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Author for correspondence:
Eric P. Webster, School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA 70803. (Email: ewebster@agcenter.lsu.edu)

Impact of Nealley's Sprangletop on Rough Rice Yield

Eric P. Webster[1], Eric A. Bergeron[2], David C. Blouin[3], Benjamin M. McKnight[4] and Matthew J. Osterholt[2]

[1]Professor, School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA, [2]Graduate Assistant, School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA, [3]Professor, Department of Experimental Statistics, Louisiana State University Agricultural Center, Baton Rouge, LA, USA and [4]Research Associate, School of Plant, Environmental, and Soil Science, Louisiana State University Agricultural Center, Baton Rouge, LA, USA

Abstract

Two field studies were conducted in Louisiana to determine the impact of Nealley's sprangletop on rough rice yield under multiple environments in 2014, 2015, and 2016. The first study evaluated optimal timings of Nealley's sprangletop removal for optimizing rough rice yields. The second study evaluated the impact of Nealley's sprangletop densities on rough rice yield. Nealley's sprangletop was removed with applications of fenoxaprop at 122 g ai ha^{-1} at 7, 14, 21, 28, 35, and 42 d after emergence (DAE). Nealley's sprangletop removal at 7 and 14 DAE resulted in higher rough rice yields of 7,880 and 6,960 kg ha^{-1}, respectively, when compared with the rice from the season-long Nealley's sprangletop competition with a 6,040 kg ha^{-1} yield. Delaying herbicide application from 7 DAE to 42 DAE resulted in a yield loss of 1,740 kg ha^{-1}. Over the 35-d delay in application, rough rice yield loss from Nealley's sprangletop interference was equivalent to 50 kg ha^{-1} d^{-1}. Nealley's sprangletop densities were established at 1, 3, 7, 13, and 26 plants m^{-2} by transplanting Nealley's sprangletop when rice reached the one- to two-leaf stage. At Nealley's sprangletop densities of 1 to 26 plants m^{-2}, rough rice yields were reduced 10 to 270 kg ha^{-1}, compared with the rice from weed-free plots. Based on regression analysis, Nealley's sprangletop densities of 1, 35, 70, and 450 plants m^{-2} reduced rough rice yield 0.14%, 5%, 10%, and 50%, respectively.

Introduction

Nealley's sprangletop is a monocot in the Poaceae family that was first described taxonomically in 1885 (Hitchcock 1903, 1950). This weed has been found predominantly along roadsides and in drainage ditches in southern Louisiana, Texas, and Mexico, but it has recently adapted to flooded environments similar to that of rice production systems in southern Louisiana (Bergeron et al. 2015). Nealley's sprangletop has been observed to survive through the winter months and to regrow during the summer months, indicating a potential perennial growth habit in Louisiana and Texas. To select the appropriate weed management program for Nealley's sprangletop, correct identification is important (Webster 2014).

At the seedling stage, Nealley's sprangletop has sparse pubescence at the base of the stem, unlike other sprangletop species commonly found in rice fields (Bergeron et al. 2015). This grass has a fringed membranous ligule similar to Amazon sprangletop [*Diplachne panicoides* (J. Presl) McNeill], which is commonly found in Mid-South rice production. Nealley's sprangletop is erect and robust with flat culms from 1 to 1.5 m tall (Hitchcock 1950). Nealley's sprangletop is simple or sparingly branching at the base, with glabrous or slightly glabrous sheaths. At maturity, Nealley's sprangletop produces a panicle-like inflorescence 25 to 50 cm long with 50 to 75 racemes that are 2 to 4 cm long. Nealley's sprangletop seeds are obtuse and 1 to 1.5 mm long.

As seen in previous studies with other sprangletop species, competitiveness of Nealley's sprangletop could potentially reduce rough rice yield. Interference of Amazon sprangletop and bearded sprangletop [*Diplachne fusca* (L.) P. Beauv. ex Roem. & Schult. ssp. *fascicularis* (Lam.) P.M. Peterson & N. Snow] reduced rough rice yield, grain quality, milling yield, and rice seed germination (Smith 1975, 1983). Season-long interference from Amazon sprangletop at 50 to 200 panicles m^{-2} reduced rice grain yield as much as 36% (Smith 1975). Smith (1983) evaluated the impact of bearded sprangletop densities on rough rice yield and reported that densities of bearded sprangletop at 11 to 108 plants m^{-2} reduced rice grain yield from 9% to 36%. Bearded sprangletop at 1 plant m^{-2} reduced rice yield 21 kg ha^{-1}, and rice yields were reduced 10% and 50% for bearded sprangletop densities of 30 and 148 plants m^{-2}, respectively (Smith 1983, 1988). Densities of 15 to 30 plants m^{-2} would be sufficient threshold levels to require control practices for bearded sprangletop.

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Carey et al. (1994) evaluated interference duration of bearded sprangletop in rice. Bearded sprangletop densities of 50 plants m^{-2} were removed from rice plots at 21, 35, 42, 56, 70, and 130 d after planting (DAP). Grain yields decreased as bearded sprangletop interference duration increased; durations of bearded sprangletop interference of greater than 56 DAP decreased rice yield more than 2,296 kg ha^{-1}. Interference of bearded sprangletop at 130 DAP reduced yields 50%. By determining the impact of Nealley's sprangletop on rough rice yield, producers, scientists, and extension personnel will better understand the management of this weed to increase yield and maximize profits.

Materials and Methods

Nealley's Sprangletop Removal Study

A field study was conducted at the Louisiana State University Agricultural Center H. Rouse Caffey Rice Research Station (RRS) near Crowley, LA (30.177147° N, −92.347743° W) to evaluate optimal removal timing of Nealley's sprangletop on rough rice yield in 2014, 2015, and 2016, and in 2015 at a grower location near Estherwood, LA (30.181449° N, −92.484208° W). These were the four multiple-environment trials for the analyses.

The soil texture at the RRS was a Crowley silt loam soil with a pH of 6.4 and 1.4% organic matter. Field preparation consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set at a 6-cm depth. Before planting, Nealley's sprangletop seed was collected from the same producer location as previously described near Estherwood, and mechanically spread over the entire study area at 30 kg ha^{-1} immediately prior to planting rice, resulting in a uniform stand of 140 to 160 plants m^{-2}. The producer at this location was in a rice–soybean rotation, where imazethapyr was applied twice at 70 g ha^{-1} on imidazolinone-resistant rice for the rice rotation, whereas the field was treated with two applications of glyphosate applied at 840 g ae ha^{-1} for the soybean rotation. The soil texture at the grower location was a Kaplan silt loam soil with a pH of 6.2 and 2.5% organic matter. Field preparation was conducted as previously described at the RRS. A uniform natural population of Nealley's sprangletop existed at this location with no additional overseeding required, resulting in a uniform stand of 130 to 150 plants m^{-2}.

Immediately after seeding Nealley's sprangletop, the long-grain rice cultivar 'CL-111' was drill-seeded in eight 18-cm rows at a planting rate of 67 kg ha^{-1} on April 1, 2014, March 30, 2015, and April 6, 2016 at the RRS on 1.5- by 5.2-m^2 plots. The grower location was planted with 'CL-111' on March 25, 2015 on 1.5- by 5.2-m^2 plots. Each year at 24 h after planting, the area was surface-irrigated to a level of 2.5 cm and drained 24 h later. A permanent flood of 10 cm depth was established when the rice reached the five-leaf to one-tiller stage and was maintained until 2 wk prior to harvest.

The experimental design was a multiple-environment trial at the RRS 2014, 2015, and 2016 and near Estherwood in 2015, where each trial was a randomized complete block with four replications. Fenoxaprop (Ricestar® HT herbicide label; Bayer Crop Protection LLC, Greensboro, NC) is the recommended control measure for Nealley's sprangletop (Webster 2016) and was used to remove Nealley's sprangletop at pre-set intervals during the growing season. Fenoxaprop was applied at 122 g ai ha^{-1} at 7, 14, 21, 28, 35, and 42 d after emergence (DAE) on Nealley's sprangletop at one- to two-leaf, two- to three-leaf, two- to four-leaf, three- to five-leaf, one- to two-tiller, and two- to three-tiller stages, respectively. Applying fenoxaprop was used to mimic producer practices for herbicide removal of Nealley's sprangletop. The soil surface was saturated prior to each fenoxaprop application by surface irrigation at 14 and 28 DAE and 25.4 mm of rainfall 24 h prior to the 7- and 21-DAE application, at both locations. A permanent flood was established 48 h prior to the 35-DAE timing. A weed-free treatment was added by utilizing herbicide application of fenoxaprop at 122 g ha^{-1} and hand-weeding as a comparison. A season-long Nealley's sprangletop competition treatment was also added for comparison. Previous research indicated quinclorac plus halosulfuron had no activity on Nealley's sprangletop; therefore, quinclorac at 420 g ai ha^{-1} plus halosulfuron at 53 g ai ha^{-1} was applied delayed preemergence (DPRE), to control grass weeds, sedges, and broadleaf weeds in the entire research area. A crop oil concentrate (COC) (Agri-Dex® label; Helena Chemical Co., Collierville, TN) at 1% vol/vol was added to all applications. Each herbicide application was applied with a CO_2-pressurized backpack sprayer calibrated at 145 kPa to deliver 140 L ha^{-1} of solution. The need for hand-weeding was minimal, due to the residual program–applied DPRE and the fenoxaprop application.

Immediately prior to harvest, rice plant heights were measured from four rice plants per plot from the soil surface to the tip of the extended panicle. The center four rows, a 0.75- by 5.2-m strip of rice, was harvested with a Mitsubishi® VM3 (Mitsubishi Corp., Tokyo, Japan) rice harvester on August 13, 2014 and July 30, 2015 at the RRS and August 4, 2015 at the grower location. Rough rice yield was not obtained in 2016 due to flooding and rice lodging from a 415-mm rainfall event on August 12 and 13, 2016.

Economic applications were based on the average long-grain rough rice price for 2015, \$0.254 kg^{-1} (USDA 2016). Fenoxaprop was priced at \$48 L^{-1}, and COC was priced at \$4 L^{-1}. The cost of an aerial application applied at 47 L ha^{-1} is \$15 ha^{-1} (Salassi et al. 2015). The total value of the product was calculated by multiplying average rough rice price by total rough rice yield. Net returns above fenoxaprop herbicide application costs, \$101 ha^{-1}, were also analyzed, by subtracting the cost of herbicide, COC, and application from total product value.

The MIXED procedure of SAS (release 9.4, SAS Institute, Cary, NC) was used. Yield data, kg ha^{-1}, were log transformed. Yield data were converted back to actual yield for ease of presentation and interpretation. Fixed effects for the model were application timing. Random effects for the model were trial, replication, and plot. Considering combinations of year and location as random effects permits inferences about treatments over a range of environments (Carmer et al. 1989; Hager et al. 2003). Type III statistics were used for tests of application timing, and Tukey's HSD was used for mean separation at the 5% probability level ($P \leq 0.05$). Normality was checked with the use of the UNIVARIATE procedure of SAS, and assumptions for normality were met (SAS 2013).

Nealley's Sprangletop Density Study

The density study was conducted at the RRS (30.177361° N, −92.345983° W) to evaluate varying Nealley's sprangletop populations in rice and the impact of these Nealley's sprangletop densities on rice yield with three environments in 2014, 2015, and 2016.

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Field preparation consisted of a fall and spring disking followed by two passes in opposite directions with a two-way bed conditioner equipped with rolling baskets and S-tine harrows set at a 6-cm depth. 'CL-111' was drill-seeded in eight 18-cm rows at a planting rate of 67 kg ha^{-1} on April 1, 2014, March 30, 2015, and April 6, 2016 at the RRS on 1.5- by 5.2-m^2 plots. Rice plant density each year averaged 130 rice plants m^{-2}.

Nealley's sprangletop seed was planted 2 wk prior to rice planting into commercial potting soil (Jiffy Mix Grower's Choice, Jiffy Products of America, Inc., Lorain, OH) in seed flats with fifty 2.5- by 2.5-cm cells. When Nealley's sprangletop plants reached the one- to two-leaf growth stage, the seedlings were transplanted into field plots with rice in the one- to three-leaf stage. Nealley's sprangletop densities were established at 1, 3, 7, 13, and 26 plants m^{-2}. The densities were established as a randomized complete block design with four replications per density. The densities of Nealley's sprangletop and the transplanting method followed the previous research in Arkansas (Smith 1983, 1988) and Louisiana (Griffin et al. 2008).

A grid planting pattern apparatus was constructed for each Nealley's sprangletop density evaluated. Braided 11-mm nylon rope was cut into 5.5-m lengths for a total of seven segments per grid. The ropes were attached to a 2-m section of 2.5-cm PVC pipe at each end of the segments at 18-cm spacings with a total length of 5.2 m. Plastic 6-cm-long sections of 3-cm-wide orange flagging tape were attached at evenly spaced intervals along each rope to establish the appropriate Nealley's sprangletop densities, 1 to 26 plants m^{-2}. Each grid was placed within individual plots based on the desired density, and each rope segment was placed in the center of each drill row. Individual Nealley's sprangletop seedlings were hand transplanted beside each orange marker to ensure uniform plant spacings. Each plot was inspected for transplanted Nealley's sprangletop mortality at 3, 5, and 7 d after transplanting, and dead plants were replaced with a healthy Nealley's sprangletop plant of a size similar to existing plants. Mortality rate was less than 2% within 1 wk of transplanting.

Prior to rice emergence and Nealley's sprangletop transplanting, the study area received an initial DPRE application of quinclorac plus halosulfuron as previously described. A surface irrigation occurred 24 h after the DPRE treatment. When rice reached the one- to two-leaf stage, the area was once again surface irrigated and drained 24 h later, and Nealley's sprangletop was transplanted 24 h after draining or 48 h after surface irrigation. Hand-weeding was used to maintain clean plots, and immediately prior to rice harvest all Nealley's sprangletop plants were clipped to ground level to prevent interference with harvest machinery.

Immediately prior to harvest, rice plant heights were measured from four rice plants per plot from the soil surface to the tip of the extended panicle. The entire plot area of rice was harvested with an Almaco Plot Combine (SPC40; Almaco, Nevada, IA) on August 13, 2014, July 30, 2015, and August 23, 2016 at the RRS. At harvest, Nealley's sprangletop plant survival counts were evaluated and recorded.

The MIXED procedure of SAS (release 9.4, SAS Institute, Cary, NC) for random coefficient models (Littell et al. 2006) was used. Yield data, kg ha^{-1}, were log transformed linearized exponential model. Fixed effects were intercept and linear regression effects for density. Random effects were trial and random subject effects for intercept, and linear regression effects were replication. Normality was checked with the use of the UNIVARIATE procedure of SAS, and assumptions for normality were met (SAS 2013).

Results and Discussion

Nealley's Sprangletop Removal Study

Rice plant heights at harvest were not affected when Nealley's sprangletop competed with rice from 7 to 35 DAE but were reduced slightly when rice competed with the weed for 42 DAE (Table 1). Smith (1968) observed lower rice heights from increased barnyardgrass [*Echinochloa crus-galli* (L.) Beauv] populations. Snipes and Street (1987) observed rice height reductions with later applications of fenoxaprop in rice, and this reduction may have been partially caused by the late application of the herbicide at 42 DAE.

Nealley's sprangletop removal at 7 and 14 DAE resulted in higher rice yield when compared with the rice with a season-long Nealley's sprangletop infestation (Table 1). Smith (1983) observed up to 36% reductions in rice yields with a season-long infestation of bearded sprangletop in rice. The earliest removal timing, 7 DAE, yielded 1,840 kg ha^{-1} more than the rice with season-long competition from Nealley's sprangletop, with a 130% yield increase. Carlson et al. (2012) evaluated imazethapyr timings on IR rice and observed an increase in rice yield with earlier imazethapyr applications. Similarly, Chauhan and Johnson (2011) reported a 20% yield loss by delaying herbicide application 28 DAE. In our study, rice maintained weed-free yielded 7,530 kg ha^{-1} compared with 7880 kg ha^{-1} from the 7-DAE removal timing, and although some damage may have occurred to rice during hand-weeding, this yield difference was not significant. Delaying herbicide application from 7 DAE to 42 DAE resulted in a yield loss of 1,740 kg ha^{-1}. Over the 35-d delay in application, rice yield loss was equivalent to 50 kg ha^{-1} d^{-1} from Nealley's sprangletop interference.

Table 2 presents economic returns based on the yield obtained in this study. The total product value was calculated using the average rice price in 2015, \$0.254 kg^{-1}. Removing Nealley's sprangletop 7 DAE resulted in a 124% increase in net returns over fenoxaprop costs compared with season-long competition; resulting in a profit increase of \$367 ha^{-1}. Delaying herbicide application to 42 DAE resulted in a 5% loss of profit and \$75 ha^{-1} less return than the rice in the season-long competition from Nealley's sprangletop, after factoring in herbicide and application cost. Carlson et al. (2012) observed a decrease in total product value when delaying imazethapyr application on rice to 42 DAE. With this research, delaying fenoxaprop application from 7 DAE to 42 DAE resulted in a net return loss of \$442 ha^{-1}. Over the 35-d delay in herbicide application, profits were reduced at a rate of \$12.63 ha^{-1} d^{-1}. Early removal of Nealley's sprangletop is essential for optimizing rice yield and gaining maximum profit.

Nealley's Sprangletop Density Study

Analysis indicated significance for the impact of Nealley's sprangletop density on rice yield ($b = -0.00153$, $P < 0.0002$). The regression equation is:

$$\log\left(\text{kg ha}^{-1}\right) = 8.8527 - 0.00153\,(\text{density}) \quad [1]$$

The impact of Nealley's sprangletop density on rice height ($b = -0.00429$) were not significant ($P = 0.8356$). The regression equation is:

$$\text{Height} = 102.8 - 0.00429\,(\text{density}) \quad [2]$$

At Nealley's sprangletop densities of 1 to 26 plants m^{-2}, rice yields were reduced 10 to 270 kg ha^{-1} (Equation 1), compared with the

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Table 1. Rough rice yields from a single application of fenoxaprop 7 to 42 d after Nealley's sprangletop emergence (DAE), 2014 through 2016, over multiple locations.[a,b]

Treatment	Growth stage at treatment	Harvest height[c]	Rough rice yield[d]	Yield of season-long competition
		cm	kg ha^{-1}	%
Weed-free[e]		97 a	7,530 ab	125
7 DAE removal	One- to two-leaf	97 a	7,880 a	130
14 DAE removal	Two- to three-leaf	97 a	6,960 bc	115
21 DAE removal	Two- to four-leaf	97 a	6,640 cd	110
28 DAE removal	Three- to five-leaf	96 ab	6,750 bcd	112
35 DAE removal	One- to two-tiller	96 ab	6,500 cd	108
42 DAE removal	Two- to three-tiller	93 b	6,140 d	102
Season-long competition		97 a	6,040 d	100

[a]Fenoxaprop was applied at 122 g ai ha^{-1} plus crop oil concentrate (Agri-dex®; Helena Chemical Co., Collierville, TN) at 1% (vol/vol) was used with all treatments.
[b]Locations: Crowley, LA and Estherwood, LA.
[c]Means followed by the same letter within columns do not significantly differ at P = 0.05 using Tukey's test.
[d]Inverse log transformed means.
[e]Weed-free plot established by herbicide application and hand-weeding Nealley's sprangletop.

Table 2. Economic returns from a single application of fenoxaprop 7 to 42 d after Nealley's sprangletop emergence (DAE), 2014 through 2016, over multiple locations.[a,b]

Treatment	Total product value[c]	Net returns above herbicide cost[d]	Change in net returns[e]
		——— $ ha^{-1} ———	
7 DAE removal	2,002 a	1,901	+ 367 (124%)
14 DAE removal	1,768 bc	1,667	+ 133 (109%)
21 DAE removal	1,687 b-d	1,586	+ 52 (103%)
28 DAE removal	1,715 b-d	1,614	+ 80 (105%)
35 DAE removal	1,651 cd	1,550	+ 16 (101%)
42 DAE removal	1,560 cd	1,459	−75 (95%)
Season-long competition	1,534 d	1,534	0

[a]Fenoxaprop was applied at 122 g ai ha^{-1} plus crop oil concentrate (Agri-dex®; Helena Chemical Co., Collierville, TN) at 1% (vol/vol) was used with all treatments.
[b]Locations: Crowley, LA and Estherwood, LA.
[c]Means followed by the same letter do not significantly differ at P = 0.05 using Tukey's test.
[d]Herbicide cost provided by Helena Chemical Co., Morse, LA.
[e]Change in net returns compared with weedy season long.

weed-free or no Nealley's sprangletop competition. Based on \$101 ha^{-1} cost for fenoxaprop treatment and an average rough rice price of \$0.254 kg^{-1}, Nealley's sprangletop at densities of 40 plants m^{-2} or greater would be sufficient threshold levels to require weed management with an application of fenoxaprop.

Smith's (1983, 1988) regression analysis predicted a 5%, 10%, and 50% rough rice yield loss with bearded sprangletop densities of 15, 30, and 148 plants m^{-2}, respectively; however, achieving the same yield loss percentage from Nealley's sprangletop would require densities of 35, 70, and 450 plants m^{-2} (Equation 1). Based on the results from this study compared with Smith (1983, 1988), bearded sprangletop is 2.3 to 3 times more competitive than Nealley's sprangletop.

Preliminary research from Louisiana indicates that Amazon sprangletop produces twice as many tillers and twice as many leaves as Nealley's sprangletop, and the specific leaf area of Amazon sprangletop is 1.4 times higher than Nealley's sprangletop (D.O. Stephenson, personal communication). These growth parameters indicate that Amazon sprangletop may be more competitive than Nealley's sprangletop. The specific leaf area allows Amazon sprangletop to potentially have a higher photosynthetic capacity and higher shading potential than Nealley's sprangletop (Horak and Loughin 2000), and it may indicate that Amazon sprangletop is a more aggressive competitor than Nealley's sprangletop (Grotkopp and Rejmánek 2007).

In conclusion, data from the removal study indicates that early control of Nealley's sprangletop will prevent season-long competition from this weed with rice, which can result in higher yields and increased profits (Tables 1 and 2). Removal of Nealley's sprangletop 7 DAE increased rough rice yield 1,840 kg ha^{-1}

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compared with season-long Nealley's sprangletop competition (Table 1). Delaying removal of Nealley's sprangletop to 42 DAE can result in profit loss of rice at $442 ha^{-1} compared with a 7-DAE removal (Table 2). Applying herbicides at 42 DAE to remove Nealley's sprangletop would result in a loss of profit due to higher application cost than profit gained compared with rice from the season-long Nealley's sprangletop competition. Competition from this weed on rice should be eliminated prior to 14 DAE to maximize yield and increase profit.

Results from the density trial indicate that Nealley's sprangletop competes with rice, resulting in reduced rough rice yield. Nealley's sprangletop populations of 26 plants m^{-2} can reduce rough rice yield by 270 kg ha^{-1}, when allowed to compete the entire growing season. These data also indicate that Nealley's sprangletop at a density of 1 plant m^{-2} reduced rough rice yield 10 kg ha^{-1} (Equation 1) or a 0.14% yield loss; however, Smith (1983) reported rough rice yield reduction of 21 kg ha^{-1}, or a 0.34% yield loss, when 1 plant m^{-2} of bearded sprangletop interfered with rice.

By determining the impact of Nealley's sprangletop on rice, producers can determine when employing control practices will produce a favorable economic return. The value of crop and cost of control programs, which are subject to change, can be correlated with rice yield losses in fields with a known density of Nealley's sprangletop.

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