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Evaluation of three grass-specific herbicides on torpedograss (*Panicum repens*) and seven nontarget, native aquatic plants

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ABSTRACT

Invasive aquatic grasses are generally managed with the nonselective herbicides glyphosate and imazapyr. Although these herbicides are generally highly efficacious, this results in a limited ability to enhance or conserve on-site native vegetation because of their lack of selectivity. The problem is compounded over time as posttreatment reinvasion by invasive grasses commonly occurs, resulting in the need for additional herbicide treatment. To address this lack of selectivity, we evaluated three grass-specific herbicides (clethodim, fluazifop-*P*-butyl, and sethoxydim) and compared outcomes to the standard operational treatments of glyphosate or imazapyr. Seven native aquatic plants were tested, which included California bulrush [*Schoenoplectus californicus* (C.A. Mey.) Palla], knotted spikerush [*Eleocharis interstincta* (Vahl) Roem. & Schult.], gulfcoast spikerush (*Eleocharis cellulosa* Torr.), common cattail (*Typha latifolia* L.), pickerelweed (*Pontederia cordata* L.), common arrowhead (*Sagittaria latifolia* Willd.), and Egyptian panicgrass [*Paspalidium geminatum* (Forssk.) Stapf]. Torpedograss (*Panicum repens* L.), which is one of the most invasive aquatic grasses in Florida, was also included. Following summer or fall treatments at recommended label rates, both glyphosate and imazapyr provided 64 to 100% biomass reduction of all nongrass species evaluated at 8 wk after treatment (WAT). That was in contrast to the grass herbicides, which did not affect any nongrass species after treatment. The grass herbicides, however, did result in a 69 to 85% shoot biomass reduction of both native grasses and torpedograss at 8 WAT and were generally similar to glyphosate and imazapyr. Results suggest a high level of selectivity exists for the grass-specific herbicides on many nontarget emergent aquatic plants. These data were used to support approval of a Florida Experimental Use Permit for the aquatic use of sethoxydim and fluazifop-*P*-butyl to further evaluate the concept of using grass-specific herbicides for selective control of invasive aquatic grasses.

Key words: aquatic plant management, graminicide, herbicide selectivity, invasive aquatic grass.

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INTRODUCTION

Invasive aquatic grasses represent both a long-term and emerging problem for resource managers in the United States. Torpedograss (*Panicum repens* L.) has been recognized as a major aquatic weed and a complex management problem in Florida for decades (Schardt and Schmitz 1991). Newer introductions of aquatic grasses, such as West Indian marsh grass [*Hymenachne amplexicaulis* (Rudge) Nees] and large watergrass (*Luziola subintegra* Swallen) represent emerging invasive grass species with the potential for displacing native aquatic habitat. Current management strategies for control of invasive aquatic grasses rely heavily on nonselective, systemic herbicides, such as glyphosate and imazapyr, applied alone or in combination (Smith et al. 1993; Hanlon and Langeland 2000; Netherland 2014). Although these products can provide effective control, even when most aquatic invasive grasses form into near monocultures, the broad-spectrum nature of those herbicides and the requirement for repeat applications can prevent conservation or delay restoration of native habitats (Gettys and Sutton 2004). Continued reliance on nonselective herbicides will limit strategies available for restoration efforts or early stage interventions before the invasive grasses become dominant. Integration of grass-specific herbicides (graminicides) into aquatic plant management programs could enhance native plant selectivity and greatly improve the success of many restoration projects.

The use of graminicides or "grass-active herbicides" is well established in terrestrial systems, primarily in agricultural settings. Graminicides belong to at least three chemical families, including the aryloxyphenoxypropionates, cyclohexanediones, and phenylpyrazolins (WSSA 2014). Graminicides target the acetyl-coenzyme A carboxylase (ACCase) enzyme, which inhibits fatty acid synthesis and causes an inability to produce the phospholipids used in building new membranes for cell growth (Burton et al. 1989). Symptoms include growth cessation in new and actively growing tissues and leaf chlorosis and necrosis within 1 to 4 wk. Broadleaf species (in general) are naturally resistant to the ACCase inhibitors because of an insensitive ACCase enzyme (Burton et al. 1989).

Although graminicides are used to control grass weeds in row crops, there are several examples of the use of graminicides in noncrop settings. For example, in forestry, control of mature grasses via graminicides is desirable, and performance is often species specific (Clay et al. 2006). Various graminicides provide good control of the highly invasive Mary's-grass [*Microstegium vimineum* (Trin.) A. Camus] (Judge et al. 2005a,b, Flory 2008); however, they have only a limited negative effect on common reed [*Phragmites australis* (Cav.) Trin. ex Steud.] (Derr 2008). Use of graminicides may require multiple applications to control established napiergrass (*Pennisetum purpureum* Schumach) (Grey et al. 2015).

Given the selectivity of graminicides and their incorporation into restoration projects in upland areas, the potential for integrating a grass-specific herbicide into aquatic restoration efforts is warranted. Early efforts to screen multiple grass-specific herbicides suggested that several of those active ingredients were efficacious on invasive aquatic grasses, such as torpedograss (*Panicum repens* L.), West Indian marshgrass, large watergrass, and paragrass [*Urochloa mutica* (Forssk.) T.Q. Nguyen] (Netherland and Lancaster 2014). These invasive grasses are perennial and can form extensive and near-monotypic stands in littoral zones of Florida waters. Review of efficacy data and consultation with private industry resulted in selection of clethodim, fluazifop-*P*-butyl, and sethoxydim for mesocosm selectivity testing. Those herbicides have a long history of agricultural use and multiple 24(c) Special Local Need use labels for selective control of terrestrial invasive grasses. The premise of using these grass-selective products in aquatics is their reported lack of effect to nongrass species. However, little is known regarding the effect of graminicides on numerous other monocots, including rushes, sedges, and cattails in aquatic sites. Therefore, evaluation of these products on those nontarget plants is clearly warranted.

To develop a new approach for selective control of aquatic invasive grasses, we evaluated the grass-specific herbicides clethodim, sethoxydim, and fluazifop-*P*-butyl under mesocosm conditions against a suite of native plant species and torpedograss in summer and early fall. The nonselective herbicides glyphosate and imazapyr were included for comparative purposes. The objective of this study was to determine selectivity of the grass-specific herbicides against established, native aquatic plant species under large-scale mesocosm conditions.

MATERIALS AND METHODS

Trials were conducted at the University of Florida, Center for Aquatic and Invasive Plants, in Gainesville, FL. Seven native species were tested and included California bulrush [*Schoenoplectus californicus* (C.A. Mey.) Palla], knotted spikerush [*Eleocharis interstincta* (Vahl) Roem. & Schult.], gulfcoast spikerush (*Eleocharis cellulosa* Torr.), common cattail (*Typha latifolia* L.), pickerelweed (*Pontederia cordata* L.), common arrowhead (*Sagittaria latifolia* Willd.), and Egyptian panicgrass [*Paspalidium geminatum* (Forssk.) Stapf]. Torpedograss, which is one of the most invasive aquatic grasses in Florida, was also included. Plants were initially established by planting small specimens, shoots, or rhizome cuttings into 3.78-L, plastic pots filled with either builder's sand or a sand–potting soil mix (50 : 50), and 10 g of Osmocote Plus[1] (15–9–12 [N–P–K]). Pots with newly established plants of each species were then transferred into 18 (900-L) mesocosm tanks on 3 June 2014. Pots were randomly placed within each tank. Two pots of each native species were assigned to 15 of the 18 tanks, and three pots of each native species were assigned to the three remaining tanks. These three additional pots of each species were used for the pretreatment harvest. For torpedograss, eight pots were placed throughout each of the 15 tanks, and nine pots were placed in the three remaining tanks; the three additional pots were specified for pretreatment harvest. Water level was maintained at a depth of 38 cm before herbicide application. All plants were allowed a 6-wk period of pretreatment growth in the tanks. At the end of that period, the three additional pots for each native species and torpedograss in the untreated control tanks were harvested, oven dried to a constant weight at 65 C, and recorded just before herbicide treatment. Aboveground biomass for the native plants was harvested while above and belowground biomass were harvested for torpedograss.

Herbicide treatments for the first experimental run were applied on 4 June 2014. The surface area of the 900-L tanks was calculated, and each herbicide was applied via a carbon-dioxide (CO_2)-pressurized sprayer equipped with a hand-held, single-nozzle spray head calibrated to deliver a spray volume of 708 L ha^{-1}. Herbicide treatments included the three graminicides (clethodim[2] [560 g ai ha^{-1}], fluazifop-*P*-butyl[3] (210 g ai ha^{-1}), and sethoxydim[4] [560 g ai ha^{-1}]) and two commercial standards (glyphosate[5] [4.2 kg ae ha^{-1}] and imazapyr[6] [1.4 kg ai ha^{-1}]). A nonionic spray adjuvant[7] was added to the fluazifop-*P*-butyl, glyphosate, and imazapyr treatments at 0.5% vol/vol. A methylated seed oil[8] was added to the clethodim and sethoxydim treatments at 1% vol/vol.

Plant biomass was harvested at 8 wk after treatment (WAT) and oven dried to a constant weight at 65 C. Aboveground biomass for native plants was harvested, whereas aboveground and belowground biomass were harvested for torpedograss.

The study was repeated as previously described, and all species were established in tanks on 21 August 2014, and given an approximate 6-wk pretreatment growth period. Plants were treated on 3 October 2014 and harvested at 8 WAT in early December. As noted with the first experimental run, all plants were well established at the time of the October herbicide application in the second experimental run.

Each herbicide treatment and the untreated control were replicated in three tanks and treatments were arranged in a completely randomized design. Data were subjected to ANOVA, and differences between the untreated and herbicide-treated native plant biomass for both experimental runs were determined via a Dunnett's test ($\alpha = 0.05$). Differences between treatments for the grass species were determined using a Student-Newman-Keuls method ($P < 0.05$). Posttreatment data are presented as the percentage of the untreated control for each experimental run.

RESULTS

Pretreatment and final posttreatment biomass of untreated reference plants are provided in Table 1. These results indicate that all species accumulated biomass during

Table 1. Native plant biomass of seven species harvested pretreatment and at 8 wk after treatment (WAT) (n = 3) in summer and fall to evaluate selectivity of graminicides.

Plant Species	June Pretreated Biomass	Untreated Biomass at 8 WAT	October Pretreated Biomass	Untreated Biomass at 8 WAT
California bulrush	10.8 (2.8)	28.2 (4.2)	9.1 (1.6)	19.8 (3.6)
Knotted spikerush	8.5 (1.6)	24.1 (3.9)	6.2 (2.4)	13.5 (4.1)
Common cattail	17.5 (3.2)	39.9 (6.8)	13.3 (2.5)	22.7 (5.3)
Gulfcoast spikerush	5.2 (1.3)	13.7 (3.0)	4.3 (1.1)	8.9 (2.6)
Common arrowhead	7.1 (2.4)	18.3 (3.8)	5.8 (2.0)	10.9 (1.7)
Pickerelweed	13.7 (2.7)	40.7 (8.9)	10.7 (2.5)	24.9 (6.4)
Egyptian panicgrass	10.1 (2.3)	23.7 (3.3)	8.5 (1.8)	18.1 (3.5)

the treatment period in both the summer and fall experimental runs. Although pretreatment biomass was generally similar between the two studies, greater posttreatment growth in experimental Run One (June and July) versus Run Two (October and November) was observed. This was substantiated by a significant interaction (P = 0.013) between the two trials; therefore, data are reported separately for each experimental run.

Nongrass, native plant response

As expected, both glyphosate and imazapyr resulted in severe injury and a significant biomass reduction for all nongrass, native plant species treated in the summer and fall experimental runs. Glyphosate reduced final biomass by 81 to 100% across all nongrass, native species (Figures 1A–F). When final biomass was compared with the untreated control, the negative impact of glyphosate was significant for all species. Imazapyr resulted in a similar pattern and reduced final biomass of all native species by 64 to 99%. Excluding California bulrush, imazapyr reduced biomass of all other native species by 89% or more across both treatment timings. For all nongrass, native plant species, results with the three graminicides were in clear contrast to glyphosate and imazapyr. Final biomass of all nongrass species was not different from untreated plants after application of clethodim, fluazifop-*P*-butyl, or sethoxydim (Figures 1A–F). Although some variation in the percentage of biomass reduction for nongrass, native plants was noted in response to treatment timing, the overall response of the native plants was not different for the summer and fall experimental runs. All three grass-selective products performed similarly with a lack of impact to native (nongrass) aquatic vegetation.

Additional observations throughout each experimental run indicated the onset of injury was faster with glyphosate than it was with imazapyr. This was expected because imazapyr is widely known to work very slowly in susceptible species. In contrast, there were no visible injury symptoms noted on nongrass native species for clethodim, fluazifop-*P*-butyl, and sethoxydim after either summer or fall applications. Immediately after treatment, some potential formulation solvent or surfactant burn associated with the fluazifop-*P*-butyl application was noted. However, plants recovered from those symptoms within a few days after the application, and there was no impact on final biomass.

Native and exotic grass response

All herbicide treatments, including glyphosate, imazapyr and the three graminicides, resulted in severe injury to the native Egyptian panicgrass and the exotic torpedograss in the summer and fall experimental runs. For Egyptian panicgrass, all treatments across both timings resulted in a 73 to 93% reduction in shoot biomass and were not different (Figure 2A). For torpedograss, all summer-applied herbicide treatments resulted in a 76 to 94% reduction in aboveground biomass and were not different (Figure 2B). However, for the fall timing, glyphosate, imazapyr, clethodim, and sethoxydim resulted in a 78 to 90% reduction in shoot biomass and were not different. Fluazifop resulted in a slightly lower reduction of 69% and was not different from clethodim (78%).

Belowground biomass reductions of torpedograss were somewhat different between experimental runs. For the summer timing, glyphosate reduced belowground biomass to a greater extent than imazapyr, clethodim, and sethoxydim did (Figure 2C). However, there were no differences among any of the graminicides or imazapyr. For the fall timing, glyphosate reduced belowground biomass more than clethodim and fluazifop did. Again, there were no differences among any of the graminicides or imazapyr. The difference between the summer and fall runs appeared to be driven by variation in the performance of sethoxydim and fluazifop. Field studies are currently being conducted to examine this issue in greater depth.

DISCUSSION

Results from these trials suggest that clethodim, fluazifop-*P*-butyl, and sethoxydim were active on torpedograss and the native Egyptian panicgrass but had no activity on the other monocotyledonous native plants evaluated. Although this is not surprising, given the level of selectivity reported for ACCase inhibitors in terrestrial systems (WSSA 2014), the lack of native plant response to those maximum-rate treatments in a large mesocosm tanks (which included invasive torpedograss) supports our working hypothesis. Although torpedograss expanded in the untreated control tanks, the graminicides stopped torpedograss expansion with no significant impact to the biomass of native plants. The short-term nature of these trials (8 wk) did not allow us to determine the long-term efficacy of these products; however, the inherent selectivity of the grass herbicides suggests that multiple applications may be possible without increasing the risk to nongraminoid native plants (Wilcox et al. 2007). Multiple applications of these grass-selective herbicides may be required to adequately control an invasive grass (Annen et al. 2005; Grey et al. 2015). The economics of multiple applications of graminicides must be balanced against their ability to restore and maintain desirable habitat. There was a strong overall contrast in selectivity when comparing these grass-selective herbicides

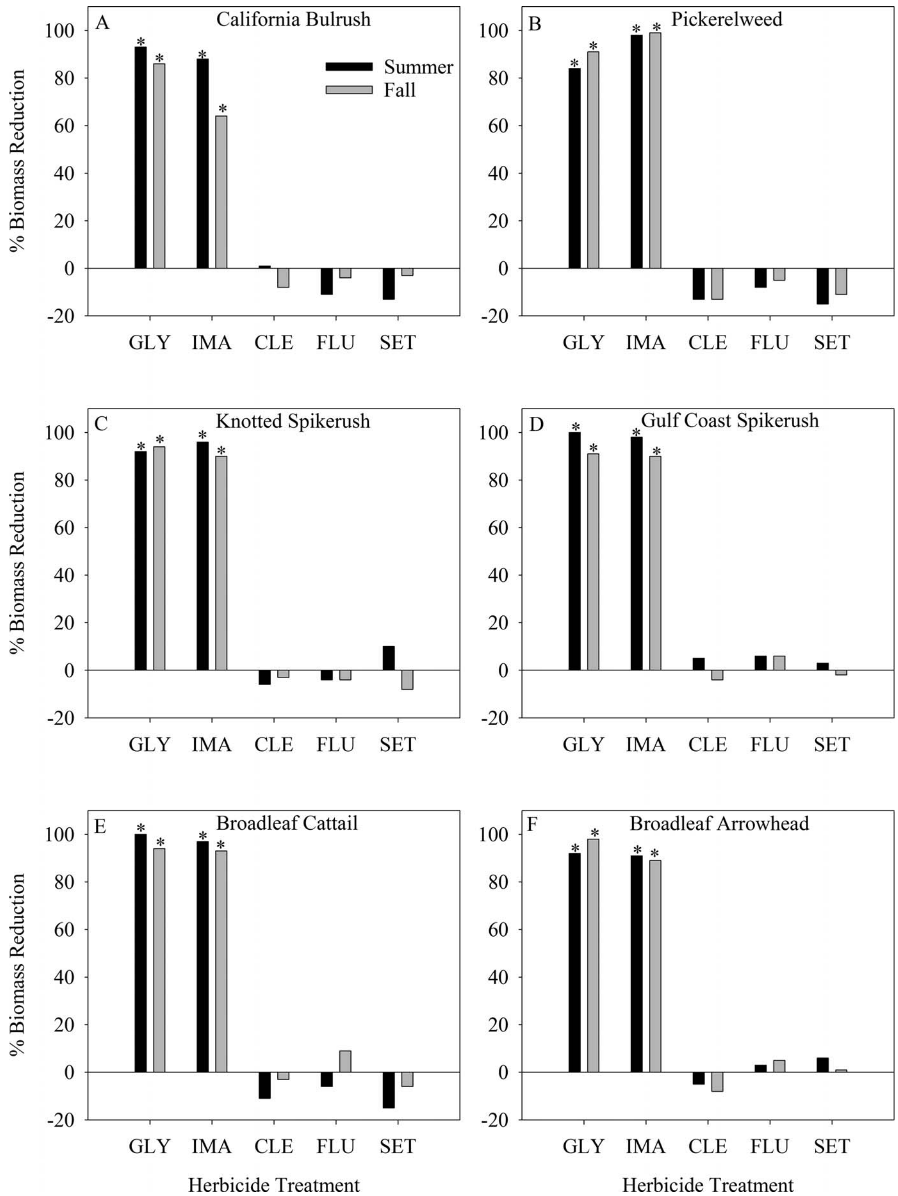

Figure 1. Percentage of biomass reduction for six native aquatic plants at 8 wk after foliar application of glyphosate (GLY), imazapyr (IMA), clethodim (CLE), fluazifop-*P*-butyl (FLU), and sethoxydim (SET). Summer and fall treatments were applied on 3 June and 3 October, respectively. Each bar represents the average of three replicates. Asterisks above bars denote a significant difference between the biomass of a given herbicide and the untreated control, according to a Dunnett's test ($\alpha = 0.05$). Negative values represent a positive growth response, even though those values are not different from the untreated reference.

to glyphosate and imazapyr. The lack of any effect on established native plants suggests the ability to spray areas in which invasive grasses are beginning to establish or reestablish without impact to native vegetation. This is a potential use pattern that does not currently exist with imazapyr and is highly limited for glyphosate to directed sprays and to the time native vegetation is dormant and the invasive target is still photosynthetically active (Frey et al. 2007).

Numerous factors influence the efficacy and longevity of glyphosate and imazapyr when used for torpedograss control in aquatic systems (Smith et al. 1993, Willard et al. 1998). Factors such as treatment timing, plant density, water depth, and multiple applications will likely influence the efficacy of grass-selective herbicides. Other research has demonstrated significant seasonal and year-to-year (environmental) variation in graminicide performance on upland species, such as yellow bluestem [*Bothriochloa ischaemum* (L.) Keng] (Harmoney et al. 2004) and reed canarygrass (*Phalaris arundinacea* L.) (Healy et al. 2015). The clear selectivity demonstrated in this study indicates that future research efforts should focus on maximizing efficacy on torpedograss and other invasive aquatic grasses of interest across complex environmental conditions. More-

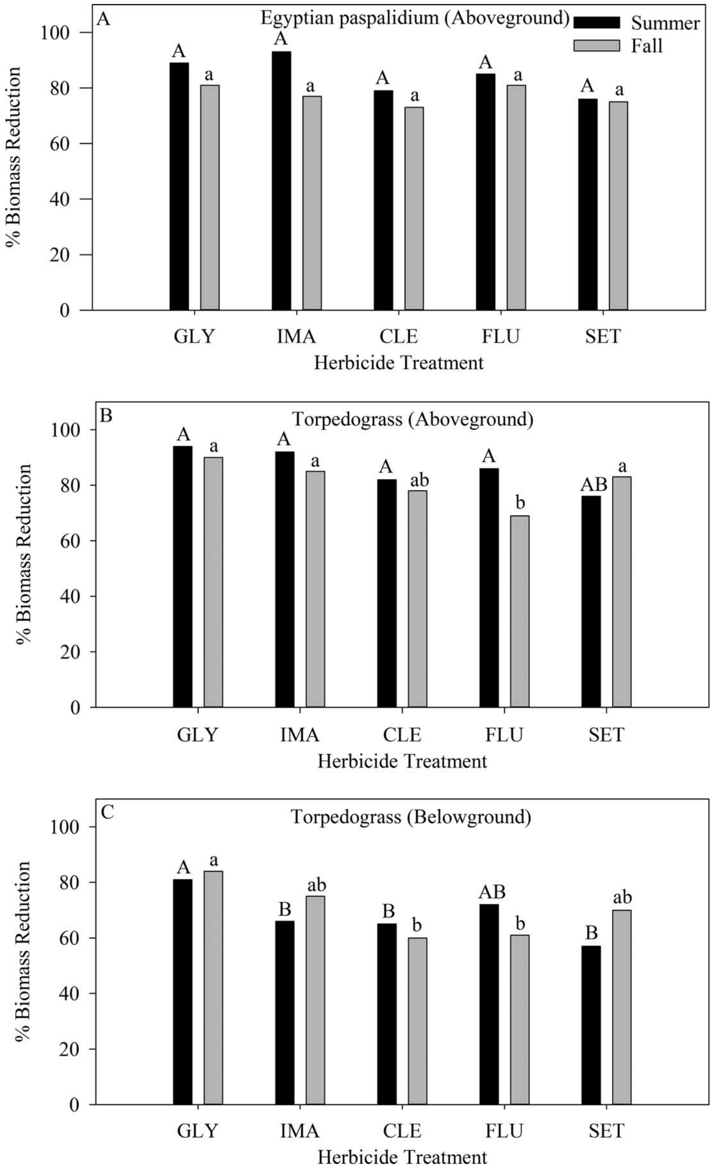

Figure 2. Percentage of biomass reduction for native Egyptian panicgrass (aboveground) (A) and torpedograss (aboveground and belowground) (B and C) at 8 wk after foliar application of glyphosate (GLY), imazapyr (IMA), clethodim (CLE), fluazifop-*P*-butyl (FLU), and sethoxydim (SET). Summer and fall treatments were applied on 3 June and 3 October, respectively. Data represent the percentage of reduction compared with the biomass of the nontreated control plants harvested at 8 wk. Each bar represents the average of three replicates, and different letters above the bars indicate differences among treatments (within summer and fall) according to a Student-Newman-Keuls test ($P < 0.05$).

over, additional selectivity research across a wider spectrum of monocotyledonous species, including other native grasses, such as maidencane (*Panicum hemitomon* Schultes), is also warranted. Data from this trial have supported the approval of two Florida Experimental Use Permits (EUPs) for sethoxydim and fluazifop-*P*-butyl. These EUPs have allowed the recent initiation of field testing for efficacy and selectivity at a wide range of locations throughout Florida.

SOURCES OF MATERIALS

[1]Osmocote Plus, The Scotts Company, 14111 Scottslawn Road, Maryville, OH 43041.

[2]Select, Valent USA Corporation, P.O. Box 8025, Walnut Creek, CA 94596.

[3]Fusilade II, Syngenta Crop Protection, LLC, P.O. Box 18300, Greensboro, NC 27419.

[4]Poast, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709.

[5]Aqua Neat, NuFarm Americas, Inc., 150 Harvester Drive, Suite 200, Burr Ridge, IL 60527.

[6]Arsenal, BASF Corporation, 26 Davis Drive, Research Triangle Park, NC 27709.

[7]Cygnet Plus, Brewer International, P.O. Box 690037, Vero Beach, FL 32969.

[8]Sunwet Brewer International, P.O. Box 690037, Vero Beach, FL 32969.

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