Weed Technology 2016 30:499–505

Tolerance of Bermudagrass and Stargrass to Aminocyclopyrachlor

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The tolerance of bermudagrass and stargrass to the relatively new herbicide, aminocyclopyrachlor (ACP), must be known before it can be recommended for weed control in these forage systems. Field experiments were conducted in 2012 and 2013 in south-central Florida to determine the tolerance of established bermudagrass and stargrass to various rates and combinations of ACP, chlorsulfuron, 2,4-D, triclopyr, and metsulfuron. Overall, bermudagrass and stargrass injury was transient and was minimal by 60 d after treatment (DAT). Similarly, biomass production was negatively affected at 30 DAT when treated with ACP at rates of 70 g ae ha^{-1} or greater, but was similar to the nontreated control by 60 DAT. Tank-mixing ACP with chlorsulfuron, 2,4-D amine, triclopyr, or metsulfuron did not increase injury compared with ACP alone applied at equivalent rates. Forage nutritive values were unaffected by herbicides. These data suggest that long-term effects of ACP on bermudagrass and stargrass are negligible, and this herbicide could be an important component of weed management programs in these forage systems.

Nomenclature: Aminocyclopyrachlor; chlorsulfuron; metsulfuron; triclopyr; bermudagrass, *Cynodon dactylon* L.; stargrass, *Cynodon nlemfuensis* Vanderyst.

Key words: Forages, hayfields, pastures.

La tolerancia del pasto bermuda y el pasto estrella al herbicida relativamente nuevo, aminocyclopyrachlor (ACP), debe ser conocida antes de poder recomendarlo para el control de malezas en sistemas de forrajes. En 2012 y 2013, se realizaron experimentos de campo en el sur-centro de Florida para determinar la tolerancia de pastizales establecidos de bermuda y estrella a varias dosis y combinaciones de ACP, chlorsulfuron, 2,4-D, triclopyr, y metsulfuron. En general, el daño a los pastos bermuda y estrella fueron transitorios y mínimos a 60 d después del tratamiento (DAT). Similarmente, la producción de biomasa fue negativamente afectada a 30 DAT cuando se trató con ACP a dosis de 70 g ae ha^{-1} o mayores, pero fue similar al testigo sin tratamiento a 60 DAT. Las mezclas en tanque de ACP con chlorsulfuron, 2,4-D amine, triclopyr, o metsulfuron no aumentaron el daño al compararse con ACP aplicado solo a dosis equivalentes. El valor nutritivo del forraje no fue afectado por los herbicidas. Estos datos sugieren que los efectos a largo plazo de ACP sobre los pastos bermuda y estrella son mínimos, y este herbicida podría ser un componente importante de los programas de manejo de malezas en estos sistemas de forrajes.

Pasture and rangelands in the United States covered approximately 248 million ha in 2007, with approximately 2 million ha located in Florida (USDA-ERS 2012). Florida grazing lands are used primarily for feeding livestock, and many different types of forages are utilized. In addition to grazing, hay is produced on approximately 129,500 ha in Florida (USDA-NASS 2013). Although bahiagrass (*Paspalum notatum* Flügge.) is the most predominant forage in Florida (Newman et al. 2010), bermudagrass and stargrass are also widely grown for both grazing and hay production (Vendramini 2010). The utilization of each species is dependent upon the environment, but also the relative ease of establishment as well as sward persistence.

Bermudagrass is an important forage species that has a high yield potential and is very responsive to nitrogen fertilization (Newman et al. 2011). 'Jiggs' and 'Florakirk' are the most widely used cultivars in south Florida. They are sterile and propagated through sprigs or stolons (Newman et al. 2011). Jiggs, a cultivar from Texas, performs better in poorly drained soils than other hybrids; in contrast, Florakirk, developed by the University of Florida, prefers drier soils, and is cold and drought tolerant,

DOI: 10.1614/WT-D-15-00167.1

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but can have high hydrocyanic acid levels (Newman et al. 2011). In general, bermudagrass crude protein (CP) and in vitro organic matter disappearance (IVOMD) values are typically higher than those of bahiagrass, with values of 10 to 13% and 52 to 55%, respectively (Mislevy and Martin 2006; Mislevy et al. 2012).

Stargrass has high fertility requirements and is established only from planting stolons, because it lacks rhizomes and produces few or no seeds (Mislevy 2002). It is more tropical in nature, as it does not tolerate temperatures below –4 C, or long periods of flooding. Although several cultivars have been developed, only 'Florona' and 'Florico' are currently utilized and are the most persistent of the released cultivars under field conditions (Mislevy 2002). Although stargrass has a shorter growing season compared with bermudagrass and bahiagrass, biomass production often exceeds 12,500 kg ha^{-1}. CP and IVOMD average 12 to 13 and 53 to 61%, respectively, and is comparable with bermudagrass (Mislevy 2002; Mislevy et al. 1989a,b).

Although warm-season forage species are highly productive and adapted to Florida, it is widely known that weeds decrease the value of any cropping system because of competition. Therefore, weed management strategies for pasture and rangeland are necessary to optimize forage production. There are several herbicides registered for use on forage grass pastures, but low pasture grass tolerance can limit the use of effective herbicides for the control of weed species of economic importance (Sellers and Ferrell 2011).

Aminocyclopyrachlor (ACP) is a relatively new growth regulator herbicide and 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 several weeds, especially broadleaf weeds (Ferrell et al. 2012; Kyser and DiTomaso 2013; Minogue et al. 2011). Moreover, grass species have also been affected by ACP applications either alone or in combination with other herbicides. For example, ACP at 52.5 g ha^{-1} combined with fenoxaprop at 80 g ha^{-1} provided 80% control of smooth crabgrass (*Digitaria ischaemum* (Schreb) Shreb. Ex Muhl.) 8 wk after treatment (McCullough et al. 2011). Applications of ACP at 280 g ha^{-1} to cogongrass suppressed seedhead formation the following year after treatment in the previous spring or fall (Enloe et al. 2012).

Previous tolerance studies found that the application of the ester formulation of ACP at 53 g ha^{-1} caused minimal injury of warm-season turf grasses such as zoysiagrass (*Zoysia japonica* Steud.), 'Tifsport' bermudagrass (*Cynodon dactylon* × *Cynodon transvaalensis* Burtt Davy), and centipedegrass [*Eremochloa ophiuroides* (Munro.) Hack.] (Flessner et al. 2011). Additionally, buffalograss [*Bouteloua dactyloides* (Nutt.) Columbus], a short-prairie forage species, exhibited 28% leaf tip necrosis 3 wk after treatment (WAT) with 240 g ha^{-1} ACP (Harmoney et al. 2012). However, buffalograss biomass production was not affected at the end of the growing season (13 WAT) over 2 yr. Injury to desirable forage grasses with ACP is a concern and few reports of this herbicide describe grass injury grown in pasture settings (Matocha et al. 2014). Therefore, the objective of this research was to determine the tolerance of bermudagrass and stargrass to ACP alone and mixtures of ACP and other herbicides.

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 and 2013. Each experiment was conducted in established hayfields containing Jiggs or Florakirk bermudagrass, and Florona or Florico stargrass. The soil was a Pomona fine sand (sandy, siliceous, hyperthermic Ultic Alaquod) with a pH of 6.0.

Bermudagrass and stargrass were fertilized with 560 kg ha^{-1} of 10–5–10 fertilizer in May of each year and were clean mowed with all grass clippings removed before initiating the experiments. Different combinations and rates of ACP (DPX MAT-28 50 SG, DuPont Crop Protection, Wilmington, DE 19898), chlorsulfuron (Telar XP 75DF, DuPont Crop Protection), 2,4-D (DPX RRW97 herbicide, DuPont Crop Protection), triclopyr (DPX RRW96 herbicide, DuPont Crop Protection), and metsulfuron (Escort 60DF, DuPont Crop Protection) as detailed in Table 1 were applied onto 3-m by 3-m plots of stargrass and bermudagrass within 14 d after clipping at 10 cm. Bermudagrass and stargrass were 14 cm tall when the herbicides were applied. The experiment was established as a randomized

https://doi.org/10.1614/WT-D-15-00167.1 Published online by Cambridge University Press

Table 1. 'Jiggs' and 'Florakirk' bermudagrass injury and biomass production after application of aminocyclopyrachlor (ACP) in Ona, FL.

Treatment	Rate	Injury			Yield	
			30 DAT[a]			
		15 DAT	2012	2013	30 DAT	60 DAT
	$g\ ha^{-1}$	%			% of nontreated	
ACP	35	10 e[b]	10 de	0	94 a-d	108 cde
	70	17 cd	13 bcd	0	84 a-e	95 e
	140	22 bc	16 ab	1	84 a-e	121 abc
	280	32 a	18 a	1	69 e	99 de
ACP + chlorsulfuron	69 + 27	20 bcd	8 e	1	82 cde	105 cde
	138 + 54	20 bcd	12 bcd	1	83 de	105 cde
ACP + 2,4-D amine	70 + 532	17 cd	11 cde	0	101 a	132 a
	140 + 1,064	20 bcd	10 de	1	92 a-d	122 abc
ACP + triclopyr	70 + 140	17 cd	9 de	0	99 abc	113 bcd
	140 + 280	24 b	11 cde	2	87 a-d	113 bcd
ACP + metsulfuron	46 + 7	14 de	9 de	0	100 ab	114 bcd
	78 + 12	18 bcd	11 cde	0	85 a-e	126 ab
	168 + 26	24 b	14 abc	0	80 de	108 cde

[a] Abbreviation: DAT, days after treatment.

[b] Means followed by the same letter within columns are not significant at $P \leq 0.05$. Columns without letters indicate the absence of significant differences between treatments.

complete block design with four replications for each cultivar. A nonionic surfactant (0.25% v/v) was included with all treatments. Herbicide treatments were applied using an air-pressurized, all-terrain vehicle sprayer calibrated to deliver 280 L ha^{-1} on June 11 in both 2012 and 2013.

Forage tolerance was evaluated by visual estimation of injury and data were recorded at 15, 30, and 60 d after treatment (DAT) using a scale from 0 (no injury) to 100% (complete plant death). Biomass was collected from a 0.6- by 2.4-m area in the center of each plot using a rotary mower with a reach catch bag at 30 DAT at a clipping height of 8 cm. Immediately after biomass data were collected, the entire experimental area was clean mowed to remove all top 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. Biomass measurements were not recorded 60 DAT in 2013 from bermudagrass plots because of flooding after the first harvest. Additionally, because of vaseygrass (*Paspalum urvillei* Steud.) and bushy bluestem [*Andropogon glomeratus* (Walt) B.S.P.] invasion, stargrass biomass was not recorded in 2013; however, the plots were clean mowed as described previously at 30 DAT to monitor injury of stargrass regrowth at 60 DAT.

Dried forage samples were ground to pass through a 1-mm screen for CP and IVOMD analysis, which was conducted at the UF-IFAS Forage Evaluation Support Laboratory in Gainesville, FL. Subsamples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975) for nitrogen analysis. Sample weight was 0.25 g, catalyst used was 1.5 g of 9 : 1 $K_2SO_4 : CuSO_4$, and digestion was conducted for at least 4 h at 375 C using 6 ml of H_2SO_4 and 2 ml of H_2O_2. Nitrogen in the digestate was determined by semiautomated colorimetry (Hambleton 1977). CP was derived by multiplying total N by 6.25. IVOMD was determined by a modification of the two-stage technique (Moore and Mott 1974).

Data were subjected to ANOVA using PROC MIXED in SAS (SAS Institute, Inc., Cary, NC), with year, treatment, and cultivar as fixed effects and replication as a random effect; year was not included as a fixed effect for the analysis of stargrass biomass and forage nutrient values. Forage biomass was converted to the percentage of the nontreated plot biomass before analysis. Visual estimations of forage injury were arcsine square-root transformed

https://doi.org/10.1614/WT-D-15-00167.1 Published online by Cambridge University Press

Table 2. Total rainfall collected at the Range Cattle Research and Education Center in Ona, FL in 2012 and 2013 compared with the 72-yr average.

Month	2012	2013	72-yr average
	cm		
January	1.3	1.2	5.3
February	1.1	1.8	6.3
March	0.7	1.7	7.8
April	6.3	9.2	6.3
May	3.7	4.8	9.4
June	24.3	25.1	21.8
July	19.3	26.8	21.2
August	17.0	19.0	21.3
September	18.5	19.0	18.5
October	13.0	1.3	7.6
November	1.4	2.3	4.7
December	3.0	0.2	5.0
Total	109.6	112.4	135.2

to meet ANOVA assumptions; however, nontransformed data are presented. Means separation was performed using Tukey–Kramer honestly significant difference ($\alpha = 0.05$).

Results and Discussion

Bermudagrass. There was no cultivar-by-treatment interaction for bermudagrass injury and biomass, so the data were pooled across cultivars. ACP at 280 g ha^{-1} resulted in the highest injury (32%) 15 DAT (Table 1). By 30 DAT there was a year-by-treatment interaction, so data were analyzed separately. Bermudagrass injury in 2012 was < 20% in all treatments. Tank-mixing ACP with chlorsulfuron, 2,4-D amine, triclopyr, or metsulfuron did not increase injury compared with ACP alone applied at equivalent rates. In 2013 there were no differences between treatments, and injury was < 2%. No injury was observed 60 DAT from any treatment (data not shown). These results are in agreement with those of Matocha et al. (2014) where ACP resulted in little to no injury to 'Tifton-85' and Jiggs bermudagrass in Texas. Similarly, buffalograss injury was negligible when ACP application rates were no greater than 140 g ha^{-1}; however, applications of 280 g ha^{-1} resulted in season-long injury if adequate rainfall was not received after application (Harmoney et al. 2012). Therefore, the lack of season-long injury on bermudagrass cultivars under Florida conditions may be the result of sufficient rainfall (Table 2) after application of ACP.

There was no year-by-treatment interaction for bermudagrass biomass at 30 DAT, so data were combined over years (Table 1). Biomass ranged from 69 to 101% of the nontreated control 30 DAT, with the lowest biomass recorded from plots treated with 280 g ha^{-1} ACP. Even with differences between treatments, biomass ranged from 95 to 132% of nontreated plots in 2012, indicating that the initial injury observed on bermudagrass had no long-term effects on biomass production. These results are similar to 'Coastal' bermudagrass response to herbicides, in which yield was slightly reduced by some herbicides compared with the nontreated control at the first harvest after herbicide application, but yield recovered by the second harvest period (Butler and Muir 2006).

The year-by-treatment interaction for bermudagrass CP was significant 30 DAT. Bermudagrass CP values were increased up to 2.5 percentage units when treated with ACP compared with the nontreated control 30 DAT (Table 3). There were no differences in CP values 60 DAT in 2012. There was no year-by-treatment interaction for digestibility (IVOMD) at 30 DAT; therefore, data were combined over years. The lowest bermudagrass IVOMD was recorded from plots treated with ACP at 140 and 280 g ha^{-1} as well as the high rate of ACP + metsulfuron and was at least 2.8 percentage units lower than the nontreated control. However, there were no differences among treatments for digestibility at 60 DAT in 2012.

Stargrass. There was no cultivar-by-treatment interactions for stargrass injury, so all data were combined over cultivars. Additionally, there was no year-by-treatment interaction at 15 or 30 DAT, so data were combined over years. Injury following ACP at 280 g ha^{-1} (33%) and the high rate of ACP + triclopyr (29%) was 0.4 to 2.8 times higher than all other treatments 15 DAT (Table 4). At 30 DAT, injury ranged from 8 to 28%, and stargrass treated with ACP at 280 g ha^{-1} resulted in at least 13% greater injury than all other treatments. The addition of chlorsulfuron, 2,4-D amine, triclopyr, or metsulfuron to ACP did not affect injury compared with ACP alone applied at equivalent rates. The injury observed at 15 and 30 DAT included stunting, reduced canopy cover, and

Table 3. 'Jiggs' and 'Florakirk' bermudagrass nutritive values after application of aminocyclopyrachlor (ACP) in Ona, FL.

Treatment	Rate	Crude protein			IVOMD[a,b]	
		30 DAT		60 DAT		60 DAT
		2012	2013	2012	30 DAT	2012
	g ha^{-1}	%				
Control	0	6.3 e[c]	7.3 e	8.9	40.4 a	46.2
ACP	35	7.1 d	8.7 bcd	9.2	40.0 ab	48.0
	70	7.9 bc	8.6 bcd	9.3	40.6 a	50.4
	140	8.5 ab	9.3 ab	9.6	37.6 bc	49.5
	280	8.8 a	8.7 bcd	10.3	37.3 c	46.3
ACP + chlorsulfuron	69 + 27	7.8 bc	8.6 bcd	9.5	38.6 abc	48.6
	138 + 54	8.2 abc	8.3 cd	9.4	39.5 abc	47.4
ACP + 2,4-D amine	70 + 532	7.8 cd	8.8 a-d	9.2	39.1 abc	46.9
	140 + 1,064	7.8 bcd	9.6 a	9.3	38.2 abc	46.7
ACP + triclopyr	70 + 140	7.8 bcd	9.5 a	9.3	38.6 abc	47.0
	140 + 280	8.7 a	8.9 a-d	9.7	38.5 abc	46.9
ACP + metsulfuron	46 + 7	7.6 cd	8.1 de	9.4	40.6 a	46.3
	78 + 12	8.0 bc	9.0 abc	9.2	40.5 a	44.9
	168 + 26	8.3 abc	9.2 abc	9.7	37.3 c	49.2

[a] Abbreviations: DAT, days after treatment; IVOMD, in vitro organic matter digestibility.

[b] Because of grass weed encroachment and flooding, bermudagrass biomass was harvested at 30 and 60 DAT in 2012, but only at 30 DAT in 2013. Therefore, data forage nutritive values contain data at 60 DAT only for 2012.

[c] Means within columns followed by the same letter are not significant at $P \leq 0.05$. Columns without letters indicate the absence of significant differences between treatments.

chlorosis. However, stargrass injury was not evident 60 DAT (data not shown).

There was no cultivar-by-treatment interaction for stargrass yield; therefore data were combined over cultivars. Biomass ranged from 52 to 92% of the nontreated plots (Table 4), with ACP at 280 g ha^{-1} resulting in at least 25% less biomass accumulation than other treatments except ACP at 140 g ha^{-1} and the high rates of ACP + chlorsulfuron, ACP + triclopyr, and ACP +

Table 4. 'Florona' and 'Florico' stargrass injury and biomass production after application of aminocyclopyrachlor (ACP) in Ona, FL.

Treatment	Rate	Injury		Yield	
		15 DAT[a]	30 DAT	30 DAT	60 DAT
	g ha^{-1}	%		% of nontreated	
ACP	35	12 e[b]	8 d	92 a	107
	70	13 de	9 cd	87 ab	108
	140	21 bc	13 bcd	65 bcd	96
	280	33 a	28 a	52 d	90
ACP + chlorsulfuron	69 + 27	16 cde	11 bcd	77 abc	107
	138 + 54	21 b	15 b	70 abcd	102
ACP + 2,4-D amine	70 + 532	16 cde	10 bcd	89 a	114
	140 + 1,064	18 bc	11 bcd	80 abc	108
ACP + triclopyr	70 + 140	16 bcd	10 bcd	78 abc	99
	140 + 280	29 a	13 bc	62 cd	99
ACP + metsulfuron	46 + 7	16 bcd	8 cd	87 ab	90
	78 + 12	16 bcd	10 bcd	82 abc	104
	168 + 26	20 bc	13 bcd	74 abc	103

[a] Abbreviation: DAT, days after treatment.

[b] Means within columns followed by the same letter are not significant at $P \leq 0.05$. Columns without letters indicate the absence of significant differences between treatments.

https://doi.org/10.1614/WT-D-15-00167.1 Published online by Cambridge University Press

Table 5. 'Florona' and 'Florico' stargrass nutritive values after application of aminocyclopyrachlor (ACP) in Ona, FL.

Treatment	Rate	Crude protein		IVOMD[a]	
		30 DAT	60 DAT	30 DAT	60 DAT
	g ha^{-1}	%			
Control	0	7.1 d[b]	10.2 b	40.8	54.8
ACP	35	7.6 cd	10.2 b	41.9	54.1
	70	8.1 bcd	10.6 ab	41.0	53.9
	140	8.8 bc	11.0 ab	40.7	55.5
	280	10.0 a	11.8 a	41.4	56.5
ACP + chlorsulfuron	69 + 27	7.8 cd	10.1 b	41.2	53.8
	138 + 54	8.5 bc	10.8 ab	40.9	54.4
ACP + 2,4-D amine	70 + 532	8.0 cd	10.1 b	40.9	53.1
	140 + 1,064	8.7 bc	10.6 ab	39.3	52.9
ACP + triclopyr	70 + 140	8.4 bc	10.5 ab	41.2	52.6
	140 + 280	9.2 ab	10.9 ab	41.5	54.3
ACP + metsulfuron	46 + 7	7.7 cd	10.3 b	41.9	53.1
	78 + 12	8.2 bcd	10.5 ab	40.6	53.9
	168 + 26	8.3 bc	10.6 ab	40.9	54.2

[a] Abbreviations: IVOMD, in vitro organic matter digestibility; DAT, days after treatment.

[b] Means within columns followed by the same letter are not significant at $P \leq 0.05$. Columns without letters indicate the absence of significant differences between treatments.

metsulfuron at 30 DAT. At 60 DAT there were no differences among treatments, and biomass ranged from 90 to 114% of nontreated plots, indicating that stargrass had recovered from the initial injury observed at 30 DAT.

There were no cultivar interactions for stargrass CP and IVOMD, and data were combined over cultivars at 30 and 60 DAT. CP values ranged from 7 to 10% 30 DAT (Table 5), with CP of stargrass treated with ACP at 280 g ha^{-1} at least 1.2 percentage units greater than all other treatments except for the high rate of ACP + triclopyr. At 60 DAT CP of stargrass was at least 0.8 percentage units greater when treated with ACP at 280 g ha^{-1} than with any other treatment. Digestibility (IVOMD) was not affected by any treatment at 30 or 60 DAT.

Previous research has shown that injury of warm-season turf grasses such as zoysiagrass, Tifsport bermudagrass, and centipedegrass was minimal after the application of the ester formulation of ACP at 53 g ha^{-1} under field conditions (Flessner et al. 2011). Higher ACP rates utilized in this study resulted in greater initial injury of both bermudagrass and stargrass. However, since biomass production is ultimately more important for cow/calf producers, transient injury observed in these studies is of little importance. Biomass of all cultivars of bermudagrass and stargrass when treated with 140 g ha^{-1} ACP was similar to the nontreated control by 60 DAT. However, it is possible that greater long-term injury could be observed when rainfall is limited, as has been reported in previous research (Etheredge 2003; Sanders et al. 2001; Tredaway Ducar et al. 2002). Forage nutritive values of bermudagrass and stargrass were not negatively affected by treatment with ACP. Overall, it appears that ACP alone or in combination with other herbicides could be an important component of weed management systems in bermudagrass and stargrass pastures of south-central Florida.

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Received November 3, 2015, and approved December 21, 2015.

Associate Editor for this paper: James Brosnan, University of Tennessee.