

## Optimizing Benzobicyclon Efficacy in Drill-Seeded Rice

Young ML<sup>1\*</sup>, Norsworthy JK<sup>1</sup> and Scott RC<sup>2</sup>

<sup>1</sup>Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR 72704, USA

<sup>2</sup>Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Lonoke, AR 72086, USA

\*Corresponding author: Young ML, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville, AR 72704, USA, Tel: 8709264194; E-mail: masony@sepro.com

Received date: January 26, 2018; Accepted date: February 07, 2018; Published date: February 13, 2018

Copyright: © 2018 Young ML, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

### Abstract

The repetitive use of the same herbicide sites of action in U.S. rice has led to the evolution of resistance in several weeds. Growers need to integrate multiple sites of action by mixing herbicides for effective weed control. Benzobicyclon is being developed as a post-flood herbicide for U.S. rice. As a Group 27 herbicide, benzobicyclon will offer a new site of action to rice producers in the U.S. Research was conducted in 2015 and 2016 to evaluate benzobicyclon efficacy based on weed size at application, flood depth, weed spectrum, tank mix with post-flood herbicides, and use rate. The greatest efficacy with benzobicyclon often occurred when applied to small weeds in a 15 cm flood depth. Barnyardgrass control with benzobicyclon was greater at 371 g ha<sup>-1</sup> than at 247 g ha<sup>-1</sup>. Amazon sprangletop and acetolactate synthase-resistant rice flats edge were controlled completely with benzobicyclon at 247 g ha<sup>-1</sup> at the early timing at both 5 cm and 15 cm flood depths. The addition of benzobicyclon at 247 g ha<sup>-1</sup> to post-flood herbicides generally increased barnyardgrass and sprangletop spp. control. Benzobicyclon at 247 g ha<sup>-1</sup> added to halosulfuron at 53 g ha<sup>-1</sup> increased barnyardgrass control. The addition of benzobicyclon at 247 g ha<sup>-1</sup> to other post-flood herbicides such as halosulfuron at 53 g ha<sup>-1</sup>, imazamox at 45 g ha<sup>-1</sup>, and cyhalofop 280 g ha<sup>-1</sup> increased red sprangletop and Amazon sprangletop control (>90%). The addition of benzobicyclon to post-flood herbicides will broaden and improve the spectrum of weed control in US rice.

**Keywords:** Efficacy; Herbicide resistance; Flood depth; Site of action; Target size

### Introduction

Rice growers in the midsouthern U.S. needed a solution for weedy rice (*Oryza sativa* L.) and barnyardgrass (*Echinochloa crus-galli* (L.) Beauv) control in the early 2000s hence, imidazolinone-resistant rice was launched in 2002, enabling the use of imazethapyr and imazamox in the crop [1]. These herbicides quickly became the foundation of many weed control programs in rice. By 2008, imidazolinone-resistant cultivars accounted for 40% of the rice acreage in Arkansas [2]. The acreage steadily increased from the time of its introduction until 2011 when imidazolinone-resistant rice accounted for 69% of the Arkansas rice acreage [1]. Thereafter, a steady decline in the imidazolinone-resistant rice acreage occurred partly due to the evolution of imidazolinone-resistant weedy rice and barnyardgrass populations [3]. In a 2012 survey of midsouthern U.S. crop consultants, barnyardgrass and weedy rice were the first and third most important weeds of rice [4].

Imidazolinone herbicides are no longer an effective option for barnyardgrass and weedy rice control for many rice producers in the midsouthern U.S. [1,5]. Additionally, overreliance of acetolactate synthase (ALS)-inhibiting herbicides has led to yellow nutsedge (*Cyperus esculentus* L.), small flower umbrellasedge (*Cyperus difformis* L.), rice flatsedge (*Cyperus iria* L.), and several aquatic weeds evolving resistance to this site of action (SOA) [3]. Annual sedges continue to become more common and problematic in Arkansas rice because of ALS resistance and extensive use of clomazone early in the growing season [6-9]. Additionally, clomazone provides no control of sedges [10].

Prior to ALS resistance, herbicides such as halosulfuron, imazethapyr, imazamox, penoxsulam, and bispyribac (WSSA Group 2) were used frequently to control most problematic weeds of rice [10-12]. Propanil, a photosystem II inhibitor (WSSA Group 7), was once exclusively relied on for postemergence control of barnyardgrass. Overreliance on this herbicide led to evolution of propanil-resistant barnyardgrass [3,13]. Today, barnyardgrass in Arkansas has evolved resistance to acetyl CoA carboxylase inhibitors (WSSA Group 1), ALS inhibitors, quinclorac (WSSA Group 4), propanil, and clomazone (WSSA Group 13) [3]. It is imperative growers preserve the effective herbicide SOA that are available for use today.

One of several strategies to mitigate the evolution of herbicide resistance is the use of multiple effective SOA over the course of a growing season [14]. Program approaches to weed control are more effective and create the opportunity to overlap applications allowing for broadened and improved weed control. The integration of multiple SOA into a herbicide program reduces the risk for resistance. For example, Beckie [15] reported that weed populations can evolve resistance to ALS-inhibiting herbicides in as few as five applications in the absence of multiple SOA.

Producers often prefer to mix herbicides because it can reduce application costs and potentially broaden the spectrum of weed control [16]. For example, Norsworthy et al. [17] showed that improved propanil-resistant barnyardgrass control can be achieved when mixing thibencarb with propanil over propanil alone. Likewise, mixing herbicides can improve control of broadleaf species such as hemp sesbania (*Sesbania herbacea* Mill.). Norsworthy et al. [18] reported increased (>95%) hemp sesbania control with the addition of propanil to triclopyr, 2,4-D, acifluorfen, carfentrazone, penoxsulam, quinclorac, halosulfuron, bentazon, and bispyribac over applying propanil alone.

Using a program approach, including the utilization of full-recommended rates in combination with multiple effective herbicide SOAs, will offer a grower the most sustainable and effective weed control program.

Growers in Asia have used benzobicyclon, a 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibiting (WSSA Group 27) herbicide, with success for controlling ALS-resistant sedge (*Cyperus* spp.) populations in paddy-rice [19,20]. Benzobicyclon provides broad-spectrum control of many aquatic, broadleaf, sedge, and grass weeds of rice [21-23]. Benzobicyclon was recently registered in U.S. rice production [24]. It is the first HPPD-inhibiting herbicide for use in U.S. rice. Benzobicyclon is expected to be rapidly adopted in the midsouthern U.S. because ALS-resistant sedge populations are becoming more difficult to control with currently available herbicides (Sandoski, personal communication).

Adding benzobicyclon to current weed control programs will incorporate a new SOA and reduce selection pressure on currently labeled herbicides [5]. Benzobicyclon will likely improve weed control when mixed with herbicides applied post-flood, especially halosulfuron [25]. Northern jointvetch (*Aeschynomene virginica* L.) and barnyardgrass control with benzobicyclon were improved by the addition of halosulfuron [25]. Furthermore, California arrowhead (*Sagittaria latifolia* Willd.), ducksalad (*Heteranthera limosa* Sw.), and ALS-resistant smallflower umbrellasedge were completely controlled (100%) by benzobicyclon alone while halosulfuron provided unacceptable control of these weeds [25].

The effectiveness of a herbicide, including herbicide mixtures, is largely dependent on herbicide rate, weed size at application, and flood depth if a flood is present at application [21,26]. Davis et al. [21] reported that rate and flood depth are critical to success with applications of benzobicyclon. Weed size is another important consideration when making late season post-flood herbicide applications. For example, Chauhan and Abugho [27] reported greater control when making postemergence applications of bispyribac, fenoxoprop plus ethoxysulfuron, or penoxsulam plus cyhalofop to 4 leaf compared with 8 leaf barnyard grass.

The objectives of this research were to 1) determine if weed control with benzobicyclon is influenced by weed size and flood depth at

application, 2) evaluate the efficacy of benzobicyclon and halosulfuron alone versus a mixture, and 3) determine what herbicide addition to benzobicyclon would broaden and improve weed control over benzobicyclon alone.

## Materials and Methods

### Influence of weed size, species, and flooding depth on benzobicyclon

A controlled field experiment was conducted in Fayetteville, Arkansas, to characterize benzobicyclon efficacy as influenced by flooding depth and rate. The experimental design was completely randomized with three replications having a two-factor factorial treatment structure in 2015 and three-factor factorial in 2016. The factors consisted of three flooding depths (saturated, 5 cm, and 15 cm) and two application rates (none and benzobicyclon at 247 g ai ha<sup>-1</sup>) in 2015 and 2016 with an additional factor of two application timings (early: target 2-leaf weeds and late: target 6-leaf weeds) in 2016.

For both years, a Pembroke silt loam (fine-silty, mixed, active, mesic Mollic Paleudalfs) soil was placed into tubs (61 cm × 47 cm × 40 cm) to an approximate 22 cm depth and then seeded to two weed species per tub in the field, except for yellow nutsedge for which tubers were planted. Each tub in 2015 and 2016 contained Amazon sprangletop and yellow nutsedge. In 2016, additional tubs were included with each containing ALS-resistant rice flatsedge and barnyardgrass. Tubers were used to ensure that the proper flood depth was maintained for the duration of the experiment. Height, leaf number, and density of each weed species at application are provided in Table 1. Immediately prior to herbicide treatment, the flood depths were established and maintained throughout the experiment by daily watering to the desired depth. The water level was marked inside each tub to the corresponding depth to ensure each tub maintained and received the proper flood depth. During rainfall events, the tubs were covered to prevent increased flood depths. Benzobicyclon was applied using a CO<sub>2</sub> pressurized backpack sprayer consisting of a three-nozzle, handheld boom equipped with 110015 AIXR nozzles (Teejet Technologies, Springfield, IL 62703) calibrated to deliver 143 L ha<sup>-1</sup> at 276 kPa.

|                    | Application timing <sup>ab</sup> |           |                                  |          |           |                                  |          |           |                                  |          |           |                                  |
|--------------------|----------------------------------|-----------|----------------------------------|----------|-----------|----------------------------------|----------|-----------|----------------------------------|----------|-----------|----------------------------------|
|                    | 2015                             |           |                                  |          |           |                                  | 2016     |           |                                  |          |           |                                  |
|                    | Early                            |           |                                  | Late     |           |                                  | Early    |           |                                  | Late     |           |                                  |
| Weed species       | Leaf no.                         | Height cm | Density plants tub <sup>-1</sup> | Leaf no. | Height cm | Density plants tub <sup>-1</sup> | Leaf no. | Height cm | Density plants tub <sup>-1</sup> | Leaf no. | Height cm | Density plants tub <sup>-1</sup> |
| Amazon sprangletop | 1-3                              | 13        | 16                               | 3-5      | 23        | 17                               | 1-2      | 13        | 11                               | 3-5      | 22        | 13                               |
| Barnyardgrass      | NP                               |           |                                  | NP       |           |                                  | 1-2      | 14        | 9                                | 5-6      | 33        | 10                               |
| Rice flatsedge     | NP                               |           |                                  | NP       |           |                                  | 1-3      | 13        | 13                               | 4-5      | 23        | 10                               |
| Yellow nutsedge    | 2-4                              | 18        | 15                               | 5-6      | 33        | 9                                | 1-2      | 18        | 10                               | 5-6      | 33        | 11                               |

**Table 1:** Leaf number, height, and density of weed species at time of application for the benzobicyclon efficacy experiment in 2015 and 2016. <sup>a</sup>“NP” Indicates not present. Barnyardgrass and acetolactate synthase-resistant rice flatsedge were not included in the 2015 experiment due to lack of germination, <sup>b</sup>“Leaf number” indicated by the number of true leaves present on the plant at application.

## Benzobicyclon plus halosulfuron mixture

A field experiment was conducted in 2015 and 2016 near Stuttgart, Arkansas to assess halosulfuron and benzobicyclon alone and as a mixture on common weeds of midsouthern US rice. The experimental design was a randomized complete block with six treatments and a nontreated control with three replications. The treatments included a low (35 g ai ha<sup>-1</sup>) and high (53 g ha<sup>-1</sup>) rate of halosulfuron, a low (247 g ha<sup>-1</sup>) and high (371 g ha<sup>-1</sup>) rate of benzobicyclon, a low rate of both benzobicyclon (247 g ha<sup>-1</sup>) and halosulfuron (35 g ha<sup>-1</sup>), and a high rate of both benzobicyclon (371 g ha<sup>-1</sup>) and halosulfuron (53 g ha<sup>-1</sup>). Individual bays were used to prevent benzobicyclon movement among treatments. The bays measured 3.0 by 45.7 m levee to levee. Two experimental plots were planted within one bay. The plots measured 1.8 by 22.8 m and were planted with a 9 row cone drill on May 7, 2015, and April 25, 2016. CL111 was planted at 66 seed m<sup>-1</sup> of row in 2015 and 2016, and a 1.5 m alley was created between plots. Maintenance applications of imazethapyr at 35 g ai ha<sup>-1</sup> (1/2X rate) were made to 2 to 3 leaf rice followed by propanil at 1,680 g ai ha<sup>-1</sup> (1/3X rate) at the 4 to 5 leaf rice growth stage to suppress weeds while ensuring the presence of some weeds after establishment of the permanent flood. Herbicide treatments were made on June 23, 2015, and June 9, 2016. Treatments were applied post-flood using a CO<sub>2</sub> pressurized backpack sprayer consisting of a four-nozzle, handheld boom equipped with 110015 AIXR nozzles (Teejet Technologies, Springfield, IL 62703), calibrated to deliver 143 L ha<sup>-1</sup> at 276 kPa. Two passes were made covering the entire plot and the water surface area adjacent to the plot. The test required 11 individual bays, with the flood maintained at an approximate 7 cm depth throughout the season, and nitrogen (168 kg ha<sup>-1</sup>) was applied immediately prior to flooding to simulate normal rice culture.

## Mixing benzobicyclon with post-flood rice herbicides

A field experiment was conducted near Lonoke, Arkansas, and near Pine Tree, Arkansas, in 2016 to assess commonly used rice herbicides and benzobicyclon alone and as a mixture on common weeds of midsouthern US rice. The experiment was a split-plot with main plots with four replications. The main plot was benzobicyclon rate (none vs. 247 g ai ha<sup>-1</sup>) and subplots were other rice herbicides, including penoxsulam at 35 g ai ha<sup>-1</sup>, bispyribac at 23 g ai ha<sup>-1</sup>, halosulfuron 53 at g ai ha<sup>-1</sup>, imazamox 45 at g ai ha<sup>-1</sup>, cyhalofop 280 at g ai ha<sup>-1</sup>, saflufenacil 25 at g ai ha<sup>-1</sup>, carfentrazone 18 at g ai ha<sup>-1</sup>, propanil at 3,360 g ai ha<sup>-1</sup>, bentazon at 840 g ai ha<sup>-1</sup>, halosulfuron plus thifensulfuron at 35 and 5 g ai ha<sup>-1</sup>, and one treatment was not treated with any herbicide representing the nontreated control. Eight individual bays were used to prevent benzobicyclon movement among treatments [21,28]. The bays measured 5 by 67 m levee to levee. Eleven experimental plots measuring 1.8 by 5.2 m were contained in each bay, consisting of nine rice rows on 18 cm spacing with a 1 m alley between plots. CL111 was planted at 66 seed m<sup>-1</sup> of row on May 14, 2016, at Pine Tree and on May 19, 2016, at Lonoke.

To provide suppression of early-season weeds while ensuring the presence of some weeds after establishment of the permanent flood, the Lonoke location received a low rate of clomazone (64 g ai ha<sup>-1</sup>) immediately after planting followed by propanil (1,680 g ai ha<sup>-1</sup>) at the 2 to 3 leaf rice growth stage. No maintenance herbicide applications were made at the Pine Tree location because the field site had a historically lower weed density and weeds emerged later than at Lonoke. Subplot treatments were applied as a mixture in the main plot bays that contained benzobicyclon. All treatments were applied post-

flood using a CO<sub>2</sub> pressurized backpack sprayer consisting of a handheld four-nozzle boom equipped with 110015 AIXR nozzles (Teejet Technologies, Springfield, IL 62703) calibrated to deliver 143 L ha<sup>-1</sup> at 276 kPa. Two passes of the boom were made to cover the entire subplot and water surface area adjacent to the subplot. Each treatment was replicated four times, and the test required eight individual main plot bays. The flood was maintained at approximately a 7 cm depth throughout the season, and nitrogen (168 kg ha<sup>-1</sup>) was applied immediately prior to flooding to simulate normal rice culture.

**Assessments:** For the benzobicyclon trial in the tubs, herbicide efficacy was assessed at 2 and 3 weeks after treatment. Ratings were based on a scale of 0 to 100%, with 0 being no control relative to the saturated, nontreated check and 100% being complete control of the evaluated weed species. Aboveground biomass was collected the day of the final assessment to determine relative biomass reduction of the experimental treatments compared to the saturated, nontreated check. All biomass was oven-dried at 66 C for 7 days and weighed.

In the trial evaluating benzobicyclon and halosulfuron alone and as a mixture, weed control was rated 3, 5, and 9 weeks after treatment (WAT) relative to the nontreated control using the method described earlier. The trial evaluating mixing post-flood herbicides with benzobicyclon was rated for weed control at 2, 4, and 6 WAT. For both trials, experimental plots were machine harvested at crop maturity to determine rough rice yield at an adjusted moisture of 12%.

**Statistical Analyses:** For the tub study, the weed control data were transformed by (log(x+1)), analyzed, and then back-transformed. In 2015, Amazon sprangletop and yellow nutsedge weed control means and standard errors were reported because the assumptions for analysis of variance (ANOVA) were not met. Each assessment date was analyzed separately. The biomass data were transformed (log(x+1)) and were subjected to ANOVA. The treatment means were separated using Fisher's protected LSD ( $\alpha=0.05$ ). Mean separation was based on the transformed data, but back-transformed means are presented.

In 2016, weed control and biomass reduction data were transformed if needed and were subjected to ANOVA and means separated using Fisher's protected LSD ( $\alpha=0.05$ ). Data transformations were performed by (log(x+1)). Mean separation was based on the transformed data, but back-transformed means are presented in the percentage form. Each assessment date was analyzed separately.

For the benzobicyclon plus halosulfuron trial, there was no significant year effect; therefore, data were combined over years. All weed control and yield data were subjected to ANOVA and means separated using Fisher's protected LSD ( $\alpha=0.05$ ). Each assessment date was analyzed separately. The yield was analyzed separately because of the different environmental conditions in 2015 versus 2016. In the trial evaluating mixing benzobicyclon with other post-flood herbicides, locations were analyzed separately due to varying weed densities, sizes, and spectrum at the locations. For the trial of mixing benzobicyclon with post-flood herbicides, all weed control and yield data were subjected to ANOVA and means were separated using Fisher's protected LSD ( $\alpha=0.05$ ). For the weed control, each assessment date was analyzed separately. All data were analyzed using JMP statistical software (JMP, Version 12.1 SAS Institute Inc., Cary, NC).

## Results and Discussion

### Influence of weed size, species, and flooding depth on benzobicyclon

The importance of flood depth and weed species on benzobicyclon efficacy in 2015 can be seen in Table 2. The results of this experiment

indicate benzobicyclon should be used only in a continuous flood environment based on the efficacy observed as a function of flood depth. For the saturated treatment, benzobicyclon controlled Amazon sprangletop only 69% at 3 WAT (Table 2). This level of weed control would be deemed unacceptable in a commercial production system; hence, the need for maintaining a flooded environment within the field.

| Treatments  |                          | Amazon sprangletop |        |   | Yellow nutsedge |         |   |
|---|--------------------------|--------------------|--------|---|-----------------|---------|---|
|   |                          | Control (%)        |        |   | Control (%)     |         |   |
| Benzobicyclon <sup>c</sup><br>g ai ha <sup>-1</sup> | Flood depth <sup>d</sup> | 2 WAT <sup>b</sup> | 3 WAT  | Dry weight reduction<br>% of nontreated | 2 WAT           | 3 WAT   | Dry weight reduction<br>% of nontreated |
| 0 (none)  | Sat                      | 0 (0)              | 0 (0)  | 0 (0)                                   | 0 (0)           | 0 (0)   | 0 (0)                                   |
|   | 5 cm                     | 0 (0)              | 0 (0)  | -4 (3)                                  | 0 (0)           | 0 (0)   | -57 (11)                                |
|   | 15 cm                    | 0 (0)              | 0 (0)  | -5 (7)                                  | 20 (7)          | 0 (0)   | -21 (14)                                |
| 247   | Sat                      | 50 (15)            | 69 (6) | 74 (4)                                  | 25 (10)         | 68 (6)  | 50 (16)                                 |
|   | 5 cm                     | 65 (12)            | 95 (5) | 75 (4)                                  | 25 (7)          | 74 (7)  | 13 (22)                                 |
|   | 15 cm                    | 71 (12)            | 89 (7) | 73 (4)                                  | 38 (5)          | 65 (10) | 25 (16)                                 |

**Table 2:** Post-flood Amazon sprangletop and yellow nutsedge control 2 and 3 weeks after treatment (WAT) as influenced by the interaction of benzobicyclon rate and flood depth in 2015<sup>ab</sup>. <sup>a</sup>Each assessment date was analyzed separately. Means followed by the standard error in parentheses, <sup>b</sup>WAT<sup>c</sup> abbreviates weeks after treatment, <sup>c</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, <sup>d</sup>Sat, saturated.

Based on these data, benzobicyclon was effective in controlling Amazon sprangletop (>89%) at 3 WAT at the 5 and 15 cm flood depths (Table 2). Flooding to a depth of 5 cm or 15 cm increased the sensitivity of Amazon sprangletop to benzobicyclon but benzobicyclon alone does not appear to provide effective yellow nutsedge control. Therefore, it is important for growers to establish and maintain a permanent flood with a minimum depth of 5 cm when applying benzobicyclon. It was noted that benzobicyclon is a slow-acting herbicide that may need as many as four weeks after application to achieve maximum control. The slowness of the herbicidal activity may be partly attributed to its SOA, but the fact that benzobicyclon must be converted to benzobicyclon hydrolysate to become biologically active may have the greatest impact on the delay in activity [29].

Yellow nutsedge control in 2015 increased 27 percentage points from 2 to 3 WAT at the 15-cm flood depth (Table 2). Nevertheless, the level of control of both species would have likely increased as time progressed after the assessment at three weeks.

In 2016, a third factor, application timing, was added to the experiment to determine if efficacy was influenced by size of the targeted weed species at application in addition to flood depth and rate (Table 3). Weed sizes are presented in Table 1. Amazon sprangletop was completely controlled by 2 WAT when benzobicyclon applied at the early timing for both the 5- and 15-cm flood depth. However, there was a 28% reduction in control at 2 WAT for the 15-cm flood depth when applied at the late timing. Similarly, a greater reduction (55%) in control was observed on a more tolerant species, barnyard grass, when comparing the early and late timings 2 WAT at the 15 cm flood depth

(Table 3). For effective management of barnyard grass, applications must be timely when treating with benzobicyclon and even then, based on these results, effective control may not be obtained. Targeting weeds at the proper size is imperative for growers to have effective herbicide applications. Weed size must be incorporated into integrated weed management strategies for consultants and growers. The size of the weed at application is an important best management practice for reducing selection for the evolution of herbicide resistance and for the proper stewardship of the herbicide [14].

In addition, it is important to note that benzobicyclon is an effective herbicide option for control of rice flatsedge, including ALS-resistant biotypes (Table 3). Benzobicyclon, a Group 27 herbicide, will offer growers a new SOA for hard-to-control annual sedge species. The importance of rice flatsedge is increasing as it continues to evolve resistance to the ALS-inhibiting herbicides and becomes widespread. The importance of weed size at application is also observed in the yellow nutsedge results as control increased 35 percentage points when applied at the early timing (1 to 4 leaf, 10 cm to 18 cm height) versus the late timing (5 to 6 leaf, 33 cm height) at 2 WAT (Table 3). For rice flatsedge, early applications containing benzobicyclon resulted in (>99%) dry weight reduction in 2016 (Table 4). Additionally, clomazone, which is ineffective in providing rice flatsedge control, continues to be applied to almost ever hectare at planting, sometimes alone, placing continued selection on post applied herbicides that have been routinely used for its control [6,30].



| Treatments                                       |                    |                  | Control <sup>a</sup> (%) |         |               |         |                |         |                 |         |
|--|--------------------|------------------|--------------------------|---------|---------------|---------|----------------|---------|-----------------|---------|
|  |                    |                  | Amazon sprangletop       |         | Barnyardgrass |         | Rice flatsedge |         | Yellow nutsedge |         |
| Benzobicyclon <sup>c</sup> g ai ha <sup>-1</sup> | Application timing | Flood depth      | 2 WAT <sup>b</sup>       | 3 WAT   | 2 WAT         | 3 WAT   | 2 WAT          | 3 WAT   | 2 WAT           | 3 WAT   |
| 0 (none)   | Early              | Sat <sup>d</sup> | 0 (0)                    | 0 (0)   | 0 (0)         | 0 (0)   | 0 (0)          | 0 (0)   | 0 (0)           | 0 (0)   |
|  |                    | 5 cm             | 0 (0)                    | 3 (3)   | 0 (0)         | 7 (3)   | 0 (0)          | 7 (3)   | 0 (0)           | 3 (2)   |
|  |                    | 15 cm            | 67 (2)                   | 58 (9)  | 38 (14)       | 42 (11) | 67 (7)         | 72 (4)  | 0 (0)           | 12 (4)  |
|  | Late               | Sat              | 0 (0)                    | 0 (0)   | 15 (0)        | 0 (0)   | 13 (13)        | 0 (0)   | 0 (0)           | 0 (0)   |
|  |                    | 5 cm             | 2 (2)                    | 0 (0)   | 18 (4)        | 0 (0)   | 5 (3)          | 0 (0)   | 7 (4)           | 0 (0)   |
|  |                    | 15 cm            | 18 (7)                   | 5 (5)   | 22 (7)        | 7 (7)   | 20 (12)        | 0 (0)   | 13 (9)          | 0 (0)   |
| 247  | Early              | Sat              | 40 (6)                   | 55 (13) | 17 (9)        | 23 (7)  | 37 (15)        | 57 (14) | 28 (4)          | 45 (12) |
|  |                    | 5 cm             | 100 (0)                  | 100 (0) | 88 (12)       | 93 (7)  | 68 (6)         | 100 (0) | 52 (7)          | 62 (4)  |
|  |                    | 15 cm            | 100 (0)                  | 100 (0) | 100 (0)       | 100 (0) | 100 (0)        | 100 (0) | 73 (4)          | 80 (6)  |
|  | Late               | Sat              | 63 (17)                  | 62 (19) | 28 (6)        | 25 (13) | 68 (6)         | 47 (7)  | 32 (2)          | 23 (7)  |
|  |                    | 5 cm             | 88 (4)                   | 100 (0) | 20 (6)        | 18 (8)  | 88 (12)        | 91 (8)  | 17 (7)          | 50 (6)  |
|  |                    | 15 cm            | 72 (10)                  | 90 (10) | 45 (13)       | 30 (13) | 80 (10)        | 90 (5)  | 38 (16)         | 53 (7)  |

**Table 3:** Post-flood control of Amazon sprangletop, barnyardgrass, rice flatsedge, and yellow nutsedge 2 and 3 weeks after treatment (WAT) as influenced by rate, application timing, and flood depth in 2016. <sup>a</sup>Each assessment was date was analyzed separately. Means followed by the standard error in parentheses, <sup>b</sup>WAT: weeks after treatment, <sup>c</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, <sup>d</sup>Sat, saturated.

| Treatments                                       |                    |                  | Dry weight reduction <sup>a</sup> (%) |               |                |                 |
|--|--------------------|------------------|---------------------------------------|---------------|----------------|-----------------|
| Benzobicyclon <sup>b</sup> g ai ha <sup>-1</sup> | Application timing | Flood depth      | Amazon sprangletop                    | Barnyardgrass | Rice flatsedge | Yellow nutsedge |
| 0 (none)   | Early <sup>c</sup> | Sat <sup>d</sup> | --                                    | --            | --             | --              |
|  |                    | 5 cm             | 77 (17)                               | 12 (16)       | 56 (22)        | -14 (11)        |
|  |                    | 15 cm            | 18 (23)                               | 59 (18)       | 39 (29)        | 5 (22)          |
|  | Late               | Sat              | 55 (55)                               | -18 (25)      | 1 (35)         | -15 (12)        |
|  |                    | 5 cm             | -31 (40)                              | -13 (29)      | 73 (18)        | -40 (32)        |
|  |                    | 15 cm            | 24 (22)                               | 13 (14)       | -7 (10)        | -16 (22)        |
| 247  | Early              | Sat              | 100 (0)                               | 61 (18)       | 99 (1)         | 58 (21)         |
|  |                    | 5 cm             | 100 (0)                               | 58 (23)       | 100 (0)        | 32 (15)         |
|  |                    | 15 cm            | 100 (0)                               | 100 (0)       | 100 (0)        | 67 (6)          |
|  | Late               | Sat              | 100 (0)                               | 33 (13)       | 26 (74)        | -26 (22)        |
|  |                    | 5 cm             | 100 (0)                               | -20 (26)      | 100 (0)        | -3 (7)          |
|  |                    | 15 cm            | 100 (0)                               | 61 (16)       | 97 (3)         | 61 (19)         |

**Table 4:** Dry weight reduction of Amazon sprangletop, barnyardgrass, rice flatsedge, and yellow nutsedge as influenced by the interaction of benzobicyclon rate, application timing, and flood depth in 2016. <sup>a</sup>Each assessment was date was analyzed separately. Means followed by the standard error in parentheses, <sup>b</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, <sup>c</sup>The 'No Benzobicyclon X Early X Saturated' treatment was the nontreated control and not included in the analysis, <sup>d</sup>Sat, saturated.

### Benzobicyclon plus halosulfuron mixture

Weed heights and densities at application are shown in Table 5.

| Weed species  | 2015                           |           | 2016                           |           |
|---------------|--------------------------------|-----------|--------------------------------|-----------|
|               | Density plants m <sup>-2</sup> | Height cm | Density plants m <sup>-2</sup> | Height cm |
| Barnyardgrass | 6                              | 28        | 9                              | 25        |
| Hemp sesbania | 5                              | 29        | 9                              | 31        |

**Table 5:** Density and height of weed species present in the experiment evaluating benzobicyclon plus halosulfuron in 2015 and 2016<sup>a</sup>.

Barnyardgrass was not effectively controlled ( $\leq 73\%$ ) by benzobicyclon alone or in combination with halosulfuron (Table 6),

which may have been partly due to its large size at application (Table 5). Hence, it is important to emphasize the need to make timely applications and avoid salvage situations, especially when barnyardgrass is present in the field.

Hemp sesbania was controlled  $>90\%$  3 WAT with the high rate of benzobicyclon alone and both rates of benzobicyclon plus halosulfuron (Table 6). Rough rice yield showed the benefit of using the high-rate mixture for weed control and that treatment had a higher yield (8880 kg ha<sup>-1</sup>) than any of the other treatments (6190 to 7380 kg ha<sup>-1</sup>) (Table 7). Yield also indicates the crop safety shown by CL111 rice to the high rate tank-mix of benzobicyclon plus halosulfuron. Therefore, it is concluded that benzobicyclon plus halosulfuron broadens and improves control of late-season problematic weeds and increases the likelihood for growers to see higher yields when weeds are present in rice after establishment of the permanent flood.

| Herbicide <sup>b</sup>                  | Rate g ai ha <sup>-1</sup> | Control <sup>a</sup> (%) |   |       |   |       |    |               |    |       |   |       |   |
|---|----------------------------|--------------------------|---|-------|---|-------|----|---------------|----|-------|---|-------|---|
|   |                            | Barnyardgrass            |   |       |   |       |    | Hemp sesbania |    |       |   |       |   |
|   |                            | 3 WAT <sup>c</sup>       |   | 5 WAT |   | 9 WAT |    | 3 WAT         |    | 5 WAT |   | 9 WAT |   |
| Halosulfuron (low)                      | 35                         | 13                       | b | 0     | b | 0     | c  | 48            | b  | 100   | a | 98    | a |
| Halosulfuron (high)                     | 53                         | 20                       | b | 0     | b | 0     | c  | 48            | b  | 99    | a | 98    | a |
| Benzobicyclon (low)                     | 247                        | 47                       | a | 40    | a | 43    | b  | 76            | ab | 90    | a | 84    | b |
| Benzobicyclon (high)                    | 371                        | 57                       | a | 46    | a | 56    | ab | 90            | a  | 88    | a | 96    | a |
| Benzobicyclon(low)+halosulfuron (low)   | 247+35                     | 51                       | a | 58    | a | 63    | a  | 94            | a  | 96    | a | 99    | a |
| Benzobicyclon(high)+halosulfuron (high) | 371+ 53                    | 49                       | a | 60    | a | 73    | a  | 99            | a  | 98    | a | 98    | a |

**Table 6:** Post-flood control of barnyardgrass and hemp sesbania with applications of benzobicyclon and halosulfuron averaged over 2015 and 2016 at Stuttgart, AR. <sup>a</sup> Means followed by the same letter within a column are not statistically different according to Fisher's protected LSD ( $\alpha=0.05$ ), <sup>b</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, <sup>c</sup>WAT, weeks after treatment.

| Herbicide                                | Rate g ai ha <sup>-1</sup> | Rough rice yield <sup>a,b</sup> kg ha <sup>-1</sup> |    |
|--|----------------------------|---|----|
| Halosulfuron (low)                       | 35                         | 6190  | d  |
| Halosulfuron (high)                      | 53                         | 6590  | cd |
| Benzobicyclon (low)                      | 247                        | 7700  | b  |
| Benzobicyclon (high)                     | 371                        | 7380  | b  |
| Benzobicyclon (low)+halosulfuron (low)   | 247+35                     | 7000  | bc |
| Benzobicyclon (high)+halosulfuron (high) | 371+53                     | 8880  | a  |

**Table 7:** Rough rice yield as influenced by weed control from applications of benzobicyclon and/or halosulfuron averaged across 2015 and 2016 at Stuttgart. <sup>a</sup>Rough rice machine harvested on September 14, 2015 and August 31, 2016, <sup>b</sup>Means followed by the same letter within a column are not statistically different according to Fisher's protected LSD ( $\alpha=0.05$ ).

### Mixing benzobicyclon with post-flood herbicides

Weed heights and densities at time of application are listed in Table 8. The addition of benzobicyclon to penoxsulam, bispyribac,

halosulfuron, saflufenacil, carfentrazone, propanil, bentazon, and halosulfuron plus thifensulfuron significantly increased control of Amazon sprangletop at Lonoke at 6 WAT (Table 9). For barnyardgrass, the only improvement in control was the addition of benzobicyclon to saflufenacil, resulting in control improving from 9% with saflufenacil alone to 64% with the mixture 4 WAT. The mixture of bispyribac-sodium plus benzobicyclon controlled barnyardgrass  $\geq 90\%$  across all evaluations at Lonoke. The addition of benzobicyclon to cyhalofop broadened control to include the broadleaf weeds hemp sesbania and Northern jointvetch. Benzobicyclon has excellent activity on northern jointvetch as seen 6 WAT when control of all benzobicyclon treatments was  $>99\%$  at Lonoke.

| Weed species        | Lonoke                        |           | Pine Tree                     |           |
|---------------------|-------------------------------|-----------|-------------------------------|-----------|
|                     | Density plantsm <sup>-2</sup> | Height cm | Density plantsm <sup>-2</sup> | Height cm |
| Barnyardgrass       | 7                             | 30        | 8                             | 36        |
| Amazon sprangletop  | 3                             | 25        | NP                            |           |
| Hemp sesbania       | 3                             | 30        | NP                            |           |
| Northern jointvetch | 1                             | 18        | NP                            |           |

|                   |    |   |    |
|-------------------|----|---|----|
| Red sprangletop   | NP | 4 | 19 |
| Asiatic dayflower | NP | 6 | 13 |
| Yellow nutsedge   | NP | 8 | 30 |

**Table 8:** Density and height of weed species present in the herbicide mixture field experiment in 2016 at Lonoke and Pine Tree<sup>a</sup>. <sup>a</sup> Abbreviation “NP” indicates weed not present at location or time of application.

At Pine Tree, benzobicyclon improved barnyardgrass control over halosulfuron, saflufenacil, carfentrazone, and bentazon alone (Table 10). Benzobicyclon improved control of red sprangletop when added to nearly all of the herbicides. Asiatic dayflower and yellow nutsedge control were improved by the addition of benzobicyclon to cyhalofop and penoxsulam.

Most herbicides applied with benzobicyclon provided adequate weed control resulting in few differences in yield among treatments (Table 11). A yield loss was documented at Lonoke when benzobicyclon was applied with bispyribac and cyhalofop. Similarly, a yield loss was documented at Pine Tree when benzobicyclon was applied with bentazon. However, for the treatments that underwent a yield loss, it was only at one of the two locations. The yields at Pine Tree were generally higher than Lonoke because of the uptake of the pre-flood fertilizer. At Pine Tree, fertilizer was applied and the field was flooded in a timely fashion. At Lonoke, the pre-flood fertilizer was applied and did not receive a flood until nearly a week later. Some of the pre-flood urea fertilizer likely volatilized as ammonia and was not taken up as efficiently by the crop.

| Herbicide <sup>a</sup>                    | Additive rate<br>g ai ha <sup>-1</sup> | Benzobicyclon rate<br>g ai ha <sup>-1</sup> | Control (%)   |                    |               |                     |
|---|--|---|---------------|--------------------|---------------|---------------------|
|   |  |   | Barnyardgrass | Amazon sprangletop | Hemp sesbania | Northern jointvetch |
| Penoxsulam                                | 35                                     | 0 (none)                                    | 53            | 80                 | 83            | 83                  |
| Penoxsulam+benzobicyclon                  | 35                                     | 247   | 40            | 73                 | 98            | 97                  |
| Bispyribac                                | 23                                     | 0   | 88            | 86                 | 70            | 88                  |
| Bispyribac+benzobicyclon                  | 23                                     | 247   | 90            | 99                 | 91            | 93                  |
| Halosulfuron                              | 53                                     | 0   | 31            | 49                 | 73            | 71                  |
| Halosulfuron+benzobicyclon                | 53                                     | 247   | 43            | 94*                | 90            | 94*                 |
| Imazamox                                  | 45                                     | 0   | 45            | 78                 | 71            | 81                  |
| Imazamox+benzobicyclon                    | 45                                     | 247   | 71            | 96*                | 94*           | 93                  |
| Cyhalofop                                 | 280                                    | 0   | 85            | 88                 | 78            | 24                  |
| Cyhalofop+benzobicyclon                   | 280                                    | 247   | 85            | 96                 | 96            | 91*                 |
| Saflufenacil                              | 25                                     | 0   | 9             | 79                 | 84            | 86                  |
| Saflufenacil+benzobicyclon                | 25                                     | 247   | 64*           | 95                 | 91            | 94                  |
| Carfentrazone                             | 18                                     | 0   | 26            | 65                 | 81            | 81                  |
| Carfentrazone+benzobicyclon               | 18                                     | 247   | 30            | 96*                | 93            | 94                  |
| Propanil                                  | 3360                                   | 0   | 80            | 61                 | 67            | 76                  |
| Propanil+benzobicyclon                    | 3360                                   | 247   | 83            | 97*                | 90*           | 93                  |
| Bentazon                                  | 840                                    | 0   | 39            | 61                 | 69            | 70                  |
| Bentazon+benzobicyclon                    | 840                                    | 247   | 23            | 96*                | 95*           | 96*                 |
| Halosulfuron+thifensulfuron               | 35+5                                   | 0   | 56            | 63                 | 73            | 78                  |
| Halosulfuron+thifensulfuron+benzobicyclon | 35+5                                   | 247   | 53            | 95*                | 90            | 90                  |

**Table 9:** Post-flood control of barnyardgrass, Amazon sprangletop, hemp sesbania, and Northern jointvetch at 4 weeks after treatment as influenced by benzobicyclon rate and additive herbicide at Lonoke in 2016. <sup>a</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, \*Indicates a statistical improvement of efficacy with the addition of benzobicyclon according to Fisher’s protected LSD ( $\alpha=0.05$ ).

| Herbicide <sup>a</sup>                   | Additive rate<br>g ai ha <sup>-1</sup> | Benzobicyclon rate<br>g ai ha <sup>-1</sup> | Control (%)   |                 |                   |                 |
|--|--|---|---------------|-----------------|-------------------|-----------------|
|  |  |   | Barnyardgrass | Red sprangletop | Asiatic dayflower | Yellow nutsedge |
| Penoxsulam                               | 35                                     | 0 (none)                                    | 84            | 53              | 0                 | 0               |
| Penoxsulam+benzobicyclon                 | 35                                     | 247   | 86            | 91*             | 89*               | 89*             |
| Bispyribac                               | 23                                     | 0   | 88            | 78              | 74                | 89              |
| Bispyribac+benzobicyclon                 | 23                                     | 247   | 86            | 88*             | 84                | 99              |
| Halosulfuron                             | 53                                     | 0   | 0             | 0               | 79                | 90              |
| Halosulfuron+benzobicyclon               | 53                                     | 247   | 82*           | 90*             | 84                | 96              |
| Imazamox                                 | 45                                     | 0   | 85            | 78              | 81                | 85              |
| Imazamox+benzobicyclon                   | 45                                     | 247   | 93            | 91*             | 79                | 95              |
| Cyhalofop                                | 280                                    | 0   | 85            | 85              | 0                 | 0               |
| Cyhalofop+benzobicyclon                  | 280                                    | 247   | 85            | 91              | 81*               | 93*             |
| Saflufenacil                             | 25                                     | 0   | 38            | 19              | 88                | 88              |
| Saflufenacil+benzobicyclon               | 25                                     | 247   | 68*           | 89*             | 90                | 94              |
| Carfentrazone                            | 18                                     | 0   | 0             | 0               | 89                | 86              |
| Carfentrazone+benzobicyclon              | 18                                     | 247   | 89*           | 88*             | 83                | 90              |
| Propanil                                 | 3360                                   | 0   | 80            | 79              | 71                | 86              |
| Propanil+benzobicyclon                   | 3360                                   | 247   | 83            | 91*             | 83                | 98              |
| Bentazon                                 | 840                                    | 0   | 0             | 0               | 74                | 90              |
| Bentazon+benzobicyclon                   | 840                                    | 247   | 71*           | 89*             | 81                | 99              |
| Halosulfuron+thifensulfuron              | 35+5                                   | 0   | 21            | 1               | 66                | 85              |
| Halosulfuro+thifensulfuron+benzobicyclon | 35+5                                   | 247   | 66            | 80*             | 79                | 94              |

**Table 10:** Post-flood control of barnyardgrass, Amazon sprangletop, hemp sesbania, and Northern jointvetch at 4 weeks after treatment as influenced by benzobicyclon rate and additive herbicide at Lonoke in 2016. <sup>a</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, \*Indicates a statistical improvement of efficacy with the addition of benzobicyclon according to Fisher's protected LSD ( $\alpha=0.05$ ).

| Herbicide <sup>a</sup>     | Additive rate g ai ha <sup>-1</sup> | Benzobicyclon rate g ai ha <sup>-1</sup> | Rough rice yield kg ai <sup>-1</sup> |           |
|----------------------------|-------------------------------------|--|--------------------------------------|-----------|
|                            |                                     |  | Lonoke                               | Pine Tree |
| None                       | -                                   | 0 (none)                                 | 4660                                 | 6230      |
| None+benzobicyclon         | -                                   | 247                                      | 5600*                                | 5800      |
| Penoxsulam                 | 35                                  | 0  | 5810                                 | 7020      |
| Penoxsulam+benzobicyclon   | 35                                  | 247                                      | 5390                                 | 7170      |
| Bispyribac                 | 23                                  | 0  | 6800                                 | 9180*     |
| Bispyribac+benzobicyclon   | 23                                  | 247                                      | 6860                                 | 6450      |
| Halosulfuron               | 53                                  | 0  | 6110                                 | 7760      |
| Halosulfuron+benzobicyclon | 53                                  | 247                                      | 5560                                 | 7830      |
| Imazamox                   | 45                                  | 0  | 6470                                 | 7650      |



|   |      |     |       |       |
|---|------|-----|-------|-------|
| Imazamox+benzobicyclon                    | 45   | 247 | 7060* | 7000  |
| Cyhalofop                                 | 280  | 0   | 5560  | 6690  |
| Cyhalofop+benzobicyclon                   | 280  | 247 | 8160* | 7910* |
| Saflufenacil                              | 25   | 0   | 5240  | 6230  |
| Saflufenacil+benzobicyclon                | 25   | 247 | 6630* | 5910  |
| Carfentrazone                             | 18   | 0   | 5800  | 5140  |
| Carfentrazone+benzobicyclon               | 18   | 247 | 6280  | 7530  |
| Propanil                                  | 3360 | 0   | 6230  | 6920  |
| Propanil+benzobicyclon                    | 3360 | 247 | 5670  | 8800* |
| Bentazon                                  | 840  | 0   | 5120  | 6680  |
| Bentazon+benzobicyclon                    | 840  | 247 | 5750* | 7630  |
| Halosulfuron+thifensulfuron               | 35+5 | 0   | 5820  | 6980  |
| Halosulfuron+thifensulfuron+benzobicyclon | 35+5 | 247 | 5910  | 7060  |

**Table 11:** Rough rice yield as influenced by benzobicyclon rate and additive herbicide application made post-flood in 2016 at Lonoke and Pine Tree. Post-flood application with the addition of 1% (v/v) crop oil concentrate. <sup>a</sup>Post-flood applications made with the addition of 1% (v/v) crop oil concentrate, \*Indicates a statistical improvement in yield with the addition of benzobicyclon according to Fisher's protected LSD ( $\alpha=0.05$ ).

Overall, this research indicates that benzobicyclon is an effective post-flood herbicide that has a broad spectrum of activity. Increased weed control is expected when benzobicyclon is tank-mixed with most other post-flood rice herbicides. The ability to apply a Group 27 herbicide, like benzobicyclon, will give growers another option to control late-season escapes in rice.

## Acknowledgments

Funding for this research was provided by the Arkansas Rice Research and Promotion Board.

## References

- Hardke JT (2014) Trends in Arkansas rice production. *BR Wells Rice Research Studies AAES Research Series* 617: 13-23.
- Wilson CE, Runsick SK (2008) Trends in Arkansas rice production. *BR Wells Rice Research Studies AAES Research Series* 571: 13-23.
- Heap I (2016) *The International Survey of Herbicide Resistant Weeds*.
- Norsworthy JK, Bond J, Scott RC (2013) Weed management practices and needs in Arkansas and Mississippi rice. *Weed Technol* 27: 623-630.
- Norsworthy JK, Scott RC, Johnson DB (2012) A six-year summary of the herbicide-resistance weed screening program in rice at the University of Arkansas: 2006-2012. *BR Wells Rice Research Studies AAES Research Series* 609: 153-158.
- Bagavathiannan MV, Norsworthy JK, Riar DS, Hill ZT, Schrage BW, et al. (2014) Growth characterization of an ALS-inhibitor resistant yellow nutsedge population from eastern Arkansas. *Proc South Weed Sci Soc* 67: 30.
- Norsworthy JK, Burgos NR, Scott RC, Smith KL (2007) Consultant perspectives on weed management needs in Arkansas rice. *Weed Technol* 21: 832-839.
- Norsworthy JK, Griffith GM, Scott RC (2008) Imazethapyr use with and without clomazone for weed control in furrow-irrigated, imidazolinone-tolerant rice. *Weed Technol* 22: 217-221.
- Scott RC, Norsworthy JK, Bagavathiannan MV (2014) Identification and control of problematic sedges in Arkansas rice. Fayetteville, AR: University of Arkansas System.
- Scott RC, Norsworthy JK, Barber LT, Boyd JW, Burgos N, et al. (2016) Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service MP442016. Little Rock, Ark, pp: 91-107.
- Masson JA, Webster EP, Williams BJ (2001) Flood depth, application timing, and imazethapyr activity in imidazolinone tolerant rice (*Oryza sativa*). *Weed Technol* 15: 315-319.
- Wilson MJ, Norsworthy JK, Scott RC, Gbur EE (2014) Program approaches to control herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in Midsouthern United States rice. *Weed Technol* 28: 39-46.
- Carey FV, Hoagland RE, Talbert RE (1995) Verification and distribution of propanil-resistant barnyardgrass (*Echinochloa crus-galli*) in Arkansas. *Weed Technol* 9: 366-372.
- Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, et al. (2012) Reducing the risks of herbicide resistance: Best management practices and recommendations. *Weed Sci* 60: 31-62.
- Beckie HJ (2006) Herbicide-resistant weeds: management tactics and practices. *Weed Technol* 20: 793-814.
- Hydrick DE, Shaw DR (1994) Effects of tank-mix combinations of non-selective foliar and selective soil-applied herbicides on three weed species. *Weed Technol* 8: 129-133.
- Norsworthy JK, Talbert RE, Hoagland RE (1998) Chlorophyll fluorescence for rapid detection of propanil-resistant barnyardgrass (*Echinochloa crus-galli*). *Weed Sci* 46: 163-169.
- Norsworthy JK, Bangarwa SK, Scott RC, Still J, Griffith GM (2010) Use of propanil and quinclorac tank mixtures for broadleaf weed control on rice (*Oryza sativa*) levees. *Crop Prot* 29: 255-259.
- Komatsubara K, Sekino K, Yamada Y, Koyanagi H, Nakahara S (2009) Discovery and development of a new herbicide, benzobicyclon. *J Pestic Sci* 34: 113-144.
- Sekino K, Joyanagi H, Ikuta E, Yamada Y (2008) Herbicidal activity of a new paddy bleaching herbicide, benzobicyclon. *J Pestic Sci* 33: 364-370.

21. Davis BM, Scott RC, Sandoski CA, Barber LT, Norsworthy JK (2013) Weed control demonstration of five rates of benzobicyclon applied at two maintained flood depths to rice weeds. *BR Wells Rice Research Studies AAES 671*: 201-205.
22. Norsworthy JK, Sandoski CA, Scott RC (2014) A review of benzobicyclon trials in Arkansas rice. *Proceedings of the 35th Rice Technical Working Group*. New Orleans, Louisiana: Louisiana State University Agricultural Center.
23. Sandoski CA, Brazzle JR, Holmes KA, Takahashi A (2014) Benzobicyclon: a novel herbicide for U.S. rice production. *Proceedings of the 35th Rice Technical Working Group*. New Orleans, Louisiana: Louisiana State University Agricultural Center.
24. Anonymous (2017) Butte® herbicide product label. Gowan Company Publication No. 01-R0417. Yuma, AZ: Gowan Company.
25. Young ML, Norsworthy JK, Sandoski CA, Scott RC, Barber LT (2016) Evaluation of a benzobicyclon plus halosulfuron premix for weed control in Arkansas rice. *BR Wells Rice Research Studies AAES Research Series 634*: 212-217.
26. Lee SD, Oliver LR (1982) Efficacy of acifluorfen on broadleaf weeds. *Times and methods for application*. *Weed Technol* 30: 520-526.
27. Chauhan BS, Abugho SB (2012) Effect of growth stage on the efficacy of postemergence herbicides on four weed species of direct-seeded rice. *Sci World J* 123071.
28. McKnight BM, Webster EP, Fish JC, Bergeron EA, Sandoski CA (2014) Potential for benzobicyclon under common Louisiana cropping systems. *Proceedings of the 35th Rice Technical Working Group*. New Orleans, Louisiana: Louisiana State University Agricultural Center, pp: 100,101.
29. Williams KL, Tjeerdema RS (2016) Hydrolytic activation kinetics of the herbicide benzobicyclon in simulated aquatic systems. *J Agri Food Chem* 64: 4838-4844.
30. Norsworthy JK, Riar DS, Scott RC (2014) Control options for ALS-resistant smallflower umbrellasedge in Arkansas rice. *B.R. Wells Rice Research Studies AAES Research Series 617*: 222-226.