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Bahiagrass Tolerance to Aminocyclopyrachlor in Florida

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Two varieties of bahiagrass were evaluated under Florida conditions for forage tolerance to the new herbicide, aminocyclopyrachlor (ACP), which is essential for product development decisions. Herbicide treatments included ACP alone at 70 and 140 g ai ha^{-1}, ACP + chlorsulfuron at 69 + 27 and 138 + 54 g ai ha^{-1}, ACP + 2,4-D amine at 70 + 532 g ai ha^{-1} and 140 + 1,064 g ai ha^{-1}, ACP + triclopyr-amine at 70 + 140 g ai ha^{-1} and 140 + 280 g ai ha^{-1}, and ACP + metsulfuron at 46 + 7, 78 + 12, and 168 + 26 g ai ha^{-1}, and also included a nontreated check. 'Argentine' bahiagrass was the most tolerant forage species, and 'Pensacola' bahiagrass was sensitive to ACP + metsulfuron and initially to ACP + chlorsulfuron. Herbicide applications using ACP, when labeled, will likely provide good to excellent control of several weed species, with little long-term impact on bahiagrass forage production when the cultivar is known.

Nomenclature: Aminocyclopyrachlor; chlorsulfuron; metsulfuron; triclopyr; bahiagrass, *Paspalum notatum* Flüggé.
Key words: 'Argentine' bahiagrass, 'Pensacola' bahiagrass, pasture, warm-season forage.

Dos variedades de pasto bahia fueron evaluadas en Florida para determinar la tolerancia del forraje al nuevo herbicida aminocyclopyrachlor (ACP), la cual es esencial para la toma de decisiones en relación al desarrollo del producto. Los tratamientos con herbicidas incluyeron ACP solo a 70 y 140 g ai ha^{-1}, ACP + chlorsulfuron a 69 + 27 y 138 + 54 g ai ha^{-1}, ACP + 2,4-D amine a 70 + 532 g ai ha^{-1} y 140 + 1,064 g ai ha^{-1}, ACP + triclopyr-amine a 70 + 140 g ai ha^{-1} y 140 + 280 g ai ha^{-1}, y ACP + metsulfuron a 46 + 7, 78 + 12, y 168 + 26 g ai ha^{-1}, y además se incluyó un testigo sin tratamiento. El pasto bahia 'Argentine' fue el más tolerante de las especies de forraje, y el pasto bahia 'Pensacola' fue sensible a ACP + metsulfuron e inicialmente a ACP + chlorsulfuron. Las aplicaciones de herbicidas usando ACP, cuando este herbicida esté registrado, brindarán un control de bueno a excelente de varias especies de malezas, con poco daño en el largo plazo sobre la producción de forraje del pasto bahia cuando se conoce el cultivar.

In 2007, pasture and rangelands in the United States covered approximately 248 million ha, with approximately 2 million ha located in Florida (U.S. Department of Agriculture–Economic Research Service [USDA-ERS] 2012). Florida grazinglands are used primarily for feeding livestock, and many different types of forages are utilized. Traditionally, ranchers in Florida grow warm-season grasses to feed beef cattle, through either grazing and/or hay production (Vendramini 2010).

Bahiagrass is widely used because it tolerates a wide range of conditions, including high temperature, drought, temporary flooding, low soil pH, and low fertility, and it persists under high grazing pressure (Newman et al. 2010). There are several bahiagrass cultivars available, but diploid 'Pensacola' and the tetraploid 'Argentine' cultivars are the most widely recommended and utilized, covering 60 and 25%, respectively, of the bahiagrass hectares in Florida (Newman et al. 2010). 'Pensacola' when compared to 'Argentine' has narrower leaves, and it is less persistent under intensive grazing; however, it has greater cold tolerance and seed production. Both cultivars are especially productive from April to September, but they have lower nutritive values compared to other warm-season species. However, both cultivars have been shown to reach similar high nutritive values for digestibility (IVOMD) and crude protein (CP) of 54 and 12%, respectively,

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when harvested every 21 d under high-nitrogen fertilization (200 kg N ha^{-1} yr^{-1}) (Interrante et al. 2009).

Although warm-season forage species are highly productive and adapted to Florida, weeds decrease their productivity and nutritional value, costing Florida ranchers more than $180 million dollars per year (Sellers and Ferrell 2014). Therefore, weed management strategies for pasture and rangeland are necessary to optimize forage production. Compared to row crops, there are fewer herbicides registered for use on forage grass pastures, so developing herbicides with good crop tolerance is of critical importance for pasture systems. The use of a specific herbicide depends upon the forage species, the weed species, growth stage of the weed species, and sometimes weather conditions (Sellers and Ferrell 2011).

A new growth-regulator herbicide, aminocyclopyrachlor (ACP), belonging to the pyrimidine carboxylic acid herbicide class, has been shown to have similar activity as the pyridine herbicides aminopyralid and picloram through foliar and soil activity (Shaner 2014). Research across the United States has shown that ACP controls numerous weed species, particularly broadleaf species (Bukun et al. 2010; Ferrell et al. 2012; Kyser and DiTomaso 2013; Lindenmayer et al. 2013; Minogue et al. 2011). Moreover, some grasses have also been impacted by ACP applications either alone or in combination with other herbicides. For example, ACP at 52.5 g ai ha^{-1} combined with fenoxaprop at 80 g ai ha^{-1} provided 80% control of smooth crabgrass [*Digitaria ischaemum* (Schreb) Schreb. ex Muhl.] 8 wk after treatment (WAT) (McCullough et al. 2011). Applications of ACP at 280 g ha^{-1} to cogongrass [*Imperata cylindrica* (L.) P. Beauv.] in the fall or spring suppressed seedhead formation the following year after treatment in either season (Enloe et al. 2012).

Although ACP has been shown to control several weed species, crop tolerance is also important. Because ACP has already been registered for use on other sites, tolerance studies were conducted, and injury of warm-season turf grasses such as zoysiagrass (*Zoysia japonica* Steud. 'Meyer' and 'Zenith'), hybrid zoysiagrass (*Z. japonica* Steud. 'Emerald'), hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt Davy 'Tifsport'] and centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] at 53 g ai ha^{-1} was minimal following the application of the ester formulation of ACP (Flessner et al. 2011). Buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus], a shortgrass plains forage species, exhibited 28% leaf tip necrosis 3 WAT with 240 g ai ha^{-1} ACP (Harmoney et al. 2012). However, buffalograss biomass production was not affected at the end of growing season (13 WAT; September) over 2 yr. Injury to desirable forage grasses with ACP is a concern, and few reports described grass injury grown in pasture settings. Therefore, the objective of this research was to determine the tolerance of two bahiagrass cultivars to ACP under Florida conditions.

Materials and Methods

Field experiments were conducted at the University of Florida–Institute of Food and Agricultural Sciences (UF-IFAS) Range Cattle Research and Education Center near Ona, FL in 2012, 2013, and 2014. Each experiment was conducted in established, weed-free pastures containing 'Argentine' or 'Pensacola' bahiagrass on a Smyrna sand soil (sandy, siliceous, hyperthermic Aeric Alaquod) with pH 5.3.

Prior to initiating the experiment in each year, the site was clean mowed, and all grass clippings were removed. No fertilizer was applied to bahiagrass plots in 2012, and the experiment was established as a randomized complete block design with four replications. In 2013 and 2014, experiments were established as a split-plot design with herbicide treatment as the whole plot, and water or liquid nitrogen fertilizer (19% urea ammonium nitrate; The Anderson's Inc., Lake Placid, FL 33852) as the subplot with four replications of each treatment. Liquid nitrogen fertilizer was applied at a rate of 56 kg N ha^{-1}. Different combinations and rates of ACP (DPX MAT-28 50 SG, DuPont Crop Protection, Wilmington, DE 19898), with chlorsulfuron (Telar XP 75DF, DuPont Crop Protection), 2,4-D (DPX RRW97 Herbicide, DuPont Crop Protection), triclopyr (DPX RRW96 Herbicide, DuPont Crop Protection), or metsulfuron (Escort 60 DF, DuPont Crop Protection) as detailed in Table 1 were applied onto 3 m by 3 m plots in 2012, or 3 m by 3 m subplots in 2013 and 2014. For subplots receiving liquid nitrogen fertilizer, herbicides were first dissolved in water

Table 1. 'Argentine' bahiagrass injury following application of aminocyclopyrachlor and tank-mix combinations in Ona, FL.[a]

Treatment	Rate	15 DAT			30 DAT			60 DAT		
		2012	2013	2014	2012	2013	2014	2012	2013	2014
	g ai ha^{-1}	% injury								
ACP	35	5 e[b]	0 f	6 bc	1 c	5 b	4 c	0 c	0 b	0
	70	3 e	3 ef	4 c	5 bc	4 b	2 c	0 c	0 b	0
	140	6 e	4 def	3 c	5 bc	6 b	3 c	0 c	0 b	0
	280	16 cde	6 c–f	3 c	13 bc	8 b	2 c	7 c	3 ab	0
ACP + chlorsulfuron	69 + 27	24 bcd	10 b–e	8 bc	5 bc	13 ab	3 c	0 c	0 b	0
	138 + 54	28 abc	14 bcd	9 bc	10 bc	15 ab	3 c	0 c	0 b	0
ACP + 2,4-D amine	70 + 532	5 e	4 def	3 c	3 c	4 b	0 c	0 c	0 b	0
	140 + 1,064	8 de	6 c–f	6 bc	6 bc	6 b	0 c	0 c	0 b	0
ACP + triclopyr	70 + 140	0 e	4 c–f	9 bc	3 c	8 b	4 c	0 c	0 b	0
	140 + 280	10 de	8 c–f	8 bc	14 bc	11 b	5 bc	8 bc	0 b	0
ACP + metsulfuron	46 + 7	30 abc	15 abc	15 abc	10 bc	14 ab	29 a	3 bc	0 b	0
	78 + 12	40 ab	18 ab	18 ab	34 ab	20 ab	13 abc	13 ab	0 b	0
	168 + 26	41 a	29 a	25 a	54 a	30 a	25 ab	21 a	9 a	0

[a] Abbreviations: ACP, aminocyclopyrachlor; DAT, days after treatment.

[b] Means followed by the same letter within columns are not significantly different based on Tukey-Kramer HSD ($\alpha = 0.05$).

prior to being added to the fertilizer solution. A nonionic surfactant (0.25% v/v) was included with all herbicides. Herbicides were applied with the use of an air-pressurized all-terrain vehicle sprayer calibrated to deliver 280 L ha^{-1} on June 11, 2012, and on July 10, 2013 and 2014.

Forage tolerance was evaluated by visual estimation of injury and data were recorded at 15, 30, and 60 d after treatment (DAT) on a scale from 0 (no injury) to 100% (plant death). Biomass was collected from a 0.6 m by 2.4 m area in the center of each plot 30 DAT at a clipping height of 5 cm. Immediately after biomass data were collected, the entire experimental area was clean mowed at a height of 5 cm to remove all aboveground growth. Regrowth was harvested 60 DAT as described previously. Fresh weight of each sample was weighed in the field and dry weight was estimated by placing subsamples in a forced-air dryer at 60 C for 4 d.

Data were subjected to ANOVA with the use of PROC MIXED in SAS (SAS Institute Inc., Cary, NC) analyzing bahiagrass cultivars separately. After determining that there was no herbicide carrier by treatment interaction ($P > 0.05$) in 2013 and 2014, data were combined over carrier. Data were further subjected to ANOVA with year and treatment as fixed effects and replication as a random effect. Forage biomass was analyzed as a percent of the nontreated control. Visual estimations of forage injury were arcsine square-root transformed to meet normality and homoscedasticity assumptions for ANOVA; however, nontransformed data are presented. Data were combined over years for each bahiagrass cultivar when year by treatment interactions were not significant. Means separation was performed with the use of Tukey-Kramer honestly significant difference (HSD) ($\alpha = 0.05$).

Results and Discussion

'Argentine' Bahiagrass. There was a year by treatment interaction for visual estimation of 'Argentine' bahiagrass injury at all evaluation timings. Therefore, data were analyzed and presented separately by year. In general, increasing the rate of ACP alone or the premixes did not result in an increase in injury in any year at 15, 30, or 60 DAT (Table 1). Injury from ACP alone, ACP + 2,4-D amine, or ACP + triclopyr was 16% or less in all 3 yr at 15, 30, and 60 DAT. The highest rate of ACP + metsulfuron resulted in the greatest injury 15 DAT, but was similar to all rates of this herbicide combination in all 3 yr. Injury from the high rate of ACP + metsulfuron was at least 18 percentage units greater than the low rate of this premix in 2012 at 30 and 60 DAT, but injury was similar at these evaluation timings in 2013 and 2014. Injury from ACP + chlorsulfuron was variable across years, with

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Table 2. 'Argentine' bahiagrass yield following application of aminocyclopyrachlor and tank-mix combinations in Ona, FL.[a]

Treatment	Rate	30 DAT	60 DAT
	g/ha	—% of nontreated—	
ACP	35	101 a[b]	115
	70	108 a	120
	140	95 a	116
	280	94 a	114
ACP + chlorsulfuron	69 + 27	88 ab	120
	138 + 54	84 ab	116
ACP + 2,4-D amine	70 + 532	100 a	116
	140 + 1,064	105 a	108
ACP + triclopyr	70 + 140	88 ab	105
	140 + 280	87 ab	102
ACP + metsulfuron	46 + 7	81 ab	126
	78 + 12	62 b	104
	168 + 26	62 b	101

[a] Abbreviations: ACP, aminocyclopyrachlor; DAT, days after treatment.

[b] Means followed by the same letter within columns are not significantly different based on Tukey-Kramer HSD ($\alpha = 0.05$).

the greatest injury occurring in 2012 at 15 DAT, but injury tended to decline over time. The injury observed by the ACP + chlorsulfuron treatment included stunting and chlorosis. In contrast, injury from ACP + metsulfuron included red coloration of leaf tissue, stunting, and chlorosis. Stunting, rather than chlorosis, was the primary injury observed from all other treatments.

There was no year by treatment interaction for 'Argentine' biomass at 30 and 60 DAT; therefore, data were combined over years (Table 2). Biomass ranged from 62 to 108% of the untreated check at 30 DAT. The mid and high rates of ACP + metsulfuron resulted in the greatest reduction in biomass (62% of the untreated check), but this was not different from bahiagrass treated with ACP + chlorsulfuron (84 to 88% of nontreated check), ACP + triclopyr (87 to 88% of nontreated check) or the low rate of ACP + metsulfuron (81% of nontreated check). The reduction in biomass was similar to that reported previously where 26 g ai ha^{-1} metsulfuron resulted in a 50% reduction in 'Argentine' bahiagrass biomass at 28 DAT (Bunnell et al. 2003). At 60 DAT there were no differences between treatments and biomass ranged from 101 to 126% of the nontreated check. Because 'Argentine' bahiagrass has been shown to be somewhat tolerant of metsulfuron (Bunnell et al. 2003), it was expected that biomass from ACP + metsulfuron treated plots would increase from 30 to 60 DAT.

'Pensacola' Bahiagrass. Similar to 'Argentine' bahiagrass, there were year by treatment interactions for visual estimation of 'Pensacola' bahiagrass injury at 15, 30, and 60 DAT (Table 3). Injury from ACP alone and the ACP premixes containing 2,4-D amine and triclopyr was <20% in all 3 yr at 15, 30, and 60 DAT. However, ACP plus either chlorsulfuron or metsulfuron resulted in >30% injury in

Table 3. 'Pensacola' bahiagrass injury following application of aminocyclopyrachlor and tank-mix combinations in Ona, FL.[a]

		15 DAT			30 DAT			60 DAT		
Treatment	Rate	2012	2013	2014	2012	2013	2014	2012	2013	2014
	g ai ha^{-1}	% injury								
ACP	35	0 c[b]	0 b	6 cd	0 b	2 c	8 cd	0 c	5 b	1 c
	70	0 c	0 b	0 d	0 b	2 c	0 d	0 c	0 b	0 c
	140	5 c	3 b	3 cd	1 b	4 c	2 d	0 c	0 b	0 c
	280	19 bc	0 b	3 cd	10 b	6 c	2 d	6 c	0 b	0 c
ACP + chlorsulfuron	69 + 27	31 ab	10 ab	10 bcd	11 b	11 abc	4 d	3 c	4 b	0 c
	138 + 54	50 a	12 ab	29 a	48 a	16 abc	24 bc	8 c	6 b	11 bc
ACP + 2,4-D amine	70 + 532	0 c	3 b	11 bcd	0 b	3 c	4 d	0 c	0 b	3 c
	140 + 1,064	7 c	3 b	6 cd	0 b	4 c	4 d	0 c	0 b	3 c
ACP + triclopyr	70 + 140	0 c	3 b	3 d	5 b	4 c	4 d	0 c	0 b	4 bc
	140 + 280	4 c	6 ab	4 cd	4 b	8 bc	3 d	0 c	0 b	4 c
ACP + metsulfuron	46 + 7	33 ab	16 ab	18 abc	64 a	17 abc	23 bc	49 b	64 a	19 bc
	78 + 12	50 a	21 a	23 ab	63 a	23 ab	43 a	75 ab	76 a	30 ab
	168 + 26	40 ab	21 a	26 a	70 a	27 a	35 ab	96 a	79 a	54 a

[a] Abbreviations: ACP, aminocyclopyrachlor; DAT, days after treatment.

[b] Means followed by the same letter within columns are not significantly different based on Tukey-Kramer HSD ($\alpha = 0.05$).

Table 4. 'Pensacola' bahiagrass yield following application of aminocyclopyrachlor and tank-mix combinations in Ona, FL.[a]

Treatment	Rate	Yield	
		30 DAT	60 DAT
	g ai ha^{-1}	—% of nontreated—	
ACP	35	101 ab[b]	97 ab
	70	106 a	114 a
	140	95 ab	118 a
	280	90 abc	96 ab
ACP + chlorsulfuron	69 + 27	76 b–e	103 a
	138 + 54	66 cde	99 a
ACP + 2,4-D amine	70 + 532	96 ab	113 a
	140 + 1,064	91 a–d	98 ab
ACP + triclopyr	70 + 140	87 a–e	100 a
	140 + 280	91 abc	113 a
ACP + metsulfuron	46 + 7	63 de	51 bc
	78 + 12	68 cde	35 c
	168 + 26	62 e	38 c

[a] Abbreviations: ACP, aminocyclopyrachlor; DAT, days after treatment.

[b] Means followed by the same letter within columns are not significantly different based on Tukey-Kramer HSD ($\alpha = 0.05$).

2012 at 15 DAT. In contrast, in 2013 and 2014 only the mid and high rates of ACP + metsulfuron resulted in >20% injury. Only ACP + metsulfuron resulted in >19% injury at 60 DAT in all 3 yr. There were differences in injury with respect to application rates of this combination in 2012 and 2014, but not in 2013, and the greatest injury (96%) was observed in 2012 with the high rate at 60 DAT. Bahiagrass injury from ACP + chlorsulfuron was variable among application rates; injury was similar in 2012 and 2013 at 15 DAT, but injury following application of the high rate of this premix was 19 percentage units greater than the low rate in 2014. Injury from the high rate of ACP + chlorsulfuron was at least 20 percentage units greater than the low rate in 2012 and 2014 at 30 DAT, but there were no differences in injury between application rates in 2013. Injury from this combination was less than 10% by 60 DAT, with no differences in injury between application rates. The reason for the differences between years is unknown, but could be due to increased rainfall (data not shown) during the 2013 growing season, resulting in increased regrowth. Injury observed on 'Pensacola' bahiagrass was similar to that of 'Argentine' bahiagrass, except that ACP + metsulfuron caused leaf tip necrosis, leaf chlorosis as well as necrosis, and stunting, but not red coloration of leaf tissue when compared to the nontreated check.

There was no year by treatment interaction for 'Pensacola' bahiagrass biomass at 30 and 60 DAT; thus data were combined over years (Table 4). Biomass ranged from 62 to 106% of the untreated check at 30 DAT. All rates of ACP + metsulfuron resulted in the lowest amount of biomass (62 to 68% of nontreated check), but was not different from biomass collected from plots treated with ACP + chlorsulfuron (66 to 76% of nontreated check) or the low rate of ACP + triclopyr (87% of nontreated check). In contrast, only the mid- and high-rates of ACP + metsulfuron resulted in significant yield reductions (35 to 38% of nontreated check) compared to all other treatments, except the low rate of this combination (51% of nontreated check) at 60 DAT. Biomass collected from plots treated with the low rate of ACP + metsulfuron was similar to that treated with the high rate of ACP + 2,4-D (98% of nontreated check) as well as the low and high rates of ACP (97 and 96% of nontreated check, respectively). These results are comparable to Bunnell et al. (2003) where 'Pensacola' bahiagrass biomass was reduced by 50% with metsulfuron rates of approximately 5 g ai ha^{-1} at 42 DAT. Thus, it is likely that the injury observed with ACP + metsulfuron treatments was mainly due to the metsulfuron component and not to the combined effect of the tank mixture.

In previous research buffalograss exhibited 28% leaf tip necrosis 3 WAT with 240 g ai ha^{-1} ACP (Harmoney et al., 2012). Comparatively, injury on both bahiagrass cultivars was <20% following application of the same rate of ACP at 15, 30, and 60 DAT, and this was similar to research conducted by Durham et al. (2016), where 'Pensacola' bahiagrass injury did not exceed 25% within the rate range of 49 to 132 g ai ACP ha^{-1}. Injury on both bahiagrass cultivars was typically higher in 2012 than in 2013 and 2014. This could be due to the increased rainfall in 2013 and 2014 than in 2012 (data not shown) resulting in slower bahiagrass recovery. However, an inverse relationship on rainfall and ACP injury was observed with buffalograss where higher injury was observed when higher rainfall occurred (Harmoney et al. 2012). In spite of initial injury on buffalograss, biomass production was not affected at the end of the growing season (13 WAT) over 2 yr (Harmoney et al. 2012). Results were similar to buffalograss for both bahiagrass cultivars when treated with up to 240 g ha^{-1} of ACP.

These results indicate that herbicide premixes or mixes containing ACP can be applied to bahiagrass pastures and hayfields as long as the forage cultivar is known. For example, premixes of ACP with metsulfuron will likely cause significant injury or death of 'Pensacola' bahiagrass, but low rates of this combination could be applied to 'Argentine' bahiagrass without any deleterious long-term effects. Similarly, ACP + chlorsulfuron caused some initial injury (stunting and chlorosis) to 'Pensacola' bahiagrass, but injury was transient and had no long-term adverse effects on biomass production.

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