are fitted values. Intercept and density effect regression estimates presented in Table 13.

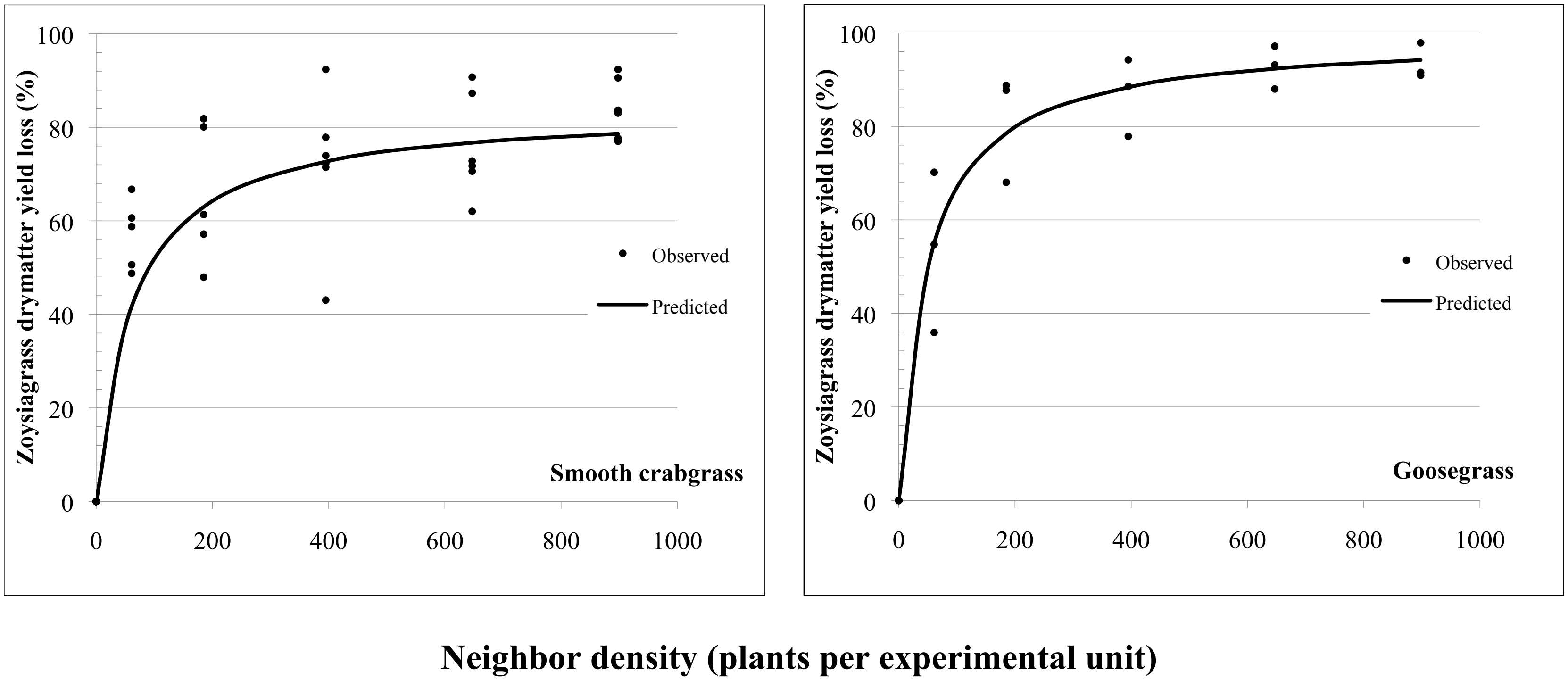

Figure 15: Zenith zoysiagrass drymatter yield loss as a function of neighbor density. Lines are the fitted hyperbolic equation with parameter estimates given in Table 14.

Appendices

Appendix 1: Weed Science Society of America approved common and chemical nomenclature

Clodinafop-propargyl	2-propynyl(2*R*)-2-[4-[(5-chloro-3-fluoro-2-pyridinyl)oxy]phenoxy]propanoate
Dazomet	tetrahydro-3,5-dimethyl-2*H*-1,3,5-thiadiazine-2-thione
EPTC	*S*-ethyl dipropyl carbamothioate
Fenoxaprop-P	(2*R*)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]propanoic acid
Glyphosate	*N*-(phosphonomethyl)glycine
Metamifop	(2*R*)-2-[4-[(6-chloro-2-benzoxazolyl)oxy]phenoxy]-*N*-(2-fluorophenyl)-*N*-methylpropanamide
Siduron	*N*-(2-methylcyclohexyl)-*N'*-phenylurea
Triclopyr	[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid
Trinexapac-ethyl	ethyl (*RS*)-4-cyclopropyl(hydroxy)methylene-3,5-dioxocyclohexanecarboxylate