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Short title: grass weed control

Title: Impact of glyphosate, imazapic, and metsulfuron on bahiagrass, vaseygrass, and guineagrass control

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Abstract

Bahiagrass, guineagrass, and vaseygrass are dominant weeds in bermudagrass pastures. Chemical control of these weeds is difficult as some herbicides damage bermudagrass. The objectives of the study were to assess the effect of glyphosate and glyphosate mixes with imazapic and nicosulfuron + metsulfuron on bahiagrass control and to evaluate the effect of glyphosate and/or imazapic, nicosulfuron + metsulfuron on guineagrass and vaseygrass control under greenhouse conditions. Bahiagrass field trials were conducted in Citra and Ona, FL, in 2016 and 2018, respectively, while greenhouse experiments were conducted in Ona in 2017 and 2018. Glyphosate tank mixes reduced bahiagrass biomass in Ona, whereas at Citra, biomass reduction did not differ between treatments although visual estimates of control were lowest with glyphosate at 0.28 kg ae ha^{-1}. Results from the greenhouse experiment showed that 0.38 and 0.50 kg ae ha^{-1} of glyphosate were needed to achieve 80% (ED_{80}) control at 30 DAT, while 0.60 and 0.47 kg ae ha^{-1} were required to reduce 80% biomass of guineagrass and vaseygrass at 60 DAT, respectively. Vaseygrass needed lower imazapic rates (0.05 and 0.19 kg ae ha^{-1}) for 80% (ED_{80}) control (visual estimates) and biomass reduction, respectively, whereas guineagrass required higher doses (0.31 and 0.28 kg ae ha^{-1} for visual estimates of control and biomass reduction, respectively). Glyphosate at 0.56 kg ae ha^{-1}, glyphosate plus imazapic, or nicosulfuron + metsulfuron reduced guineagrass biomass while imazapic only, glyphosate tank mixes, and nicosulfuron + metsulfuron resulted in the highest vaseygrass biomass reduction. Glyphosate and glyphosate tank mixes were consistent in controlling all grasses, yet imazapic was effective at higher rates for guineagrass.

Nomenclature

Glyphosate; imazapic; metsulfuron; nicosulfuon; bahiagrass, *Paspalum notatum* Flugge.; guineagrass, *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs; vaseygrass, *Paspalum urvillei* Steud.; bermudagrass, *Cynodon dactylon* (L.) Pers.

Keywords: biomass reduction, grass weeds, tank mix, hayfields.

Introduction

Bermudagrass is a perennial warm-season grass that grows from mid-spring to mid-fall. It reproduces through rhizomes and stolons, with a few cultivars producing seeds (Wallau et al. 2024). The leaves are gray-green and the seedheads form from upright spikelets. Bermudagrass is an important species in livestock grazing and hay production in Florida and other areas of the Southeastern United States (Sellers et al. 2019). It is highly productive, tolerant of drought, and withstands heavy grazing. However, weeds, especially grass weeds, tend to establish and compete with bermudagrass, reducing productivity. Grass weeds such as bahiagrass, guineagrass, and vaseygrass predominate in bermudagrass pastures due to their low nutritive value and palatability, and their presence in the field contaminates fodder, reducing its quality and appearance (Gonzalez 2010; Putman and Orloff 2014; Rouquette et al. 2020). Also, the success of these weeds is influenced by their ability to grow and reproduce during the growing season of bermudagrass (Sellers 2019), their tolerance to mowing (Henry et al. 2007), and differences in cultivar response to herbicides (Bunnell et al. 2003; Jeffries et al. 2017), which result in difficult weed control.

Bahiagrass, a perennial warm-season forage crop cultivated throughout Florida, is a common weed in bermudagrass pastures. Its dense sod and vegetative propagation through rhizomes and stolons with a deep root system enable establishment. Also, it reproduces by seeds and the tall seedheads consist of 2-3 smooth and shiny spike-like racemes with multiple tiny spikelets. The seeds are ovoid-shaped and glossy yellowish (Wallau et al. 2023). The leaves are formed at the base of the plant and are flat, folded, and tapered at the tip. However, bahiagrass control in bermudagrass pastures with selective herbicides is challenging and often inconsistent. For example, metsulfuron is reported to be ineffective against several bahiagrass cultivars, but bermudagrass is tolerant (Bunnell et al. 2003; Matocha and Grichar 2013). Conversely, Grichar et al. (2008) reported that imazapic completely controlled bahiagrass but significantly damaged bermudagrass. Therefore, exploring combinations of these herbicides to reduce bahiagrass dominance while encouraging bermudagrass growth is important.

Vaseygrass and guineagrass, perennial grasses characterized by smaller fibrous roots, have also become common weeds in bermudagrass pastures throughout the Southeastern United States (Webster 2000). Controlling these species is challenging since they are often misidentified as johnsongrass. Vaseygrass is a bunch-type grass that grows well in wet fields and alongside drainage ditches (Sellers et al. 2019). The leaves are elongated and narrow with an indented midrib, and wrinkled leaf margins. Also, the grass contains hair where the leaves join the stem, but these hairs disappear as the stems lengthen. It reproduces by seed and the seedhead has alternating spikelets forming silky hairs around the seeds. The seeds are produced throughout the seedhead branch and are flat with some hairs (Sellers et al. 2019). Conversely, guineagrass colonizes disturbed sites, including roadsides, and prefers drier areas. The leaves have a prominent white midrib, and their undersides are rough with stiff hair. Additionally, the leaf blades are long, narrow, and finely tipped. The stems have scattered but abundant hairs, and the hair density varies with biotypes. The seedhead of guineagrass is a single open panicle with smaller green to purple wrinkled seeds. However, there is limited information on effective chemical management techniques for these grasses. Fewer studies (Sellers et al. 2019) have identified glyphosate as an effective herbicide to control these weeds, though spot spray applications are recommended to avoid bermudagrass injury. Other efficacious herbicides are imazapic, nicosulfuron, and metsulfuron (Jeffries et al. 2017).

Controlling undesirable grass weeds in bermudagrass pastures depends on applying non-selective herbicides such as glyphosate, which injures bermudagrass. Preliminary observations indicate that established bermudagrass is relatively tolerant to low glyphosate application rates (Abreu et al. 2020). For example, Webster et al. (2004) reported that common bermudagrass was tolerant to glyphosate rates < 0.84 kg ae ha^{-1} applied at 15 cm height. Additionally, Abreu et al. (2020) reported that the bermudagrass cultivars ‘Greenfield’ and ‘Goodwell’ had minimal visual injury (< 55%) 16 days after treatment (DAT), which was transient as regrowth resumed approximately 24 DAT. Therefore, weed management can be enhanced by understanding how each herbicide, whether applied alone or in combination, improves bahiagrass, guineagrass, and vaseygrass control. Hence, the objectives of the study were to i) evaluate the efficacy of glyphosate and glyphosate tank mixes on bahiagrass control under field conditions and ii) evaluate the efficacy of glyphosate, imazapic, nicosulfuron + metsulfuron on the control of guineagrass and vaseygrass under greenhouse conditions.

Materials and Methods

Control of Bahiagrass with Glyphosate Alone and in Tank-Mixes

Field experiments were conducted at the Plant Science Research and Education Unit (PSREU) near Citra, FL (29°24’19” N, 82°10’8” W) in June, 2016 and repeated at the Range Cattle Research and Education Center (RCREC) near Ona, FL (27°39’84” N, 81°94’07” W) in July 2018. The soil at the Citra location was Arredondo sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudults) with 1% OM and a pH of 5.3 while the soil at the Ona location was a Pomona fine sand (sandy, siliceous, hyperthermic Ultic Alaquods) with 1% OM and a pH of 4.8.

The experiment had eight treatments of either glyphosate (Roundup PowerMAX™) at 0.28 and 0.56 kg ae ha^{-1} applied alone or in a tank mix with metsulfuron (Escort™, Bayer, Whippany, NJ) at 0.008 kg ae ha^{-1}, imazapic (Impose, Adama Essentials, Raleigh, NC) at 0.11 kg ae ha^{-1}, or nicosulfuron + metsulfuron (Pastora™, DuPont, Wimington, DE) at 0.06 + 0.02 kg ae ha^{-1}, with four replicates in a randomized complete block design (RCBD). A non-treated check was included for comparison. A non-ionic surfactant (NIS) (Activator 90; Loveland Products, Loveland, CO) at 0.25% v/v was added to each treatment per label instructions. Each experimental site consisted of pure, ‘Pensacola’ bahiagrass with plots measuring 3.1 m x 6.2 m. Fertilizer was not applied. The experimental area was mowed to an initial height of 6 to 8 cm seven days before herbicide application to simulate a haying operation in bermudagrass hayfields. A CO_2 pressurized backpack sprayer with an AM11002 low-pressure AirMix venturi nozzle (Greenleaf Technologies, Covington, Louisiana) calibrated to deliver 187 L ha^{-1} at 193 kPa was used to apply herbicide treatments.

Vaseygrass and Guineagrass Response to Glyphosate and Herbicide Mixes

Three experimental runs were conducted at the RCREC greenhouse in 2017 and 2018. Individual vaseygrass and guineagrass culms with undamaged roots were separated from field-dug clumps and planted into individual 3.8 L plastic pots, filled with a commercial potting soil mix (Sungro Professional Growing Mix, Sungro Horticulture, Agawam, MA). Miracle-Gro fertilizer (N: P: K, 24-8-16) was applied at 35 kg N ha^{-1}, 12 kg P ha^{-1}, and 23 kg K ha^{-1} at weekly intervals. Plants were grown in a greenhouse with a day/night 30/24 C and were irrigated as needed. After establishment, the plants in each pot were clipped to a height of 6 to 8 cm, and one month of regrowth was allowed prior to cutting to the same height and treatment application. During the regrowth phase, plants were fertilized biweekly.

The experimental design for each experiment was a randomized complete block design with four replications. The herbicide treatments were divided into three experiments: 1) glyphosate only treatments with six application rates (0.14, 0.28, 0.56, 0.84, 1.12, and 2.24 kg ae ha^{-1}); 2) imazapic only treatments with five application rates (0.02, 0.04, 0.07, 0.14, and 0.28 kg ae ha^{-1}); and 3) a tank mix experiment containing glyphosate at 0.28 or 0.56 kg ae ha^{-1} alone or in combination with 0.07 kg ae ha^{-1} imazapic or nicosulfuron + metsulfuron at 0.06 + 0.02 kg ae ha^{-1}; imazapic and the premix of nicosulfuron + metsulfuron were also applied without glyphosate. Treatments were applied with a compressed air-powered moving nozzle spray chamber (Generation II Spray Booth, Devries Manufacturing Corp., Hollandale, MN), equipped with a Teejet 8001 EVS spray nozzle (Teejet Technologies Southeast, Tifton, GA), calibrated to deliver 187 L ha^{-1} at 172 kPa. All herbicide treatments included NIS(Activator 90; Loveland Products, Loveland, CO) at 0.25% v/v.

Data collection

Control of grasses was evaluated using a visual estimate of a control scale of 0 to 100, with 0 representing no control and 100 indicating complete death. Bahiagrass visual estimates of control were recorded at 30 and 60 days after treatment (DAT), while vaseygrass and guineagrass visible estimates of control were recorded at 15 and 30 DAT. A 1.5 m x 1.8 m swath was harvested from each bahiagrass plot for biomass determination at 30 and 60 DAT. In the greenhouse experiment, biomass was determined by clipping the treated plants at 30 DAT and re-clipping at 60 DAT. Samples were dried at 60 C in a forced-air oven for 72 hours, and dry weight was recorded. Biomass was expressed as percent of non-treated in the bahiagrass field study and the greenhouse studies.

Data analyses

Data were analyzed using the open-source statistical software R 4.3.1 (R Core Team 2022). Bahiagrass data for control and biomass were subjected to ANOVA to test for glyphosate and glyphosate tank mix effect per study area. Visual estimates of control and biomass for guineagrass and vaseygrass were determined by mixed-effects models using the package "*nlme*" in R. Glyphosate, imazapic, tank-mix rates, and their interactions were the fixed effects, the experimental run was a random effect. The effective imazapic rate for visual estimates of control and biomass reduction by 80% (ED_{80}) for guineagrass and vaseygrass was obtained from a three-

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parameter log-logistic model (Equation 1), whereas for glyphosate was obtained from a four-parameter log-logistic model (Equation 2) using the ED function under the "*drc*" package in the R statistical environment (Equation 1 and 2):

$$Y = 0 + \{d– 0/ 1 + \exp[b(\log (x) – \log (e)]\} \quad (1),$$

$$Y = c + \{d – c / 1 + \exp[b(\log (x) – \log (e)]\} \quad (2)$$

Where Y is biomass or visual estimates of control of guineagrass or vaseygrass, x is glyphosate or imazapic application rate (kg ae ha^{-1}), b is the relative slope at the inflection point, d is the upper limit of the curve, c is the lower limit of the curve, and e is the fitted line's inflection point (ED_{80}). Simple linear regression, two, three and four-parameter log-logistic models were first run, and the best model was chosen using Akaike's information criterion (AIC) in the "qpcR" package of R (Ritz and Spiess 2008). A lack-of-fit test at the 95% confidence level ($P \leq 0.05$) was conducted to assess the model fit of the linear regressions (Ritz and Streibig 2005). Standard error, t, and F tests were used to assess the differences in parameter estimations at the 5% significance level.

Results and Discussion

Control of Bahiagrass with Glyphosate Alone and in Mixtures

Visual estimates of bahiagrass control in Citra were different among treatments. Glyphosate at 0.28 kg ae ha^{-1} resulted in 34 and 46% control at 30 and 60 DAT, respectively (Table 1), and increasing the glyphosate rate to 0.56 kg ae ha^{-1} did not increase control at either evaluation. However, the addition of imazapic or nicosulfuron + metsulfuron to glyphosate at 0.28 kg ae ha^{-1} resulted in at least 1.6-times greater control than glyphosate alone 30 DAT; this trend was also observed 60 DAT with the same mixtures providing at least 1.2-times greater control. Adding either metsulfuron, imazapic, or nicosulfuron + metsulfuron resulted in at least 1.3-times greater control than glyphosate alone at 0.56 kg ae ha^{-1} 30 DAT. However, only glyphosate mixtures containing metsulfuron or nicosulfuron + metsulfuron resulted in greater control than glyphosate alone at 0.56 kg ae ha^{-1} 60 DAT. At Ona, glyphosate at 0.28 kg ae ha^{-1} resulted in the least bahiagrass control 30 (48%) and 60 (9%) DAT. Increasing the glyphosate rate to 0.56 kg ae ha^{-1} resulted in 1.5- and 3-times greater bahiagrass control 30 and 60 DAT, respectively; however, bahiagrass control following the high rate of glyphosate 60 DAT was < 30% (Table 1). Only the addition of nicosulfuron + metsulfuron resulted in increased bahiagrass

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control compared to the high rate of glyphosate alone 30 DAT. Conversely, bahiagrass control 60 DAT with glyphosate + imazapic or metsulfuron or nicosulfuron + metsulfuron was at least 7.8- and 2.3-times greater than glyphosate alone at 0.28 and 0.56 kg ae ha^{-1}, respectively. These data indicate that a tank-mix partner is necessary with glyphosate to control bahiagrass as bahiagrass control was transient when using glyphosate alone.

Although herbicide treatments resulted in differences in bahiagrass control at Citra, there were no differences in bahiagrass biomass among the treatments 30 or 60 DAT (Table 1). Biomass30 DAT ranged from 43% to 69% of the non-treated control, and from 56% to 104% of the non-treated control 60 DAT. Conversely, there were differences in biomass among treatments 30 and 60 DAT at Ona. Bahiagrass biomass ranged from 10 to 18% of the non-treated control 30 DAT. Biomass was 1.9-times greater with glyphosate at 0.28 kg ae ha^{-1} than this rate of glyphosate applied with nicosulfuron + metsulfuron. Additionally, bahiagrass biomass was 1.8-times greater when glyphosate was applied at a low rate versus a high rate. Bahiagrass fully recovered by 60 DAT when glyphosate was applied at either rate, as biomass was at least 103% of the non-treated control. Adding metsulfuron, imazapic, or nicosulfuron + metsulfuron to glyphosate at either rate 60 DAT reduced biomass production with bahiagrass biomass ranging from 0.4 to 32% of the non-treated control.

Bahiagrass recovery following glyphosate applied alone was expected, as recommendations to kill bahiagrass for pasture renovation are usually 3.36 kg ae ha^{-1} (Rogers et al. 1987; Bunnell et al. 2003). The variability in responses at the Citra location could be due to contamination of diploid ‘Pensacola’ bahiagrass with tetraploid ‘Argentine’ bahiagrass as tetraploid cultivars are tolerant to ALS-inhibiting herbicides (Bunnell et al. 2003). The differences between the two locations with regards to bahiagrass response could be due to differences in soil pH as the Citra location soil pH was near the optimum soil pH of 5.5 (Wallau et al. 2023), which likely made the bahiagrass more resilient to herbicide applications. The tank mixes of glyphosate and/or imazapic and nicosulfuron + metsulfuron at Ona showed increased bahiagrass control and biomass reduction and this was likely due to the combined effect of the herbicides. Metsulfuron controls broadleaf and grass weeds and is effective against bahiagrass (McElroy and Martin 2013). Therefore, glyphosate plus nicosulfuron + metsulfuron mixtures demonstrate potential for use in bermudagrass pastures, as glyphosate applied at these rates and

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nicosulfuron + metsulfuron causes minimal damage to bermudagrass while removing bahiagrass (Abreu et al. 2020; Matocha et al. 2010). The herbicide label recommends the application of nicosulfuron + metsulfuron earlier in the growing season (March–April) than the application in this study (June–July). However, a delayed application schedule was chosen because the rainy season in Florida begins from mid-to-late June, hence increasing the efficacy of the herbicide at this application timing.

Vaseygrass and Guineagrass Response to Glyphosate and Herbicide Mixes

There was no glyphosate × experimental run effect for visual estimates of control and biomass for either grass species. Increasing glyphosate rates significantly influenced visual estimates of control for both guineagrass and vaseygrass (Figure 1). The greatest control of guineagrass 15 and 30 DAT was observed with glyphosate rates>0.56 kg ae ha^{-1}, whereas control of vaseygrass was observed with glyphosate rates >0.84 kg ae ha^{-1}. Additionally, the effective glyphosate rate needed to achieve 80% (ED_{80}) guineagrass control was 0.44 and 0.38 kg ae ha^{-1}, while for vaseygrass the effective glyphosate rate was 0.65 and 0.60 kg ae ha^{-1} 15 and 30 DAT, respectively. Biomass ED_{80} value estimates showed that glyphosate rates of 0.34 and 0.47 kg ae ha^{-1} were required for 80% (ED_{80}) guineagrass biomass reduction, while glyphosate rates of 0.38 and 0.50 kg ae ha^{-1} were required for vaseygrass30 and 60 DAT, respectively (Table 2, Figure 2). The findings corroborate work by Silva et al. (2018), who reported effective guineagrass control with glyphosate at 0.54 kg ae ha^{-1}.

There was no imazapic × experimental run effect for either grass species' visual estimates of control or biomass. Increasing imazapic rates substantially affected visual estimates of control for both guineagrass and vaseygrass (Table 2, Figure 3). Imazapic at >0.04 kg ae ha^{-1} caused the most damage to guineagrass and vaseygrass at 15 and 30 DAT. In addition, the effective imazapic rate needed to obtain 80% (ED_{80}) guineagrass control was 52.7 and 0.31 kg ae ha^{-1}, while for vaseygrass, the effective imazapic rate was 1.71 and 0.05 kg ae ha^{-1}15 and 30 DAT, respectively. Biomass ED_{80} values showed that guineagrass required imazapic rates of 0.20 and 0.28 kg ae ha^{-1} for biomass reduction30 and 60 DAT, respectively, whereas vaseygrass required imazapic rates of 0.019 kg ae ha^{-1} at both sampling times (Table 2, Figure 4). However, the ED_{80} imazapic dose requirements for guineagrass control are above the evaluated rates.

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The results indicate that higher rates of imazapic are needed for guineagrass control whereas lower rates are required for vaseygrass. However, these rates are relatively high for broadcast applications in the field since imazapic has been shown to damage bermudagrass. Grichar et al. (2008) reported ‘Coastal’ bermudagrass injury of 73 to 87% with imazapic rates of 0.2 and 0.24 kg ae ha^{-1}, respectively, when broadcast in a bermudagrass pasture. Lemus and White (2015) also reported a yield decrease in bermudagrass of 43% from applications of imazapic at 0.23 kg ae ha^{-1} applied before green up. Therefore, spot application of imazapic should be considered, to target guineagrass and limit bermudagrass damage.

There was no glyphosate tank mix × experimental run effect for guineagrass control and biomass. Visual estimates of guineagrass control were greatest with glyphosate at 0.56 kg ae ha^{-1}, glyphosate + imazapic, or nicosulfuron + metsulfuron (>90%) 15 and 30 DAT. Guineagrass control was lowest with glyphosate at 0.28 kg ae ha^{-1} (38%) and imazapic (43%) 15 DAT and glyphosate at 0.28 kg ae ha^{-1} 30 DAT (Table 3). Guineagrass biomass with imazapic or nicosulfuron + metsulfuron was at least 20-times greater than that treated with glyphosate at 0.56 kg ae ha^{-1} 60 DAT. However, adding these active ingredients with glyphosate at 0.56 kg ae ha^{-1} resulted in similar biomass. These data indicate that glyphosate alone at 0.56 kg ha^{-1} effectively controls guineagrass, and that additional active ingredients are not required. There is little published information regarding the control of guinegrass in forage systems. However, the sensitivity of guineagrass to glyphosate demonstrated in the glyphosate-only experiment and glyphosate tank mix experiment supports the commonly recommended spot treatment with glyphosate for this species (Sellers et al. 2019).

There was no glyphosate tank mix × experimental run effect for vaseygrass control and biomass. Imazapic resulted in the greatest (88%) vaseygrass control at 15 DAT, but the level of control was not different from glyphosate + imazapic treatments or the high rate of glyphosate + nicosulfuron + metsulfuron (Table 4). By 30 DAT, treatments with glyphosate at 0.56 kg ae ha^{-1} plus imazapic and either rate of glyphosate + nicosulfuron + metsulfuron provided at least 95% control, and this was at least 1.3 times greater than control observed with either rate of glyphosate, imazapic, or nicosulfuron + metsulfuron alone. Vaseygrass biomass was greatest with glyphosate at the low rate of 30 DAT and was at least 1.4 times greater than all other treatments. By 60 DAT, biomass in all treatments was <28% of the non-treated control, indicating that all treatments can significantly suppress vaseygrass. Unlike guineagrass, adding

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other active ingredients to glyphosate may enhance vaseygrass control, especially if a low rate of glyphosate is utilized. These results are consistent with Twidwell et al. (2014), who reported that nicosulfuron + metsulfuron and glyphosate + nicosulfuron + metsulfuron provided 58 to 78% control after two consecutive years of treatment. Furthermore, Jeffries et al. (2017) reported that nicosulfuron + metsulfuron applied to not mowed vaseygrass resulted in 80% cover reduction52 weeks after treatment.

Practical Implications

Applying glyphosate, imazapic, and/or nicosulfuron + metsulfuron provides efficient long-term control of bahiagrass and vaseygrass. Glyphosate at 0.56 kg ae ha^{-1} controls guineagrass effectively, and ranchers can save on herbicide costs by applying at this rate, since applying at higher rates results in similar control. Guineagrass is tolerant to imazapic, therefore, higher rates are required for adequate control; ranchers need to spot-apply the herbicide to minimize bermudagrass injury at high rates. Future studies need to investigate the susceptibility of hybrid bermudagrass cultivars to these rates and tank mixes, and vaseygrass and guineagrass field studies should be conducted to validate the greenhouse results.

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Competing Interests

The authors declare none.

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Table 1. Effect of glyphosate and glyphosate tank mixes on bahiagrass control and biomass at Citra and Ona, FL, in 2016 and 2018, respectively[1].

		Control								Biomass[3]							
		30 DAT[2]				60 DAT				30 DAT				60 DAT			
Herbicide	Rate	Citra		Ona		Citra		Ona		Citra		Ona		Citra		Ona	
	kg ae ha^{-1}	———% Control———								———% of non-treated———							
Glyphosate	0.28	34	c	48	c	46	d	9	e	60.9	a	23.1	a	104.4	a	150.6	a
Glyphosate	0.56	42	bc	71	b	53	cd	26	d	52.1	a	13.2	b	91.4	a	102.9	a
Glyphosate + metsulfuron	0.28 + 0.007	43	bc	70	b	54	bcd	70	bc	61.5	a	17.7	ab	83.4	a	10.5	b
Glyphosate + metsulfuron	0.56 + 0.007	55	a	75	ab	64	ab	75	bc	67.4	a	10.3	b	81.1	a	8.1	b
Glyphosate + imazapic	0.28 + 0.07	46	ab	71	b	56	abc	75	bc	48.0	a	17.1	ab	67.9	a	15.1	b
Glyphosate + imazapic	0.56 + 0.07	56	a	70	b	60	abc	61	c	42.9	a	10.4	b	66.5	a	32.3	b
Glyphosate + metsulfuron +	0.28 + 0.009 +	54	a	73	ab	61	abc	83	ab	63.6	a	12.4	b	55.5	a	12.6	b

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nicosulfuron	0.033								
Glyphosate + metsulfuron + nicosulfuron	0.56 + 0.009+ 0.033	56 a	79 a	65 a	91 a	69.4 a	11.2 b	60.1 a	0.4 b
p		0.0019	<0.0001	0.0182	<0.0001	0.2663	0.0316	0.1627	0.0003

[1]Means followed by the same letter within columns are not significantly different at $p \leq 0.05$.

[2]Abbreviations: days after treatment (DAT).

[3]Biomass of non-treated bahiagrass at the Citra location was 531 and 667 kg ha^{-1} at 30 and 60 DAT, respectively. Non-treated bahiagrass biomass at the Ona location was 444 and 275 kg ha^{-1} at 30 and 60 DAT, respectively.

Table 2. Log-logistic regression parameter estimates (±standard error) for visual control at 15 and 30 days after treatment (DAT), and biomass at 30 and 60 DAT of guineagrass and vaseygrass experiments under greenhouse conditions in Ona,FL, in 2017 and 2018.

		Parameter estimates			
Response variable	Species	*b*	*c*	*d*	ED_{80}
Imazapic visual control at 15 DAT (%)	Guineagrass	-0.24(±0.16)	-	-	52.7a (±0.14)
	Vaseygrass	-0.36 (±0.17)	-	-	1.71b (±0.02)
Glyphosate visual control at 15 DAT (%)	Guineagrass	-5.93(±1.19)	14.63(±3.18)	98.99(±1.88)	0.44 a (±0.04)
	Vaseygrass	-1.77(±0.42)	-10.93(±16.76)	96.43(±4.39)	0.65 a (±0.08)
Imazapic visual control at 30 DAT (%)	Guineagrass	-0.62(±0.20)	-	-	0.31a (±0.01)
	Vaseygrass	-0.62(±0.37)	-	-	0.05b (±0.005)
Glyphosate visual control at 30 DAT (%)	Guineagrass	-5.20(±2.29)	24.21(±4.31)	100.10(±1.93)	0.38 ab (±0.05)
	Vaseygrass	-1.86(±0.42)	-9.89(±16.74)	100.93(±4.10)	0.60 a (±0.07)
Imazapic biomass at 30 DAT (%)	Guineagrass	0.19(±0.26)	-	-	0.20 b (±045)
	Vaseygrass	2.66(±4.57)	-	-	0.019 b (±0.01)

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Glyphosate biomass at 30 DAT (%)	Guineagrass	13.85(±2.35)	3.83(±0.99)	68.34(±2.04)	0.34 b (±0.04)
	Vaseygrass	4.31(±0.73)	1.47(±1.41)	54.66(±2.40)	0.50 a (±0.04)
Imazapic biomass at 60 DAT (%)	Guineagrass	1.57(±0.43)	-	-	0.28 a (±0.1)
	Vaseygrass	2.11(±3.03)	-	-	0.019 b (±0.01)
Glyphosate biomass at 60 DAT (%)	Guineagrass	5.02(±2.45)	-0.07(±1.30)	46.32(±3.20)	0.38 b (±0.05)
	Vaseygrass	1.09(±1.06)	-2.82(±5.90)	53.72(±86.23)	0.47 ab (±0.68)

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Table 3. Effect of herbicide tank mixes on guineagrass under greenhouse conditions in Ona, FL, in 2017 and 2018.[1]

		Control				Biomass[3]			
Herbicide	Rate	15 DAT[2]		30 DAT		30 DAT		60 DAT	
	kg ae ha^{-1}	—% Control—				—% of non-treated—			
Glyphosate	0.28	38	d	33	d	65.6	a	74.4	a
Glyphosate	0.56	90	ab	99	a	10.3	cd	1.5	c
Imazapic	0.07	43	d	85	b	18.1	c	32.9	b
Glyphosate + imazapic	0.28 + 0.07	90	ab	95	a	13.6	cd	42.4	b
Glyphosate + imazapic	0.56 + 0.07	94	a	98	a	8.8	cd	2.2	c
Glyphosate + nicosulfuron + metsulfuron	0.28 + 0.06 + 0.02	83	b	95	a	9.5	cd	0.4	c
Glyphosate + nicosulfuron + metsulfuron	0.56 + 0.06 + 0.02	92	ab	100	a	4.5	d	0.0	c
Nicosulfuron + metsulfuron	0.06 + 0.02	67	c	75	c	38.3	b	31.2	b
p-value		<0.0001		<0.0001		<0.0001		<0.0001	

[1]Means followed by the same letter within columns are not significantly different at $p \leq 0.05$.

[2]Abbreviations: days after treatment (DAT).

[3]Non-treated guineagrass biomass averaged 11.1 and 10.1 g (dry weight) at 30 and 60 DAT, respectively, over all three experimental runs.

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Table 4. Effect of glyphosate and glyphosate tank mixes on control of vaseygrass under greenhouse conditions in Ona, FL, in 2017 and 2018.[1]

Herbicide	Rate	Control		Biomass[3]	
		15 DAT[2]	30 DAT	30 DAT	60 DAT
	kg ae ha^{-1}	———% Control———		—% of non-treated—	
Glyphosate	0.28	23 d	46 e	67.9 a	27.6 a
Glyphosate	0.56	61 c	64 d	49.9 abc	8.1 b
Imazapic	0.07	88 a	73 bc	15.0 d	4.5 bc
Glyphosate + imazapic	0.28 + 0.07	84 ab	80 b	20.0 cd	2.2 bc
Glyphosate + imazapic	0.56 + 0.07	83 ab	98 a	23.8 cd	2.0 c
Glyphosate + nicosulfuron + metsulfuron	0.28 + 0.06 + 0.02	70 bc	95 a	38.7 abc	1.6 c
Glyphosate + nicosulfuron + metsulfuron	0.56 + 0.06 + 0.02	79 ab	97 a	32.7 abc	1.0 c
Nicosulfuron + metsulfuron	0.06 + 0.02	68 bc	67 d	19.8 cd	0.2 c
p-value		<0.0001	<0.0001	0.0002	<0.0001

[1]Means followed by the same letter within columns are not significantly different at $p \leq 0.05$.

[2]Abbreviations: days after treatment (DAT).

[3]Vaseygrass biomass removed from non-treated pots averaged 8.9 and 6.9 g (dry weight) at 30 and 60 DAT, respectively, over all three experimental runs.

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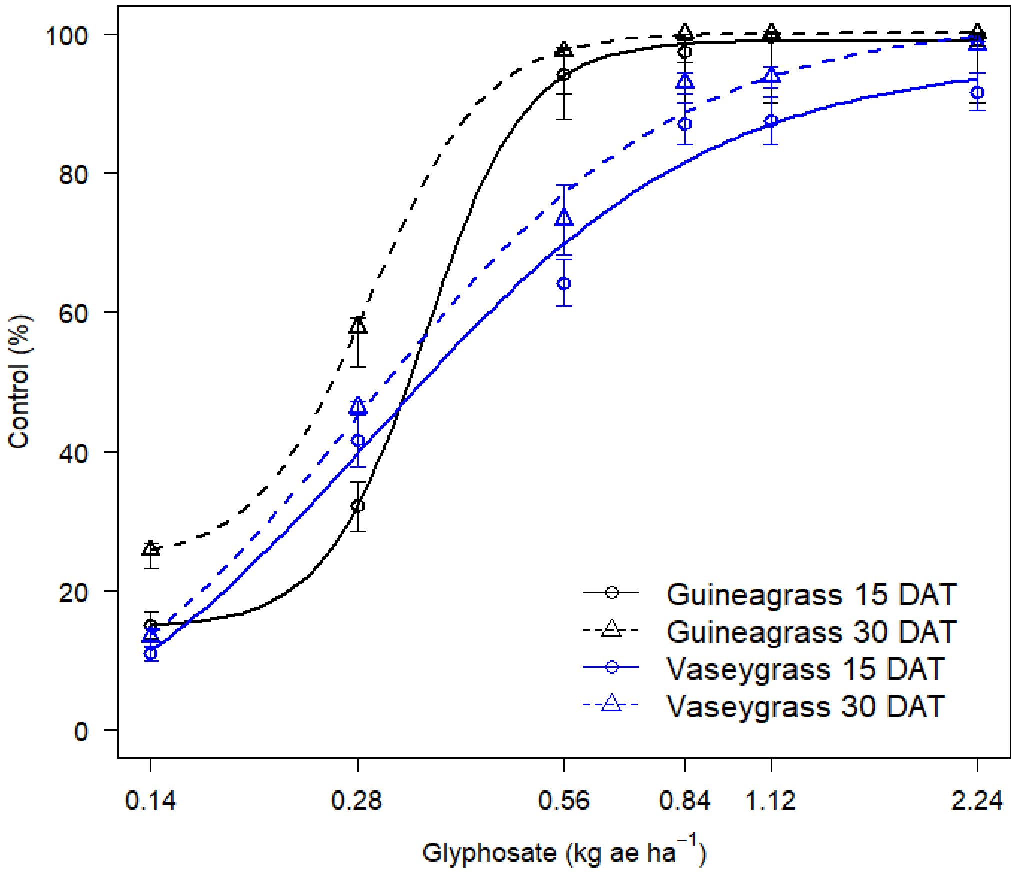

Figure 1. Visual estimates of control (%) of guineagrass and vaseygrass at 15 and 30 days after treatment (DAT) in response to glyphosate rates under greenhouse conditions in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a four-parameter log-logistic regression model: Y = c + {d – c / 1 + exp[b(log (x) – log (e)]}, where Y is visual estimates of guineagrass or vaseygrass control, x is glyphosate application rate (kg ae ha^{-1}), b is the relative slope at the inflection point, d is the upper limit of the curve, c is the lower limit of the curve, and e is the fitted line's inflection point (ED_{80}).

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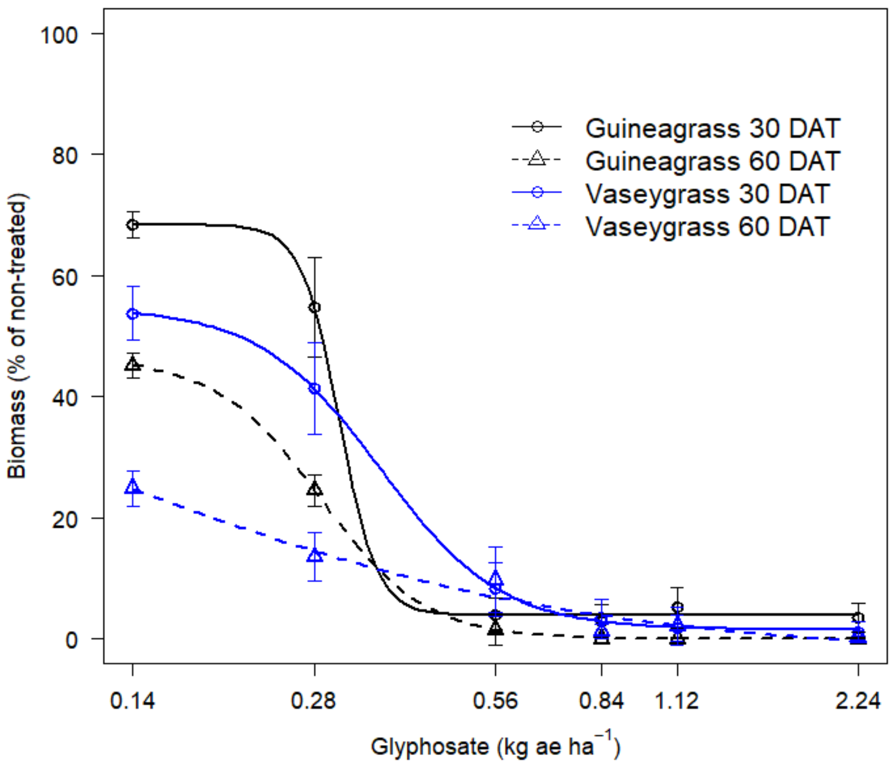

Figure 2. Biomass reduction (%) at 30 and 60 days after treatment (DAT) of guineagrass and vaseygrass in response to glyphosate rates under greenhouse conditions in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a four-parameter log-logistic regression model: Y = c + {d – c / 1 + exp[b(log (x) – log (e)]}, where Y is visual estimates of guineagrass or vaseygrass biomass, x is glyphosate application rate (kg ae ha^{-1}), b is the relative slope at the inflection point, d is the upper limit of the curve, c is the lower limit of the curve, and e is the fitted line's inflection point (ED_{80}).

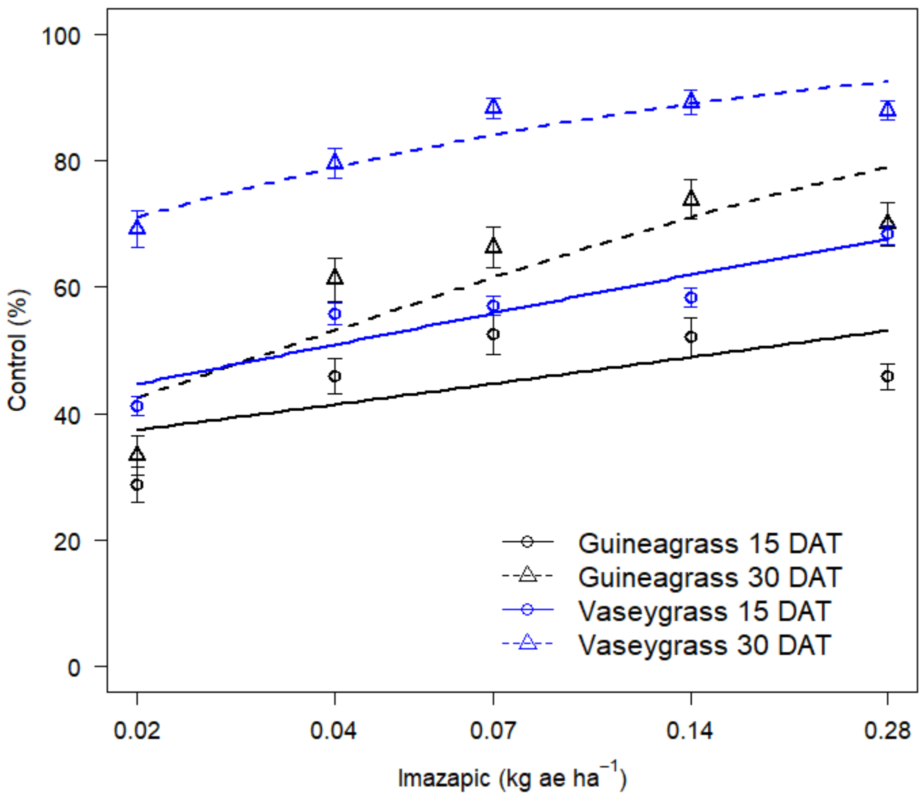

Figure 3. Visual estimates of control (%) of guineagrass and vaseygrass at 15 and 30 days after treatment (DAT) in response to imazapic rates under greenhouse conditions in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a three-parameter log-logistic regression model: Y = 0 + {d– 0/ 1 + exp[b(log (x) – log (e)]}, where Y is visual estimates of guineagrass or vaseygrass control, x is glyphosate application rate (kg ae ha^{-1}), b is the relative slope at the inflection point, d is the upper limit of the curve, and e is the fitted line's inflection point (ED_{80}).

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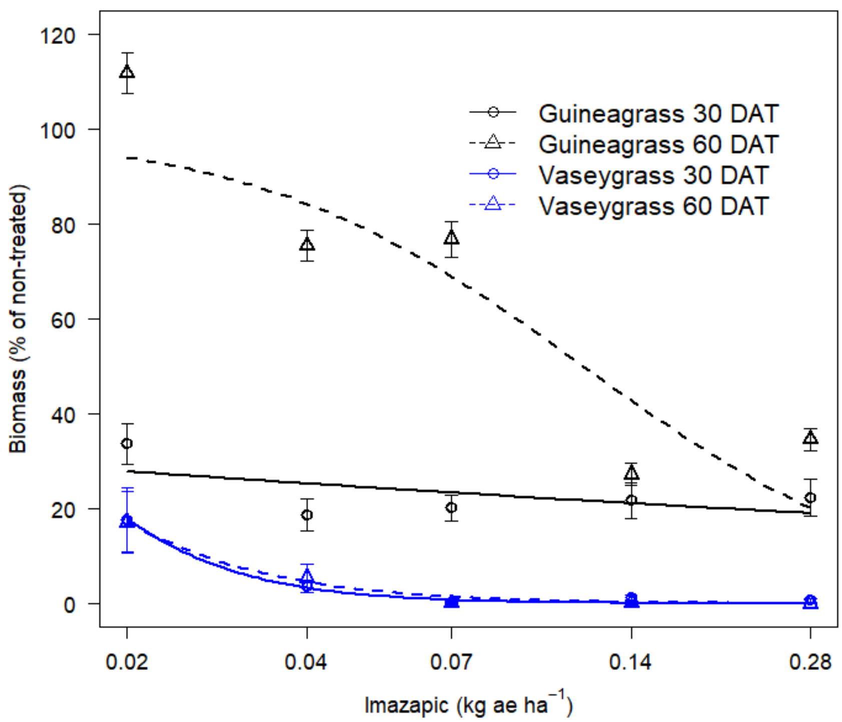

Figure 4. Biomass reduction (%) at 30 and 60 days after treatment (DAT) of guineagrass and vaseygrass in response to imazapic rates under greenhouse conditions in 2017 and 2018. Solid and dashed lines represent predicted values. Data were fit to a three-parameter log-logistic regression model: Y = 0 + {d– 0/ 1 + exp[b(log (x) – log (e)]}, where Y is the visual estimates of guineagrass or vaseygrass biomass, x is glyphosate application rate (kg ae ha^{-1}), b is the relative slope at the inflection point, d is the upper limit of the curve, and e is the fitted line's inflection point (ED_{80}).

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