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Several individuals assisted in the development, proofreading, and assembly of the BMP document: Liberta Scotto, Mike Ziegler, Jane Foos, Donna Smith. Paul Whalen and Boyd Gunsalus developed the initial sections for the final document. Sam Phares and Audrey Beany spent many hours preparing the manuscript for publication.

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A PEER REVIEWED PAPER

EFFECT OF GLYPHOSATE AND ITS 2,4-D FORMULATION ON SOME DIFFICULT TO CONTROL WEEDS

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Abstract. **Glyphosate formulations (Rodeo®, Roundup®, Roundup® Ultra) and glyphosate + 2,4-D as Landmaster® II were evaluated against Brazil pusley *(Richardia brasiliensis* L.), dayflower *(Commelina communis* L.), and hairy beggarticks *(Bidens frondosa* L.). Landmaster® provided 99% control of *R.brasiliensis* while glyphosate formulations (1.0 lb a.i./acre) had only marginal control (14 to 18%). Landmaster® also provided higher control of *C. communis*, 87% at 0.13 qt. product/acre and 100% at 2.0 qt./acre while glyphosate formulations (1.0 lb and 1.25 lb a.i./acre) had no control. The response of *B. frondosa* to herbicide treatment varied with age. Glyphosate formulations (1.0 lb a.i./acre) provided 38 to 55% control of *B. frondosa* as compared to 78% with Landmaster® (0.50 qt./acre) at the 12-week stage. The control of *B. frondosa* further decreased when the treatments were applied to the plants with regrowth. Glyphosate formulations were effective only at the 4- to 5-week stage, when even a lower dose of 0.25-0.50 lb a.i./acre effectively controlled *B. frondosa*. Overall, Roundup® and Roundup® Ultra were superior to Rodeo® but Landmaster® provided the best control in general. Poor performance of Rodeo® was probably due to lack of adjuvant in the formulation and superior performance of Landmaster® was due to presence of 2,4-D.**

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In the state of Florida, climate ranges from temperate in the northern part of the peninsula and panhandle to subtropical along the coast of the southeastern peninsula. Habitats range from dry to wet and has more naturalized non-native plant species than any other state in the continental United States. The vast majority of these species are harmless and have become valuable assets for the state. Florida does have approximately 800 species of plants that are weeds of economic importance (Hall et al., 1998), including some difficult-to-control weeds, e.g., hairy beggarticks, goatweed, dayflower, Brazil pusley, etc.

Glyphosate is the world's most widely used herbicide, accounting for 11% of worldwide herbicide sales (Powles et al., 1998). It is a non-selective herbicide with no soil activity (Grossbard and Atkinson, 1985). Extensive use of herbicides in agriculture has led to resistant weed populations (Holt et al., 1993; Powles and Holtum, 1994). In few agricultural areas, the development of widespread resistance in weeds has compromised the use of certain herbicide chemistries (Powles et al., 1998). In some cases, such as the acetolactate-inhibiting sulfonylurea herbicides, resistance has appeared remarkably rapidly (Gill, 1995; Saari et al., 1994). However, for other herbicides, resistance has appeared sporadically or not at all. This is so for glyphosate where, through more than two decades of its use, some cases of herbicide resistance from field use have been reported (Bardshaw etal., 1997; Dyer, 1994). With the increasing use of glyphosate, there is interest in either using different formulations or use of other tank-mix conventional herbicides with glyphosate to reduce the number of applications required for improved bioefficacy. Diphenylether herbicides are potential candidates for tank-mixture with glyphosate since they provided excellent control of weeds, such as morning-glory species (*Ipomoea* spp.) and hemp sesbania [*Sesbania exalata* (Raf.) Rydb. Ex. A. W. Hill], which are not always effectively controlled with glyphosate (Bennett et al., 1999).

Hairy beggarticks is an annual weed reproduced by seeds. A single plant can produce 3,000 to 6,000 seeds and many seeds readily germinate at maturity. Seed as old as 3 to 5 yrs may give as high as 80% germination. It is found widely in cultivated fields, citrus groves, gardens, and waste sites. Hairy beggarticks has become a major annual weed that is difficult to control, often with large-scale infestations in Florida citrus groves (Holm et al., 1977). Dayflower is an annual, reproducing by seeds and creeping stems. It is mostly found in gardens, dooryards, under citrus and other trees in shade and moist conditions. During the winter season, the seeds or creeping stems remain in a dormant situation under soil and germinate in summer (Singh and Sharma, University of Florida, pers. comm.). Brazil pusley is a perennial reproducing from seed and the root system. This weed is present year round under the climatic conditions of Florida. It is found in lawns, roadsides, and disturbed areas. It is native to South America (Colvin et al., 1996). Between Florida and Brazil pusley, the latter was considered to be the dominant species in central Florida in a survey of 14 citrus growing counties of Florida (Sharma et al., 2000). But in Georgia, Florida pusley was determined to be the most prevalent weed species (Johnson and Mullinix, 1997). In citrus groves it is a very troublesome weed, growing mostly in between tree rows but also under the trees. In many groves, it completely covers the rows in the middles (Singh and Sharma, University of Florida, pers. comm.).

There is interest in either using different formulations of glyphosate or using other tank mix conventional herbicides with glyphosate to reduce the increasing use of glyphosate. This will help to reduce the number of applications required, improve glyphosate efficacy, and avoid any development of resistance with the continuous use of one formulation of glyphosate (Powles et al., 1998). The objective of this study was to compare the efficacy of different glyphosate formulations including: Rodeo® (contains no surfactant); Roundup® (contains some surfactant); Roundup® Ultra (contains all the desired surfactant); and glyphosate + 2,4-D mixture (Landmaster® II) on the control of these species.

Materials and Methods

Plant materials

Three difficult-to-control weed species, hairy beggarticks, dayflower, and Brazil pusley, were used in this study. Actively growing Brazil pusley plants of almost uniform height (4 inches tall) were carefully dug from a nearby citrus grove at the University of Florida, Citrus Research and Education Center, Lake Alfred. The plants were transplanted into 1-qt. plastic pots which were filled with the top 12- to 18-inch layer of a Candler fine sand (Entisol, hyperthermic, uncoated, Typic Quartzipsamments), which is typical of the ridge area of central Florida, and kept in the greenhouse. This depth of sand was particularly used to avoid the presence of natural weed seeds. The soil was collected from a citrus orchard near Davenport, Florida and consists of 7.0 pH (water), 96.7% sand, 0.8% silt, 2.5% clay, and 0.65 to 1.3% organic matter. The plants were allowed to establish from transplanting shock for 2 weeks and fertilized with Tracite foliar fertilizer (Helena Chemical Company, Memphis, TN) containing 20-20-20 (N-P-K) during the second week. The plants were treated after almost 3weeks of transplanting when they developed sufficient foliage for spraying. Visual observations were recorded up to 5 weeks after treatment (WAT). Brazil pusley plants were harvested at soil level 5 WAT and were left in the greenhouse for resprouting for another 6 weeks. Growth parameters such as weight of sprouted shoots, number of viable roots and weight of viable roots were recorded at the end of 6 weeks.

Dayflower seedlings at the 2- to 3-leaf stage were dug from the Water Conserv II grove in Orange County, Florida and transplanted in 1-qt. plastic pots filled with potting mix media. The dayflower seedlings were grown for 2 weeks in a greenhouse to recover from the transplanting shock and treatments were applied at the 4 to 5 leaf stage. In citrus groves, it was observed that the dayflower plants grew only under citrus trees, which may be because of more moisture and shade in comparison to the other areas. No dayflower plants were observed between the two rows of citrus trees. Therefore, to check the herbicidal effects on this plant, treatments were applied to plants grown under light and shade, but kept under controlled greenhouse conditions. Artificial shade was created with a dark black polyethylene cover on the bench at a height of about 3 feet.

Hairy beggarticks seeds were collected from mature plants growing in citrus groves in Lake Alfred and Lake Garfield, Florida. Seeds were stored at 41°F until future use. The seeds were sown in 1-qt. plastic pots filled with potting mix medium, and thinned to two seedlings per pot. Five-week-old seedlings of hairy beggarticks were used for treatment application in the initial study.

All the plants before and after treatment application were kept under controlled greenhouse conditions at temperature of 25/16°C (±0.5°C) day/night and relative humidity of 70% (±5%) under normal day light (no supplemental light) conditions.

Herbicide chemicals

Study 1. Glyphosate formulations, Rodeo® (contains no surfactant); Roundup® (contains nonionic surfactant) and Roundup® Ultra (no additional surfactant recommended) were applied at 1.0 lb a.i./acre, and Landmaster® II [mixture of glyphosate + 2,4-D (0.9 + 0.8 lb ae/gal, isopropylamine salt)] at 2 qt. product/acre. All formulations were applied using a Chamber Track Sprayer (Allen Track Sprayer, Allen Machine Works, Midland, MI) fitted with flat fan nozzle (Teejet 8002 Flat Fan Spray nozzles, Spraying System Co., Wheaton, IL) delivering 20 gal/acre of water at 20-psi pressure. Distilled water was used as a spray carrier. Weekly visual observations were taken up to 4 WAT. A scale of 0 to 100 was used: 0—indicating no effect and 100—indicating complete damage as approved by the Weed Science Society of America (Frans et al., 1986). All individual weeds species were assessed separately under conditions representative of natural habitats.

Study 2. This study was required when application of 1.0 lb a.i./acre glyphosate to dayflower plants in the first study did not show any effect while Landmaster® II (2 qt./acre) achieved 100% control of dayflower under both light and shade conditions. Therefore, higher rate of 1.25 lb a.i./acre glyphosate in addition to 1.0 lb a.i./acre was evaluated but only under natural day light conditions. Landmaster® II was applied to dayflower at three different but lower rates of 0.13, 0.25, and 0.50 qt. product/acre.

Study 3. In Study 1 glyphosate killed all hairy beggarticks plants within 2 weeks of application. Therefore, a study was designed with lower rates of glyphosate at 0.25 and 0.50 lb a.i./acre in addition to the 1.0 lb a.i./acre rate; Landmaster® II was applied at 0.13, 0.25, and 0.50 qt. product/acre. The effects of glyphosate and Landmaster at four different stages, e.g. 4-, 6-, 8-, and 10-week-old plants were evaluated. In a separate experiment, the same treatments were applied to two different age plants: 12-weeks-old chopped and not-chopped plants. In chopped plants, 6-weeks-old seedlings were chopped off 2H inches above the soil level and were allowed to regrow for another 6 weeks. These seedlings were sprayed with the same treatments as mentioned in this section.

Statistical analysis

All the experiments were conducted with a randomized complete block design and were repeated once. Each experiment had four replications. The data from two experiments were combined to present the mean values after performing a test of homogeneity of variance. Each weed species was analyzed separately. The data were subjected to ANOVA after performing an arcsin transformation but are presented in the original form for clarity. The means were separated using Fisher's Protected Least Significant Difference test (LSD at Pð0.05).

Results and Discussions

The data on visual observation expressed as percent of control treatments were recorded at 4WAT and have been presented for individual species. For Brazil pusley, the data were recorded up to 5 WAT, however, there was no significant difference among observations recorded at 4 and 5 WAT.

Brazil pusley. Application of glyphosate formulations had only marginal effects on Brazil pusley control (14 to 18%), while Landmaster® II resulted in near complete (99%) control of Brazil pusley at 5 WAT. There was no regrowth of any shoots from the pots which received the Landmaster® treatment. No significant differences with glyphosate formulations were recorded between the fresh weight of re-sprouted shoots, and weight and number of viable roots (Table 1). Therefore, the presence of 2,4-D in Landmaster® might be the main component for the control of Brazil pusley. Another study on the effect of 2,4-D alone and tank mix glyphosate revealed that 2,4-D is the major component in Landmaster® II or tank-mix glyphosate + 2,4-D for achieving higher control of Brazil pusley plants than glyphosate formulations (Sharma etal., 2000).

Dayflower. Glyphosate formulations used at 1.0 lb a.i./acre had no effect on dayflower control while Landmaster® (2 qts./acre) killed 100% of the dayflower plants (Table 2). Shading and light conditions also had no effect on the efficacy of glyphosate, as the visual phytotoxic symptoms and ratings under both conditions were similar. The plants kept under ambient light conditions grew less and showed some symptoms of phytotoxicity, e.g., chlorosis of leaves. The plants under shade grew tall and were dark green in color. Although plants growing under shade remained green, comparison with corresponding untreated plants (light/shade) did not show

Table 1. Effect of glyphosate formulations and Landmaster® on the control of Brazil pusley.

				Regrowth 6 weeks after harvesting at 5 WAT		
					Viable roots[w]	
Herbicide formulation	Rates (per acre)	Percent control[z]	Shoot wt[y] (g)	Shoot wt[x] (g)	No.	Wt (g)
Rodeo®	1.0 lb a.i.	17	3.12	0.94	<1	0.73
Roundup®	1.0 lb a.i.	18	3.53	1.01	<1	1.04
Roundup® Ultra	1.0 lb a.i.	14	4.42	1.76	<1	1.15
Landmaster® II	2.0 qt product	99	0.00	0.10	<1	0.20
Untreated		0	6.58	2.48	1.0	1.92
LSD (P ð 0.05)		3.94	1.19	0.79	0.27	0.61

[z]Visual rating at 5 weeks after treatment (WAT).
[y]Weight of shoot 5 WAT.
[x]Weight of shoot regrowth
[w]Viable number of roots

significant differences. When Landmaster® was applied, it was noticed that the plant stem at the soil level became weak and thin at the end of first week; later the stem was completely decayed. It was assumed that quick herbicide-translocation into the root system resulted in root tissue collapse prior to translocation to the shoot portion. In a separate study conducted only under normal day light conditions, the rate of glyphosate was increased to 1.25 lb a.i./acre and Landmaster® II was applied at three different but lower rates of

Table 2. Effect of glyphosate formulations and Landmaster® on the control of dayflower weed.

Herbicide formulation	Rates (per acre)	Percent control[z]	
		Light[y]	Shade[y]
Rodeo®	1.0 lb a.i.	33	36
Roundup®	1.0 lb a.i.	27	21
Roundup® Ultra	1.0 lb a.i.	51	56
Landmaster® II	2.0 qt product	100	100
Untreated		0	0
LSD (P ð 0.05)		8	6

[z]Visual rating at 4 WAT.
[y]See Materials and Methods section for light and shade condition.

0.13, 0.25, and 0.50 qt./acre. There was no significant difference between the control values of dayflower obtained with 1.0 and 1.25 lb a.i./acre glyphosate (Table 3). The percent control with the application of Landmaster® II applied at all the rates was significantly higher than glyphosate formulations. This suggested that the presence of 2,4-D was an important component in Landmaster® II. Lencse et al. (1998) also reported that a glyphosate tank mix with bentazon (Basagran®) or bentazon + aciflurofen (Storm®) significantly improved dayflower control as compared to Roundup® Ultra alone. Only with the repeated use of Roundup® formulation and applied at five times the recommended application rate, there was complete control of dayflower. A single application had no effect on this plant (Parsons and Morgon, University of Florida, pers. comm.).

Hairy beggarticks. The rate of herbicides used in this experiment provided 100% kill of hairy beggarticks plants 3 WAT and a minimum of 68% control was achieved even 1 WAT (data not given). Therefore, the study was continued but with different rates and different plant growth stages.

(1) *Growth characteristics.* Glyphosate formulations and Landmaster® were evaluated for a range, e.g., 4-, 6-, 8-, 10-, and 12-weeks, of growth stages treated with different rates. Plant

Table 3. Effect of different rates glyphosate formulations and Landmaster® applied to dayflower.

Herbicide formulations	Rates (per acre)	Percent control[z]
Rodeo®	1.0 lb a.i.	16
Rodeo®	1.25 lb a.i.	23
Roundup®	1.0 lb a.i.	20
Roundup®	1.25 lb a.i.	23
Roundup® Ultra	1.0 lb a.i.	15
Roundup® Ultra	1.25 lb a.i.	23
Landmaster® II	0.13 qt. product	87
Landmaster® II	0.25 qt. product	94
Landmaster® II	0.50 qt. product	96
Untreated		0
LSD (P ð 0.05)		10

[z]Visual ratings at 4 WAT.

height, number of trifoliate leaves per plant, and number of branch or sub-branch sprouting per plant were counted at all stages before the treatment application to record the physical changes in plants. The values of these characteristics were averaged for 50 plants at each stage. Obviously, the plants were shorter, which were chopped at 6 weeks and allowed to regrow for 6 weeks than 12-week normal plants but the sprouting branches were longer. The most sensitive stage of hairy beggarticks to herbicide was 4- to 5-weeks of age; later on, the percent control decreased as growth stage advanced.

(2) *Bioefficacy.* Herbicide treatments were applied to 4-, 6-, 8-, and 10-week-old seedlings. Plants were most sensitive to herbicide at 4weeks and least sensitive at 12 weeks of age. In general, the application of different rates of glyphosate and Landmaster® showed a decrease in percent control of hairy beggarticks with advancing growth stage (Table 4). At the lowest rate of 0.25 lb a.i./acre, control was minimum with Rodeo® (45%) and maximum with Roundup® (90%) 4 WAT of 4-week-old plants. There was 100% control of hairy beggarticks plants when glyphosate formulations were applied at 0.50 and 1.0 lb a.i./acre and Landmaster® at 0.50 qt./acre to 4-week old plants. Application of Landmaster® at 0.25 qt./acre provided 66% control at this developmental stage. All hairy beggarticks plants showed leaf malformation and typical 2,4-D symptoms with all Landmaster® treatments. When the plants were sprayed at a 6-week developmental stage, there was a significant drop in percent control. The control values of 86, 88, and 91% were obtained when the plants were sprayed with 1.0 lb a.i./acre glyphosate as Rodeo®, Roundup® Ultra, and Roundup® at the 6-week stage, respectively. Thereafter, the control values were only 76% with Roundup® Ultra and 56 to 59% with Rodeo® and Roundup® when applied to 8-week-old plants; the corresponding values for 10-week-old plants were between 33 and 41% with any glyphosate formulation (1.0 lb a.i./acre) tested. Landmaster® at 0.50 qt./acre provided 59% control of hairy beggarticks when applied to 6- and 8-week-old plants (Table 4).

In separate experiments, the same treatments were applied to two different aged plants, 12-week-old chopped and not-chopped plants. In chopped plants, 6-week-old seedlings were chopped off

Table 4. Effect of different rates of glyphosate formulations and Landmaster® applied to hairy beggarticks at different growth stages.

Herbicide formulation	Rates (per acre)	Age of hairy beggarticks plants (percent control)[z]			
		4 wks	6 wks	8 wks	10 wks
Rodeo®	0.25 lb a.i.	45	43	17	24
Rodeo®	0.50 lb a.i.	99	42	31	29
Rodeo®	1.0 lb a.i.	100	86	59	33
Roundup®	0.25 lb a.i.	90	39	19	25
Roundup®	0.50 lb a.i.	98	41	25	24
Roundup®	1.0 lb a.i.	100	91	56	41
Roundup® Ultra	0.25 lb a.i.	67	13	17	20
Roundup® Ultra	0.50 lb a.i.	96	35	27	20
Roundup® Ultra	1.0 lb a.i.	100	88	76	36
Landmaster® II	0.13 qt product	18	11	20	24
Landmaster® II	0.25 qt product	66	23	26	43
Landmaster® II	0.50 qt product	100	59	59	78
Untreated		0	0	0	0
LSD (P ð 0.05)		7	11	10	10

[z]Visual ratings at 4 WAT.

2H inches above the soil level and were allowed to regrow for another 6 weeks (Table 5). The maximum control values of 55, 41, and 38% with Roundup® Ultra, Roundup®, and Rodeo®, respectively, were recorded with glyphosate at 1.0 lb a.i./acre sprayed at the 12-week stage (not-chopped plants). The application of 0.50 qt/

acre of Landmaster® II provided 78% hairy beggarticks control. Only marginal control (21 to 38%) was obtained with the lower doses of glyphosate and Landmaster® (non-chopped plants) (Table 5). When the plants were chopped at the 6-week stage and were sprayed at the 12-week stage, there was almost no control (<10%) of hairy beggarticks plants even with glyphosate applied at 1.0 lb a.i./acre. But Landmaster® at 0.50 qt/acre provided 70% kill of hairy beggarticks. Typical 2,4-D symptoms marginally appeared when lower rates of Landmaster® were used (Table 5).

The investigation of hairy beggarticks control suggested that glyphosate formulations were effective only at the early stages of development (4 to 5 weeks), where an even lower rate of 0.25-0.50 lb a.i./acre can effectively control this weed. Roundup® or Roundup® Ultra provided better weed control than Rodeo®, which suggests the importance of surfactant in the other two formulations. Landmaster® used at 0.50 qt/acre was effective to control this plant. This is likely due to the presence of 2,4-D in Landmaster®, which has shown better to control of other species in the present and previously studies. In this study, 2,4-D was the main component in Landmaster® which enhanced its phytotoxic effect. Similar results have been reported by many workers, namely tank mixing glyphosate with other conventional herbicides improved its efficacy and reduced the number of applications of glyphosate alone (Lencse et al., 1998; Bennett et al., 1999; Nelson et al., 1999).

Table 5. Effect of different rates of glyphosate formulations and Landmaster® applied to hairy beggartick plants.

Herbicide formulations	Rates (per acre)	Percent control[z] (12 wks old)	
		Not chopped	Chopped[y]
Rodeo®	0.25 lb a.i.	21	1
Rodeo®	0.50 lb a.i.	31	0
Rodeo®	1.0 lb a.i.	38	4
Roundup®	0.25 lb a.i.	28	1
Roundup®	0.50 lb a.i.	31	1
Roundup®	1.0 lb a.i.	41	8
Roundup® Ultra	0.25 lb a.i.	27	8
Roundup® Ultra	0.50 lb a.i.	30	4
Roundup® Ultra	1.0 lb a.i.	55	9
Landmaster® II	0.13 qt product	37	14
Landmaster® II	0.25 qt product	51	28
Landmaster® II	0.50 qt product	78	71
Untreated		0	0
LSD (P ð 0.05)		12	6

[z]Visual ratings at 4 WAT.
[y]Plants chopped at 6th week after planting and treatments applied at 12th week.

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