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Evaluation of Herbicides for the Control of Yellow Nutsedge (*Cyperus esculentus* L.) and Johnsongrass (*Sorghum halepense* L.) Under Non-Crop Conditions

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Abstract

Yellow nutsedge (*Cyperus esculentus* L.) and Johnsongrass (*Sorghum halepense* (L.) Pers.) are two of the most difficult weeds to control mostly due to their asexual reproduction. Yellow nutsedge reproduces through underground tubers and Johnsongrass through rhizomes. In addition, Johnsongrass is a problematic weed because of its competitive nature due to its C4 carbon fixation pathway metabolism. It typically grows to 1.8 to 2.5 m tall and can severely reduce yields in corn, cotton, soybeans, and other crops. Two separate field studies were conducted in 2020 at the Delta Research and Extension Center in Stoneville, Mississippi to evaluate the effectiveness of various herbicides on yellow nutsedge and Johnsongrass control in a non-crop scenario. The experiments were conducted as randomized complete block designs with 7 and 11 herbicide treatments for yellow nutsedge and Johnsongrass, respectively. All treatments were replicated three times. Research plots were 4-m wide and 6-m long with 3-m alleys between replications. The 7 yellow nutsedge herbicide treatments consisted of trifloxysulfuron, bentazon, halosulfuron, halosulfuron + thifensulfuron, glyphosate, glufosinate, and paraquat. The 11 Johnsongrass herbicide treatments included clethodim, quizalofop, fluazifop, cyhalofop, fenoxaprop, pinoxaden, glufosinate, glyphosate, clethodim + glyphosate, glufosinate + clethodim, and glufosinate + clethodim + glyphosate. Glyphosate and halosulfuron + thifensulfuron provided only 77 and 72% control of yellow nutsedge by five-weeks after application (WAA). On the other hand, glyphosate, clethodim + glyphosate, glufosinate + clethodim, and glufosinate + clethodim + glyphosate provided 99 to 100% Johnsongrass control 4 WAA. Johnsongrass regrowth evaluation was assessed 3-weeks after the experimental area was mowed. Johnsongrass regrew in every herbicide treatment except for glyphosate which was the only treatment that provided 100% Johnsongrass control with no-regrowth.

Keywords: herbicides, mowing, perennial weeds, postemergence herbicides, weed control

1. Introduction

Yellow nutsedge (*Cyperus esculentus* L.) is a perennial troublesome weed species in many crops around the globe. For example, The Weed Science Society of America, for example, classifies yellow nutsedge as one of the most problematic weeds in rice (*Oryza sativa* L.). This species can reproduce by seeds and vegetative propagules, such as tubers and rhizomes, which makes it difficult to control (Bendixen 1973; Nelson et al., 2002; Norsworthy et al., 2013). Inadequate yellow nutsedge control can result in fast crop infestation and severe yield loss. A high infestation (250-400 plant m^{-2}) of yellow nutsedge can cause more than 90% yield loss in vegetables, such as onions *(Allium cepa* L.) and Brussel sprouts (*Brassica oleracea* var. gemmifera) (Total et al., 2018). Soybean (*Glycine max* L. Merr.) yield can be decreased by more than 30% due to yellow nutsedge competition (Nelson & Smoot, 2010), while yield losses of more than 50% have been reported in rice and corn (*Zea mays* L.) infested 150-500 plants of yellow nutsedge m^{-2} (Keeley, 1987).

Johnsongrass (*Sorghum halepense* (L.) Pers.) is another problematic weed species across the world (Warwick & Black, 1983; Korres et al., 2015, 2017). Johnsongrass, like yellow nutsedge, reproduces both by seed and asexual reproduction means. Johnsongrass is considered a noxious weed species in more than twenty states across the U.S. (USDA, 2022). Several studies have reported yield losses due to Johnsongrass competition in corn, soybean, and cotton (*Gossypium hirsutum* L.) with yield decreases of 83, 60, and 90%, respectively (Keeley et al., 1989; Mitskas et al., 2003; Toler et al., 1996). Drastic yield losses can be explained due to the increased Johnsongrass ecotypes rhizome production observed in agricultural areas compared to non-agricultural environment (Klein & Smith, 2021).

Effective control of these weed species is difficult because of the belowground vegetative structures, which store carbohydrates and facilitate regrowth and spread of the weed (Bangarwa et al., 2012). Different methods can be used to control these weed species, including tillage, mowing, the use of mulch, and herbicide applications. However, the effectiveness of these methods alone or in combination is disputed. For example, weekly tillage for 12 weeks did not eradicate yellow nutsedge (Lal, 2005). Furthermore, the combination of tillage and glyphosate application resulted in a similar Johnsongrass control compared to a single glyphosate application (Griffin et al., 2006). In addition, frequent tillage increases soil erosion, and it should be avoided when possible (Lal, 2005).

However, alternatives to tillage methods, such as mowing, can reduce yellow nutsedge growth. It has been shown that weekly, biweekly, and monthly shoot-clipping of emerged tissues reduced the proliferation of yellow nutsedge (Bangarwa et al., 2012). The use of mulches is another important tool to control yellow nutsedge in vegetable crops. Webster (2005) reported that tuber production was reduced by approximately 50% with the use of mulch. Another option for controlling yellow nutsedge is the use of cover crops. However, Reddy (2001) found that yellow nutsedge control in soybean is cover-crop specific. Bangarwa and Norsworthy (2014) found that Brassicaceae cover crops in tomato controlled yellow nutsedge and Johnsongrass, by 40 and 45%, respectively. Nevertheless, herbicide applications are the most common method to control these weed species. In European countries, Johnsongrass has been managed with post emergence applications of ALS and ACCase herbicides (Travlos et al., 2019). However, continuous application of these herbicides in combination with the absence of alternative herbicide modes of action have led to increases in herbicide resistance. Currently, Johnsongrass biotypes are resistant to herbicides in the ALS, ACCase, and glyphosate (Heap, 2022). Although glyphosate-resistant biotypes have been identified and are still spreading, glyphosate still provides effective control of susceptible Johnsongrass populations (Koger et al., 2005).

Current options to control these weed species are still focused on the use of herbicides alone or in combination due to the lack of new chemistries. Therefore, the objective of this study is to evaluate the efficacy of various herbicides in controlling yellow nutsedge and Johnsongrass under non-crop conditions.

2. Materials and Methods

2.1 Field Experiments and Herbicide Applications

Field experiments were conducted in 2020 at the Mississippi State University Delta Research and Extension Center in Stoneville, MS. Experiments were established on Sharkey clay (very fine, smectitic, thermic Chromic Epiaquerts) with 2.4% organic matter and pH 7.5.

A conventional seedbed was prepared by moldboard plowing and tandem disking twice in early April and a natural population of yellow nutsedge and Johnsongrass emerged to produce uniform populations of yellow nutsedge and Johnsongrass with an average density 63 and 3 plants rn^{-2}, respectively. Plot size was 4-m wide and 6-m long. The experimental design was a randomized complete block with three replications. Information on herbicides used for the control of targeted weed species such as trade name, active ingredient, site of action, manufacturer application rate (kg a.i. ha^{-1}) are listed in Tables 1 and 2. Herbicide treatments for yellow nutsedge control included five sites of actions (Table 1), while the Johnsongrass herbicides included three sites of action (Table 2). A non-treated control was also used in the study. The experiment was repeated twice (*i.e.*, two runs) in two different fields at the same time. Herbicide treatments for the control of yellow nutsedge were applied at 5- to 8-leaf stage when the plant was15- to 20-cm tall. Herbicide treatments for the control of Johnsongrass applied to 4- to 14-leaf when the plant was 20- to 25-cm tall. Herbicide applications were made using a CO_2-pressurized backpack sprayer calibrated to deliver 141 L ha^{-1} at 276 kPa. The sprayer boom consisted of 51-cm nozzle spacing equipped with Turbo TeeJet (TeeJet Technologies, Springfield, IL) Induction (TTI) 110015 nozzles.

Table 1. Herbicide treatments for the control of yellow nutsedge used in this study

Trade name	Active Ingredient	Site of Action*	Manufacturer	Application Rate (kg a.i. ha^{-1})
Envoke	Trifloxysulfuron	2	Syngenta	0.008†
Basagran	Bentazon	6	Microflo	1.12
Permit	Halosulfuron	2	Gowan	0.068‡
Permit Plus	Halosulfuron +thifensulfuron	2 + 2	-	0.039‡
Roundup	Glyphosate	9	Bayer	1.26
Liberty	Glufosinate	10	BASF	0.75
Gramoxone	Paraquat	22	Syngenta	0.21

Note. *2 = Inhibition of Acetolactate Synthase; 6 = Inhibition of Photosynthesis at PSll; 9 = Inhibition of Enolpyruvyl Shikimate Phosphate Synthase; 10 = Inhibition of Glutamine Synthetase; 22 = PS I Electron Diversion (based on Weed Science Society of America); † = plus Induce (non-ionic surfactant) at 1% v/v (volume by volume); ‡ = plus crop oil concentrate

Table 2. Herbicide treatments for the control of Johnsongrass used in this study

Trade name	Active Ingredient	Site of Action*	Manufacturer	Application Rate (kg a.i. ha^{-1})
Select	Clethodim	1	Valent	0.224
Assure II	Quizalofop	1	Corteva	0.071
Fusilade	Fluazifop	1	Syngenta	0.21
Clincher	Cyhalofop	1	Corteva	0.314
Ricestar	Fenoxaprop	1	Bayer	0.123†
Axial	Pinoxaden	1	Syngenta	0.059†
Liberty	Glufosinate	10	BASF	0.657†
Roundup	Glyphosate	9	Bayer	1.27†
Select+Roundup	Clethodim+Glyphosate	1+9	-	0.224 + 1.27
Liberty+Select	Glufosinate+Clethodim	10+1	-	0.657 + 0.224
Liberty+Select+Roundup	Glufosinate+Clethodim+Glyphosate	10+1+9	-	0.657 + 1.27 + 0.224

Note. *1 = Inhibition of Acetyl CoA Carboxylase; 6 = Inhibition of Photosynthesis at PSll; 9 = Inhibition of Enolpyruvyl Shikimate Phosphate Synthase; 10 = Inhibition of Glutamine Synthetase (based on Weed Science Society of America); † = Crop oil concentrate at 1% v/v was added in all herbicide applications except fenoxaprop, pinoxaden, glufosinate, and glyphosate.

2.2 Mowing

The entire Johnsongrass experimental area was mowed using Case 155 tractor with Alamo Bush Hog after the last herbicide evaluation for Johnsongrass control (4-WAA). The purpose of mowing the test area after the final herbicide evaluation was to examine the effectiveness of herbicide applications on Johnsongrass rhizomes (underground) control. Mowing allowed us to assess which herbicide application was effective against both above-ground biomass and below-ground rhizomes. It is important to realize that controlling only the above-ground Johnsongrass biomass is not sufficient since the weed can repopulate (regrow) through its underground rhizomes, hence generating a new infestation. Mowing, after herbicide application, will allow effective Johnsongrass control, preventing further infestation through Johnsongrass regrowth.

2.3 Herbicide Efficacy Evaluation and Data Analysis

Visual injury assessments for both weed species were based on a 0 to 100% scale relative to the nontreated check. Zero percentage (0%) represented no control, while 100% being complete plant death. Yellow nutsedge was evaluated weekly from 1 to 5 WAA and Johnsongrass was evaluated weekly from 1 to 4 WAA. Weekly assessments for each species were analyzed separately using the glimmix procedure by SAS statistical software (SAS Institute Inc., Cary, NC). Prior to analysis, all data was examined for normality using the univariate procedure in SAS. The homogeneity of variance was tested with Bartlett's test. The herbicide treatments were considered fixed effects, whereas replication was considered as random. No run (two separate field studies means two run of the experiment) effect was detected, hence data were pooled over the run prior to data analysis. Means were separated using t-grouping at significance level $\alpha = 0.05$. A principal component analysis was performed to classify which groups of the treatments investigated in this experiment were more efficient for the control of Johnsongrass.

3. Results and Discussion

3.1 Yellow Nutsedge Control

One-week after application (1 WAA), yellow nutsedge control from non-selective herbicides paraquat, glyphosate, and glufosinate were 42, 33, and 30%, respectively (Figure 1).

As it was expected, the effects of paraquat on yellow nutsedge was revealed few hours after the application of the herbicide. In contrast, the effects of glyphosate were visually noticeable 7- to 10-days after its application. The mixture of halosulfuron + thifensulfuron and trifloxysulfuron alone were the weakest herbicides with only 13% control of yellow nutsedge relative to the untreated plots. Herbicide activity, as anticipated, increased over time. Glyphosate application increased yellow nutsedge control from 33 to 74% whereas that by glufosinate was increased from 30 to 70% at 2 WAA (Figure 1). On the contrary, Bentazon found to be the weakest herbicide to control yellow nutsedge 2 WAA, with only 25% control. At 3 WAA, Glyphosate and glufosinate were remained the two most effective herbicides against yellow nutsedge with 78% and 72% control relative to untreated plants (Figure 1). Yellow nutsedge control was not changed significantly when herbicide performance was assessed 4 WAA with bentazon and paraquat being the least effective herbicides for the control of yellow nutsedge (Figure 1). Glyphosate, which again performed better against yellow nutsedge control provided 78 % control whereas halosulfuron, usually an effective product for the control of yellow nutsedge, provided only 65% control. However, halosulfuron + thifensulfuron and glufosinate provided comparable result to glyphosate. No significant changes were observed for yellow nutsedge control at 5 WAA (Figure 1) compared to 4 WAA. Glyphosate and halosulfuron + thifensulfuron provided 77 and 72% control of yellow nutsedge, respectively.

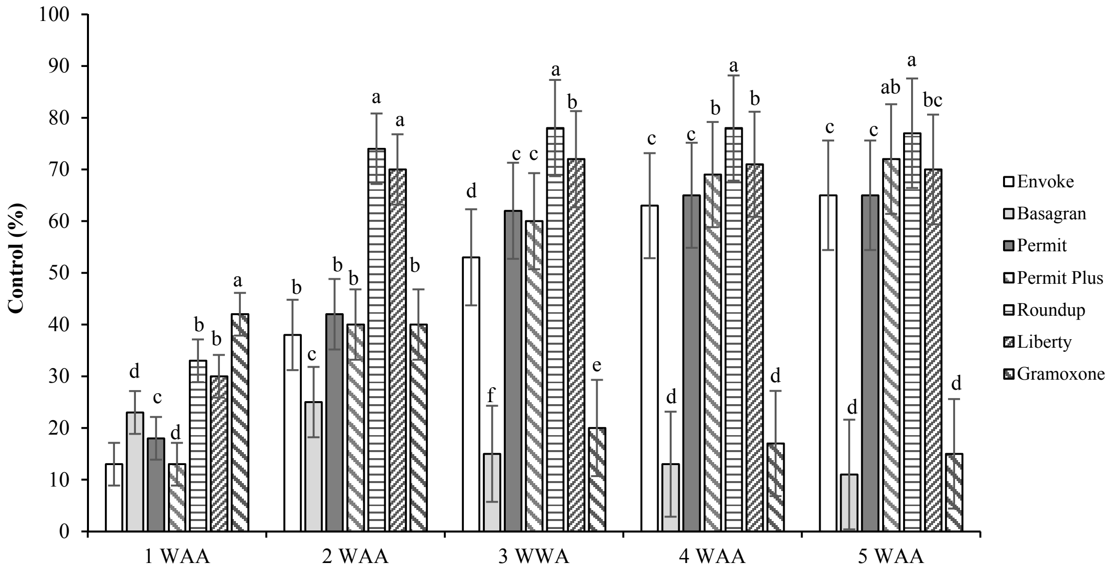

Figure 1. Yellow nutsedge response to herbicide applications 5 WAA. Treatments associated with the same letter are not significantly different (α = 0.05). Vertical bars represent ±standard error of the mean for each assessment time (WAA) separately. WAA = Weeks after application

Yellow nutsedge control with ALS herbicides (site of action 2, see Table 1) exhibited low weed control, which was equivalent to glyphosate or glufosinate. Similar results were obtained by Ackley et al. (1996) when they assessed a series of ALS-inhibiting herbicides on natural populations of yellow nutsedge without the presence of a crop. In addition, the postemergence application of bentazon, a photosystem II-histidine 215 binder inhibitor (site of action 6, see Table 1), controlled yellow nutsedge in several crops although two applications were frequently required (Pichburg et al., 1993). In this research, bentazon was applied as postemergence herbicide only once. However, bentazon despite it has been reported as a selective herbicide to control yellow nutsedge, it was not adequately effective on yellow nutsedge plants when it was applied early postemergence in rice (Johnson, 1975; Stoller et al., 1975). On the other hand, glyphosate can control both nutsedges in many row crops (Tehranchian et al., 2016) but its maximum efficacy on shoot injury and tuber production is critically dependent on the application timing and plant age (Keeley et al., 1985; Tharp & Kells, 1999). Differences in glyphosate efficacy on foliar control and tuber production have been documented between yellow and purple nutsedges (Pereira & Grabtree, 1986; Webster et al., 2008). However, as mentioned by Hoss et al. (2003), Nelson et al. (2002) and Rao and Reddy (1999) sequential application of glyphosate during the growing season is needed for sufficient control of yellow nutsedge under field conditions. In the results presented here a single application of glyphosate was able to offer a satisfactory control of yellow nutsedge under non-crop conditions.

3.2 Johnsongrass Control

Johnsongrass control was 90, 91, 91, 93, and 95% for glufosinate, glyphosate clethodim+ glyphosate, glufosinate+clethodim and glufosinate+clethodim+glyphosate treatments 1 WAA. The rest of the herbicide treatments, as shown in Table 1, *i.e.*, clethodim, quizalofop, fluazifop, cyhalofop, fenoxaprop and pinoxaden resulted in less than 68% control of Johnsongrass (Figure 2). Pinoxaden was the weakest herbicide 1 WAA providing only 9% Johnsongrass control.

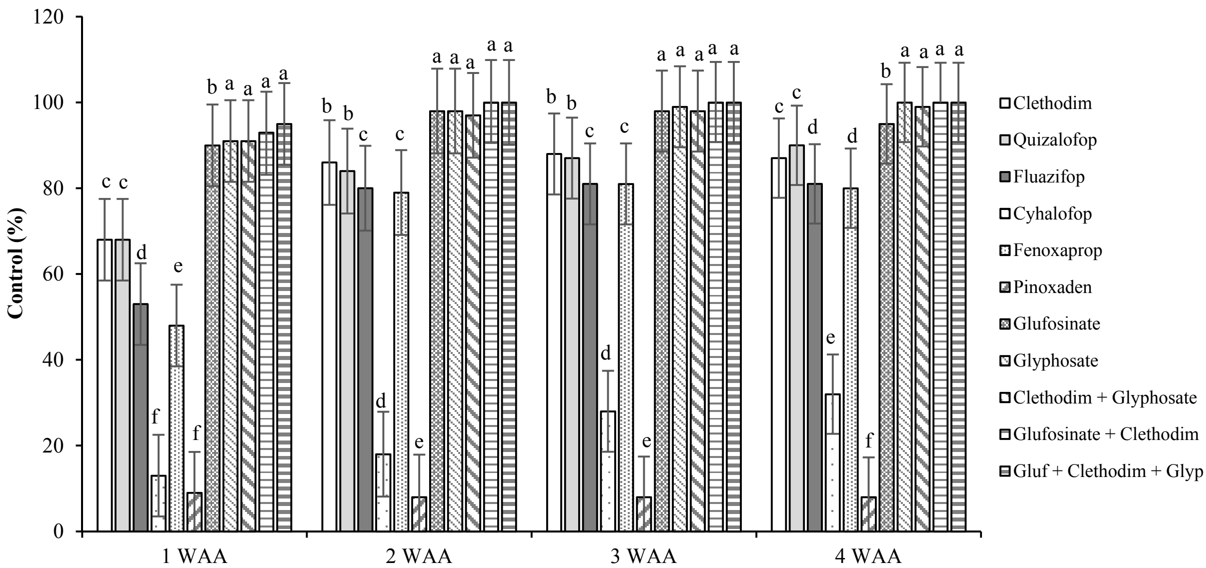

Figure 2. Johnsongrass response to herbicide applications throughout the entire experimental period. Treatments associated with the same letter within same week after application are not significantly different (α = 0.05). Vertical bars represent ±standard error of the mean for each assessment time (WAA) separately. WAA=Weeks after application

By 2 WAA, Johnsongrass control increased from 68% to 86% compared to 1 WAA assessment from the application of clethodim. Glyphosate, glufosinate, and their tank-mix combinations provided 97 to 100% control of Johnsongrass whereas pinoxaden application by 2 WAA did not improve the control of the weed as it was resulted at only 8% control. Johnsongrass control increased from quizalofop and fluazifop applications by 2 WAA (80 to 84% respectively) (Figure 2).

Clethodim provided 88% johnsongrass control by 3 WAA. Glufosinate, glyphosate, clethodim + glyphosate, glufosinate + clethodim, and glufosinate+clethodim+glyphosate exhibited 98 to 100% Johnsongrass control. Pinoxaden with 8% and cyhalofop with 28% were the less effective herbicide on Johnsongrass control by 3 WAA (Figure 2).

Johnsongrass control reduced from 98 (3 WAA) to 95% by 4 WAA from the application of glufosinate (Figure 2). Glyphosate, clethodim + glyphosate, glufosinate + clethodim, and glufosinate+clethodim+glyphosate provided 99 to 100% control of Johnsongrass.

Johnsongrass regrowth evaluation was made 3-weeks after the test area was mowed. There was Johnsongrass regrowth from every herbicide application except from glyphosate (Figure 3). Therefore, all herbicide applications controlled only the above ground Johnsongrass biomass (shoot) and failed to control below ground or rhizomes. Glyphosate was the only herbicide application that controlled Johnsongrass shoot or above ground biomass and rhizomes (below ground).

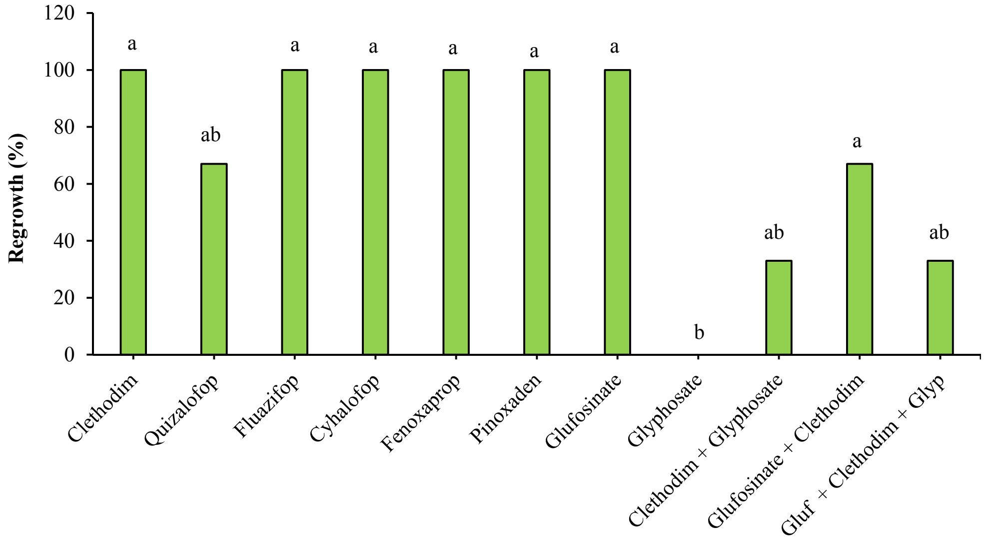

Figure 3. Response of Johnsongrass regrowth after mowing to herbicide applications 7 WAA. Treatments associated with the same letter are not significantly different (α = 0.05)

As reported by Meyer et al. (2015) effective management of severe infestations or escapes of 15-cm tall Johnsongrass was achieved by various herbicide combinations consisting mainly of glufosinate plus clethodim, as it has been observed in this study (Figure 4).

In addition, herbicide treatments consisting of postemergence applications of sethoxydim, fenoxaprop, fluazifop-P, haloxyfop, quizalofop, imazethapyr, and clethodim provided 70 to 90% Johnsongrass control except those with fenoxaprop and imazethapyr (Johnson et al., 1991). Similarly, clethodim provided Johnsongrass control greater than 70% in all the assessments conducted in this research except 1WAA, whereas quizalofop, fenoxaprop and fluazifop resulted in high Johnsongrass control (> 70%) 3 WAA. Johnson and Norsworthy (2014) demonstrated the importance of herbicide selection, particularly for controlling Johnsongrass plants larger than 30 cm and the benefits of a single application of glyphosate or clethodim on Johnsongrass control for decreasing the soil seedbank and reducing the success of Johnsongrass progeny in future years. Based on our results (Figure 3) we might add the importance of mowing at approximately 10 weeks after herbicide application, as an effective tool to prevent regrowth of Johnsongrass rhizomes to prevent seed production.

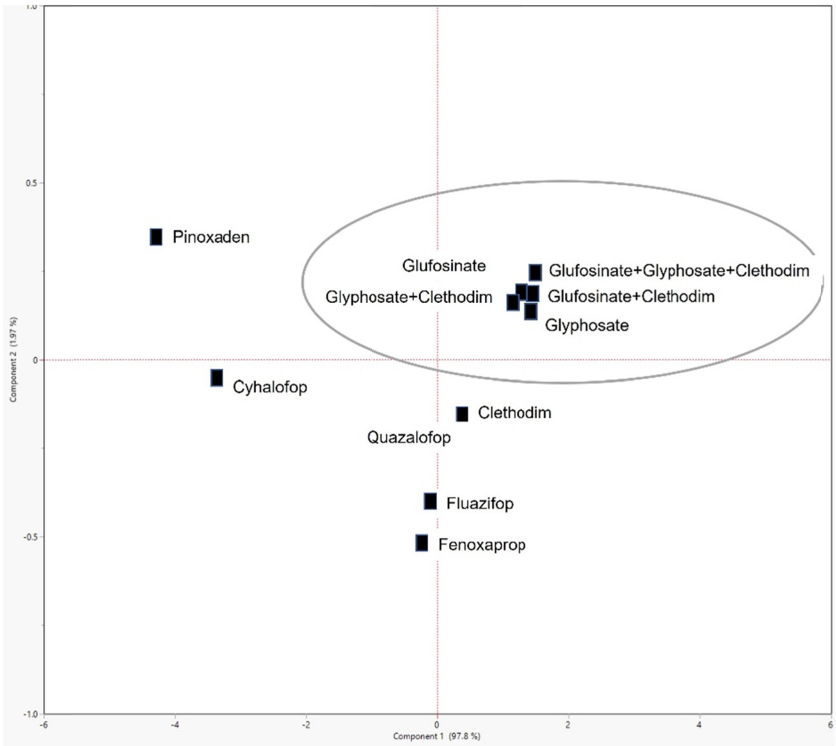

Figure 4. Principal components analysis of herbicide mixtures vs. single herbicide application on the percentage control of Johnsongrass

4. Conclusions

Yellow nutsedge and Johnsongrass are two most difficult weeds to control since yellow nutsedge propagates through underground tubers and johnsongrass through rhizomes. It is easy to control the aboveground biomass, but it is difficult to control both aboveground shoot and underground reproductive organs. Glyphosate) and halosulfuron + thifensulfuron with 77 and 72% yellow nutsedge control were the best herbicide applications by 5 WAA, respectively. Glyphosate application alone was the only treatment that provided 100% Johnsongrass control with no-regrowth.

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