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White Bean and Weed Desiccation With Pelargonic Acid

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Abstract

Few studies have evaluated pelargonic acid for desiccating white bean and annual weeds. Five field experiments were conducted from 2021 to 2023 near Exeter and Ridgetown, Ontario, Canada to assess pelargonic acid applied alone or sequentially at different rates and several alternative herbicides for desiccating white bean and annual weeds. Pelargonic acid applied at 3400 g ai ha^{-1} desiccated white bean 88, 92, and 98% at 5, 8, and 14 days after application (DAA), respectively. Increasing the application rate, using sequential application, or adding 28% urea ammonium nitrate (UAN), did not improve white bean desiccation. Pelargonic acid applied at 3400 g ai ha^{-1} desiccated green pigweed 0, 2, and 1%; common ragweed 4, 3, and 3%; common lambsquarters 0, 0, and 0%; green foxtail 8, 12, and 15%; and barnyardgrass 5, 5, and 4% at 5, 8, and 14 DAA, respectively. Increasing the application rate, using sequential applications, or adding 28% UAN did not improve overall weed desiccation, except for green foxtail where desiccation was enhanced 14, 14, and 15% with pelargonic acid applied at 6800 g ai ha^{-1} at 5, 8, and 14 DAA, respectively and common ragweed where desiccation was increased 5% with pelargonic acid applied at 6800 g ai ha^{-1} at 8 DAA. At 14 DAA, green pigweed, common ragweed, common lambsquarters, green foxtail and barnyardgrass desiccation with carfentrazone-ethyl was 30, 6, 0, 11, and 7%; with ammonium salt of fatty acid was with 60, 12, 0, 59, and 36%; with flumioxazin was 54, 68, 31, 90, and 69%; with saflufenacil was 100, 96, 75, 37, and 55%; with tiafenacil was 100, 88, 5, 80, and 42%; with glufosinate was 100, 95, 100, 99, and 96%; and with diquat was 100, 99, 99, 99, and 96%, respectively. Dry bean desiccation with ammonium salt of fatty acid, glufosinate, carfentrazone-ethyl, flumioxazin, saflufenacil, tiafenacil, and diquat was 98-99% at 14 DAA. Among the desiccants evaluated, diquat and glufosinate were the most effective with 99% white bean desiccation and 95-100% desiccation of annual weeds at 14 DAA.

Keywords: weed desiccation, white bean, green pigweed, common ragweed, common lambsquarters, green foxtail, barnyardgrass, herbicide efficacy

1. Introduction

Dry bean (*Phaseolus vulgaris* L.) is a valuable pulse crop frequently grown by Ontario farmers as part of a rotation with corn, soybean, and winter wheat to promote crop diversity, improve soil quality, disrupt pest cycles, and enhance overall farm profitability (Goodwin, 2005; Janovicek et al., 2021; Uebersax et al., 2023). The dry bean industry plays a significant role in Ontario's agriculture economy with farmers planting around 48,000 hectares with a farm-gate value of approximately $100 million annually (Bedford, 2021; Goodwin, 2005; IndexBox, 2024; Soltani et al., 2022). White bean (also known as navy bean) makes up nearly half of dry bean production in the province (Hensall Co-op, 2024).

Seed moisture content at harvest is critical in dry bean production to prevent spoilage and mould, preserve bean quality, reduce drying costs, and meet market standards (McNaughton et al., 2015a, b; Soltani et al., 2013; Subedi et al., 2017; Tkachuk, 2024). White bean seeds are generally considered mature when 80% of the pods changed from green to shades of yellow, tan, purple, or striped (Smith, 1996; Subedi et al., 2017; Tkachuk, 2024; Wilson & Smith, 2002). Achieving consistent maturity across the field can be difficult due to the indeterminate growth pattern of white bean and field variability. To address these inconsistencies and desiccate weeds that can discolour beans and hinder harvesting, farmers frequently apply herbicides as harvest aids (desiccants) (Baig et al., 2003; McNaughton et al., 2015a, b; MPSG, 2024). These desiccants promote even and rapid drying of both the beans and weeds (Coleman & Penner, 2006; Wilson & Smith, 2002). The choice and application timing of each desiccant is critical, as improper application can reduce white bean yield and may result in unacceptable herbicide residues in white bean seeds at harvest (Azlin & McWhorter, 1981; Cerkauskas et al., 1982; MPSG, 2024).

In Ontario, the following herbicides are registered as desiccants in dry beans: carfentrazone-ethyl, diquat, flumioxazin, glufosinate, glyphosate, and saflufenacil (OMAFRA, 2024). Glyphosate has been the preferred choice for desiccation because of its efficacy and affordability (Baig et al., 2003; McNaughton et al., 2015a, 2015b). However, concerns about glyphosate residues in dry bean seed at harvest have led to restrictions on its use (Dawson, 2020; Hensall Co-op, 2024; Tkachuk, 2024), reducing desiccant options available to farmers. Additionally, some dry bean buyers prohibit the use of glufosinate as there is a risk of residues above the maximum residue limit (MRL) which may result in trade disruption (Dawson, 2020). This situation highlights the necessity for additional research to identify herbicides that cause rapid and uniform desiccation of dry beans, effectively desiccate annual weeds, and have minimal residues in dry bean seed.

Pelargonic acid, a naturally occurring fatty acid, has attracted attention in recent years as a potential desiccant because of its biodegradable properties and low toxicity (Label, 2020; Loddo et al., 2023; PMRA, 2020). Pelargonic acid is a saturated nine-carbon fatty acid ($CH_3(CH_2)_7CO_2H$, n-nonanoic acid) that is found in the essential oil of *Pelargonium* species and can be derived from various vegetable oils (Loddo et al., 2023; PMRA, 2020). Pelargonic acid functions as a harvest-aid herbicide by destabilizing the plant cuticle, leading to rapid tissue desiccation (Coleman & Penner, 2006; Loddo et al., 2023; Travlos et al., 2020). It causes cellular membrane leakage and induces necrosis through light-driven peroxidative activity by singlet oxygen (Loddo et al., 2023; Travlos et al., 2020). Its effects are visible within hours of application. Pelargonic acid only damages plant parts directly contacted by the spray, as it is not translocated within the plant (Coleman & Penner, 2006; Loddo et al., 2023). Contrasting results of pelargonic acid efficacy have been reported in various crops. Loddo et al. (2023) reported that pelargonic acid, even at higher doses, caused minimal and transient injury in grass weeds including *Alopecurus myosuroides* and *Lolium rigidum*. Conversely, broadleaf weeds such as *Conyza sumatrensis* and *Solanum nigrum* were more sensitive to pelargonic acid (Loddo et al., 2023). Webber et al. (2014a, 2014b) also reported inconsistent desiccation of grass and broadleaf weeds in vegetable crops with pelargonic acid. Similarly inconsistent weed desiccation efficacy was reported with pelargonic acid in other crops (Cabrera-Pérez et al., 2022; Kanatas et al., 2021; Martelloni et al, 2020; Rowley et al., 2011; Travlos et al., 2020).

Pelargonic acid efficacy when applied alone or sequentially (7 days apart), at different rates, has not been studied under Ontario climatic conditions. In addition to pelargonic acid, other herbicidal options, including ammonium salt of fatty acid (Axxe®), carfentrazone-ethyl + Merge®, flumioxazin + MSO concentrate, tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90, offer different mechanisms of action that may prove beneficial for dry bean and annual weed desiccation (McNaughton et al., 2015a, 2015b; Soltani et al., 2013; Sprague, 2015; Tkachuk, 2024).

To our knowledge, no published studies have evaluated the desiccant efficacy of pelargonic acid applied at three doses alone and sequentially. In addition, we are not aware of any studies where the activity of ammonium salt of fatty acid, carfentrazone-ethyl + Merge®, flumioxazin + MSO concentrate, tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90 were compared for both dry bean and weed desiccation. Accurate data of different harvest aids is essential to identify those that not only provide excellent desiccation but also adhere to strict standards thus promoting unfettered global marketing opportunities.

The objective of this study was to evaluate the efficacy of pelargonic acid applied alone or sequentially at three doses and evaluate ammonium salt of fatty acid, carfentrazone-ethyl + Merge®, flumioxazin + MSO concentrate, tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90 for desiccating white bean and annual weeds under Ontario environmental conditions.

2. Materials and Methods

Between 2021 and 2023, five field experiments were conducted at two Ontario, Canada locations: one site at the Huron Research Station near Exeter, Ontario, Canada in 2021; two sites at the same location in 2023; and two sites at the University of Guelph's Ridgetown Campus near Ridgetown, Ontario, Canada in 2022. Seedbed preparation consisted of autumn moldboard plowing followed by (fb) two spring passes with a field cultivator equipped with rolling basket harrows.

Experiments were arranged in a randomized complete block design with four replications. Treatments evaluated are listed in Tables 1-4. All plots were 3 m wide (4 white bean rows spaced 75 cm apart) by 10 m long at Exeter and 8 m long in Ridgetown. White bean was seeded 3-5 cm deep at a density of approximately 230,000 seeds ha^{-1} in late May to early June of each year. Herbicide applications were made with a CO_2-pressurized backpack sprayer calibrated to deliver 200 L per ha^{-1} aqueous solution at approximately 210 kPa. Herbicide application (A) was applied at ~30% dry bean seed moisture content. For the sequential application of pelargonic acid, the second application (B) was applied 7 days after application A (as shown in Tables 1-4). The boom was 1.5 m long equipped with four ultra-low drift nozzles (ULD120-02, Hypro, New Brighton, MN) spaced 50 cm apart producing a spray width of 2.0 m.

Desiccation of dry bean (leaf, stem, and pods combined) as well as weed desiccation was visually estimated on a scale from 0 (no desiccation) to 100% (complete dry bean/weed desiccation compared to the non-treated control) at 5, 8, and 14 days after herbicide application (DAA).

Data were analyzed using the GLIMMIX procedure via SAS Studio v9.4 (SAS OnDemand for Academics, SAS Institute, Cary, NC). The non-treated control (for weed desiccation data) and treatments with a mean and variance of zero were excluded from analyses. Similarly, treatments with a mean of 100% and variance of zero were excluded. However, each treatment was compared to the non-treated control by independently comparing each mean to zero. Dry bean and weed desiccation data were analyzed with the distribution that met the assumptions of normality best. The fixed effect was herbicide treatment, and the random effects were environment, replication nested within environment, and the environment-by-treatment interaction. Significance of the fixed effect and random effects were tested using an F-test and Z-tests, respectively. Data was pooled across environments where environment-by-treatment interactions were non-significant. Assumptions of normality and homogeneity of variance were confirmed using plots of studentized residuals for treatment, replication, and environment. Chi-Square df and Shapiro-Wilk statistics were used to evaluate goodness-of-fit and normality, respectively. Evaluation of studentized residual boxplots identified extreme observations that significantly affected treatment means and were therefore removed. Non-orthogonal contrasts were constructed to further compare single and two-pass desiccation treatments. Data subject to transformations for analysis were back transformed for presentation of results. An alpha level of 0.05 was carried through all analyses and means were separated using the Tukey-Kramer multiple range test.

3. Results and Discussion

The dominant weed species in plots evaluated included green pigweed (*Amaranthus powellii* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarters (*Chenopodium album* L.), green foxtail (*Setaria viridis* L.), and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.]. There was no significant interaction between environments and treatments, therefore data were pooled and averaged over environments.

3.1 Pelargonic Acid

3.1.1 White Bean Desiccation

Pelargonic acid (3400 g ai ha^{-1}) caused 88, 92, and 98% white bean desiccation at 5, 8, and 14 days after application (DAA), respectively (Table 1). These results were similar to the non-treated control. Increasing the rate of pelargonic acid to 5100 or 6800 g ai ha^{-1} caused no significant increase in white bean desiccation. The sequential application of pelargonic acid of 3400 fb 3400 g ai ha^{-1}, 5100 fb 5100 g ai ha^{-1} or 6800 fb 6800 g ai ha^{-1} did not increase desiccation. The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve white bean desiccation. Based on contrasts, no significant differences were observed between single application (App A) and sequential applications (App A fb B) of pelargonic acid across rates for white bean desiccation (Table 1).

Table 1. White bean (*Phaseolus vulgaris* L.), green pigweed (*Amaranthus powellii*) and common ragweed (*Ambrosia artemisiifolia*) desiccation with pelargonic acid applied as a desiccant from five field trials conducted in southwestern Ontario, Canada in 2021, 2022 and 2023

Herbicide treatment	Rate[a]	App timing[b]	White bean desiccation (DAA)[e]			Weed desiccation (DAA)					
						Green pigweed			Common ragweed		
			5	8	14	5	8	14	5	8	14
	g ai ha^{-1}		%								
Non-treated control	-	-	87 a	92 a	98 a	0 b	0 a	0 b	0 b	0 c	0 b
Pelargonic acid	3400	A	88 a	92 a	98 a	0 b	2 a	1 ab	4 a	3 bc	3 a
Pelargonic acid	5100	A	90 a	94 a	98 a	0 b	0 a	13 ab	3 a	5 ab	2 a
Pelargonic acid	6800	A	91 a	94 a	98 a	0 b	0 a	0 b	5 a	8 a	5 a
Pelargonic acid fb	3400	A	90 a	93 a	98 a	0 b	0 a	0 b	3 a	2 bc	3 a
Pelargonic acid	3400	B									
Pelargonic acid fb	5100	A	91 a	94 a	99 a	3 a	6 a	31 a	4 a	6 ab	5 a
Pelargonic acid	5100	B									
Pelargonic acid fb	6800	A	92 a	95 a	99 a	0 b	0 a	13 ab	5 a	6 ab	5 a
Pelargonic acid	6800	B									
Pelargonic acid + 28% UAN	3400 + 5[c]	A	89 a	92 a	98 a	0 b	0 a	0 b	3 a	5 ab	3 a
Contrasts											
App A vs. App A *fb* B			NS	NS	NS	NS	-	-	NS	NS	NS
App A vs. App A *fb* B at 3400 g ai ha^{-1}			NS	NS	NS	NS	-	NS	NS	NS	NS
App A vs. App A *fb* B at 5100 g ai ha^{-1}			NS	NS	NS	NS	-	-	NS	NS	*
App A vs. App A *fb* B at 6800 g ai ha^{-1}			NS	NS	NS	NS	-	-	NS	NS	NS

Note. Abbreviations: App, application; DAA, days after application; NS, non-significant.

[a] Herbicide rates are presented in g ai ha^{-1} and adjuvants in L ha^{-1}.

[b] Herbicide application A was made at 30% seed moisture content and application B was made seven days after application A.

[c] Rate presented in L ha^{-1}.

[d] Rate presented as %v/v.

[e] Means followed by the same letter within unbroken columns are not significantly different according to Tukey-Kramer multiple range test (P > 0.05).

[d] Significance at P < 0.05 denoted by *.

3.1.2 Green Pigweed Desiccation

Pelargonic acid at 3400 g ai ha^{-1} desiccated green pigweed only 0, 2, and 1% at 5, 8, and 14 DAA, respectively (Table 1). Increasing the rate of pelargonic acid to 5100 or 6800 g ai ha^{-1} did not increase in green pigweed desiccation. The sequential application of pelargonic acid of 3400 fb 3400 g ai ha^{-1}, 5100 fb 5100 g ai ha^{-1} or 6800 fb 6800 g ai ha^{-1} did not increase green pigweed desiccation with the exception that the 5100 fb 5100 g ai ha^{-1} treatment increased green pigweed desiccation 3% at 5 DAA. The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve green pigweed desiccation. Based on contrasts, no significant differences were observed between single (App A) and sequential applications (App A fb B) of pelargonic acid across rates for desiccation of green pigweed at 5 DAA (Table 1). In other studies, pelargonic acid was applied at 4.5, 9, and 13.5 kg ha^{-1} to squash and desiccated broadleaf weeds that included spiny amaranth (*Amaranthus spinosus*) 45, 75, and 86% at 11 DAA, respectively (Webber et al., 2014a). Panacci et al. (2022) established the dose-response curve for pelargonic acid on several broadleaf weeds, evaluating doses from 1.4 to 21.8 kg ha^{-1}. They reported ED50 values were 11.7 kg ha^{-1} for *Amaranthus retroflexus*, 3.0 kg ha^{-1} for *Heliotropium europaeum*, and 18.7 kg ha^{-1} for *Portulaca oleracea* (Panacci et al., 2022).

3.1.3 Common Ragweed Desiccation

Pelargonic acid at 3400 g ai ha^{-1} desiccated common ragweed only 4, 3, and 3% at 5, 8, and 14 DAA, respectively (Table 1). Increasing the rate of pelargonic acid to 5100 or 6800 g ai ha^{-1} caused no significant increase in common ragweed desiccation with the exception that the 6800 g ai ha^{-1} treatment increased common ragweed desiccation 5% at 8 DAA. The sequential application of pelargonic acid of 3400 fb 3400 g ai ha^{-1}, 5100 fb 5100 g ai ha^{-1} or 6800 fb 6800 g ai ha^{-1} did not increase common ragweed desiccation. The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve common ragweed desiccation. Based on contrasts, generally, no significant differences were observed between single and sequential applications of pelargonic acid across rates for desiccation of common ragweed (Table 1). There was one small difference (2 vs 5%) at 14 DAA between application A vs application A fb B at 5100 g ai ha^{-1} (Table 1).

3.1.4 Common Lambsquarters Desiccation

At 5, 8, and 14 DAA, pelargonic acid at 3400, 5100, or 6800 g ai ha^{-1} applied alone or sequentially 7 days apart did not provide any desiccation of common lambsquarters (Table 2). The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve common lambsquarters desiccation.

Table 2. Common lambsquarters (*Chenopodium album*), green foxtail (*Setaria viridis*) and barnyardgrass (*Echinochloa crus-gali*) desiccation with pelargonic acid applied as a desiccant from five field trials conducted in southwestern Ontario, Canada in 2021, 2022 and 2023

Herbicide treatment	Rate[a]	App timing[b]	Weed desiccation (DAA)								
			Common lambsquarters			Green foxtail			Barnyardgrass		
			5	8	14	5	8	14	5	8	14
	g ai ha^{-1}		%								
Non-treated control	-	-	0	0	0	0 c	0 c	0 c	0 b	0 b	0 a
Pelargonic acid	3400	A	0	0	0	8 bc	12 bc	15 bc	5 ab	5 ab	4 a
Pelargonic acid	5100	A	0	0	0	9 bc	17 abc	18 abc	8 ab	5 ab	4 a
Pelargonic acid	6800	A	0	0	0	22 a	26 a	30 a	10 a	10 a	7 a
Pelargonic acid fb	3400	A	0	0	0	8 bc	13 bc	18 abc	5 ab	5 ab	3 a
Pelargonic acid	3400	B									
Pelargonic acid fb	5100	A	0	0	0	12 abc	17 abc	26 ab	7 ab	9 a	5 a
Pelargonic acid	5100	B									
Pelargonic acid fb	6800	A	0	0	0	18 ab	24 a	29 a	15 a	13 a	8 a
Pelargonic acid	6800	B									
Pelargonic acid + 28% UAN	3400 + 5[c]	A	0	0	0	9 bc	12 bc	19 abc	9 ab	6 ab	2 a
Contrasts											
App A vs. App A *fb* B			-	-	-	NS	NS	NS	NS	NS	NS
App A vs. App A *fb* B at 3400 g ai ha^{-1}			-	-	-	NS	NS	NS	NS	NS	NS
App A vs. App A *fb* B at 5100 g ai ha^{-1}			-	-	-	NS	NS	NS	NS	NS	NS
App A vs. App A *fb* B at 6800 g ai ha^{-1}			-	-	-	NS	NS	NS	NS	NS	NS

Note. Abbreviations: App, application; DAA, days after application; NS, non-significant.

[a] Herbicide rates are presented in g ai ha^{-1} and adjuvants in L ha^{-1}.

[b] Herbicide application A was made at 30% seed moisture content and application B was made seven days after application A.

[c] Rate presented in L ha^{-1}.

[d] Rate presented as %v/v.

[e] Means followed by the same letter within unbroken columns are not significantly different according to Tukey-Kramer multiple range test (P > 0.05).

[d] Significance at P < 0.05 denoted by *.

3.1.5 Green Foxtail Desiccation

Pelargonic acid at 3400 g ai ha^{-1} desiccated green foxtail only 8, 12, and 15% at 5, 8, and 14 DAA, respectively (Table 2). Increasing the rate of pelargonic acid to 5100 g ai ha^{-1} caused no increase in green foxtail desiccation. However, increasing the rate of pelargonic acid from 3400 g ai ha^{-1} to 6800 g ai ha^{-1} improved green foxtail 14, 14, and 15% at 5, 8, and 14 DAA, respectively. The sequential applications of pelargonic did not increase green foxtail desiccation (Table 2). The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve green foxtail desiccation. Based on contrasts, no significant differences were observed between a single and sequential applications of pelargonic acid across rates for green foxtail desiccation. In other studies, pelargonic acid was applied at 4.5, 9, and 13.5 kg ha^{-1} to squash and desiccated smooth crabgrass 45, 89, and 9% 11 DAA, respectively (Webber et al., 2014a).

3.1.6 Barnyardgrass Desiccation

Pelargonic acid at 3400 g ai ha^{-1} desiccated barnyardgrass only 5, 5, and 4% at 5, 8, and 14 DAA, respectively (Table 2). Increasing the rate of pelargonic acid to 5100 or 6800 g ai ha^{-1} caused no significant increase in barnyardgrass desiccation. The sequential application of pelargonic acid 7 days apart at 3400 fb 3400 g ai ha^{-1}, 5100 fb 5100 or 6800 fb 6800 g ai ha^{-1} did not increase barnyardgrass desiccation. The addition of 28% UAN to pelargonic acid at 3400 g ai ha^{-1} did not improve barnyardgrass desiccation. Based on contrasts, there were no significant differences between single and sequential applications of pelargonic acid across all rates for barnyardgrass desiccation (Table 2). In other studies, Ogbangwor and Söchting (2022) found only 0.2% loss in fresh weight of barnyardgrass with pelargonic acid applied at 31 kg ai ha^{-1}.

3.2 Other Desiccants

3.2.1 White Bean Desiccation

At 5, 8, and 14 DAA, ammonium salt of fatty acid, carfentrazone-ethyl + Merge®, flumioxazin + MSO concentrate, tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90 desiccated white bean 88 to 97%, 95 to 100% and 99% at 5, 8, and 14 DAA, respectively; there were no differences in white bean desiccation among the desiccants evaluated. These results align well with other studies in which carfentrazone-ethyl, glufosinate, saflufenacil, diquat, and flumioxazin, caused 79, 85, 87, 88, and 90% white bean leaf desiccation at 8 DAA, respectively (Soltani et al., 2013). In another study, carfentrazone-ethyl, flumioxazin, glufosinate, diquat, and saflufenacil increased the progress of leaf desiccation by 0.73, 1.43, 1.45, 1.46, and 1.48 times compared to the non-treated control (McNaughton et al., 2015a). In another study, black bean was desiccated 76-98% with saflufenacil (50 g ai ha^{-1}) + MSO (1.0% v/v) (Goffnett el al., 2016). Sprague (2015) reported excellent dry bean desiccation with saflufenacil (70 g ai ha^{-1}) + MSO (1.0% v/v) + AMS.

3.2.2 Green Pigweed Desiccation

At 5, 8, and 14 DAA, green pigweed was desiccated 5, 50, and 60% with the ammonium salt of fatty acid; 0, 5, and 30% with carfentrazone-ethyl + Merge®; 2, 21, and 54% with flumioxazin + MSO concentrate; 13, 96, and 100% with tiafenacil + MSO concentrate, 8, 100, and 100% with saflufenacil + Merge®; 97, 100, and 100% with glufosinate; and 100, 100, and 100% with diquat + Agral® 90, respectively (Table 3). In other studies, carfentrazone-ethyl, flumioxazin, saflufenacil, glufosinate, and diquat caused 34, 44, 66, 68, and 78% redroot pigweed desiccation at 8 DAA, respectively (Soltani et al., 2013). Other reports have shown 29, 38, 41, 64, 65, and 78% desiccation of pigweeds 8 DAA with carfentrazone-ethyl, glyphosate, flumioxazin, saflufenacil, glufosinate, and diquat, and in dry bean (OMAFRA, 2017).

Table 3. White bean (*Phaseolus vulgaris* L.), green pigweed (*Amaranthus powellii*) and common ragweed (*Ambrosia artemisiifolia*) desiccation with various herbicides applied as a desiccant from five field trials conducted in southwestern Ontario, Canada in 2021, 2022 and 2023

Herbicide treatment	Rate[a]	App timing[b]	White bean desiccation (DAA)[e]			Weed desiccation (DAA)					
						Green pigweed			Common ragweed		
			5	8	14	5	8	14	5	8	14
	g ai ha^{-1}		%								
Non-treated control	-	-	87 a	93 a	98 a	0 c	0 d	0 b	0 d	0 d	0 d
Ammonium salt of fatty acid	15[d]	A	95 a	97 a	99 a	5 b	50 b	60 a	10 cd	14 c	12 c
Carfentrazone-ethyl + Merge®	28 + 0.1[d]	A	88 a	95 a	99 a	0 c	5 cd	30 ab	5 cd	7 cd	6 cd
Flumioxazin + MSO concentrate	54 + 2.5[c]	A	96 a	100 a	99 a	2 bc	21 c	54 a	23 c	59 b	68 b
Tiafenacil + MSO concentrate	25 + 1[d]	A	97 a	99 a	99 a	13 b	96 a	100	58 b	85 a	88 a
Saflufenacil + Merge®	50 + 1[c]	A	96 a	99 a	99 a	8 b	100	100	66 ab	93 a	96 a
Glufosinate	450	A	96 a	100 a	99 a	97 a	100	100	74 ab	93 a	95 a
Diquat + Agral® 90	550 + 0.1[d]	A	96 a	99 a	99 a	100	100	100	91 a	96 a	99 a

Note. Abbreviations: App, application; DAA, days after application; NS, non-significant.

[a] Herbicide rates are presented in g ai ha^{-1} and adjuvants in L ha^{-1}.

[b] Herbicide application A was made at 30% seed moisture content.

[c] Rate presented in L ha^{-1}.

[d] Rate presented as %v/v.

[e] Means followed by the same letter within unbroken columns are not significantly different according to Tukey-Kramer multiple range test (P > 0.05).

3.2.3 Common Ragweed Desiccation

At 5, 8, and 14 DAA, common ragweed was desiccated 10, 14, and 12% with the ammonium salt of fatty acid; 5, 7, and 6% with carfentrazone-ethyl + Merge®; 23, 59, and 68% with flumioxazin + MSO concentrate; 58, 85, and 88% with tiafenacil + MSO concentrate, 66, 93, and 96% with saflufenacil + Merge®; 74, 93, and 95% with glufosinate; and 91, 96, and 99% with diquat + Agral® 90, respectively (Table 3). Other studies have shown that carfentrazone-ethyl, glyphosate, flumioxazin, glufosinate, saflufenacil, and diquat caused 12, 17, 52, 66, 73 and 80% common ragweed desiccation, respectively, at 8 DAA in dry beans (Soltani et al., 2013). Other reports have shown 12, 17, 52 66, 73, and 80% common ragweed desiccation 8 DAA with carfentrazone-ethyl, glyphosate, flumioxazin, glufosinate, saflufenacil, and diquat, respectively in dry bean (OMAFRA, 2017).

3.2.4 Common Lambsquarters Desiccation

At 5, 8, and 14 DAA, common lambsquarters was desiccated 0, 0, and 0% with the ammonium salt of fatty acid and carfentrazone-ethyl + Merge®; 3, 20, and 31% with flumioxazin + MSO concentrate; 0, 5, and 5% with tiafenacil + MSO concentrate; 5, 40, and 75% with saflufenacil + Merge®; 91, 100, and 100% with glufosinate; and 96, 97, and 99% with diquat + Agral® 90, respectively (Table 4). In other studies, carfentrazone-ethyl, flumioxazin, glufosinate, saflufenacil, and diquat desiccated common lambsquarters 12, 52, 66, 73, and 80%, respectively at 8 DAA (Soltani et al., 2013). Other reports have shown 29, 30, 38, 46, 70, and 73% common lambsquarters desiccation with glyphosate, carfentrazone-ethyl, flumioxazin, saflufenacil, glufosinate, and diquat, respectively in dry bean at 8 DAA (OMAFRA, 2017).

Table 4. Common lambsquarters (*Chenopodium album*), green foxtail (*Setaria viridis*) and barnyardgrass (*Echinochloa crus-gali*) desiccation with various herbicides applied as a desiccant from five field trials conducted in southwestern Ontario, Canada in 2021, 2022 and 2023

Herbicide treatment	Rate[a]	App timing[b]	Weed desiccation (DAA)								
			Common lambsquarters			Green foxtail			Barnyardgrass		
			5	8	14	5	8	14	5	8	14
	g ai ha^{-1}		%								
Non-treated control	-	-	0 b	0 d	0 c	0 c	0 e	0 e	0 c	0 d	0 c
Ammonium salt of fatty acid	15[d]	A	0 b	0 d	0 c	44 ab	56 bcd	59 bc	44 ab	45 abc	36 abc
Carfentrazone-ethyl + Merge®	28 + 0.1[d]	A	0	0 d	0 c	6bc	15 d	11 d	9 b	7 cd	7 bc
Flumioxazin + MSO concentrate	54 + 2.5[c]	A	3 b	20 c	31 b	22 bc	80 ab	90 ab	36 ab	57 ab	69 ab
Tiafenacil + MSO concentrate	25 + 1[d]	A	0 b	5 cd	5 bc	23 bc	60 bc	80 abc	23 abc	37 abcd	42 abc
Saflufenacil + Merge®	50 + 1[c]	A	5 b	40 b	75 a	13 bc	25 cd	37 dc	30 abc	27 bcd	55 ab
Glufosinate	450	A	91 a	100	100	56 ab	97 a	99 a	83 ab	89 a	96 a
Diquat + Agral® 90	550 + 0.1[d]	A	96 a	97 a	99 a	80 a	99 a	99 a	90 a	91 a	96 a

Note. Abbreviations: App, application; DAA, days after application; NS, non-significant.

[a] Herbicide rates are presented in g ai ha^{-1} and adjuvants in L ha^{-1}.

[b] Herbicide application A was made at 30% seed moisture content.

[c] Rate presented in L ha^{-1}.

[d] Rate presented as %v/v.

[e] Means followed by the same letter within unbroken columns are not significantly different according to Tukey-Kramer multiple range test (P > 0.05).

3.2.5 Green Foxtail Desiccation

At 5, 8, and 14 DAA, green foxtail was desiccated 44, 56, and 59% with the ammonium salt of fatty acid; 6, 15, and 11% with carfentrazone-ethyl + Merge®; 22, 80, and 90% with flumioxazin + MSO concentrate; 23, 60, and 80% with tiafenacil + MSO concentrate, 13, 25, and 37% with saflufenacil + Merge®; 56, 97, and 99% with glufosinate; and 80, 99, and 99% with diquat + Agral® 90, respectively (Table 4). In other studies, herbicides such as carfentrazone-ethyl, saflufenacil, flumioxazin, glufosinate, and diquat caused 18, 41, 42, 64, and 65% green foxtail desiccation at 8 DAA, respectively (Soltani et al., 2013). Other reports have shown 7, 26, 32, 47, 52, 63% desiccation of foxtails with carfentrazone-ethyl, saflufenacil, flumioxazin, diquat, glufosinate, and glyphosate, respectively in dry bean 8 DAA (OMAFRA, 2017).

3.2.6 Barnyardgrass Desiccation

At 5, 8, and 14 DAA, barnyardgrass was desiccated 44, 45, and 36% with the ammonium salt of fatty acid; 9, 7, and 7% with carfentrazone-ethyl + Merge®; 36, 57, and 69% with flumioxazin + MSO concentrate; 23, 37, and 42% with tiafenacil + MSO concentrate, 30, 27, and 55% with saflufenacil + Merge®; 83, 89, and 96% with glufosinate; and 90, 91, and 96% with diquat + Agral® 90, respectively (Table 4). In other studies, Gaultier and Gulden (2016) reported 18, 41, 42, 55, 58, 64 and 65% desiccation of grasses with carfentrazone-ethyl, saflufenacil, flumioxazin, carfentrazone-ethyl + glyphosate, glyphosate, glufosinate, and diquat, in dry bean, respectively.

4. Conclusions

Overall, pelargonic acid provided limited desiccation of green pigweed, common ragweed, common lambsquarters, green foxtail, and barnyardgrass. Generally, there was no benefit from the sequential application compared to the single application, and there was no benefit from the addition of 28% UAN. The alternative herbicides ammonium salt of fatty acid, carfentrazone-ethyl + Merge®, flumioxazin + MSO concentrate, tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90 caused similar white bean desiccation; however, weed desiccation was weed species-specific. Tiafenacil + MSO concentrate, saflufenacil + Merge®, glufosinate, and diquat + Agral® 90 provided the best desiccation of green pigweed and common ragweed; while glufosinate, and diquat + Agral® 90 provided the best desiccation of common lambsquarters, green foxtail and barnyardgrass. In conclusion, among the desiccants evaluated in this study, glufosinate, and diquat + Agral® 90 provided the best white bean and annual weed desiccation.

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Authors Contributions

Drs. Peter Sikkema and Nader Soltani were responsible for this manuscript's study design and writing. Christian Willemse conducted the statistical analysis of the data collected.

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