American Journal of Plant Sciences, 2018, 9, 1321-1333
http://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Efficacy of 2,4-D, Dicamba, Glufosinate and Glyphosate Combinations on Selected Broadleaf Weed Heights

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How to cite this paper: Joseph, D.D., Marshall, M.W. and Sanders, C.H. (2018) Efficacy of 2,4-D, Dicamba, Glufosinate and Glyphosate Combinations on Selected Broadleaf Weed Heights. *American Journal of Plant Sciences*, **9**, 1321-1333.
https://doi.org/10.4236/ajps.2018.96097

Received: April 24, 2018
Accepted: May 27, 2018
Published: May 30, 2018

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Abstract

Palmer amaranth, sicklepod and pitted morningglory are the three most common and troublesome weeds in soybean in South Carolina. They exhibit very aggressive growth capabilities and if left uncontrolled in fields will cause significant reductions in soybean yields. Dicamba and 2,4-D herbicides are currently having a resurgence in usage due to the recent commercialization of soybean trait technologies with tolerance to these herbicides. Dicamba and 2,4-D when tank mixed with glufosinate and glyphosate may offer additional weed control to resistant weeds through the process of herbicide synergism. Greenhouse experiments were conducted in 2013 at Edisto Research and Education Center near Blackville, SC to evaluate the efficacy of glyphosate, glufosinate, dicamba and 2,4-D treatments alone and in combination on Palmer amaranth, sicklepod, and pitted morningglory at selected heights. Results suggested that glufosinate alone provided the overall best control for all 3 weed species. Glyphosate alone provided the lowest control of all 3 species at all heights. Synergism or improved sicklepod control was observed when glufosinate was tank mixed with dicamba. However, as sicklepod increased in height, glufosinate + 2,4-D or dicamba combination offered the best control compared to glufosinate alone (90% versus 86% in 20 cm plants and 87% versus 85% in 30 cm plant). In the 5 cm Palmer amaranth, decreased control was observed when glyphosate or glufosinate was tank mixed with 2,4-D. These experiments showed that glufosinate alone and/or in combination with 2,4-D or dicamba was the overall best treatment on the three broadleaf weed species.

Keywords

Palmer Amaranth, Pitted Morningglory, Sicklepod, Synergism, Antagonism, Glufosinate, Dicamba, 2,4-D, Glyphosate

1. Introduction

Dicamba (3,6-dichloro-2-methoxybenzoic acid) and 2,4-D (2,4-dichlorophenoyacetic acid) are herbicides that have been used throughout the United States for more than half a century to control broadleaf weeds in grass crops [1] [2] [3]. Dicamba and 2,4-D are synthetic growth regulating herbicides that control susceptible broadleaf weeds by mimicking naturally occurring auxins found in plants [4]. The susceptible weed shows distinct visual symptomology, which include the twisting of petioles and leaves outward and downward referred to as epinasty. The weeds also exhibit leaf chlorosis, stem tissue proliferation, and abnormal apical growth [4] [5]. Dicamba and 2,4-D, although widely used, have long been scrutinized by regulators because of potential injury to off target plants caused by herbicide volatilization [6]; however, the release of new low volatility formulations of dicamba and 2,4-D has addressed most of those concerns [7] [8] [9] [10] [11]. Recently, attention has been drawn to new formulations of dicamba and 2,4-D herbicides due to the release of the 2,4-D and dicamba tolerant soybean and cotton technologies that will assist in the management of difficult-to-control glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Watson) and other difficult-to-control broadleaf weeds.

Palmer amaranth, sicklepod [*Senna obtusifolia* (L.) Irwin & Barneby] and pitted morningglory [*Ipomoea lacunosa* (L.)] all exhibit aggressive growth capacities [12] [13] [14]. Aggressive growth allows the weed to grow quickly and set up dominance in a field by rapidly shading out the crops present. Palmer amaranth is capable of diaheliotropism (solar tracking) which allows the leaves to orient themselves perpendicular to the rays of the sun thus maximizing light interception and photosynthesis potential [15]. Higher rates of photosynthesis coupled with diaheliotropism allow Palmer amaranth to accumulate biomass at faster rates than non-solar tracking plant species [16]. Similarly, pitted morningglory uses its high growth rates to affect crop yields in soybean and cotton fields [17]. Its rapid increase in leaf area index causes pitted morningglory to interfere with the final soybean yield from the early stages of soybean development [18]. Along with competition for sunlight and resources, pitted morningglory produces a unique challenge during harvest due to its vining nature. It increases crop lodging and interferes with the mechanical harvest of cotton [17].

As more knowledge on the weed's growth abilities becomes more evident, timing has become critical in weed herbicide application programs. Weeds treated at small growth stages are more easily controlled [19] [20]. However, when treatment is delayed and weeds are much larger at application, weed size can reduce the efficacy of the herbicide [20] [21]. Herbicide application rates needs to be optimized by the grower according to the weed size or height, as weeds increase in size, the herbicide rates must also increase to ensure effectiveness. When applying 2,4-D, plant size is a vital factor that influences the degree of weed control achieved. Siebert *et al.* (2004) observed 100% control of 30 cm red morningglory (*Ipomoea coccinea* L.); however, a 6% to 19% reduction in control was observed when 2,4-D was applied to 60 cm tall plants [22]. Everitt and Keeling (2007) observed similar results on horseweed when using 2,4-D on heights of 10 - 15 cm tall horseweed versus 25 - 46 cm tall horseweed [23].

Herbicide synergism and antagonism are two terms that become important whenever herbicides are applied together in tank mixture [24] [25]. Growers typically apply two or more herbicides sequentially or as a tank mixture to improve the spectrum of weed control and prevent the development of weed resistance. This practice is done on the assumption that when applied together, each herbicide may improve the performance of the other thus increasing the herbicide's performance versus it being applied alone. Herbicide synergism is the improvement of the overall weed activity of the herbicide combination compared to the activity of each herbicide applied individually [24] [25] [26] [27]. Conversely, herbicide antagonism occurs when the control activity of an herbicide mixture is reduced compared to each herbicide applied alone [28] [29]. Craigmyle *et al*., (2013) observed when glufosinate and 2,4-D combinations were applied to 15 cm plants, glufosinate improved control of common waterhemp (*Amaranthus rudis* Sauer.) across all rates of 2,4-D compared to the application of glufosinate alone at 0.45 and 0.59 kg·ha^{-1} [30].

Herbicide synergism is an important weapon for the management and control of herbicide resistant weed biotypes. Therefore, greenhouse experiments were conducted with two objectives: 1) to evaluate the efficacy of 2,4-D, dicamba, glyphosate and glufosinate combinations on selected Palmer amaranth, sicklepod and pitted morningglory sizes. 2) to evaluate if there was a synergistic or antagonistic effect of the herbicides when paired together and applied to various sizes of Palmer amaranth, sicklepod and pitted morningglory.

2. Materials and Methods

Greenhouse experiments were conducted at the Edisto Research and Education Center (33.36˚N, −81.32˚W) located near Blackville, SC in 2013 to evaluate the efficacy of 2,4-D, dicamba, glyphosate, and glufosinate alone and in combination on varying sizes of Palmer amaranth, sicklepod and pitted morningglory (**Table 1**). Weed seed was planted in 1680 cm^3 plastic pots filled with a commercial potting mix containing sphagnum peat moss, coir, perlite, wetting agent, and fertilizer at 0.21% N, 0.11% P, and 0.16% K by weight (Miracle Grow Moisture Control Potting Mix, Marysville, OH, USA). Seedling plants were thinned to two plants per pot. Pots were watered twice daily using an overhead sprinkler system and fertilized each week with a 24:8:16 (N:P:K) water soluble commercial fertilizer mix. Two runs of the experiment were performed.

The experimental design was a randomized complete block with 3 weed species and 9 herbicide treatments including an untreated check with 4 replications. The plants were treated with the herbicides at the following heights; 5, 10, 20, and 30 cm. Herbicide treatments were applied in water with a CO_2 pressurized back pack sprayer which delivered 140 L·ha^{-1} spray volume at a 207 kPa pressure

Table 1. Herbicide treatments, application rates, commercial names and manufacturers used in these experiments.

Herbicide	Rate[a] kg ai ha^{-1} or kg ae ha^{-1}	Trade name	Manufacturer
glyphosate	0.84	Roundup PowerMAX	Monsanto Company, St. Louis, MO, USA
glufosinate	0.59	Liberty 280 SL	Bayer Crop Science AG, Monheim am Rhein, Germany
dicamba	1.12	Clarity	BASF Corporation, Research Triangle Park, NC, USA
2,4-D	1.12	2,4-D Ester	Loveland, Loveland, CO, USA
glyphosate + dicamba	0.84 + 1.12	Roundup PowerMAX + Clarity	Monsanto Company, St Louis, MO, USA + BASF Corporation, NC, USA
glyphosate + 2,4-D	0.84 + 1.12	Roundup PowerMAX + 2,4-D Ester	Monsanto Company, St. Louis, MO, USA + Loveland, Loveland, CO, USA
glufosinate + dicamba	0.59 +1.12	Liberty 280 SL + Clarity	Bayer Crop Science AG, Rhein, Germany + BASF Corporation, Research Triangle Park, NC, USA
glufosinate + 2,4-D	0.59 + 1.12	Liberty 280 SL + 2,4-D Ester	Bayer Crop Science AG, Rhein, Germany + Loveland, Loveland, CO, USA

[a]Active ingredients (ai) rate used for glufosinate. Acid equivalent (ae) rates were used for glyphosate, dicamba and 2,4-D.

via a single nozzle boom fitted with a Teejet® 8002 (Teejet, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189) flat fan spray nozzle.

After treatment, plants were returned to the greenhouse with the same growing conditions before application where they remained for an additional 28 days. The untreated plants were kept in a separate greenhouse with the identical growing conditions from the treated pots to prevent injury from the 2,4-D and dicamba vapors from the treated pots. After treatment, pots were watered and fertilized using the same procedure as the untreated plants. After 28 days, plants were clipped at the soil level in the pots, placed in paper bags, and oven dried for 3 days. Dry weights of the plants were collected and the percent weed control was calculated as a percent of control weight (untreated check) according the formula:

$$\%\ \text{Weed Control} = \left[1 - \frac{\text{Weight treated plant}}{\text{Weight untreated check plant}}\right] \times 100\%$$

This protocol was repeated in time as each weed height was achieved.

The percent weed control data for the two runs of the experiment were collected and arranged by height, run, and treatment. Data was analyzed with PROC MIXED procedure using JMP® Pro 10.0.0 software (SAS Institute Inc., Cary, NC). The random effects were trial and weed species. The fixed effects were herbicide treatment and weed height. Due to significant differences in weed height by treatment and across both trials, data were analyzed separately.

3. Results

There was a significant height by treatment and trial by treatment interaction in the experiment; therefore, those results will be presented separately.

3.1. Pitted Morningglory

In trial 1, a significant effect of height and treatment ($F_{10,117} = 2.4256$, $p = 0.0116$) was observed, trial 2 also showed a significant effect of height and treatment ($F_{10,117} = 10.2506$, $p < 0.0001$). Across trial 1 and trial 2, glufosinate alone provided the best weed control with 86% and 97% control at 5 cm pitted morningglory, respectively. Glyphosate alone treatments were less effective with 71% and 95% control in trial 1 and 2, respectively. There was a significant difference between the glyphosate alone treatment and the dicamba alone treatment, with dicamba offering better control. A tank mix of those same herbicides offered better control than when they were applied alone (Figure 1). In trial 2, significant differences were only observed in glufosinate alone and glyphosate alone treatments.

At the 10 cm pitted morningglory height, there were no significant differences between treatments in trial 1. In trial 2, the glyphosate alone treatment and the 2,4-D alone treatment were not significantly different; however, when they were tank mixed there was a slight increase in pitted morningglory control (Figure 2).

In 20 cm pitted morningglory height during trial 1, no significant differences among treatments were observed. However, in trial 2, there were significant differences in treatments, as was observed in trial 1, glyphosate + 2,4-D mixture provided 97% pitted morningglory control. The treatment with the lowest pitted morningglory control was glyphosate alone at 93%. Although not statistically significant, synergism with glufosinate in combination with 2,4-D was observed

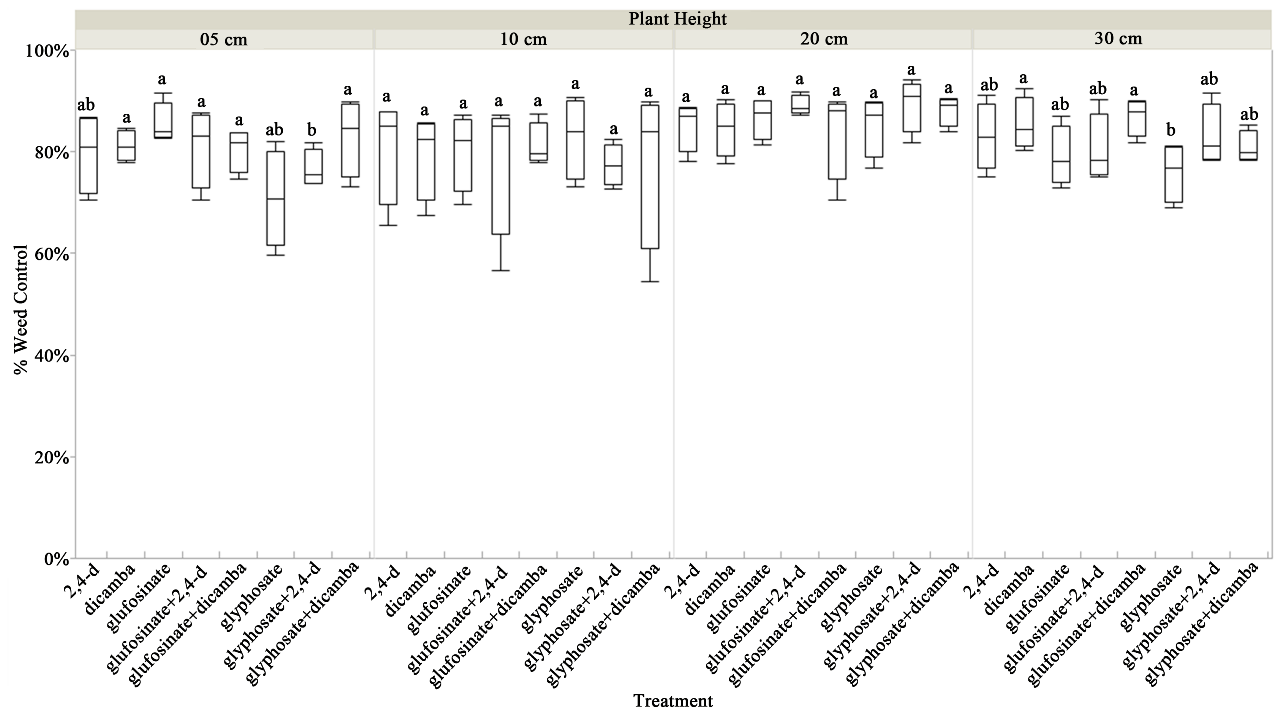

Figure 1. Pitted morningglory percent control at 5, 10, 20, and 30 cm heights as affected by selected herbicide treatments in trial 1. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's t-test (p = 0.05).

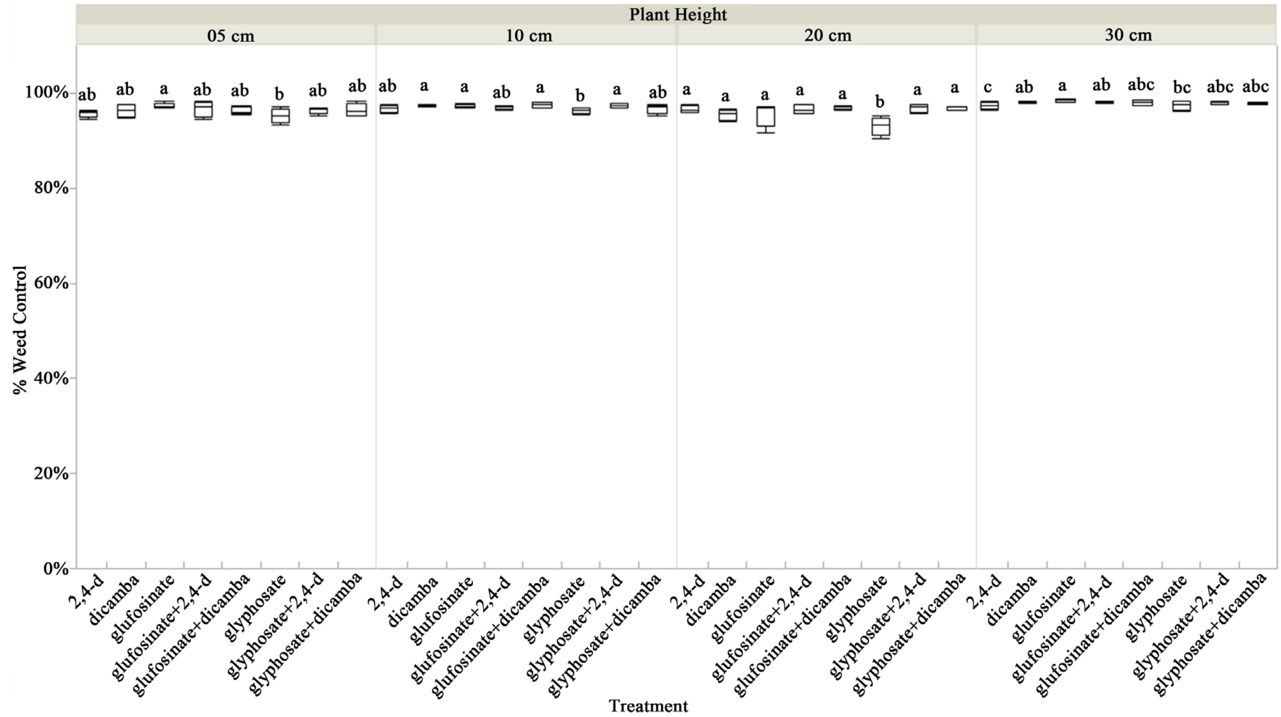

Figure 2. Pitted morningglory percent control at various heights as affected by selected herbicide treatments in trial 2. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's *t*-test (p = 0.05).

with a 1.5% increase in control. Craigmyle *et al.* (2013) similarly observed in 15 cm common waterhemp that when glufosinate and 2,4-D were applied in combination, it improved the control of common waterhemp compared to applications of glufosinate alone or 2,4-D alone [30]. Merchant *et al.* (2013) also observed excellent control on larger pitted morningglory with mixtures of glufosinate, 2,4-D, 2,4-DB, and dicamba [31].

In the 30 cm height pitted morningglory in trial 1, glufosinate plus dicamba was most effective with 87% control. Glyphosate alone treatment was significantly less at 76%. In trial 2, little variation was observed among the data points for each treatment. Glufosinate alone was the best treatment at 98% control. For the first time in all application timings 2,4-D was the least effective in controlling pitted morningglory. The tank mix of glufosinate + 2,4-D enhanced the control of 2,4-D compared to the 2,4-D alone treatment. Siebert *et al.* (2004) [22] observed red morningglory heights increased, 2,4-D control decreased between 6% - 19%. To effectively control the larger morningglory plants 2,4-D should be tank mixed with another herbicide.

3.2. Palmer Amaranth

A significant treatment and height effect for both trial 1 and trial 2 ($F_{10,117}$ = 26.5329, p < 0.0001) and ($F_{10,117}$ = 71.5111, p < 0.0001) respectively were observed. In 5 cm Palmer amaranth plants in trial 1, 2,4-D alone provided complete control (100%) and glyphosate + 2,4-D tank mix provided 99% Palmer amaranth control. Glufosinate or glyphosate plus 2,4-D had a slight antagonistic effect by lowering Palmer amaranth control when compared to the 2,4-D alone treatment (**Figure 3**). In trial 2, there were no significant differences in treatments and variability amongst data points were small (**Figure 4**). Across both trials, treatments were very effective for the 5 cm Palmer amaranth plants with a 1% difference separating the highest and lowest control values.

At the 10 cm height in trial 1, all treatments provided excellent weed control. 2,4-D was the most effective at 97% control followed by dicamba at 94% (**Figure 3**). In trial 2, all treatments showed excellent weed control; however, there were significant differences among treatments, glufosinate alone and glyphosate alone provided the best Palmer amaranth control (**Figure 4**). As was observed in small Palmer amaranth, all treatments controlled Palmer amaranth very effectively with a 6% difference among treatments across both trials (99% and 94%, respectively).

In the 20 cm Palmer amaranth during trial 1, glufosinate alone provided 98%. In contrast, glyphosate alone provided 94%. Glyphosate + dicamba tank mix improved Palmer amaranth control slightly (3%) versus glyphosate alone treatment, a similar effect was observed with 2,4-D + glyphosate tank mix that boosted control by 4% compared to glyphosate alone (**Figure 3**).

Glyphosate + dicamba tank mix provided 92% control, whereas, dicamba alone provided 84% control in the 30 cm Palmer amaranth in trial 1. Dicamba alone and glyphosate alone treatments were not significantly different; however,

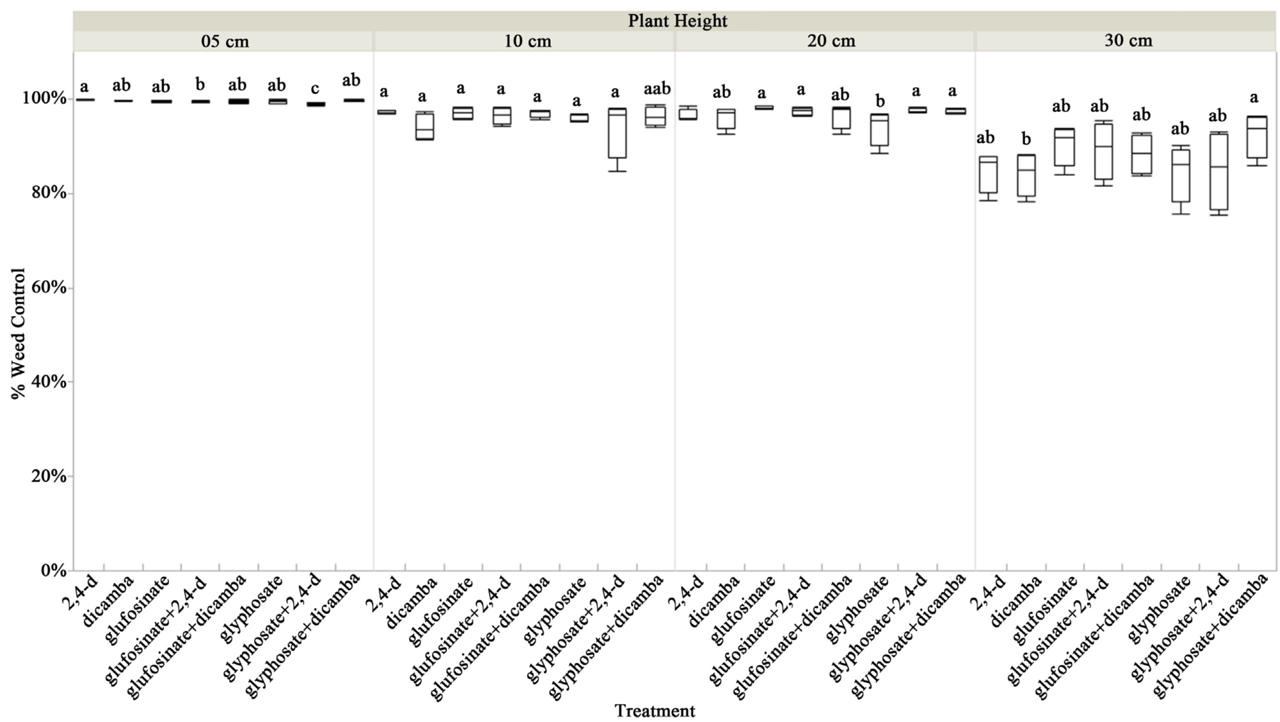

Figure 3. Palmer amaranth percent control at various heights as affected by selected herbicide treatments in trial 1. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's t-test (p = 0.05).

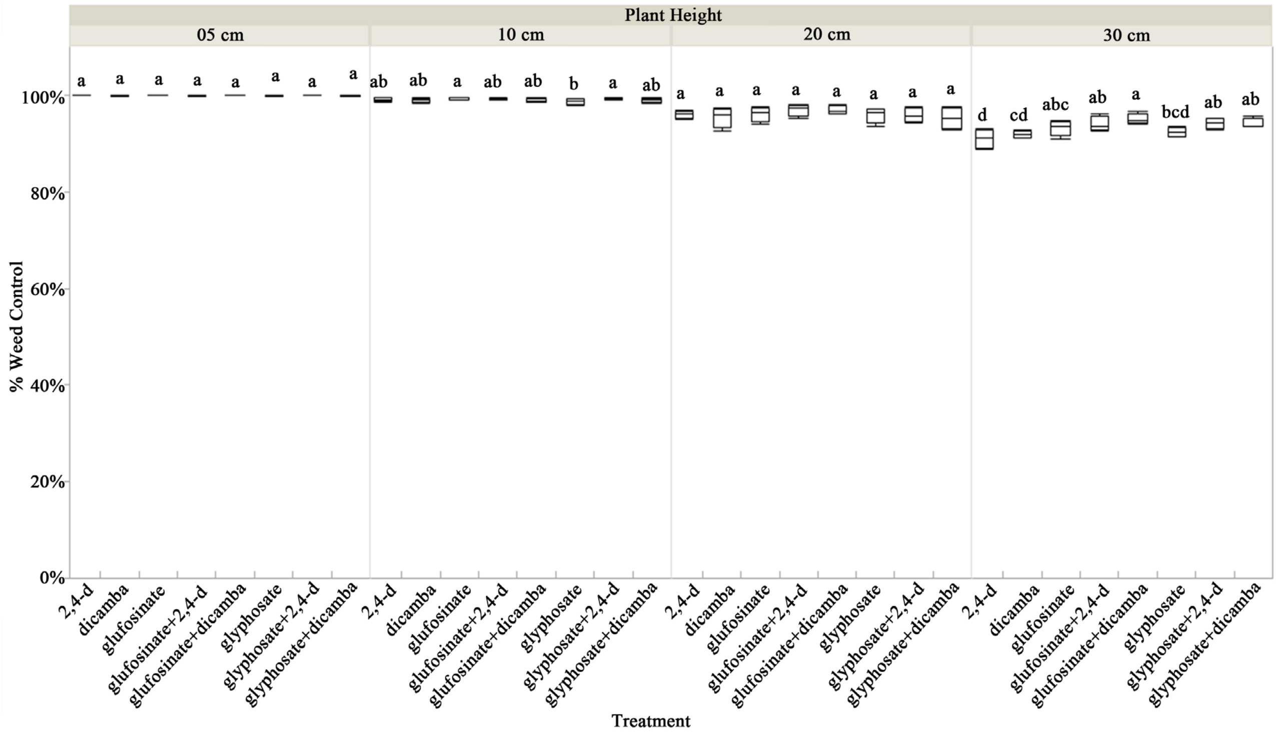

Figure 4. Palmer amaranth percent control at various heights as affected by selected herbicide treatments in trial 2. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's t-test ($p = 0.05$).

in combination there was a synergistic overall effect on Palmer amaranth control, with glyphosate + dicamba tank mix treatment showing an 8% increase in Palmer amaranth control compared to the dicamba alone treatments (Figure 3). In trial 2, the glufosinate + dicamba tank mix treatment provided 95% control while the 2,4-D alone treatment provided 91% control (Figure 4). Similarly, Merchant *et al.* (2013) observed 92% Palmer amaranth control with mixture of glufosinate at 431 $g \cdot ha^{-1}$ plus dicamba at 560 $g \cdot ha^{-1}$ [31]. Glyphosate when tank mixed with 2,4-D showed an improvement in Palmer amaranth control compared to the glyphosate alone and 2,4-D alone treatments, although their differences were not significantly different, this demonstrated a synergistic effect was observed when these herbicides are combined.

3.3. Sicklepod

A significant effect of height and treatment were observed in both trials 1 and 2 ($F_{10,117} = 23.3925$, $p < 0.0001$) and ($F_{10,117} = 33.9983$, $p < 0.0001$), respectively. In the 5 cm sicklepod height in trial 1, percent control was 98% and 96% with glyphosate and dicamba treatments, respectively. When dicamba + glyphosate was tank mixed there was a reduction in sicklepod control due to a decrease in efficacy compared to glyphosate alone treatment (Figure 5). In trial 2, glufosinate was the most effective treatment with 97% sicklepod control and glyphosate was the least effective at 92% control (Figure 6). Glyphosate + 2,4-D tank mixture

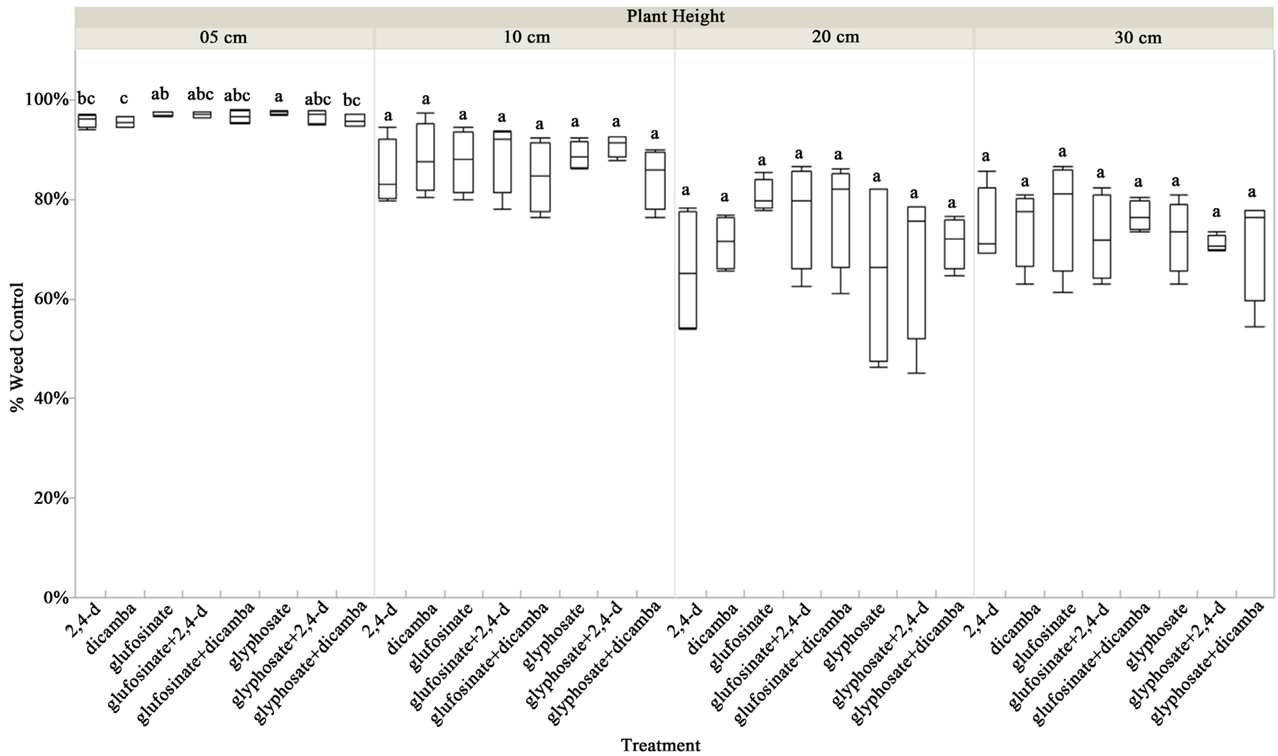

Figure 5. Sicklepod percent control at various heights as affected by selected herbicide treatments in trial 1. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's t-test (p = 0.05).

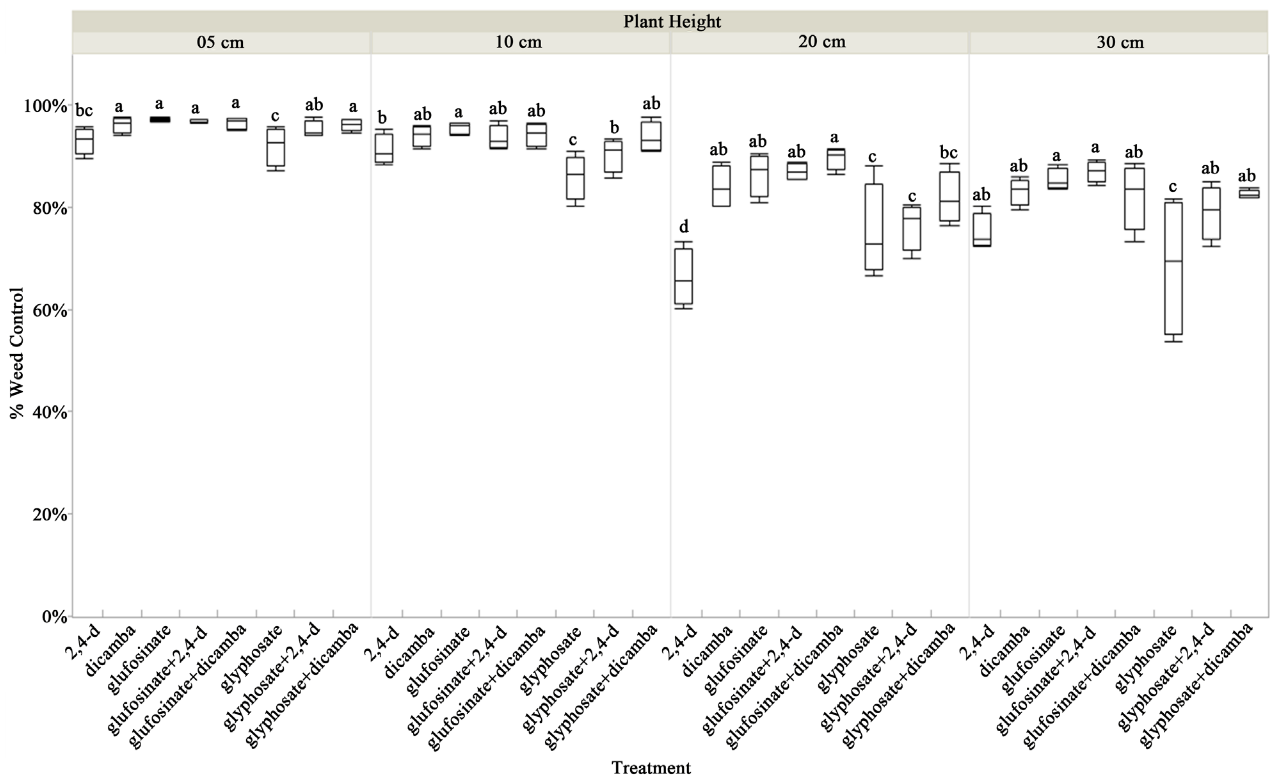

Figure 6. Sicklepod percent control at various heights as affected by selected herbicide treatments in trial 2. Boxplots within the same plant height not connected by the same letter (s) are significantly different according to the Student's t-test (p = 0.05).

provided 4% higher sicklepod control compared to the glyphosate alone and 2,4-D alone treatments.

In the 10 cm sicklepod height, glufosinate was the most effective treatment with 96% control and glyphosate was the lowest at 86% control (**Figure 6**). In the 20 cm sicklepod height, glufosinate + dicamba tank mix exhibited the best sicklepod control with 90% (trial 2) and 2,4-D alone provided the lowest sicklepod control at 66%. Glyphosate increased sicklepod control when tank mixed with 2,4-D compared to 2,4-D alone. Leon *et al.* (2016) also observed higher sicklepod control (87% to 98%) with 2,4-D and glyphosate combination compared to 45% to 77% when each was applied separately [32]. Synergism was observed when glufosinate was tank mixed with dicamba because the control observed with the tank mixture treatment was greater than the control observed from the glufosinate alone and dicamba alone treatments.

In the 30 cm sicklepod height in trial 1, there were no significant differences among treatments; however, glufosinate alone offered the most effective control at 78% (**Figure 5**). Trial 2 showed significant differences among treatments. Glufosinate + 2,4-D provided the highest level of sicklepod control at 87%, whereas, 30 cm sicklepod control with glyphosate alone was 18% lower (**Figure 6**). Glyphosate exhibited synergistic effects when combined with 2,4-D by increasing sicklepod control by 11% compared to glyphosate alone and 7% compared to 2,4-D alone treatments. The 30-cm sicklepod control was also increased by 12% when 2,4-D was tank mixed with glufosinate compared to 2,4-D alone and 4% when compared to glufosinate alone treatments.

4. Discussion

The results of this experiment indicated that across all weed heights, regardless of species, glufosinate alone was the most consistent and effective treatment. There was a statistical difference with weed height across all species; therefore, we concluded that weed size at the time of application significantly impacts the treatment efficacy. Glufosinate plus 2,4-D or dicamba provided the best overall efficacy of all the treatment across weed species. In addition, evidence of herbicide synergism was observed when glufosinate was tank mixed either 2,4-D or dicamba, especially on larger weed sizes. Glyphosate alone treatment across all application times and weed species was the least effective herbicide treatment. Sicklepod and pitted morningglory typically exhibit tolerance to topical postemergence applications of glyphosate alone, especially as weed size increases [33]. Observations on some large Palmer amaranth and sicklepod plants showed that after glyphosate treatment, visual symptomology was observed about 3 to 4 days after application, which allowed the plant additional time to accumulate biomass although at a reduced growth rate.

An interesting observation may be noted that with both growth regulating herbicides (dicamba and 2,4-D) but more specifically 2,4-D, when applied to large (30 cm) sicklepod plants, there was an over proliferation of the stem cells which led to abnormally thickened stem diameters. Twenty-eight days after treatment, sicklepod stems were often inflated and larger in diameter than untreated sicklepod plant stems. Similarly, West *et al.* observed an overall increase in cucumber stem diameter and dry weight when treated with 2,4-D [34]. This phenomenon was attributed to 2,4-D which stimulates uncontrolled cell growth and proliferation in treated plants. This may have also skewed the control data on the larger sicklepod plants which would lower the control rating by 2,4-D alone treatments and to a lesser extent, the dicamba alone treatments. These effects were not observed with the Palmer amaranth or pitted morningglory stem diameters.

5. Conclusion

These experiments demonstrated that glufosinate alone and glufosinate plus dicamba or 2,4-D were the most effective and consistent herbicide treatments for the broadleaf weed species in this study. Although there was interaction between both trial runs, the results clearly showed differences between treatments and differences in treatment by weed height. Varying degrees of synergism were observed (*i.e.*, glufosinate plus dicamba in sicklepod) and some antagonism (*i.e.*, glyphosate plus dicamba in sicklepod) was observed when herbicides were applied in mixture.

Acknowledgements

Technical Contribution No. 6651 of the Clemson University Experiment Station. This material is based upon work supported by the NIFA/USDA, under project number SC-1700539. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the USDA.

Disclaimer

Mention of a trade name does not imply endorsement of the product by Clemson University to the exclusion of others that might be available.

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