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COMMON POKEWEED (*PHYTOLACCA AMERICANA* L.) MANAGEMENT IN PENNSYLVANIA FIELD CROPS

A Thesis in

Agronomy

by

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ABSTRACT

Common pokeweed (*Phytolacca americana* L.) is a perennial broadleaf weed with a large persistent taproot that is also capable of abundant seed production. It has become a frequent problem in agronomic crops in Pennsylvania. Traditionally, plowing was used to manage pokeweed; however, the wide-spread adoption of conservation tillage, a decline in the use of soil residual herbicides, and a decrease in diverse cropping rotations may have allowed pokeweed populations to increase in recent years. This research was conducted in order to identify opportunities to better manage pokeweed in corn, soybean, and other Northeast U.S. cropping rotations and shows that an integrated approach which includes both cultural and chemical tactics enables successful management of pokeweed in conservation tillage systems.

Experiments were conducted in order to investigate the biology of common pokeweed in order to better time control tactics. In a pokeweed seedling emergence timing experiment, seedlings emerged throughout the summer, but peak emergence occurred in mid to late May. By August, pokeweed seedling emergence ceased. Both above- and below-ground pokeweed biomass decreased with delayed emergence and plants which emerged in late July did not produce mature berries by the end of the season. Experiments were also conducted to assess herbicide efficacy on pokeweed control. In corn, glyphosate, plant growth regulators, and other herbicides provided at least 80% control in trials conducted over a 3-year period. In soybean, glyphosate provided the best control of pokeweed; all treatments including glyphosate provided at least 80% control, while non-glyphosate treatments provided less than 62% control. Other glyphosate experiments examined herbicide rate, nozzle selection, carrier volume, and application timing. Air induction and flat fan nozzles provided the same level of control and in one of two years, 93 L/ha carrier provided better control than greater carrier volumes. The highest rates of 1.27 and 1.73 kg ae/ha provided the best control 12 weeks after application (WAA), but at 44 WAA, there was no difference in control due to glyphosate rate. Glyphosate application after mid-June provided better control than earlier in the summer. Even though pokeweed is a challenging weed to control, the results from this research show that there are options for controlling pokeweed in Pennsylvania field crops. Understanding the emergence pattern and current herbicide options has provided insight on how to better time control tactics and reduce this problematic weed. In order to control pokeweed, an integrated approach must be taken. Crop rotation and selection and timing of herbicide application are important for effective control.

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Chapter 1

Prologue

Common pokeweed (*Phytolacca americana* L.) is a simple herbaceous perennial weed native to North America that can be found in most of the 50 states as well as Canada, Mexico, and Europe (Penn State University n.d., USDA NRCS n.d.). The most common occurrences are in the eastern United States and southeastern Canada (Penn State University n.d.). Pokeweed typically infests wooded areas, pond edges, roadsides, fencerows, farm fields, and other disturbed areas. Traditionally, plowing was used to keep pokeweed at bay; however, the wide-spread adoption of no-till, along with a decrease in the use of diverse crop rotations and decline in the use of soil residual herbicides has allowed pokeweed populations to expand (Nolte et al. 2002). Over the last five years, questions about pokeweed control have become commonplace at extension grower meetings in Pennsylvania (Curran 2011). Common pokeweed can be difficult to manage due to the large, persistent taproot as well as abundant seed production.

The presence of pokeweed in corn and soybean fields hinders the growth and yield of the crop as it competes for nutrients, sunlight, and water. In producing crops such as corn and soybean, minimizing the negative effects of competitive weeds is essential for optimum yield. Corn and soybean are two important crops in Pennsylvania, especially for the many dairy farms located across the state. Corn is used for ethanol, animal and human food, and various other products. In Pennsylvania, about 562,000 ha of corn grain and silage were harvested over the last five years, yielding an average of 3.3 million Mg of grain and 6.8 million Mg of silage (USDA NASS n.d.) each year. Soybeans are used for oil, biofuel, and animal and human food. Over the last five years, about 200,000 ha were planted in Pennsylvania each year (Pennsylvania Soybean

Promotion Board 2013, USDA NASS n.d.), yielding a total annual average of 621,000 Mg (USDA NASS n.d.).

Farmers have increasingly adopted no-till over the last decade. The percentage of ha in no-till corn (*Zea mays* L.) in Pennsylvania has doubled from 30% in 2001(Horowitz et al. 2010) to 60% in 2013 (USDA NASS 2014). The percentage of ha in no-till soybean [*Glycine max* (L.) Merr] in Pennsylvania has increased from 64% in 2007 to 74% in 2013 (USDA NASS 2014). There are several reasons for this increase in no-till; the first is soil conservation. In the Chesapeake Bay Watershed, soil conservation is and has been a large emphasis over the last couple decades in an effort to increase water quality in the Bay and its tributaries. No-till reduces cost and labor by reducing the number of passes through a field (Duiker and Myers 2002, Duiker 2013). However, no-till also allows for the establishment of perennial weeds, such as pokeweed, since the taproot can no longer be broken up by the plow (Bernstein et al. 2014, Buhler et al. 1994, Murphy et al. 2006, Owen 2008). The use of residual herbicides has decreased due to glyphosate-resistant soybeans, as well an emphasis on reducing rates of atrazine use in corn in certain geographies (USDA NASS n.d.).

Much of the recent scientific literature on pokeweed has focused on some medicinal and antiviral opportunities and not management as a weed in field crops (Baldwin et al. 2009, Domashevskiy et al. 2012, Maness et al. 2012, Mansouri et al. 2012). Previous research on the control of pokeweed is slightly more abundant in corn than in soybean, but both are limited. In a study investigating the effect of residual herbicides on control of pokeweed seedlings, eight out of 11 commonly used soil applied herbicides had at least 85% control (VanGessel 1999), which suggests that soil residual herbicides are a viable option for preventing pokeweed establishment. The Penn State Agronomy Guide lists several POST herbicides as having some activity on pokeweed in both corn and soybean, but only glyphosate has a rating of 90% control (Curran et al. 2013a, 2013b). Several studies have investigated the effectiveness of foliar applied herbicides on pokeweed with control ranging between 60 and 93% during the season of application (Glenn and Phillips 1994, Marcelli and Glenn 1993, Nolte et al. 2002, Young and Nolte 2002). Tank mixing glyphosate with other herbicides, including 2,4-D or dicamba, increased control compared to the same herbicides applied alone (Glenn and Phillips 1994, Marcelli and Glenn 1993, Nolte et al. 2002). A study in Maryland examining application timing reported 93% control when herbicides were applied to 30 cm-tall pokeweed; however control declined when pokeweed reached 60 cm tall (Marcelli and Glenn 1993). Control with some treatments appears short-lived, as 11 months following application of nicosulfuron or primisulfuron, with or without 2,4-D or dicamba, achieved less than 50% control (Glenn and Phillips 1994). Previous work in soybean mostly focused on glyphosate applied at several rates and timings reported that pokeweed control ranged from 88 to 100% (Glenn and Kalnay 2000, Nolte et al. 2002); however, soybean yield was reduced when glyphosate was not applied until the V-8 stage (Glenn and Kalnay 2000), showing that application timing is also important for preventing weed-crop competition.

Previous work reported that pokeweed produces about 58 fruits per raceme (Armesto et al. 1983) and there are nine to ten seeds per fruit (Armesto et al. 1983, Braun and Brooks 1987, Stapanian 1982). Viable seeds are reported to survive in the soil for at least 40 years (Mitich 1994). Several studies have examined various ways to induce pokeweed seed germination, including mechanical and acid scarification, stratification, and exposure to different light and temperature regimes (Armesto et al. 1983, Edwards et al. 1988, Farmer and Hall 1970, Kang et al. 1997); however, germination and emergence in a field setting has not been studied. Birds are believed to be a main mechanism of dispersal (Armesto et al. 1983, McDonnell et al. 1984), and seedling plants are often seen under trees or power lines where birds roost. Other animals, such as box turtles, have also been shown to disperse pokeweed seeds (Braun and Brooks 1987). Previous research on pokeweed seed burial has shown that buried seed reduces plant populations (Orrock and Damschen 2007) but also the potential for seed predation (Hyatt 1998). Plant toxicity is also a concern with pokeweed. At a young age, pokeweed is edible if cooked (Mitich 1994); however, mature plants are poisonous. The leaves, roots, and stems are poisonous to animals, including humans, while the berries appear only poisonous to humans. The toxin, called phytolaccatoxin, causes damage the to the digestive, nervous, and respiratory system and can result in death (Hill 1986, Penn State University n.d.).

Herbicide efficacy research on pokeweed has not been conducted in Pennsylvania and it has been over 10 years since anything was published in the literature. Efficacy research will allow the assessment of the current herbicide options for pokeweed control to better provide recommendations to our Pennsylvania farmers. Research on pokeweed germination, seedling emergence, and plant growth and reproduction should provide better insight into the development of integrated management strategies that can more effectively reduce this weed in field crops. These goals provide the foundation for four research objectives that include: 1) study the efficacy of corn and soybean herbicides on pokeweed control; 2) specially examine several application factors that influence glyphosate efficacy; 3) identify the emergence periodicity of pokeweed seedlings in the field; and 4) quantify the effect of seedling emergence timing on pokeweed height, fecundity, and above- and below-ground biomass. These objectives embody the basis of my Master's of Agronomy Thesis.

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Chapter 2

The Efficacy of Corn and Soybean Herbicides on Common Pokeweed

Abstract

Common pokeweed (*Phytolacca americana* L.) is a perennial broadleaf weed with a large persistent taproot that is also capable of abundant seed production. It has become a frequent problem in agronomic crops in Pennsylvania. Traditionally, plowing was used to manage pokeweed; however, the wide-spread adoption of no-till, as well as a decrease in the use of diverse crop rotations, and a decline in the use of soil residual herbicides may have allowed pokeweed populations to increase in recent years. The objective of this research was to identify effective herbicides for control of common pokeweed in corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. Herbicide efficacy experiments were conducted in separate locations in 2011 (corn only), 2012, and 2013 in fields with known infestations of common pokeweed. Herbicides were applied POST emergence to both crops and weed. The common pokeweed at application time ranged from seedling to about 1 m in height. Glyphosate-resistant corn and soybean varieties were used and several herbicides were tested alone and in combination. A total of 14 corn and 15 soybean herbicide treatments were evaluated across the three years. Most corn treatments provided at least 80 percent control throughout the season and significantly reduced common pokeweed biomass compared to the untreated control. In general, control with combinations that included glyphosate provided similar results to glyphosate alone and adding a soil residual herbicide may be important for control of seedling emergence. In soybean, glyphosate was the most effective herbicide tested. When glyphosate was included in the treatment, 79 to 91% control was achieved, whereas control was less than 62% when glyphosate

was absent. Above-ground biomass was reduced in non-glyphosate treatments, but not as much as treatments that contained glyphosate. Spring regrowth the year after application showed a similar trend to results from the fall in both corn and soybean. The results from this herbicide work show that glyphosate is an important ingredient for successful control of pokeweed in soybean, while in corn, several herbicides with various modes of action are possible options since all corn herbicides examined provided adequate control.

Introduction

Common pokeweed (*Phytolacca americana* L.) is a simple perennial broadleaf weed which infests wooded margins, pond edges, waterways, roadsides, fencerows, farm fields, and other disturbed areas. In agriculture, plowing was historically used to keep common pokeweed (pokeweed) at bay; however, the wide-spread adoption of no-till, along with the reduced diversity of crop rotations, and a decline in the use of soil residual herbicides has allowed pokeweed populations to expand (Nolte et al. 2002). Over the last five years, questions about pokeweed control have become commonplace at extension meetings in Pennsylvania (Curran 2011).

Farmers in the Northeast U.S. are increasingly adopting no-till over the last decade. The percentage of no-till corn ha planted in Pennsylvania has doubled from 30% in 2001 (Horowitz et al. 2010) to 60% in 2013 (USDA NASS 2014). The percentage of no-till soybean ha planted in Pennsylvania has increased from 64% in 2007 (USDA NASS 2008) to 74% in 2013 (USDA NASS 2014). This adoption of no-till is due to several reasons; the first is concern for soil loss, along with water quality concerns. In the Chesapeake Bay watershed, soil conservation is and has been a large emphasis over the last two decades in an effort to increase water quality in the Bay and its tributaries. In addition to soil conservation, no-till allows for fewer passes through the field, reducing labor and fuel costs, as well as decreasing the possibility for soil compaction

(Duiker and Myers 2002, Duiker 2013). However, no-tilling in annual crops can allow for the establishment of perennial weeds including pokeweed (Bernstein et al. 2014, Buhler et al. 1994, Murphy et al. 2006, Owen 2008). A decrease in the diversity of crop rotations has been seen in Pennsylvania as crop rotations shift to an annual rotation of corn and soybean. Although the number of harvested wheat (*Triticum aestivum* L.) ha have remained approximately the same, harvested ha of oats (*Avena sativa* L.), barley (*Hordeum vulgare* L.), rye (*Secale cereale* L.), and hay crops have decreased by 75, 37, 45, and 28%, respectively, in Pennsylvania over the last 20 years (USDA NASS n.d.). Decreasing crop rotation diversity reduces the ability to apply herbicides later in the season as well as reduces competition with emerging pokeweed. Finally, residual herbicide use declined with the introduction and adoption of glyphosate-resistant soybean starting in 1996 and the reduced use of atrazine in corn due to water quality concerns in certain geographies starting back in the early 1990's (USDA NASS n.d.). Residual herbicides may be important for controlling pokeweed seedlings which emerge later in the season.

Corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr] are two important crops in Pennsylvania, especially for the numerous dairy farms across the state. In Pennsylvania, an average of 562,000 ha of corn grain and silage were harvested annually over the last five years, yielding an average of 3.3 million Mg of grain and 6.8 million Mg of silage (USDA NASS n.d.) each year. Over the last five years, an average of 200,000 ha were planted to soybean each year in Pennsylvania (Pennsylvania Soybean Promotion Board 2013, USDA NASS n.d.), yielding a total annual average of 621,000 Mg (USDA NASS n.d.).

Much of the recent scientific literature on pokeweed has focused on some medicinal and antiviral properties, and not management as a weed in field crops (Baldwin et al. 2009, Domashevskiy et al. 2012, Maness et al. 2012, Mansouri et al. 2012). Most of the research on the weedy nature of pokeweed is not peer-reviewed, but rather from research reports and conference proceedings. Previous research on the control of pokeweed in corn is slightly more abundant than control in soybean, but research in both is limited. The Penn State Agronomy Guide lists several POST applied herbicides as having some activity on pokeweed in both corn and soybean, but only glyphosate has a control rating as high as 90% (Curran et al. 2013a, 2013b).

Previous research in corn showed that foliar applied herbicides provide between 60 and 90% control of perennial pokeweed during the season of application (Glenn and Phillips 1994, Marcelli and Glenn 1993, Nolte et al. 2002, Young and Nolte 2002). Tank-mixing glyphosate with 2,4-D, dicamba, or other herbicides provided better pokeweed control in corn than the same herbicides used alone (Glenn and Phillips 1994, Marcelli and Glenn 1993, Nolte et al. 2002). In an application timing study in Maryland, pokeweed control reached 93% when herbicides were applied to 30 cm tall pokeweed, but declined to 85% when pokeweed was up to 60 cm tall (Marcelli and Glenn 1993). Control with some treatments was relatively short-lived; 11 months following application of nicosulfuron or primisulfuron with or without 2,4-D or dicamba only achieved 50% control (Glenn and Phillips 1994). For a simple perennial like pokeweed, annual seed production is critical to sustain or increase populations. A study investigating the effect of residual herbicides on control of pokeweed seedlings reported that eight out of 11 commonly used soil applied herbicides resulted in greater than 85% control in both corn and soybean (VanGessel 1999). This suggests that soil residual herbicides could play an important role in preventing establishment and spread of pokeweed.

Previous work in soybean mostly focused on glyphosate and reported that pokeweed control was good (88-100% control) at various rates and application timings (Glenn and Kalnay 2000, Nolte et al. 2002); however, weed-crop competition as impacted by application timing also appears critical as soybean yield was reduced when glyphosate was not applied until the V-8 stage (Glenn and Kalnay 2000). Although glyphosate-resistant soybean which enables in-crop glyphosate application has been in the marketplace since 1996, numerous inquiries from private applicators and farmers suggest that glyphosate performance seems to vary for control of pokeweed and pokeweed remains an important weed of concern in soybean. Glyphosate may not provide complete control, and plants which are not killed are able to regrow and produce more seeds. Stopping seed production is critical, since pokeweed heavily relies on seed production and dispersal in order for the population to survive. Application methods, such as timing, may also play an important role in the amount of achieved control.

Specific guidelines for managing pokeweed in no-till corn and soybean are not currently available for the Mid-Atlantic region. The objective of this research was to characterize the effectiveness of some common POST herbicides for control of pokeweed in no-till corn and soybean. In addition, when soil residual herbicides were included, an attempt was made to determine their effect on seedling pokeweed control.

Materials and Methods

Corn. Field experiments testing the efficacy of corn herbicides on pokeweed control were conducted in 2011, 2012, and 2013. In 2011 and 2013, the trials were located at the Penn State University Russell E. Larson Agricultural Research and Education Center, Rock Springs, Centre County, PA (40°44’N, 77°57’W). In 2012, the experiment was conducted on a private farm near Mt. Joy, Lancaster County, PA (40°7’N, 76°27’W). All field locations had historically been farmed no-till, producing mostly corn grain, and had a history of pokeweed infestation. The soil series were Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) in 2011 and 2012 and Andover channery silt loam (fine-loamy, mixed, active, mesic Typic Fragiaquults) in 2013. The soil pH and organic matter were 5.8 and 3.0% in 2011, 7.1 and 2.2% in 2012, and 5.4 and 4.1% in 2013. Corn was no-till planted at each location between late April and early May. The Rock Springs sites were established using a John Deere 1780 6-row no-till planter[1], while the Mt. Joy location was planted with a John Deere 1760 8-row no-till planter.[1] The phosphorus (P) and potassium (K) fertility was amended each year based on analysis by the Penn State Agricultural Analytical Services Lab[2] for the Rock Springs sites or Spectrum Analytic, Inc.[3] for the Mt. Joy site, and slightly different fertility programs were used each year depending on location. The fertility program typically included a broadcast nitrogen application as urea just prior to planting or urea ammonium nitrate (UAN) as a sidedress application and starter fertilizer banded at planting. Glyphosate-resistant corn (DKC 58-83[4] in 2011; Pioneer P1184AM1[5] and 33T55[5] in 2012; and Pioneer PO891AM1[5] in 2013) was planted at each site in 76-cm rows at approximately 78,300 seeds/ha; the variety used in 2013 was also glufosinate-resistant. In 2011 and 2013, 0.82 kg ae/ha glyphosate plus 1.87 kg/ha s-metolachlor were broadcast applied at planting to aid in the control of emerged weeds and provide some residual control of annuals. In 2012, 0.82 kg/ha glyphosate, 1.87 kg/ha s-metolachlor, 0.84 kg/ha atrazine, and 0.188 kg/ha mesotrione were broadcast applied for this same purpose.

The experiment was arranged as a randomized complete block design with three replications in 2011 and four replications in 2012 and 2013. Individual plots measured 3 by 35 m in 2011, 3 by 23 m in 2012, and 4.5 by 23 m in 2013. Plots were made larger than typical research plots in order to ensure adequate pokeweed populations in each plot. Herbicides were applied using an RTV-mounted CO_2 boom sprayer[6] equipped with TeeJet AIXR11002 nozzles[7] calibrated to deliver a volume of 140 L/ha in 2011 and 187 L/ha in 2012 and 2013 at 275 kPa. Herbicide treatments were applied at standard labeled rates and included appropriate adjuvants (Table 2-1). Herbicides were applied POST at the V4-V6 stage of corn on June 17, 2011, May 25, 2012, and June 12, 2013, when pokeweed ranged from seedling to 122 cm tall with perennial plants averaging 91 cm tall and in the vegetative stage of growth. The 2012 location is approximately 140 km south of the 2011 and 2013 locations and approximately 10 days ahead relative to growing degree days (GDD). Treatments varied somewhat each year based on available land area, ranging from seven in 2011 to ten in 2013. Untreated control plots were always included.

Pokeweed control was visually assessed in August of each season on a scale of 0 to 100 (0 = no control and 100 = complete control). Plots were also rated on a scale of 0 to 3 (0 = no control and 3 = complete control) for control of newly emerged seedlings. This scale was later transformed to a 0 to 100 scale as defined above. In addition, three pokeweed plants were tagged with plastic ribbon in each plot at the time of POST application in order to track herbicide efficacy at subsequent evaluations. The biomass from these tagged plants was harvested by hand by removing all above-ground plant material between mid August and mid September depending on the location and year, and both fresh and dry weights were recorded. For dry weight, plants were oven-dried for a minimum of 96 h at 60°C. For 2011 only, regrowth was assessed the following spring based on presence or absence of living plants from previously treated plots.

Soybean. Field experiments testing the efficacy of soybean herbicides on pokeweed control were conducted in 2012 and 2013 at the Penn State research farm previously identified in the corn section. As with the corn research, the field location had historically been farmed in no-till with a history of pokeweed infestation. The soil series was a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) with a soil pH and organic matter of 6.3 and 3.0% in both 2012 and 2013. Soybeans were no-till planted each year at the end of May and P and K levels were maintained according to soil tests. Glyphosate-resistant soybean (Asgrow 3833[4] in 2012 and FS HS31A03[8] in 2013) were planted at each site in 76-cm rows at 370,500 seeds/ha. The variety used in 2012 was also sulfonylurea tolerant (STS).

The soybean experiment was arranged as a randomized complete block design with four replications. Individual plots measured 4.5 by 18 m. Herbicides were applied as described in the corn section at 187 L/ha and 275 kPa. Herbicides were applied at standard labeled rates and included appropriate adjuvants (Table 2-2). Herbicides were applied POST at the V2 stage of soybean on June 28, 2012, and June 19, 2013. In addition, a single treatment investigated a sequential application of glyphosate where a second application occurred at the V3-V4 stage of soybean on July 12, 2012, and July 3, 2013 (LPOST). At the POST and LPOST application dates in both years, the treated pokeweed ranged from seedling to 122 cm tall with perennial plants averaging 91 cm tall and in the vegetative to early reproductive stages of growth. Treatments were similar both years, with eleven in 2012 and thirteen in 2013. Untreated control plots were also included.

Pokeweed control was assessed in September as described in the corn section. Soybean yield was collected in both years using a Massey Ferguson 550 combine.[9] In 2012 only, spring regrowth of treated plants was assessed about 11 mo. after application. Percent control and above-ground fresh and dry weight data were collected using the same methods as the previous fall.

Statistical Analyses. Analyses were performed in SAS 9.3[10] with the Mixed procedure. Analysis of variance (ANOVA) was used to test for differences in pokeweed control with the different herbicide treatments. Means were separated using Fisher's Protected LSD with significance set at $P < 0.05$. The data from the corn study in 2011 was analyzed separately due to multiple changes made in the treatment list for the studies in 2012 and 2013. For both the corn and soybean 2012 and 2013 studies, each year was analyzed separately and if error terms were homogenous, then the common treatment data were pooled over the two years. Treatments only included in one out of the two years were not included in the pooled analysis. "Treatment" was treated as a fixed variable, and "Rep" and "Year" were treated as random variables. Control ratings, given in percentages, were analyzed using the raw data. Pokeweed biomass was transformed [$y = log(x + 10)$] in order to normalize the variance and meet the assumptions of ANOVA.

Sources of Materials
[1]John Deere, Moline, IL 61265-8098
[2]Tower Road, University Park, PA 16802
[3]Washington Court House, OH 43160-8748
[4]Monsanto Company, St. Louis, MO 63167
[5]DuPont Pioneer, Johnston, IA 50131-0184
[6]Ranger HD 700 EFI, Polaris Industries, Medina, MN 55340
[7]Spraying Systems Co., Wheaton, IL 60187
[8]Growmark FS, Milford, DE 19963
[9]AGCO, Duluth, GA 30096
[10]SAS® statistical analysis software, SAS Institute Inc., Cary, NC 27513

Results and Discussion

Corn. Control in corn was variable in 2011 by 8 weeks after application (WAA) with the herbicides providing 37 to 80% pokeweed control (Table 2-3). The greatest control was provided by the glyphosate + mesotrione and the high rate of glyphosate, which achieved 79 and 80%, respectively. All other herbicides provided less than 55% control (Table 2-3). Pokeweed fresh wt varied greatly and was only reduced by glyphosate alone and the glyphosate + halosulfuron + dicamba tank mix (Table 2-3). However, pokeweed dry wt was less variable and was reduced by all herbicides except the high rate of dicamba + diflufenzopyr compared to the untreated check. The differing results between fresh and dry wt was likely due to size variability and moisture content; in the end, dry wt appears to be the more accurate measure of treatment effects in 2011. The spring after application (44 WAA), all herbicides provided 66 to 89 percent control of pokeweed and there was a trend for tank mixes with glyphosate having greater control; however, no treatments were statistically different (Table 2-3).

In 2012 and 2013, visual ratings, plant fresh and dry weights, and yields were pooled across years because the error terms were homogenous. All of the herbicide treatments provided at least 80% control 12 WAA and did not differ from one another (Table 2-4). Pokeweed biomass was reduced by all herbicides and showed a similar trend across treatments. The untreated check plots had the highest fresh and dry weights (4120 and 557 g, respectively) compared to the herbicide treatments and, like the visual control ratings, no differences were observed between any of the herbicide treatments (Table 2-4). In 2013, glufosinate + atrazine was included in the trial, providing 69% control, which was lower than the other treatments, but plant biomass was reduced and similar to the other herbicide treatments. The glufosinate + atrazine mixture is not systemic, so greater plant regrowth would be expected following application. These results indicate that glufosinate + atrazine will not completely control pokeweed but it will likely reduce pokeweed competition in corn.

All of the treatments provided good seasonal control in corn, but since there was some green or living tissue remaining at the end of the season, none of the herbicides provided complete control. This could indicate the potential for recovery and regrowth the following year. The on-farm location in 2012 did not allow for a year after application assessment because of field management issues (spring tillage and soil disturbance), and year after observations have not yet been collected for 2013. Corn grain was harvested from each plot in 2013, but treatment effects were not significant for most treatments (data not presented). This was likely due to variable pokeweed and annual weed density, as well as variability in soil properties across the fields. As a simple perennial, individual pokeweed plants tend to be somewhat scattered in most fields, so some plots had higher densities than others. In 2011, 2012, and 2013, plant density per plot at the time of herbicide application ranged from 3 plants up to a dozen or more perennial plants. One goal was to have at least 3 plants in each plot to adequately assess performance and collect biomass. In general, pokeweed control was slightly lower in 2011 than in 2012 and 2013, but the population was more scattered, making it more difficult to evaluate treatment performance. Pokeweed density in 2012 was relatively uniform and individual plot width was increased in 2013 to ensure sufficient populations within each individual plot.

The results from this corn research are similar to previous work showing that several herbicides can achieve 80% or greater seasonal control. Glyphosate, 2,4-D, and dicamba are all active on pokeweed and previous research with these herbicides has reported from 67 to 95% control (Glenn and Phillips 1994, Marcelli and Glenn 1993, Young and Nolte 2002). Tank-mixing 2,4-D or dicamba with other herbicides has provided between 75 and 85% control (Marcelli and Glenn 1993), which is similar to the levels observed in our study. One study reported 94% control with mesotrione alone 56 d after application (Young and Nolte 2002); our research showed that mesotrione + atrazine alone or in combination with glyphosate provides about 80% control and is similar to other effective herbicides.

An attempt was made to evaluate mid-summer seedling control in 2012 and 2013, but seedling density varied due to factors beyond herbicide treatments. However, some plots had relatively high densities of new seedlings and this appeared to be related to the exclusion of soil residual herbicide. Although meaningful quantitative data was not collected on seedling emergence, seedling control will be important for management since seedling pokeweed can become perennial within several weeks and likely maintain or increase the population (Patches and Curran 2013). A Delaware study reported that eight of eleven herbicides provided at least 85% control of pokeweed seedlings, indicating that there are herbicide options for controlling seedlings (VanGessel 1999). The residual herbicide atrazine was included at 0.56 kg/ha in three treatments and some of these plots seemed to have fewer seedlings. Atrazine applied at 0.84 kg/ha provided 84% control in the Delaware study, showing that it will help with seedling control.

Soybean. Visual ratings, plant fresh and dry weights, and yields were pooled across years because the error terms were homogenous. Pokeweed control in soybean was more variable than in corn. In general, treatments which included glyphosate provided 80% control or higher, while those that excluded glyphosate achieved 39 to 62% control (Table 2-5). As anticipated, the untreated control plots had the greatest above-ground fresh and dry wt (2181 and 464 g, respectively) at 12 WAA, while glyphosate containing treatments had the lowest biomass. Non-glyphosate herbicides also reduced biomass compared to the untreated check, but not as much as the glyphosate treatments (Table 2-5). Chlorimuron and thifensulfuron were included alone and in combination with glyphosate, and thifensulfuron proved to be slightly more effective than chlorimuron, but even the highest rate of the combination (STS soybean rate) only provided 62% control. In 2013, cloransulam and imazamox were also included in the experiment, but are not included in the two-year pooled analysis. Both of these treatments performed similar to the other non-glyphosate treatments, with imazamox providing 61% control and cloransulam only 21% control. Imazamox significantly reduced both fresh and dry weights when compared to the untreated check; however, weights were still significantly higher than the glyphosate treatments. Pokeweed biomass in the cloransulam treatment was not different than the untreated check.

Year after application spring regrowth was assessed for 2012 only, and results showed that glyphosate treatments generally provided better control than non-glyphosate treatments (Table 2-6). Glyphosate applied at 1.74 kg/ha in a single or sequential application provided the numerically highest control at greater than 90%. All other treatments ranged from 53 to 80% control. Although above-ground biomass was similar across treatments, the split application of glyphosate provided complete control of pokeweed (Table 2-6).

Soybean grain yield was collected from individual plots both years, but because of variable pokeweed and annual weed populations, yields did not always follow pokeweed control (data not presented). The 2012 yield data was more consistent than 2013 and did show that not controlling pokeweed reduced soybean yield by about 47% compared to the highest yielding glyphosate treatment (2990 vs. 1453 kg/ha).

The results indicate that glyphosate is a key herbicide for controlling pokeweed in soybean. Previous studies have reported similar findings. Glyphosate applied at three different rates and three different growth stages in soybean provided 97 to 100% control (Glenn and Kalnay 2000). Tank-mixing glyphosate with cloransulam or thifensulfuron + chlorimuron provided an increase in control of at least 29% from cloransulam or chlorimuron + thifensulfuron alone (Nolte et al. 2002); this research found an increase in control of pokeweed of 62 and 34%, respectively, when glyphosate was tank mixed with cloransulam and chlorimuron + thifensulfuron compared to those herbicides alone. Glyphosate does not have residual activity, which may be important for seedlings emerging after the POST herbicide application. Seedlings were scattered across the soybean plots in late season but not specific to any one herbicide treatment. However, tank mixing glyphosate with an effective residual herbicide could be important for controlling both the perennial pokeweed and the seedlings that may emerge mid and late summer.

Corn herbicides provided at least 80% control of pokeweed at 12 WAA; however, none provided complete control since there was some green or living tissue remaining at the end of the season. This indicates a potential for recovery and regrowth the following year. Glufosinate + atrazine was tested in the second year of the study. It only provided 69% control, but did reduce biomass similarly to the other treatments. The glufosinate + atrazine treatment was not systemic, so greater plant regrowth would be expected following application. While it will not completely control pokeweed, it may help to reduce pokeweed competition in corn. Soybean herbicides provided a wide range of pokeweed control. At 12 WAA, treatments which included glyphosate provided 80% control or higher, while those treatments without glyphosate only provided 39 to 62% control. Non-glyphosate treatments reduced pokeweed biomass compared to the untreated check, but not as much as the glyphosate treatments. Residual herbicides may play an important role in controlling the pokeweed seedlings which were observed emerging throughout the summer. Seedlings which emerge later in the summer may be able to survive the winter and fully regrow in the following year. Regrowth in the spring after application showed results similar to what was observed the year of application, with the glyphosate treatments providing better control than the non-glyphosate treatments. This research indicates that glyphosate is an important herbicide for controlling pokeweed in soybean. However, in corn, which may be more competitive with pokeweed than soybean, there are several herbicide options in addition to glyphosate, since all herbicide treatments examined provided adequate control.

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Tables

Table 2-1. Treatment list for the corn herbicide trial at Rock Springs in 2011 and 2013 and Mt. Joy in 2012.

Herbicide(s)	**2011**	**2012**	**2013**
	Rate (kg ae or ai/ha)		
2,4-D	-	0.56	0.56
dicamba	-	0.56	0.56
dicamba + diflufenzopyr	0.14 + 0.056 and 0.28 + 0.11	0.28 + 0.11	0.28 + 0.11
glufosinate + atrazine	-	-	0.59 + 1.12
glyphosate	0.84 and 1.26	1.26	1.26
glyphosate + dicamba + diflufenzopyr	0.84 + 0.14 + 0.056	1.26 + 0.28 + 0.11	1.26 + 0.28 + 0.11
glyphosate + mesotrione + atrazine	0.84 + 0.11[a]	1.26 + 0.11 + 0.56	1.26 + 0.11 + 0.56
glyphosate + halosulfuron + dicamba	0.84 + 0.035 + 0.15	-	-
glyphosate + halosulfuron + dicamba + diflufenzopyr	-	1.26 + 0.035 + 0.28 + 0.11	1.26 + 0.031 + 0.0037[b] + 0.28 + 0.11
halosulfuron + dicamba + diflufenzopyr	-	0.035 + 0.28 + 0.11	0.031 + 0.0037 + 0.28 + 0.11[b]
mesotrione + atrazine	-	0.11 + 0.56	0.11 + 0.56

[a] Atrazine was excluded in 2011.

[b] Thifensulfuron was added in 2013.

Table 2-2. Treatment list for the soybean herbicide trial at Rock Springs in 2012 and 2013.

Herbicide(s)	**Rate (kg ae or ai/ha)**
cloransulam	0.000194[a]
chlorimuron	0.0131
chlorimuron + thifensulfuron	0.0058 + 0.00175 and 0.0173 + 0.00525
glyphosate	0.87 and 1.74 and 0.87 followed by 0.87
glyphosate + cloransulam	0.87 + 0.000194
glyphosate + chlorimuron	0.87 + 0.0058
glyphosate + chlorimuron + thifensulfuron	0.87 + 0.0058 + 0.00175
glyphosate + imazamox	0.87 + 0.044
imazamox	0.044[a]
thifensulfuron	0.0044

[a] The cloransulam and imazamox alone treatments were excluded in 2012.

Table 2-3. Effect of corn herbicides on pokeweed control, 8 and 44 weeks after application (WAA) and the spring following application, 2011.

		8 WAA			**44 WAA**
Herbicide(s)	**Rate (kg ai or ae/ha)**	**% Control**	**Fresh weight** (g)**	**Dry weight** (g)**	**% Control**
Control	--	--	1261 (± 469) a	215 (± 82) a	--
glyphosate	0.87	55 (± 5) b	114 (± 22) bc	21 (± 4) b	78 (± 14) a
glyphosate	1.27	80 (± 5) a	62 (± 25) c	22 (± 5) b	77 (± 14) a
dicamba + diflufenzopyr	0.14 + 0.056	43 (± 5) bc	284 (± 123) abc	36 (± 14) b	66 (± 14) a
dicamba + diflufenzopyr	0.28 + 0.11	36 (± 5) c	505 (± 175) ab	66 (± 25) ab	66 (± 14) a
glyphosate + dicamba + diflufenzopyr	0.87 + 0.14 + 0.056	52 (± 5) b	361(± 150) abc	55 (± 19) b	89 (± 14) a
glyphosate + mesotrione	0.87 + 0.11	79 (± 5) a	320 (± 146) abc	50 (± 14) b	89 (± 14) a
glyphosate + halosulfuron + dicamba	0.87 + 0.04 + 0.15	37 (± 5) c	314 (± 183) bc	52 (± 26) b	89 (± 14) a

*Standard errors are in parentheses. Values followed by the same letter are not significant using Fisher's LSD at $P < 0.05$.

**Means and standard errors are from the raw data. Significance letters are from the transformed data.

Table 2-4. Effect of corn herbicides on pokeweed control, 12 weeks after application (WAA), 2012-2013.

Herbicide(s)	**Rate (kg ai or ae/ha)**	**% Control**	**Fresh weight** (g)**	**Dry weight** (g)**
Control	--	--	4120 (± 558) a	557 (± 86) a
glyphosate	1.27	85 (± 3) a	287 (± 91) b	39 (± 12) b
2,4-D	0.56	87 (± 3) a	303 (± 107) b	79 (± 22) b
dicamba	0.56	86 (± 3) a	353 (± 162) b	57 (± 11) b
dicamba + diflufenzopyr	0.28 + 0.11	86 (± 3) a	205 (± 95) b	41 (± 19) b
mesotrione + atrazine	0.11 + 0.56	84 (± 3) a	600 (± 196) b	85 (± 30) b
halosulfuron + dicamba + diflufenzopyr	0.04 + 0.28 + 0.11	81 (± 3) a	404 (± 117) b	60 (± 19) b
glyphosate + dicamba + diflufenzopyr	1.27 + 0.28 + 0.11	82 (± 3) a	513 (± 179) b	71 (± 27) b
glyphosate + mesotrione + atrazine	1.27 + 0.11 + 0.56	82 (± 3) a	519 (± 163) b	82 (± 24) b
glyphosate + halosulfuron + dicamba + diflufenzopyr	1.27 + 0.035 + 0.28 + 0.11	85 (± 3) a	414 (± 141) b	84 (± 35) b

*Standard errors are in parentheses. Values followed by the same letter are not significant using Fisher's LSD at $P < 0.05$.

**Means and standard errors are from the raw data. Significance letters are from the transformed data.

Table 2-5. Effect of soybean herbicides on pokeweed control, 12 weeks after application (WAA), 2012-2013.

Herbicide(s)	**Rate (kg ai or ae/ha)**	**% Control**	**Fresh weight** (g)**	**Dry weight** (g)**
Control	--	--	2181 (± 443) a	464 (± 103) a
glyphosate	0.87	79 (± 4) b	108 (± 39) c	34 (± 9) d
glyphosate	1.74	91 (± 4) a	60 (± 20) c	23 (± 6) d
glyphosate	0.87 fb 0.87	88 (± 4) ab	69 (± 17) c	33 (± 6) d
chlorimuron	0.0131	39 (± 4) d	689 (± 124) b	134 (± 24) b
thifensulfuron	0.0044	54 (± 4) c	816 (± 206) b	144 (± 36) b
chlorimuron + thifensulfuron	0.0058 + 0.00175	51 (± 4) c	647 (± 151) b	115 (± 26) b
chlorimuron + thifensulfuron	0.0173 + 0.0525	62 (± 4) c	377 (± 54) b	75 (± 12) bc
glyphosate + chlorimuron + thifensulfuron	0.87 + 0.0058 + 0.00175	85 (± 4) ab	169 (± 72) c	44 (± 16) d
glyphosate + chlorimuron	0.87 + 0.0058	81 (± 4) ab	124 (± 45) c	36 (± 10) d
glyphosate + cloransulam	0.87 + 0.000194	83 (± 4) ab	112 (± 57) c	60 (± 26) cd
glyphosate + imazamox	0.87 + 0.044	84 (± 4) ab	90 (± 30) c	39 (± 10) d

*Standard errors are in parentheses. Values followed by the same letter are not significant using Fishers' LSD at $P < 0.05$.

**Means and standard errors are from the raw data. Significance letters are from the transformed data.

Table 2-6. Effect of soybean herbicides on pokeweed spring regrowth, spring after the 2012 season.

Herbicide(s)	**Rate (kg ai/ha)**	**% Control**	**Fresh weight** (g)**	**Dry weight** (g)**
Control	--	--	2 (± 2) cd	0.3 (± 0.3) bcd
glyphosate	0.87	77 (± 12) ab	6 (± 5) d	0.5 (± 0.4) cd
glyphosate	1.74	99 (± 12) a	0 (± 0) d	0 (± 0) d
glyphosate	0.87 fb 0.87	91 (± 12) a	4 (± 4) d	0.5 (± 0.5) cd
chlorimuron	0.0131	31 (± 12) c	137 (± 79) a	12 (± 6) a
thifensulfuron	0.0044	44 (± 12) bc	23 (± 9) abcd	2 (± 0.8) bcd
chlorimuron + thifensulfuron	0.0058 + 0.00175	27 (± 12) c	84 (± 60) abc	7 (± 5) ab
chlorimuron + thifensulfuron	0.0173 + 0.0525	39 (± 12) c	55 (± 26) ab	5 (± 2) abc
glyphosate + chlorimuron + thifensulfuron	0.87 + 0.0058 + 0.00175	99 (± 12) a	0 (± 0) d	0 (± 0) d
glyphosate + chlorimuron	0.87 + 0.0058	91 (± 12) a	2 (± 2) d	0.2 (± 0.2) d
glyphosate + chloransulam	0.87 + 0.000194	82 (± 12) a	20 (± 20) bcd	2 (± 2) bcd
glyphosate + imazamox	0.87 + 0.044	91 (± 12) a	1 (± 1) d	0.2 (± 0.2) d

*Standard errors are in parentheses. Values followed by the same letter are not significant using Fisher’s LSD at $P < 0.05$.

**Means and standard errors are from the raw data. Significance letters are from the transformed data.

Chapter 3

Glyphosate Application Methods on Common Pokeweed Control

Abstract

Common pokeweed (*Phytolacca americana* L.) is a perennial broadleaf weed with a large persistent taproot that is also capable of abundant seed production. It has become a frequent problem in agronomic crops in Pennsylvania. Glyphosate is a commonly used herbicide in agricultural systems for management of perennial weeds. In order to examine the glyphosate-common pokeweed relationship more closely, four individual experiments were conducted in 2012 and 2013 in fields infested with pokeweed. The experiments focused on nozzle selection, herbicide rate, carrier volume, and application timing. In most experiments, individual pokeweed plants were treated with glyphosate at 0.84 kg ae/ha using air induction nozzles at 187 L/ha in mid-June. In the nozzle study, air induction nozzles were compared to standard flat fan nozzles. For the rate study, glyphosate was applied at 0.84, 1.26, and 1.68 kg/ha and for the volume study, 94, 187, and 374 L/ha were compared. The results showed that control was similar for the two nozzles, there was a trend for better control with the higher rates, and a trend for reduced control as volume increased. For the application timing study, individual pokeweed plants were treated every two to four weeks from mid May to late September. For each application timing, treated and untreated plants were collected eight weeks after application (2012 and 2013) and at the end of the season (2013). Results showed that applications before mid June provided less than 70% control, and applications at or after mid June provided at least 93% control. The results from these experiments showed no clear advantage to increasing glyphosate rate above 0.84 kg/ha, no difference in air induction and flat fan nozzle performance or reducing carrier volume to improve

common pokeweed control. Late spring application timings proved less effective than summer-time application timings, which should target control after mid June in central Pennsylvania.

Introduction

Common pokeweed (*Phytolacca americana* L.) is an herbaceous perennial weed that is a frequent problem in no-till agriculture (Curran 2011, Owen 2008). Glyphosate is an important herbicide in agricultural cropping systems and is often used to target pokeweed and other weeds in no-till systems. A number of factors influence glyphosate efficacy on weeds, including susceptibility of the species (Bowmer and Eberbach 1993, Sandberg et al. 1980). The Penn State Agronomy Guide lists several POST applied herbicides as having activity on pokeweed in both corn and soybean, but only glyphosate has a control rating as high as 90% (Curran et al. 2013a, 2013b). Herbicide selection may be only the first step for achieving effective chemical weed control. Other studies report glyphosate performance at a range of 88 to 100% control at various rates and application timings (Curran et al. 2013a, Curran et al. 2013b, Glenn and Kalnay 2000, Nolte et al. 2002). Even though glyphosate-resistant technology is available, pokeweed continues to be a problem. Pokeweed may be a harder perennial weed to control with glyphosate compared to other perennials such as Canada thistle [*Cirsium arvense* (L.) Scop.] and hemp dogbane (*Apocynum cannabinum* L.), possibly due to its abundant seed production and emergence throughout the summer, as well as ineffective application methods. Other factors such as spray equipment, nozzle selection, herbicide rate, spray volume, water quality, application timing, and weather all play an important role in herbicide performance (Peterson et al. 2013).

Previous research has examined the effect of nozzle type, spray volume, herbicide rate, and application timing on glyphosate performance. A few of these looked at pokeweed, but most focused on other weeds. Etheridge et al. (2001) observed similar control between an air induction and a flat fan nozzle on common cocklebur (*Xanthium strumarium* L.) three weeks after treatment, while a third nozzle with more coarse droplets provided slightly less control. The same study also found that glyphosate efficacy was no different with a carrier volume of 100 L/ha than 50 L/ha by three weeks after treatment. Bruce and Kells (1990) reported that a volume of 98 L/ha was just as effective as 210 L/ha on horseweed [*Conyza canadensis* (L.) Cronq.]. Knoche (1994) reported that seven out of eight studies showed an increase in glyphosate efficacy with lower spray volumes. Several other studies also indicate that lower spray volumes increase control of other annual (Blank 1980, Kudsk 1988, Ramsdale and Messersmith 2001) and perennial weeds (Jordan 1981, Miller et al. 1984, Troutman et al. 1981). The glyphosate product label supports lower herbicide application rates for some annual weed species when water carrier volumes are reduced below 142 L/ha (Anonymous 2012).

Numerous studies have examined the effect of glyphosate rate on herbicide performance. For common pokeweed, the glyphosate label recommends application of 1.26 kg ae/ha glyphosate in 28 to 373 L/ha carrier to actively growing plants up to 61 cm tall (Anonymous 2012). The label does not mention alternative rates or carrier volumes based on pokeweed size or growth stage. Herbicide rate may be particularly important for control of perennial weeds, where herbicide translocation to vegetative structures is necessary for complete control. Knezevic et al. (2013) reported a 2 to 9% increase in control with a higher rate of glyphosate (2.5 kg/ha) compared to the lower rate (1.25 kg/ha) on the perennial common reed [*Phragmites australis* (Cav.) Trin. ex Steud.]. Dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers) control significantly increased as glyphosate rate was increased from 0.42 to 0.84 kg/ha, regardless of whether glyphosate was applied in the spring or fall (Franssen and Kells 2007). Wild garlic (*Allium vineale* L.) control increased with increasing glyphosate rate (Troutman et al. 1981) and Carlson and Donald (1988) reported that the number of visible adventitious root buds on Canada thistle decreased as the rate of glyphosate increased. Finally, mugwort (*Artemisia vulgaris* L.) control one yr after treatment increased from 60 to 100 percent as glyphosate rate increased from 0.28 to 8.9 kg/ha (Bradley and Hagood 2002).

Herbicide application timing is critical, especially for perennial weed control. Previous research reported that common pokeweed control ranged from 88 to 100% from herbicides applied postemergence at various rates and growth stages (Glenn and Kalnay 2000, Nolte et al. 2002). Lingenfelter and Curran (2007) reported peak control of wirestem muhly [*Muhlenbergia frondosa* (Poir.) Fern.], a perennial grass, with glyphosate applied around mid June; glyphosate applied prior to this date was less effective. Froese et al. (2005) reported better dandelion control with glyphosate applied post harvest to spring canola (*Brassica napus* L.) compared to either preplant or in crop. Glyphosate applied postemergence in double crop soybean provided better control of trumpetcreeper [*Campsis radicans* (L.) Seem. ex Bureau] than glyphosate applied preemergence (Bradley et al. 2004). Dandelion control with glyphosate was better with a fall application than a spring application (Franssen and Kells 2007, Hacault and Van Acker 2006). A number of studies have shown that late summer application of herbicides to perennials such as dandelion and Canada thistle can maximize control, probably because of increased herbicide translocation to underground storage organs (Stewart-Wade et al. 2002, Tworkoski 1992, Wilson and Michiels 2003).

Previous research examining glyphosate performance on pokeweed is lacking. Much of what has been published is not peer-reviewed, but rather is from research reports and conference proceedings. Over the last decade, glyphosate-resistant soybean and the use of glyphosate have been widely adopted in U.S. soybean producing states, with 89 percent of the soybean acres surveyed receiving a POST glyphosate application (USDA NASS 2013), yet pokeweed continues to be problematic in this crop. Guidelines for maximizing glyphosate efficacy for pokeweed control could help growers better manage this problem weed in no-till environments. In order to develop those guidelines, several studies were initiated to investigate the efficacy of glyphosate on pokeweed control. The objectives were to determine the effect of nozzle tip selection, carrier volume, herbicide rate, and application timing on control of perennial pokeweed with glyphosate.

Materials and Methods

Field experiments were conducted in 2012 and 2013 at the Penn State University Russell E. Larson Agricultural Research and Education Center, Rock Springs, Centre County, PA (40°44’N, 77°57’W). Different areas of the same field were used both years at a site that had historically been farmed no-till, producing mostly corn grain (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.]. The field had a severe natural infestation of pokeweed. The soil series was Andover channery silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) and the soil pH and organic matter were 5.4 and 4.1%, respectively. In both years, soybean was planted in late May in 76-cm rows and 0.82 kg/ha glyphosate plus 1.87 kg/ha s-metolachlor were broadcast preemergence to aid in the control of emerged weeds and provide some residual control of annuals; however, soybean growth and performance was not a component of this experiment and was only included to help manage the field site. Four independent experiments were conducted within the field in order to test nozzle tip selection, carrier volume, herbicide rate, and application timing. No fertilizer or soil amendments were applied during the duration of the experiment.

In each experiment, glyphosate was applied to individual plants of similar size and growth stage using a four-nozzle 1.5 m CO_2 backpack hand-held boom sprayer. The sprayer was calibrated to deliver the required carrier volume and rate as needed in each of the experiments and all applications were applied at 4.8 km/h and 220 kPa. No surfactant was added to the glyphosate in any of the four studies. Each individual treatment was applied to three plants per replication with four replications for the nozzle, volume, and rate studies. For the application timing study, six individual plants were treated separately at each application time. Most herbicide applications occurred before 12 noon, with occasional afternoon applications. Specific application information for each experiment is provided in Table 3-1. For the timing experiment, application occurred about every 14 days from mid to late May through July (2012) or August (2013), then monthly through September (Table 3-2). Pokeweed phenology was characterized at each application timing based on vegetative and reproductive development. An equivalent number of untreated plants were identified and marked at each application for biomass collection at harvest.

Pokeweed control was assessed 12 weeks after application (WAA) for the nozzle, volume, and rate studies. For the application timing study, the control assessment data were collected 8 WAA (2012 and 2013) with an additional subset collected at the end of the season (2013 only). For all four studies, spring regrowth was evaluated the following spring for the 2012 season only. Data collection included visual percent control (0 = no control; 100 = complete control) and above-ground pokeweed biomass. Pokeweed biomass was collected by cutting plant stems at the soil surface, weighing immediately in the field, bagging entire plants and oven drying for a minimum of 96 hours at 60°C and recording dry weight. Pokeweed plant height was also recorded at the spring regrowth collection time.

Statistical Analyses. Analyses were performed in SAS 9.3[2] with the Mixed procedure. Analysis of variance (ANOVA) was used to test for the differences in pokeweed control with the different application methods within the nozzle, volume, and rate studies. For the application timing study, the visual control ratings taken in the season of application were analyzed with regression using a non-linear model with a binomial distribution:

$$Y = C + (A - C) * (1 - \exp(-b_1 * GDD))$$

where Y is the predicted percent control, C is the lower threshold, A is the asymptote, b_1 is the rate of increase, and GDD is the cumulative number of growing degree days with a start of January 1. Means and standard errors were calculated using this model for each of the application times.

ANOVA was used to analyze height and fresh and dry weight reductions. Percent weight reductions were calculated as compared to the untreated control. ANOVA and the Glimmix procedure were used to contrast application times at different pokeweed growth stages. Orthogonal contrasts (d.f. = 1) were constructed to compare growth stage effects on percent control of pokeweed.

Where appropriate, means were separated using Fisher's Protected LSD with significance set at $P < 0.05$. For the data collected over two years, a separate analysis was done for each year. If the error terms were homogenous, then the data was pooled over years. "Treatment" was treated as a fixed variable, and "Rep" and "Year" were treated as random variables. All percentage data were transformed using the arcsin transformation; all other data were transformed using the log transformation [$y = log(x + 10)$] when appropriate in order to normalize the variance and meet the assumptions of ANOVA.

Air temperature data for 2012 and 2013 were downloaded from the National Oceanic and Atmospheric Administration (NOAA)[3] which has a weather collection station at the Rock Springs research center (40°72'N, 77°93'W). This weather station is approximately 2.3 kilometers from the field site. The number of accumulated growing degree days (GDD) were calculated for the application timing experiment using January 1 as a start date and 9° C as a base temperature:

$$\text{GDD} = ((\text{maximum temp °C} + \text{minimum temp °C}) \div 2) - 9$$

This base temperature has been used in previous research as the minimum temperature for weed germination, growth, and development (Forcella et al. 2000, Myers et al. 2004).

Sources of Materials

[1] Spraying Systems Co., Wheaton, IL 60187

[2] SAS® statistical analysis software, SAS Institute Inc., Cary, NC 27513

[3] NOAA, US Department of Commerce, http://www.esrl.noaa.gov/gmd/grad/surfrad/pennstat.html

Results and Discussion

Nozzle Study. The AIXR11002 nozzle is an air induction, extended range nozzle with a spray angle of 110° and an output of 0.76 liters per minute (Lpm) at 220 kPa. The FF11002 nozzle is a standard flat fan nozzle with the same output as the air induction tip. The flat fan nozzles are hypothesized to provide better control than the air induction tip because of better coverage due to the greater number of small droplets compared with air induction nozzles. Both pokeweed control and biomass responded similarly in 2012 and 2013, which allowed for pooling the data over the two years. The results showed that both nozzles achieved similar control, providing 83 and 84% control and over a 90% reduction in both fresh and dry weights 12 WAA (Table 3-3). However, some regrowth occurred by the following spring, with control averaging 62% 44 WAA (Table 3-3). While recommendations for harder to control species such as annual ryegrass [*Lolim perenne* L. *ssp. multiflorum* (Lam.) Husnot] suggest not using air induction nozzles for improved control (Plumer et al. 2014), common pokeweed control was similar for the two nozzle types. Etheridge et al. (2001) reported similar results for common cocklebur where control with an air induction and a flat fan nozzle three weeks after treatment was the same. While good coverage is important with all herbicides, nozzle performance might be greater with herbicides other than glyphosate and especially contact-type herbicides. Glyphosate is a systemic herbicide and can translocate throughout the plant, making thorough leaf coverage less important and especially for susceptible weed species.

Carrier Volume Study. Glyphosate was applied at a single rate in three different carrier volumes (93, 187, and 374 L/ha) and the 187 L/ha rate is considered the “standard” volume in these experiments. Data for this study could not be pooled over the two years due to differences in pokeweed response each year. In 2012, control ranged from 66 to 84% 12 WAA and there was a slight trend for better control at the lowest volume (Table 3-4). By 44 WAA, pokeweed control ranged from 83 to 92% with no differences in the effect of carrier volume. Fresh and dry weights were in concert with the control ratings at both 12 and 44 WAA with only the control plants being different from the treated. Relative to plant height at 44 WAA, only the 93 L/ha carrier volume successfully reduced plant height compared with the control plants. In 2013, the highest volume provided the least amount of control compared to the lower two volumes, and both fresh and dry weights in the lowest carrier volume was less than in the highest volume (374 L/ha) treatment (Table 3-4). The results from this volume study are similar to other studies with glyphosate which show that glyphosate can be more effective on certain weeds when applied at lower volumes. Bermudagrass [*Cynodon dactylon* (L.) Pers.] control increased and regrowth decreased with lower spray volumes (Jordan 1981). Wild garlic control was reduced with higher spray volumes (Troutman et al. 1981) and a review of eight studies reported greater control with lower spray volumes in seven of the eight (Knoche 1994). There are several theories as to why lower spray volume can improve glyphosate performance. Lower spray volumes can reduce the amount of antagonism with cations in the solution and improve efficacy (Sandberg et al. 1978, Stahlman and Phillips 1979) and the reduced surfactant-to-water ratio as well as runoff from the leaf surface may contribute to reduced glyphosate effectiveness at higher spray volumes (O'Sullivan et al. 1981).

Glyphosate Rate Study. Three different rates of glyphosate (0.87, 1.27, and 1.73 kg/ha) were applied to individual pokeweed plants and 0.87 kg/ha was considered the standard rate in this experiment. Both the percent control and biomass data responded similarly in 2012 and 2013 which allowed pooling across years. The 1.73 kg/ha rate provided 97% control and the 1.27 kg/ha rate provided 93% control 12 WAA; both were higher than the low rate (Table 3-5). Fresh and dry weights were equally reduced by herbicide rate and were lower than the control treatment by at least 85% (Table 3-5). By 44 WAA, there was no difference in control due to herbicide rate, but plant height and fresh and dry weights were reduced by glyphosate by at least 89% compared to the control treatment. Higher rates of glyphosate have been shown to provide better control of some perennial weeds, including common reed and wild garlic (Knezevic et al. 2013, Troutman et al. 1981). In this study, rates were compared which ranged from the standard up to a double (2X) rate and similar control was observed across rates at 44 WAA. This lack of rate response likely indicates that the lowest rate was sufficiently effective and that doubling it did not consistently provide a benefit, or a much higher than “labeled” rate would be necessary to elicit a positive response. These results suggest that “normal” application rates will provide maximum control and that doubling the rate is unnecessary. The effect of increasing the rate above 1.73 kg/ha on pokeweed control is uncertain based on these results. Several other studies have reported increased perennial weed control with increased glyphosate rate. These weeds include Canada thistle (Carlson and Donald 1988), common reed (Knezevic et al. 2013), wild garlic (Troutman et al. 1981), and mugwort (Bradley and Hagood 2002).

Application Timing Study. Glyphosate was applied to pokeweed starting in mid May and then every two weeks through either July (2012) or August (2013) and then monthly to late September. The control data at 8 WAA could not be pooled over the two years due to varying pokeweed response each year, so the results for each individual year are presented in Figure 3-1. In 2012, 90% control was achieved by 8 WAA when the application occurred at approximately 800 GDD or on June 26 (Figure 3-1a). In 2013, this same level of control was achieved 8 WAA when the application occurred on about 600 GDD, or June 22 (Figure 3-1b), a few days earlier than in 2012. Similar results were reported by Lingenfelter and Curran (2007) for wirestem muhly control with at least 90% control with glyphosate by a mid June application. In 2012, there appeared to be a slight decrease in control at the fourth application timing that was not observed in 2013. The weather had been dry for several days during this application timing which may have inhibited glyphosate performance and reduced control. In 2013, half of the treated plants were allowed to remain in the field beyond 8 WAA and not harvested until just prior to frost. This allowed for additional time for glyphosate to affect treated plants and resulted in slightly better control than at the 8 WAA evaluation. Ninety percent control was achieved by approximately 500 GDD, or on June 13, which was about 100 GDD and nine days earlier than the 8 WAA evaluation suggested (Figure 3-1b).

In both 2012 and 2013, pokeweed control increased from the first glyphosate application to its maximum around early July where it remained through the rest of the summer. Starting in mid June to early July, pokeweed was becoming reproductive, forming flower buds, then flowers, and eventually developing ripe fruit; this would typically be the time when perennials translocate sugars and carbohydrates to the roots (Stewart-Wade et al. 2002, Tworkoski 1992, Wilson and Michiels 2003). Any glyphosate which was applied during the reproductive stages should have had greater translocation to below ground tissues and provided better control. In both years, control was less at the vegetative stage than at any other growth stage and application at the flowering stage was generally not different from berry formation or ripening (Table 3-6). In 2013, glyphosate application at berry formation provided better control than at berry ripening 8 WAA, but by the end of the season, control was the same (Table 3-6). Knezevic et al. (2013) showed a similar trend with glyphosate and common reed with better control as plants turned reproductive compared to application during the vegetative stages. Other research showed that horsenettle (*Solanum carolinense* L.) control increased when glyphosate was applied prior to the onset of leaf senescence compared with during senescence and post frost (Whaley and VanGessel 2002a). Glyphosate applied in the fall prior to horsenettle senescence also reduced horsenettle height the following spring (Whaley and VanGessel 2002b). In this research on pokeweed, glyphosate appeared to be more effective when applied during berry formation vs. berry ripening, but results were similar at the late season evaluation. Seed set or seed viability was not evaluated in this study, but application prior to berry ripening would also potentially reduce viable seed production. In general, several studies show better perennial weed control with glyphosate application mid-summer or later compared to earlier in the season (Franssen and Kells 2007, Froese et al. 2005, Hacault and Van Acker 2006).

Above-ground fresh and dry weights were pooled across years due to the similar response pattern. Fresh and dry weights were reduced by 15 to 18% at the early application time 8 WAA, and at least 34% at subsequent applications (Table 3-7). Relative to fresh weight, the greatest reduction occurred by the third application (mid June) with a similar result for the fourth and subsequent application times. Dry weight response was more variable, with the greatest reduction occurring from the mid June through mid July application timings, while the late July application appeared slightly less effective. However, end of season biomass collected only in 2013 did not completely agree with the 8WAA evaluation. Fresh and dry weights were reduced at all application times, with the mid June through late July timings achieving a similar result. Results from the August and September applications were more variable in both level of control and biomass. These later treatments had less time between application and plant harvest, which is likely responsible for the reduced impact on fall biomass compared to the untreated controls (Table 3-7); that is, the treated plants had not completely died and desiccated.

Spring regrowth was only assessed in the first year of the study where both the untreated controls and treated plants were given control ratings. The evaluation attempted to consider both herbicide performance and natural mortality which was based on survival of untreated plants (Table 3-8). Treated plant survival ranged from 0 to 75% with no survival from applications occurring late July and beyond. Fresh and dry weight reductions also showed a clear relationship between application timing and survival with some plants surviving through the fourth or late June/early July application timing and no survival with later applications. In general, spring height, fresh weight, and dry weight percent reductions all increased as the application timing the previous season was delayed (Table 3-8).

The results from this research show that nozzle type does not affect nor improve glyphosate efficacy on pokeweed. Carrier volume can impact pokeweed control and the results show that lower volumes have the potential to increase control of pokeweed. Glyphosate can be an important component of successful weed control and the results showed that higher rates tended to give better control in the fall, but not necessarily the following spring, suggesting that doubling the 0.87 kg/ha rate is likely not beneficial. One of the most important factors affecting glyphosate performance was application timing. Applications after 600 to 800 GDD, or late June/early July in central Pennsylvania when pokeweed begins to flower, resulted in increased control. The implication of a later application timing providing greater control provides a challenge for pokeweed management in corn. By late June/early July in central Pennsylvania, corn is generally too mature for most herbicide applications. Planting a shorter statured crop such as soybean or a crop that allows mid to late summer herbicide application would allow for a timelier glyphosate application and potential better control of pokeweed. Including small grains or other crops in the crop rotation which allow mid-summer harvest could also present a better opportunity for an effective glyphosate application in late summer.

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Tables and Figures

Table 3-1. Application Methods for the Nozzle, Carrier Volume, Rate, and Application Timing Glyphosate Studies, Rock Springs, 2012-2013.

Study	Nozzles (TeeJet®[1])	Volume (L/ha)	Rate (kg ae/ha)	Application Time
Nozzle	AIXR11002 FF11002	187	0.87	June 20, 2012 June 24, 2013
Carrier Volume	AIXR11002	93 187 374	0.87	June 20, 2012 June 25, 2013
Rate	AIXR11002	187	0.87 1.27 1.73	June 20, 2012 June 24, 2013
Timing	AIXR11002	187	1.40	every 2-4 weeks from mid-May to late September

Table 3-2. Application Date, Height, Growth State, and Growing Degree Days (GDD) for the Application Timing Study, 2012 and 2013.

	2012*				***2013*****			
Application time	**Application date**	**Height (cm)**	**Growth stage**	**GDD (cum)**	**Application date**	**Height (cm)**	**Growth stage**	**GDD (cum)**
1	May 18	40	vegetative	388	May 23	25.8	vegetative	295
2	May 31	90	vegetative	540	June 4	66.5	vegetative	409
3	June 15	103	flower	669	June 19	120.2	vegetative	552
4	June 28	108	flower	817	July 2	124.5	flower	721
5	July 12	109	berry formation	1032	July 15	152.0	flower	912
6	July 27	120	berry formation	1247	July 30	147.3	berry formation	1112
7	--	--	--	--	Aug. 13	162.6	berry formation	1263
8	Aug. 29	126	berry ripening	1658	Aug. 27	155.4	berry ripening	1402
9	Sept. 28	143	berry ripening	1926	Sept. 23	153.3	berry ripening	1676

*For 2012, data for Times 8 and 9 are only presented for the Spring Regrowth, since there was not a full 8 weeks from application to frost in the fall.
**For 2013, data for Time 9 are not presented for the fall, since there was not a full 8 weeks from application to frost in the fall. It will be included in the spring regrowth assessment once it is completed this spring.
***GDD start January 1.

Table 3-3. Effect of nozzle selection with a glyphosate application on pokeweed control, 12 and 44 weeks after application (WAA), 2012-2013.

	12 WAA (2012-2013)			***44 WAA (2012)***			
Nozzle Type	**% Control**	**Fresh weight (g)**	**Dry weight (g)**	**% Control**	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**
Control	--	5473 (± 1554) a	1361 (± 444) a	--	33 (± 12) a**	259 (± 120) a**	17 (± 8) a
FF11002	84 (± 3) a	568 (± 171) b	120 (± 33) b	67 (± 13) a	12 (± 8) a**	105 (± 93) a	7 (± 6) ab
AI11002	83 (± 6) a	444 (± 113) b	97 (± 15) b	57 (± 8) a	7 (± 1) a**	6 (± 3) a**	0.5 (± 0.2) b

**Means and standard errors are from the raw data. Significance letters are from the transformed data. Standard errors are in parentheses. Values followed by the same letter within a column are not significant using Fisher’s LSD at P < 0.05.
**Not significant due to data transformation.

Table 3-4. Effect of carrier volume with a glyphosate application on pokeweed control, 12 and 44 weeks after application (WAA), 2012-2013.

	12 WAA						**44 WAA**			
	2012			***2013***			***2012***			
Spray volume (L/ha)	**% Control**	**Fresh weight (g)**	**Dry weight (g)**	**Rating (%)**	**Fresh weight (g)**	**Dry weight (g)**	**% Control**	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**
Control	--	2200 (± 534) a	458 (± 113) a	--	8741 (± 1960) a	2258 (± 600) a	--	33 (± 12) a	259 (± 120) a	18 (± 8) a
93	84 (± 4) a	240 (± 88) b	53 (± 17) b	88 (± 7) a	690 (± 376) c	155 (± 59) c	83 (± 17) a	3 (± 3) b	6 (± 6) b	0.4 (± 0.4) b
187	74 (± 12) a	462 (± 239) b	78 (± 37) b	81 (± 7) a	1430 (± 439) bc	327 (± 82) bc	89 (± 9) a	7 (± 3) ab	6 (± 3) b	0.5 (± 0.3) b
374	66 (± 15) a	620 (± 315) ab	105 (± 48) b	49 (± 8) b	3872 (± 1147) ab	773 (± 233) b	92 (± 4) a	10 (± 4) ab	23 (± 16) b	2 (± 1) b

*Means and standard errors are from the raw data. Significance letters are from the transformed data. Standard errors are in parentheses. Values followed by the same letter within a column are not significant using Fisher's LSD at $P < 0.05$.

Table 3-5. Effect of glyphosate rate on pokeweed control, 12 and 44 weeks after application (WAA), 2012-2013.

	12 WAA (2012-2013)			***44 WAA (2012)***			
Rate (kg ae/ha)	**% Control**	**Fresh weight (g)**	**Dry weight (g)**	**% Control**	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**
Control	--	6800 (± 1271) a	1586 (± 383) a	--	36 (± 11) a	278 (± 107) a	21 (± 9) a
0.87	84 (± 4) b	982 (± 406) b	236 (± 88) b	89 (± 9) a	2 (± 2) b	4 (± 4) b	0.4 (± 0.4) b
1.27	93 (± 2) a	624 (± 196) b	176 (± 54) b	91 (± 8) a	4 (± 4) b	6 (± 6) b	0.4 (± 0.4) b
1.73	97 (± 1) a	503 (± 169) b	178 (± 51) b	82 (± 9) a	4 (± 2) b	5 (± 4) b	0.5 (± 0.4) b

** Means and standard errors are from the raw data. Significance letters are from the transformed data. Standard errors are in parentheses. Values followed by the same letter within a column are not significant using Fisher's LSD at $P < 0.05$.

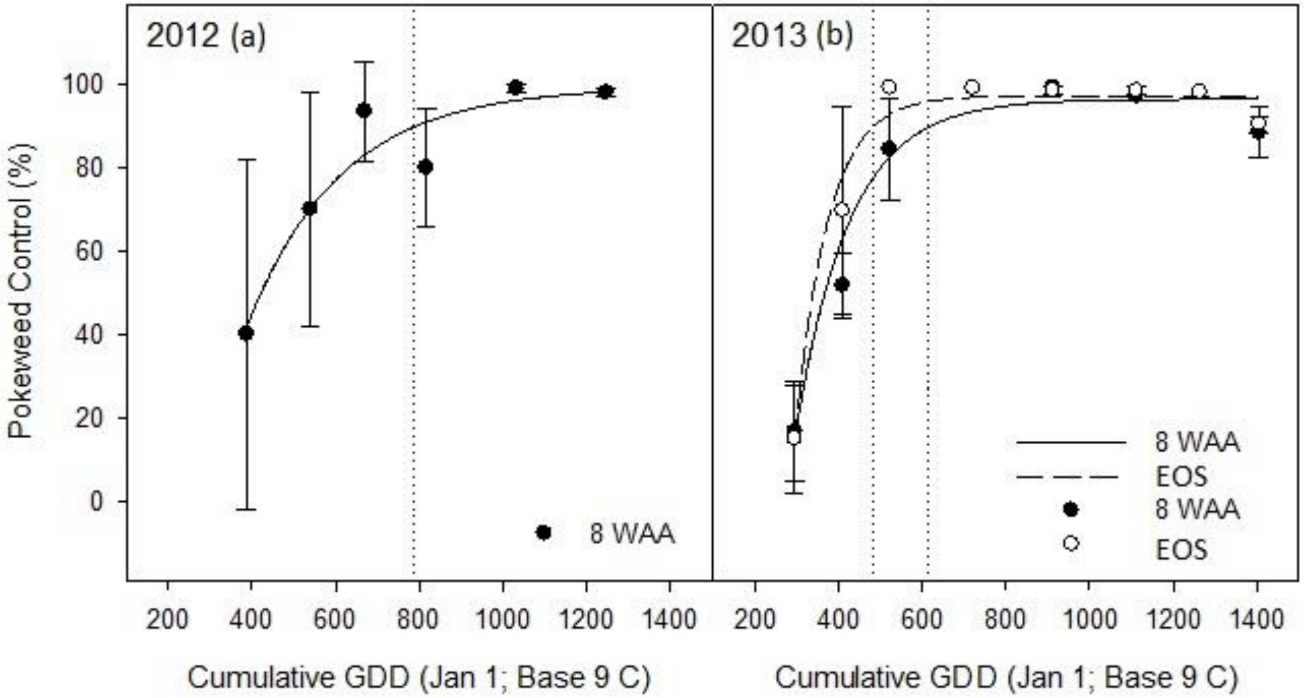

Figure 3-1. Effect of glyphosate application timing on pokeweed control, 2012 (a) and 2013 (b). Data shown are from 8 weeks after application (WAA) and End of Season (EOS; 2013 only). Means and standard deviations are shown for each application timing. The vertical dotted lines represent the GDD at which 90% control was achieved. GDD start January 1. The equation for the 2012 line is: Y = -226 + (99 + 226) * (1 - exp(-0.0045 * GDD)). The equation for the 2013 - 8 WAA line is: Y = -719 + (96 + 719) * (1 - exp(-0.0078 * GDD)). The equation for the 2013 - EOS line is: Y = -3542 + (97 + 3542) * (1 - exp(-0.0128 * GDD)).

Table 3-6. Effect of glyphosate application time on different pokeweed growth stages and their contrast p-values, 8 weeks after application (WAA) and End of Season, 2012 and 2013.

		Contrast growth stages p-value		
2012 – 8 WAA	**% Control**	**Vegetative**	**Flower**	**Berry Formation**
Vegetative	57 (± 6) a			
Flower	87 (± 6) b	0.0036		
Berry Formation	98 (± 7) b	< 0.0001	0.0982	
Berry Ripening	**--***			
2013 – 8 WAA				
Vegetative	51 (± 7) a			
Flower	99 (± 8) bc	< 0.0001		
Berry Formation	98 (± 8) c	< 0.0001	0.3317	
Berry Ripening	88 (± 11) d	< 0.0001	0.0037	0.0203
2013 – End of Season				
Vegetative	61 (± 8) a			
Flower	99 (± 10) b	< 0.0001		
Berry Formation	98 (± 10) b	< 0.0001	0.8223	
Berry Ripening	90 (± 14) b	0.0088	0.0692	0.0972

* Plants sprayed in 2012 did not reach the berry ripening stage.
**Standard errors are in parentheses. Values followed by the same letter within an evaluation time are not significant using Fisher's LSD at $P < 0.05$.

Table 3-7. Effect of glyphosate application timing on pokeweed fresh and dry weight reductions as compared to the control plants, 8 weeks after application (WAA), 2012-2013 and End of Season, 2013.

		8 WAA, 2012-2013		***End of season, 2013***	
Application time	**Application date**	**Fresh weight reduction (%)**	**Dry weight reduction (%)**	**Fresh weight reduction (%)**	**Dry weight reduction (%)**
1	mid May	15 (± 7) c	18 (± 8) d	30 (± 30) c	29 (± 29) c
2	early June	37 (± 11) b	40 (± 11) bc	50 (± 29) bc	55 (± 29) abc
3	mid June	48 (± 12) a	48 (± 12) a	96 (± 2) a	92 (± 3) a
4	early July	47 (± 11) a	45 (± 11) ab	89 (± 1) ab	88 (± 2) ab
5	mid July	48 (± 12) a	44 (± 11) ab	85 (± 1) ab	67 (± 3) abc
6	late July	44 (± 11) ab	34 (± 10) c	85 (± 2) ab	67 (± 5) abc
7	mid August	--	--	58 (± 6) bc	25 (± 13) c
8	late August	--	--	61 (± 6) bc	54 (± 9) bc

*Means and standard errors are from the raw data. Significance letters are from the transformed data. Standard errors are in parentheses. Values followed by the same letter within a column are not significant using Fisher's LSD at $P < 0.05$.

Table 3-8. Effect of glyphosate application timing on pokeweed regrowth the spring following application as compared to the untreated control, 2012.

Application time	**Application date (2012)**	**Plants alive (%)**	**Height reduction (%)**	**Fresh weight reduction (%)**	**Dry weight reduction (%)**
1	May 18	75	25 (± 25) b	28 (± 24) b	29 (± 24) b
2	May 31	40	68 (± 21) ab	78 (± 20) a	78 (± 20) a
3	June 15	17	100 (± 0) a**	93 (± 7) a	91 (± 9) a
4	June 28	50	77 (± 16) a	89 (± 10) a	89 (± 10) a
5	July 12	20	85 (± 15) a	100 (± 0) a**	100 (± 0) a**
6	July 27	0	100 (± 0) a	100 (± 0) a	100 (± 0) a
8*	Aug. 29	0	100 (± 0) a	100 (± 0) a	100 (± 0) a
9	Sept. 28	0	100 (± 0) a	100 (± 0) a	100 (± 0) a

*An application in late July, which was considered Time 7 in this study, did not occur in 2012.
**$n = 5$; one sample was compromised
*** Means and standard errors are from the raw data. Significance letters are from the transformed data. Standard errors are in parentheses. Values followed by the same letter within a column are not significant using Fisher's LSD at $P < 0.05$. $N = 6$.

Chapter 4

Pokeweed Seedling Emergence Periodicity and Subsequent Effect on Biomass and Fecundity

Abstract

Common pokeweed (*Phytolacca americana* L.) is a perennial broadleaf weed with a large persistent taproot that is also capable of abundant seed production. It has become a frequent problem in agronomic crops in Pennsylvania. Traditionally, plowing was used to manage pokeweed; however, the wide-spread adoption of conservation tillage, a decrease in diverse crop rotations, and a decline in the use of soil residual herbicides may have allowed pokeweed populations to increase in recent years. The objective of this research is to identify opportunities to better manage pokeweed in corn, soybean, and other Northeast cropping systems. Understanding the biology of the plant will allow for better recommendations for pokeweed control. In this study, the emergence period of pokeweed seedlings and the effect of emergence timing on biomass and fecundity were quantified. Throughout the summers of 2012 and 2013, the number of pokeweed seedlings were counted every two weeks and removed from plots established in the field. Select plants were preserved and allowed to mature and biomass and fecundity measurements were collected at the end of the season. Pokeweed seedlings emerged throughout the summer with a peak emergence in mid to late May. Both above- and below-ground biomass decreased with delayed emergence. Plants which emerged after mid June 2012 and late July 2013 did not produce mature berries by the end of the season.

Introduction

Although common pokeweed (*Phytolacca americana* L.) is a plant native to North America, it has been a common weed in some cropping systems for many years. The biology and ecology of this species has not been widely examined with little published information about the weedy nature of this plant. Most of the information on common pokeweed (pokeweed) biology is more than ten years old. Some previous research focused on the reproductive biology reported that pokeweed produces about 58 fruits per raceme (Armesto et al. 1983) and there are nine to ten seeds per fruit (Armesto et al. 1983, Braun and Brooks 1987, Stapanian 1982). An often cited piece of information is that seeds can remain viable for at least 40 years (Mitich 1994). Birds are believed to be a primary mechanism for seed dispersal (Armesto et al. 1983, McDonnell et al. 1984) and seedling plants are often observed under trees or power lines where birds roost. Passage through the gut of birds does not increase viability; however, viable seeds which pass through the gut can have higher germination rates (Orrock 2005). Other animals, such as box turtles, have also been shown to eat pokeweed berries and effect the germination rates (Braun and Brooks 1987). Other research reported that buried seed reduces pokeweed populations (Orrock and Damschen 2007) and also the potential for seed predation (Hyatt 1998).

Previous research has examined seedling emergence patterns, identifying the onset, peak, and concluding periods for a number of weed species (Myers et al. 2005, Zhu et al. 2013). Weed species are often classified as winter or summer annual weeds; however, emergence timing varies widely within those classifications. Environmental conditions and dormancy also play a large role in determining emergence periods. Common pokeweed is a simple herbaceous perennial that relies on seed production and dispersal to maintain and extend its distribution. Previous research with pokeweed seed focused on dormancy and its effect on germination (Armesto et al. 1983, Edwards et al. 1988, Farmer and Hall 1970, Kang et al. 1997). However, nothing has been published on pokeweed seed germination timing in a field setting. Boyd and Murray (1982) studied the emergence timing of silverleaf nightshade (*Solanum elaeagnifolium*), an aggressive perennial weed found in cropland in the Western and Southern United States (USDA NRCS n.d.). Their research reported that silverleaf nightshade seedling emergence after July 1 did not successfully produce fruit with viable seeds. In addition, above-ground biomass was reduced as emergence was delayed. Additional research reported that redroot pigweed (*Amaranthus retroflexus*) biomass and fecundity was less in grain sorghum (*Sorghum vulgare*) as weed emergence was delayed (Knezevic and Horak 1998). Previous research with burcucumber [*Sicyos angulatus*] (Esbenshade et al. 2001), velvetleaf [*Abutilon theophrasti*] (Cardina et al. 1995, Teasdale 1998), and redstem filaree [*Erodium cicutarium*] (Blackshaw and Harker 1998) also showed a direct relationship between delayed seedling emergence and decreased weed biomass and seed production. In general, seedling emergence of these species beyond mid-summer resulted in no seed production.

Research on pokeweed seedling emergence timing and potential for growth and fecundity should help provide management guidelines for Northeastern U.S. field crops. The objectives of this research were to: 1) Characterize the emergence periodicity of common pokeweed seedlings in the field and; 2) Identify the effect of seedling emergence timing on common pokeweed plant height, above and below ground biomass, and fecundity.

Materials and Methods

Field experiments were conducted in 2012 and 2013 at the Penn State University Russell E. Larson Agricultural Research and Education Center, Rock Springs, Centre County, PA (40°44’N, 77°57’W). Field plots were established to observe the emergence timing of pokeweed from seed and to quantify the emergence timing effect on pokeweed biomass and fecundity. The field site had a mixture of two silt loam soils: Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) and Murrill channery silt loam (fine-loamy, mixed, semiactive, mesic Typic Hapludults) with a pH of 6.7 and 2.5% organic matter. The site had previously been used for corn and soybean demonstration research and had no history of pokeweed infestation. A second location was used in 2013 to repeat the emergence timing experiment. This field site was historically in a no-till corn-soybean rotation with a history of pokeweed infestation. The soil class was a Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) with a soil pH of 6.3 and organic matter content of 3.0%. Both sites were managed as fallow non-crop areas during the experiment and no supplemental fertility was applied to either of the sites during the duration of the study.

In the late fall prior to the 2012 growing season, the field was tilled using a heavy disc followed by a roller harrow to produce a smooth seedbed. Fifty dried mature berries (approximately 450 seeds), which had been collected from several local populations at the research farm during the previous weeks, were evenly distributed over 0.25 m^2 plots in early November (supplemented plots). The berries/seeds were lightly incorporated and plots were covered with approximately 100 g/m^2 wheat straw and left undisturbed until the spring. This procedure was repeated in an adjacent location in the spring of 2013. However, because plots were not established until springtime (2013), a nearby field infested with a natural population was also identified for the emergence timing experiment. Seedling emergence was monitored starting in early April (or at first occurrence) and then every two weeks throughout the growing season. At each assessment date, the total number of seedlings were counted in each plot and then removed by hand. When available, two or three seedlings were allowed to remain in each plot for a few weeks, after which time they were thinned to a single individual which remained for the rest of the season for the biomass and fecundity assessment. Plots were maintained weed-free (other than pokeweed) by hand weeding and spot treating areas 2 to 3 times per season with an application of 1.40 kg ae/ha glyphosate. The selective herbicide applications occurred immediately after an emergence assessment and conserved individuals were covered to avoid contact with the herbicide. Single conserved plants in each plot were harvested prior to a light frost in early to mid October. Plant height, number of berries per plant, and fresh weight of both above- and below- ground biomass was recorded at harvest. Below ground portions were removed by excavating individual plots using a backhoe and then carefully removing all plant material. Plant biomass was oven-dried for a minimum of 96 h at 60°C in order to determine dry weight. The number of approximate seeds per plant was also calculated by multiplying the number of berries by 9 seeds per berry (Stapanian 1982). Forty individual plots were established at the beginning of the experiment that would allow up to 10 emergence timing assessments with four replications for conserved plants. In 2013, 40 supplemented plots were used to assess emergence timing on biomass and fecundity and 20 natural population plots were used to monitor seedling emergence timing.

Rainfall data for 2012 and 2013 were provided by the NRCS National Water and Climate Center[2] which has a weather station at the Rock Springs research center (40°43’N, 77°56’W). This weather station is approximately 0.1 to 1 kilometer from the field sites. Air temperature data for 2012 and 2013 were acquired from the National Oceanic and Atmospheric Administration (NOAA)[3] which has a weather collection station at the Rock Springs research center (40°72’N, 77°93’W). This weather station is approximately 0.5 to 1 kilometer from the field sites. Growing degree days were calculated for each emergence date using January 1 as a start date and 9° C as a base temperature:

$$\text{GDD} = ((\text{maximum temp °C} + \text{minimum temp °C}) \div 2) - 9$$

This base temperature has been used in previous research for spring and summer emerging seedlings (Forcella et al. 2000, Myers et al. 2004). The proportion of total plot emergence was calculated by comparing the number of seedlings which emerged in any one plot at a certain emergence time with the total number of seedlings which emerged in that plot throughout the season. Common pokeweed root to shoot ratios were calculated by dividing the average below-ground dry wt by the average above-ground dry wt for each emergence time.

In 2013, viable pokeweed seeds were not distributed until late April in the supplemented plots, eliminating our ability to capture the full emergence timing. For this reason, the emergence period experiment was established in a different field utilizing a natural population. The 2013 supplemented plots were still used for the biomass and fecundity assessment. The 2012 season had a warm spring with a wet May and slightly dry late summer, while the 2013 season had less rainfall early and late compared to 2012 (Table 4-1). During dry periods in late summer, plots were supplemented with additional water.

Statistical Analyses. Seedling emergence was modeled using the NLMixed procedure in SAS 9.3[1] with year as a random effect in order to account for variation across sites and years. The Gompertz equation was used to model seedling emergence:

$$Y = 1*\exp(-\exp(-b_1*(GDD-b_0)))$$

where Y is the cumulative percentage of emergence, b_1 is the rate of increase of emergence once it has begun, GDD is the number of growing degree days (base 9°C; January 1 start) at the time of emergence, and b_0 is the point of inflection on the x axis. The Gompertz equation is a time series function that has been frequently used to predict weedy plant growth (Hill et al. 2014, Izqueirdo et al. 2013).

All other data were analyzed using analysis of variance (ANOVA), and means were separated using Fisher's Protected LSD with significance set at $P < 0.05$. A separate analysis was done for each year. The error terms were not homogenous, and therefore the data were unable to be pooled over the two years. "Emergence Time" was treated as a fixed variable and "Rep" was treated as a random variable. All height and root:shoot data were analyzed using the raw data.

The number of mature berries and seeds as well as all weight data were transformed using the log transformation [$y = log(x + 10)$] in order to normalize the variance and meet the assumptions of ANOVA.

Sources of Materials.
[1] SAS statistical analysis software, SAS Institute Inc., Cary, NC 27513.
[2] NRCS, US Department of Agriculture, http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=2036&state=pa
[3] NOAA, US Department of Commerce, http://www.esrl.noaa.gov/gmd/grad/surfrad/pennstat.html

Results and Discussion

Emergence Period. Pokeweed emergence was first observed on April 20, 2012, and May 7, 2013. Milder spring temperatures came earlier in 2012 than in 2013, which accounts for much of the difference in emergence start date and higher GDD accumulation (Table 4-2). In fact, in 2012, an unusually warm period occurred in the middle of March, but pokeweed did not first emerge until April 20. For about two weeks in March, daily high temperatures were around 20°C with lows near 10°C; these temperatures are usually not reached for the first time until April in central Pennsylvania. In 2012, peak emergence was observed on May 18 (388 GDD), with 29% of the total seedlings emerging. In 2013, peak emergence occurred on May 21 (266 GDD), with 30% of the total seedlings emerging. By August 10, 2012 (1445 GDD), and July 15, 2013 (911 GDD), 100% of the seedlings had emerged with no additional emergence after those dates. Emergence timing by Julian calendar dates were clearly different between years (Table 4-2).

The Gompertz equation was selected because it provided a reasonable fit of the data. The use of GDD instead of Julian calendar dates to fit the data showed that emergence timing within years was still somewhat different, but the trend was similar (Figure 4-1). Examining emergence timing on a GDD scale rather than the Julian calendar improved the relationship over years and pokeweed seedling emergence, whether from a supplemented (2012) or naturally occurring population (2013), was similar. Fifty percent of the population was predicted to emerge at 345 GDD, which was May 12, 2012, and May 30, 2013 (Table 4-3). Ninety percent of the population was predicted to emerge at 620 GDD, which was June 10, 2012, and June 24, 2013. Since most weed control tactics are implemented before the end of June, effective weed management should control most emerged seedlings. However, a small percentage of seedlings were observed to emerge through the end of the summer. This scattered emergence is possibly due to dormancy and the hard seed coat and could impact future populations. Even if a small amount of pokeweed is left in a field, those plants have the potential to produce many more seeds and new plants. In 2012, a total of about 3,800 seedlings were counted, while in 2013, the number totaled 473. Twice as many plots were established and monitored in 2012 compared to 2013 and the supplemented population included about 450 seeds per plot, while a naturally occurring population was monitored in 2013. These factors are responsible for the differences in seedling numbers between years.

In both 2012 and 2013, by late fall, seedlings emerging by late July were at least 18 cm tall with above- and below- ground dry matter of at least 5 to 7 g, respectively (Tables 4-4 and 4-5). Plants appeared well established with sufficient growth to potentially survive the winter. In 2013, plants emerging on or after mid August were less than 10 cm tall with above- and below-ground dry matter of less than 0.5 to 0.3 g, respectively, by late fall (Table 4-5). The minimum time or threshold biomass for pokeweed perenniality or winter survival has not been investigated, so whether or not these plants could survive the winter is uncertain. Other perennial weeds have been reported to become perennial fairly early on. Canada thistle [*Cirsium arvense* (L.) Scop.] seedlings can reproduce vegetatively at seven to nine weeks old (Holm et al. 1977, Ross and Lembi 1999). Wilson (1979) suggests that this could occur as early as when Canada thistle is 19 days old with two true leaves. Johnsongrass [*Sorghum halepense* (L.) Pers.] can produce rhizomes at just three to five weeks after seedling emergence (McWhorter 1961, Anderson et al. 1960). Hemp dogbane (*Apocynum cannabinum* L.) can become perennial in just ten days (Lanini and Wertz n.d. a), while yellow nutsedge (*Cyperus esculentus* L.) requires four weeks (Keeley and Thullen 1975). Field bindweed (*Convolvulus arvensis* L.) has been reported to become perennial six weeks after emergence (Lanini and Wertz n.d. b); however, other research has reported perenniality at 20 true leaves (Zimdahl 1993). Pokeweed seedlings emerging on or after mid-August had less than eight weeks before a frost would have occurred; whether eight weeks is sufficient for pokeweed winter survival is uncertain.

Timing of management, as well as using effective management tactics, is key to prevent pokeweed population from increasing. Pokeweed in our research achieved 100% emergence between mid-July and August 10, depending on the year. Published literature on emergence timing for seedling perennials is rare. Myers et al. (2004) reported that eight summer annual weeds required less cumulative GDD for 95% emergence than pokeweed. In addition, pokeweed displayed a single peak emergence period declining from that point on, while annual weeds often display two peak emergence periods with the first peak being the largest (Myers et al. 2005). Common ragweed (*Ambrosia artemisiifolia* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and giant foxtail (*Setaria faberi* Herrm.) have been shown to have emergence periods slightly earlier than pokeweed (Myers et al. 2005, Stoller and Wax 1973). The first emergence peaks of velvetleaf (*Abutilon theophrasti* Medik.), smooth pigweed (*Amaranthus hybridus* L.), jimsonweed (*Datura stramonium* L.), and yellow foxtail [*Setaria pumila* (Poir.) Roemer & J.A. Schultes] were shown to be similar to that of pokeweed (Myers et al. 2005, Stoller and Wax 1973). The peak emergence period for common lambsquarters (*Chenopodium album* L.) was shown to be either slightly earlier (Ogg and Dawson 1984) or similar (Myers et al. 2005) to pokeweed, while the second emergence peak for common cocklebur (*Xanthium strumarium* L.) was also similar to pokeweed (Stoller and Wax 1973). These previous studies suggest that although pokeweed emergence periodicity may be slightly different than for some annual weeds, there are similarities that can provide insight into future management opportunities.

Biomass and Fecundity. In 2012, emerged seedlings were conserved from mid April to late July (Table 4-4) and from early June to late September in 2013 (Table 4-5). Seedlings emerged later in 2013 compared to 2012; spring dispersal rather than fall was likely responsible for the prolonged emergence period observed in 2013. In both years, plant size, biomass, and reproduction decreased as emergence date was delayed. This is similar to results from other studies which also showed reduced plant biomass and fecundity as seedling emergence was delayed (Blackshaw and Harker 1998, Boyd and Murray 1982, Esbenshade et al. 2001, Knezevic and Horak 1998). Interestingly, plants emerging mid June or later in 2012 and late July or later 2013 produced no mature berries or seeds. Differences in GDD between 2012 and 2013 do not explain why plants that emerged about six weeks later successfully produce mature seed in 2013 compared with 2012. The source of seed and other management factors were the same during the two years of the study. The only difference was the date that seeds were dispersed in the plots (fall vs. spring).

Controlling plants which are capable of reaching reproductive maturity will be important for reducing the overall population and the seedbank. Zhu et al. (2013) conducted a study on silverleaf nightshade and found that later emergence resulted in shorter plants, reduced above- and below-ground biomass, and fewer numbers of fruits per plant for both new seedlings and regrowth from established roots. Researchers in France studying yellow nutsedge reported that delayed emergence decreased biomass and tuber production; however, at all emergence times, tubers were still produced, indicating that midsummer emerging plants can still increase populations (Dodet et al. 2008). Although no minimum threshold has been established for the emergence date, size, or weight necessary for pokeweed seedling winter survival, plants emerging after mid August had above- and below-ground dry weight less than 1 g; this small amount of biomass may indicate a lack of resource to survive the winter. Root to shoot ratios (R:S) were variable throughout the two years, but a peak was observed either in mid June 2012 or mid August 2013 and it declined from this point on. Most R:S were above one, indicating that the roots had a higher dry biomass than the shoots.

In summary, pokeweed seedlings emerged throughout the summer with a peak emergence in mid to late May. This pattern is similar to several summer annual weed species and should allow for timely seedling control in several Pennsylvania field crops. Above- and below-ground biomass was reduced as emergence is delayed and seedlings emerging after mid June 2012 and late July 2013 did not successfully produce mature berries or seed by the end of the season. These data suggest that management of early emerging seedlings is most critical to reducing plant size, potential for weed competition, reproductive fitness, and overall pokeweed population. Management of mid-summer emerging seedlings may also be critical, since those seedlings may be able to survive the winter and regrow the following spring. These seedlings which emerge after typical weed management strategies occur may be the reason for the continued increase in pokeweed populations in no-till. Our results also suggest that plants that emerge in late summer are less likely to survive the winter because of low above and below ground biomass, suggesting limited carbohydrate storage.

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Tables and Figures

Table 4-1. Monthly rainfall totals for the Rock Springs Research Farm, 2012 and 2013.

	Rainfall (cm)	
Month	**2012**	**2013**
April	6.7	7.0
May	27.4	4.8
June	10.4	15.2
July	13.9	11.1
August	13.9	4.2
September	12.4	4.8
Total	*84.7*	*47.1*

Table 4-2. Emergence Date, Growing Degree Days (GDD), and Proportion of Total Plot Emergence, 2012 and 2013.

2012				***2013***			
Date of Emergence	**GDD at Emergence**	**Proportion of Total Plot Emergence (%)**	**Cumulative Proportion of Total Plot Emergence (%)**	**Date of Emergence**	**GDD at Emergence**	**Proportion of Total Plot Emergence (%)**	**Cumulative Proportion of Total Plot Emergence (%)**
April 20	222	15 (± 8)	15 (± 8)	--	--	--	--
May 4	285	17 (± 7)	31 (± 10)	May 7	176	20 (± 16)	20 (± 16)
May 18	388	29 (± 10)	60 (± 13)	May 21	266	30 (± 17)	50 (± 19)
May 31	540	25 (± 9)	85 (± 9)	June 4	409	11 (± 11)	61 (± 16)
June 15	669	12 (± 8)	97 (± 2)	June 18	541	14 (± 12)	75 (± 15)
June 29	831	1 (± 1)	98 (± 2)	July 2	721	7 (± 6)	81 (± 17)
July 13	1046	0 (± 1)	99 (± 2)	July 15	912	18 (± 17)	100 (± 1)
July 31	1300	1 (± 1)	99 (± 1)	July 30	1112	0 (± 1)	100 (± 1)
Aug. 10	1445	0 (± 0)	100 (± 1)	Aug. 13	1263	0 (± 0)	100 (± 1)
Aug. 28	1646	0 (± 1)	100 (± 1)	Aug. 28	1422	0 (± 1)	100 (± 0)
Sept. 7	1776	0 (± 0)	100 (± 0)	Sept. 10	1571	0 (± 0)	100 (± 0)
Sept. 21	1883	0 (± 0)	100 (± 0)	Sept. 24	1680	0 (± 0)	100 (± 0)
Oct. 5	1971	0 (± 0)	100 (± 0)	Oct. 8	1802	0 (± 0)	100 (± 0)

*Standard deviations are in parentheses. GDD start January 1.

Table 4-3. Predicted Growing Degree Days (GDD) of pokeweed percent population emergence by the Gompertz equation, 2012 and 2013.

Population Emergence (%)	**GDD**	**2012 Date**	**2013 Date**
10	50	March 14	April 9
50	345	May 12	May 30
90	620	June 10	June 24
95	720	June 19	July 1
100	1080	July 15	July 26

*GDD start January 1.

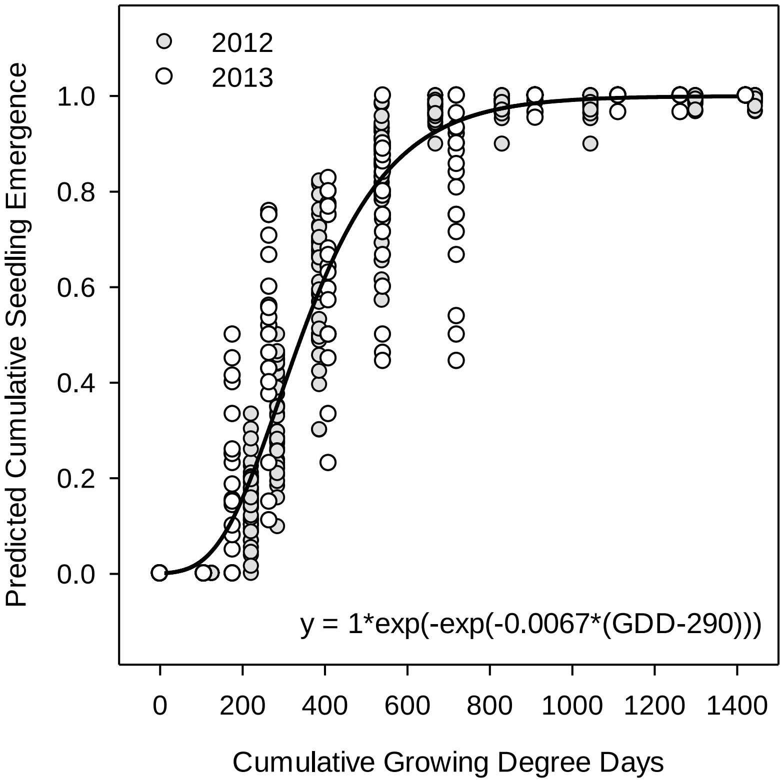

Figure 4-1. Predicted cumulative pokeweed seedling emergence over Growing Degree Days (GDD) using the Gompertz equation, 2012 and 2013. GDD start January 1.

Table 4-4. Effect of emergence date on pokeweed biomass and fecundity, average per plant, October 2012.

					Above-ground		***Below-ground***		
Date of emergence	**GDD at emergence**	**Height (cm)**	**No. mature berries**	**Approx. no. seeds*****	**Fresh weight (g)**	**Dry weight (g)**	**Fresh weight (g)**	**Dry weight (g)**	**Root:shoot ratio**
April 20	222	78 (± 9) a	274 (± 124) a	2466 (± 1112) a	923 (± 414) a	176 (± 83) a	931 (± 415) ab	205 (± 89) ab	1.7 (± 0.4) b
May 4	285	71 (± 9) ab	203 (± 63) a	1829 (± 570) ab	903 (± 300) a	154 (± 46) a	962 (± 305) a	197 (± 49) a	1.4 (± 0.4) b
May 18	388	62 (± 9) abc	194 (± 31) a	1742 (± 275) ab	619 (± 131) a	115 (± 25) a	953 (± 284) a	219 (± 54) a	1.9 (± 0.4) ab
May 31	540	63 (± 9) abc	94 (± 68) b**	848 (± 611) b	391 (± 179) ab	76 (± 37) ab	475 (± 183) ab	113 (± 42) ab	2.1 (± 0.4) ab
June 15	669	45 (± 11) bcd	0 (± 0) b	0 (± 0) c	163 (± 88) bc	25 (± 14) bc	300 (± 160) bc	70 (± 35) bc	3.0 (± 0.4) a
June 29	831	18 (± 11) d	0 (± 0) b	0 (± 0) c	45 (± 26) c	11 (± 0) bc	40 (± 24) d	7 (± 4) d	1.3 (± 0.7) ab
July 31	1300	36 (± 11) cd	0 (± 0) b	0 (± 0) c	139 (± 93) bc	13 (± 10) c	104 (± 57) cd	17 (± 8) cd	2.4 (± 0.4) ab

*Standard errors are in parentheses. Values followed by the same letter within a column are not significantly different using Fisher's LSD at $P < 0.05$. Means and standard errors are from the raw data. Significance letters for all data except the height are from the transformed data. GDD start January 1.

**Not significant from subsequent emergence times due to data transformation.

***Calculated using 9 seeds per berry.

Table 4-5. Effect of emergence date on pokeweed seedling biomass and fecundity, average per plant, October 2013.

					Above-ground		***Below-ground***		
Date of emergence	**GDD at emergence**	**Height (cm)**	**No. mature berries**	**Approx. no. seeds*****	**Fresh weight (g)**	**Dry weight (g)**	**Fresh weight (g)**	**Dry weight (g)**	**Root:Shoot ratio**
June 4	409	79 (± 8) a	236 (± 110) a	2124 (± 993) a	1161 (± 471) a	308 (± 145) a	1786 (± 582) a	509 (± 182) a	2.0 (± 6) a
June 18	541	58 (± 8) ab	189 (± 95) a	1698 (± 856) a	552 (± 297) ab	143 (± 84) b	876 (± 292) a	249 (± 88) a	5.3 (± 6) a
July 2	721	41 (± 7) b	22 (± 22) b	196 (± 196) b	143 (± 79) b	31 (± 16) cd	320 (± 151) b	87 (± 41) b	3.1 (± 5) a
July 15	912	47 (± 7) b	6 (± 4) b**	52 (± 38) b**	216 (± 49) b	40 (± 9) bc	354 (± 111) b	92 (± 29) b	2.4 (± 5) a
July 30	1112	18 (± 7) c	0 (± 0) b	0 (± 0) b	25 (± 4) c	5 (± 1) de	81 (± 19) c	21 (± 5) c	4.1 (± 5) a
Aug. 13	1263	3 (± 7) c	0 (± 0) b	0 (± 0) b	0.3 (± 0.2) d	0.08 (± 0.04) e	0.3 (± 0.2) d	0.1 (± 0.1) d	14.8 (± 5) a
Aug. 28	1422	4 (± 8) c	0 (± 0) b	0 (± 0) b	0.7 (± 0.5) d	0.1 (± 0.1) e	0.6 (± 0.4) d	0.2 (± 0.2) d	1.4 (± 6) a
Sept. 10	1571	7 (± 8) c	0 (± 0) b	0 (± 0) b	3 (± 2) cd	0.5 (± 0.3) e	1 (± 0.1) d	0.3 (± 0.005) d	1.1 (± 6) a
Sept. 24	1680	4 (± 8) c	0 (± 0) b	0 (± 0) b	0.6 (± 0.1) cd	0.1 (± 0.01) e	0.3 (± 0.1) d	0.2 (± 0.03) d	1.9 (± 6) a

*Standard errors are in parentheses. Values followed by the same letter within a column are not significantly different using Fisher's LSD at $P < 0.05$. Means and standard errors are from the raw data. Significance letters for all data except the height are from the transformed data. GDD start January 1.

**Not significant from subsequent emergence times due to data transformation.

***Calculated using 9 seeds per berry.

Epilogue

The increased interest in pokeweed management has provided motivation to study the efficacy of current control options and investigate aspects on pokeweed biology to better time control tactics. This research has shown pokeweed seedlings emerging throughout the summer with a peak emergence in mid to late May. As might be predicted, above- and below-ground biomass is reduced as emergence is delayed. Interestingly, seedlings which emerged before mid June 2012 and late July 2013 produced mature berries by the end of the season, while those emerging later than these dates did not. This difference between years indicates that the length of time necessary for individual plants to reach reproductive maturity varies considerably depending on environment and perhaps genetics; however, this is uncertain. There has not been a threshold set for the age, weight, or size which pokeweed seedlings must achieve in order to survive to the next season; however, plants which emerged after mid-August attained less than 1 g total plant dry matter before cold temperatures stopped plant development, and winter survival is doubtful with these late emerging plants. The results from the emergence timing and plant growth and reproduction study suggest that most pokeweed seedlings would be controlled with effective management applied by late June or July in central Pennsylvania. However, a small percentage can emerge beyond early July and in at least one of two years still reached reproductive maturity. Although these later emerging seedlings account for a small proportion of the total population, they have the potential to survive the winter, regrow the following spring, produce more seeds, and increase the population.

Glyphosate is a widely used herbicide in agricultural systems. Although several different tactics were examined with glyphosate, application timing had the largest effect on pokeweed control. Air induction and flat fan nozzles provided similar control. Lower spray volumes increased control in one of two years. The highest rates of glyphosate (1.27 and 1.73 kg ae/ha) provided the best control initially, but control was similar to the lower rate by the following spring. Application timings after mid June provided at least 90% control of pokeweed. This is possibly due to increased glyphosate translocation when pokeweed was flowering and producing ripe fruit; perennials typically translocate sugars and carbohydrates to vegetative structures once they turn reproductive, and phloem-mobile glyphosate should have moved at the same time. Spring regrowth assessments showed a similar trend, with later application timings providing higher control. Application after mid June often poses a problem in corn due to herbicide label restrictions and taller corn impeding effective herbicide application. Planting a shorter statured crop, such as soybean, allows for a timelier glyphosate application and potentially increased control of pokeweed. Including small grains or other crops in the rotation which allow for mid-summer harvest can also present a better opportunity for an effective glyphosate application in late summer.

Corn herbicides provided at least 80% control of pokeweed by the end of the season. However, no treatments provided complete control as there was still some green or living tissue remaining 12 weeks after application (WAA); this indicates the potential for recovery and regrowth the following year. Soybean herbicides produced a wide range of pokeweed control and treatments that included glyphosate provided 80% control or higher, while those treatments without glyphosate only provided 39 to 62% control. Non-glyphosate treatments reduced pokeweed biomass compared to the untreated check, but not as much as the glyphosate treatments. Spring regrowth confirmed that the glyphosate treatments provided better control than the non-glyphosate treatments. Finally, although soil residual herbicides for seedling control were not compared in this work, this research indicates that residual herbicide will help suppress seedling emergence in both corn and soybean and reduce the pokeweed population over time. Residual herbicides should be included where pokeweed seedbanks are established.

This research indicates that glyphosate is an important herbicide for controlling pokeweed in soybean and it can also be useful in corn; however, there are other options for corn. With the concern for glyphosate resistant weeds and over reliance of glyphosate in much of the corn and soybean growing areas of the Northeast, our suggestion is to preserve glyphosate for soybean where other effective alternatives for pokeweed control do not currently exist and use alternative effective modes of action in corn. Increasing the diversity of the crop rotation to include crops such as small grains and hay will also allow for late season applications, competition with emerging seedlings, and reduced pokeweed populations.

Appendix A

Burial Time and Depth Effect on Common Pokeweed Seeds

Introduction

An experiment to investigate the effect of burial time and depth was conducted at the Penn State Russell E. Larson Research Farm near State College, Pennsylvania (40°44’N, 77°57’W). The field site had a mixture of two silt loams: Hagerstown silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) and Murrill channery silt loam (fine-loamy, mixed, semiactive, mesic Typic Hapludults) with a pH of 6.7 and 2.5% organic matter. The site had previously been used for corn and soybean demonstration research and had no history of pokeweed infestation. In the fall of 2011, the field was tilled using a heavy disc followed by a roller harrow. On November 8, 2011, 20 pokeweed berries (approximately 180 seeds) were placed in 7.6 square centimeter mesh bags (Figure A-1) and buried under the ground at two different depths (2.5 and 15 cm). After six, twelve, and eighteen months, different bags were exhumed and seed viability was quantified. After the bags were exhumed, they were put through visual, forceps, germination, and tetrazolium tests. After each test, seeds were put into one of two categories: dead or viable. For the purpose of this study, dead seeds include those which had germinated in the bag while buried, hollow seeds, seeds which were soft after the forceps test, and those whose radicle was not stained by the tetrazolium. After each test, the dead seeds were separated out, and the potentially viable seeds were allowed to go on to the next test until a final count of viable seeds was reached after the final tetrazolium test.

The visual test was performed immediately after the bags were exhumed. Seeds which had visually germinated were counted as dead. For the forceps test, seeds were squeezed with forceps, and any seeds which were soft were counted as dead, while those seeds which were hard were counted as potentially viable. These potentially viable seeds were placed in petri dishes on top of Whatman Number 3 filter paper[1] disks and moistened with 7.5 mL of water. The germination chamber was set at a minimum temperature of 60° F, a maximum of 80° F, and given 11 hours of light per day. Seeds were in the chamber for 10 to 14 days. Seeds which germinated were counted as viable. The seeds which had not germinated were put through a final tetrazolium test. A one percent tetrazolium (2,3,5-triphenyl tetrazolium chloride)[2] solution was made. Tetrazolium stains tissue in the seed which is still respiring, indicating its potential viability. Seeds were placed in petri dishes with 10 mL of the tetrazolium solution and allowed to soak for 24 hours. Seeds which were at least 60% stained, including the radicle, were counted as viable. Seeds which were less than 40% stained were counted as dead.

This experiment was replicated four times for the 12 and 18 month burial times, and eight times for the six month burial time. All data was analyzed using the Mixed procedure in SAS 9.3[3]. Analysis of variance (ANOVA) was used to test for differences in burial depth and time. Means were separated using Fisher’s Protected LSD with significance set at $P < 0.05$. The variables “Time” and Depth” were treated as fixed variables, and “Rep” was treated as a random variable. All data was analyzed using the raw data. The experiment was not repeated in 2012.

Source of Materials.
[1] Whatman International Ltd, UK
[2] Affymetrix, Inc., Cleveland, OH 44128-5933
[3] SAS® statistical analysis software, SAS Institute Inc., Cary, NC 27513

Results

After six months, no difference was observed between the two burial depths in the percentage of dead or viable seeds (Table A-1). However, burying seeds at the shallower depth for 12 or 18 months resulted in a higher percentage of dead seeds at the shallower depth compared to the deeper depth (Table A-1). Shallower depths could increase the chances of seed predation, and therefore increase seed mortality. Also, the longer a seed is in the soil, the longer it is exposed to degradation and seed predators, especially at shallower depths. The results from this study indicate that pokeweed seeds kept in the soil at shallower depths for longer than six months will have a higher mortality than seeds buried deeper for a shorter amount of time.

Tables and Figures

Figure A-1. Mesh bag used to bury pokeweed seeds.

Table A-1. Effect of burial time and depth on the percentage of dead pokeweed seeds, 2011.

Burial time (mo)	**Burial depth (cm)**	
	2.5	**15**
	% Dead	
6	53 (± 5) ab	45 (± 5) bc
12	50 (± 7) ab	27 (± 7) c
18	71 (± 7) a	28 (± 7) c

*Standard errors are in parentheses. Means followed by the same significance letter within the table are not significantly different.

Appendix B

The Effect of Clipping Frequency on Common Pokeweed Suppression

Introduction

A study was conducted in 2012 and 2013 at the Penn State University Russell E. Larson Research Farm near State College, Pennsylvania (40°44’N, 77°57’W) in order to measure the effects of clipping frequency on common pokeweed suppression. Clipping or mowing is often used as control tactic for perennial weeds in order to deplete their reserves for winter storage. Different areas of the same field were used both years at a site which had historically been farmed no-till, producing mostly corn grain and soybean, and also had a severe natural infestation of pokeweed. The soil series was Andover channery silt loam (fine, mixed, semiactive, mesic Typic Hapludalfs) and the soil pH and organic matter were 5.4 and 4.1%, respectively. In both years, soybean was planted in late May in 76 cm rows; however, soybean growth and performance was not a component of this experiment and was only included to help manage the field site. Individual pokeweed plants were selected based on similar growth stage and size and were subjected to several clipping regimes including: 1) none (control); 2) once per summer (July, August, or September); 3) twice per summer (July and August or July and September) or; 4) three times per summer (July, August, and September). Clipping occurred around the first day of the month and was accomplished by using a pair of hand-held brush cutters to cut any above-ground growth to the soil level. The average heights of the plants at each relevant clipping time are shown in Table B-1. At all clipping times, above-ground growth was cut off and discarded. In early October, plant regrowth was assessed, including height, and above-ground biomass was harvested. For the 2012 growing season only, regrowth was also measured the following spring on June 6, 2013.

Four individual plants were subjected to each treatment, resulting in four replications. All data were analyzed using the Mixed procedure in SAS 9.3[1]. Data could not be pooled over the two years due to varying responses. Analysis of variance (ANOVA) was used to test for differences in treatments. Means were separated using Fisher's Protected LSD with significance set at $P < 0.05$. "Treatment" was treated as a fixed variable, and "Rep" was treated as a random variable. All data was transformed using the log transformation [$y = log(x + 10)$] in order to normalize the variance and meet the assumptions of ANOVA.

Results

Mowing in September (whether by itself or in addition to mowing in July) produced the least amount of regrowth in October in 2012 (Table B-2). A similar trend occurred in 2013 (Table B-2). In both years of the study, mowing in July reduced biomass compared to the control, but both height and biomass were greater than the other treatments. This indicates that the July clipping will reduce plant biomass, but the later mowing times are producing the greatest reductions. Although no data on berry production was collected, later mowing times and more frequent mowing often resulted in the lack of berry production by the end of the season.

By the spring following the first year of the study, the three-time clipping regime produced no regrowth (Table B-3), while some plant recovery occurred with all other treatments. Although there were some numerical differences, only the three-clipping regime completely controlled the pokeweed. In conclusion, this study suggests that frequent clipping or mowing will control pokeweed and that increasing diversity in a crop rotation by including alfalfa or other hay crops which are mowed several times throughout the year would be a sound strategy to reducing pokeweed populations.

Sources of Materials
[1]SAS® statistical analysis software, SAS Institute Inc., Cary, NC 27513

Tables

Table B-1. Height of pokeweed plants at each relevant mowing time, 2012 and 2013.

	2012 Height (cm)			***2013 Height (cm)***		
Time of mowing	**July**	**August**	**September**	**July**	**August**	**September**
July (J)	123	--	--	138	--	--
August (A)	--	166	--	--	34	--
September (S)	--	--	135	--	--	163
J, A	88	60	--	149	53	--
J, S	105	--	84	148	--	90
J, A, S	90	73	15	144	56	27

Table B-2. Effect of mowing frequency on pokeweed heights and biomass, October 2012 and 2013.

	October 2012			***October 2013***		
Time of mowing	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**
none	145 (± 13) a	995 (± 223) a	269 (± 49) a	138 (± 5) a	2104 (± 506) a	862 (± 169) a
July (J)	114 (± 13) a	201 (± 88) b	40 (± 18) b	69 (± 10) b	86 (± 11) b	16 (± 2) b
August (A)	12 (± 7) bc	18 (± 16) c	3 (± 3) c	7 (± 1) de	2 (± 0.5) d	0.5 (± 0.1) cd
September (S)	0 (± 0) c	0 (± 0) c	0 (± 0) c	2 (± 1) f	0.3 (± 0.2) d	0.1 (± 0.04) d
J, A	21 (± 9) b	14 (± 10) c	2 (± 1) c	23 (± 3) c	15 (± 4) c	3 (± 0.8) c
J, S	0.4 (± 0.4) c	0.3 (± 0.3) c	0.01 (± 0.01) c	6 (± 1) ef	1 (± 0.4) d	0.2 (± 0.1) d
J, A, S	30 (± 20) b	92 (± 85) c	16 (± 15) c	12 (± 3) d	4 (± 1) d	0.8 (± 0.2) cd

* Standard errors are in parentheses. Means and standard errors are from the raw data; significance letters are from the transformed data.

Table B-3. Effect of mowing frequency on pokeweed heights and biomass, spring following the 2012 season.

	Spring after 2012 season (June 2013)		
Time of mowing	**Height (cm)**	**Fresh weight (g)**	**Dry weight (g)**
none	46 (± 16) ab	159 (± 66) a	12 (± 5) a
July (J)	42 (± 7) a	146 (± 56) a	11 (± 4) a
August (A)	11 (± 11) bc	67 (± 67) ab	5 (± 5) a
September (S)	26 (± 16) abc	116 (± 67) ab	9 (± 5) a
J, A	28 (± 11) ab	146 (± 85) ab	10 (± 6) a
J, S	20 (± 7) abc	25 (± 14) ab	2 (± 1) a
J, A, S	0 (± 0) c	0 (± 0) b	0 (± 0) a

* Standard errors are in parentheses. Means and standard errors are from the raw data; significance letters are from the transformed data.

Appendix C

Exploring Methods for Common Pokeweed Seed Germination

Pokeweed seeds have a hard seed coat and are reported to remain viable up to 40 years in the soil. Pokeweed seeds which had been collected from the field in 2011 were planted in the greenhouse at Penn State University in an attempt to culture plants for greenhouse research; however, the lack of successful seed germination stimulated the investigation of several germination experiments.

Pokeweed seeds collected from multiple plants during the fall of 2011 were subjected to five different treatments prior to examining germination and emergence during the spring of 2012. Pokeweed fruits were harvested, allowed to air dry and stored under ambient conditions in the greenhouse. Seeds were removed by crushing the dried fruits and sieving to remove debris. The seeds were then subjected to five different treatments: 1) air-dried seed stored under ambient conditions (control); 2) mechanical scarification; 3) soaking in water for 24 hours; 4) air-dried cold storage and; 5) moist cold stratification. The seeds under the dry, ambient treatment were kept in the greenhouse for a minimum of 6 months before planting. The seeds for all other treatments were kept in a cold storage room at 4° C for a minimum of 6 months until treatment and/or planting. Mechanically scarified seeds were mechanically scarified by partially or fully removing the seed coat with a knife and/or sandpaper. For the soaking treatment, seeds were placed in distilled water for 24 hours and the water was changed after five minutes, five hours, and eight hours. After 24 hours, the water was drained and the seeds were planted. The air-dried cold storage seeds were stored at 4° C for 6 months prior to planting. The cold stratified seeds were placed in a sealed plastic bag with damp vermiculite and stored at 4°C for either two, three, or four months prior to planting. Sample size for each treatment differed based on the number of seeds available (Table C-1). After treatment, seeds were planted in 13 cm plots filled with soil-less media, placed in the greenhouse under natural light, and watered daily. Minimum and maximum greenhouse temperatures were approximately 18° and 24° C. Germination was monitored for eight to 12 weeks.

Seeds in the control dry cold storage treatment had the highest germination rate of 37% after 12 weeks, followed by the dry ambient conditions at 29% germination after 8 weeks (Table C-1). All other treatments produced no germinating seeds. The mechanical scarification method of using a knife or sandpaper may have damaged the actual seed in addition to the seed coat, rendering the seed no longer viable. The seeds under cold, wet conditions had not germinated within two months of the planting date, and therefore the study was terminated; perhaps waiting for a longer period of time may have shown some germination. The results of this study indicate that the dormancy of pokeweed seeds is hard to break, and that the best option for trying to germinate pokeweed seeds is to store them in cool, dry conditions.

Table C-1. Sample size and percent germination for five different germination treatments of pokeweed seeds, 2012.

Treatment	***n***	**% Germination**
dry, cold	100	37
dry, ambient	21	29
mechanical scarification	100	0
soaking in water	50	0
cold, wet	50	0