Roadside Vegetation Management Research – 2024 Report

ANNUAL REPORT

June 30, 2024

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THE PENNSYLVANIA STATE UNIVERSITY

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16. Abstract This report details a cooperative research project performed for the Pennsylvania Department of Transportation's Bureau of Operations by Penn State. The report includes the following: Evaluation of Foliar Applications to Callery Pear *(Pyrus calleryana)*-Third Year , Evaluation of Foliar Applications to Eastern Red Cedar *(Juniperus virginiana)*-First Year, Evaluation of Native Grass and Pollinator Seed Mixes and Seeding Methods for Conversion and Establishment Along Roadsides-Fourth Year, Herbicide Efficacy on Johnsongrass *(Sorghum halepense*(L.) Pers.*),* Demonstration of Three Bareground Programs with Alternative Site of Action-Year One, Evaluation of Alternative Bareground Herbicide Mixes.			
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INTRODUCTION

In October 1985, personnel at Penn State began a cooperative research project with the Pennsylvania Department of Transportation (PennDOT) to investigate several aspects of roadside vegetation management. An annual report has been submitted each year that describes the research activities and presents the data. The previous reports are listed below:

Report # PA86-018 + 85-08 - Roadside Vegetation Management Research Report

Report # PA87-021 + 85-08 - Roadside Vegetation Management Research Report - Second Year Report

Report # PA89-005 + 85-08 - Roadside Vegetation Management Research Report - Third Year Report

Report # PA90-4620 + 85-08 - Roadside Vegetation Management Research Report - Fourth Year Report

Report # PA91-4620 + 85-08 - Roadside Vegetation Management Research Report - Fifth Year Report

Report # PA92-4620 + 85-08 - Roadside Vegetation Management Research Report - Sixth Year Report

Report # PA93-4620 + 85-08 - Roadside Vegetation Management Research Report - Seventh Year Report

Report # PA94-4620 + 85-08 - Roadside Vegetation Management Research Report - Eighth Year Report

Report # PA95-4620 + 85-08 - Roadside Vegetation Management Research Report - Ninth Year Report

Report # PA96-4620 + 85-08 - Roadside Vegetation Management Research Report - Tenth Year Report

Report # PA97-4620 + 85-08 - Roadside Vegetation Management Research Report - Eleventh Year Report

Report # PA98-4620 + 85-08 - Roadside Vegetation Management Research Report - Twelfth Year Report

Report # PA99-4620 + 85-08 - Roadside Vegetation Management Research Report - Thirteenth Year Report

Report # PA00-4620 + 85-08 - Roadside Vegetation Management Research Report - Fourteenth Year Report

Report # PA01-4620 + 85-08 - Roadside Vegetation Management Research Report - Fifteenth Year Report

Report # PA02-4620 + 85-08 - Roadside Vegetation Management Research Report - Sixteenth Year Report

Report # PA03-4620 + 85-08 - Roadside Vegetation Management Research Report
-Seventeenth Year Report

Report # PA04-4620 + 85-08 - Roadside Vegetation Management Research Report
-Eighteenth Year Report

Report # PA05-4620 + 85-08 - Roadside Vegetation Management Research Report
-Nineteenth Year Report

Report # PA-2008-003-PSU 005 Roadside Vegetation Management Research Report
-Twenty-second Year Report

Report # PA-4620-08-0/LTI 2009-23 Roadside Vegetation Management Research Report

-Twenty-third Year Report

Report # PA-2010-005-PSU-016 Roadside Vegetation Management Research Report
-Twenty-fourth Year Report

Report # PA-2011-006-PSU RVM Roadside Vegetation Management Research

– 2011 Report

Report # PA-2012-007-PSU RVM Roadside Vegetation Management Research

– 2012 Report

Report # PA-2013-008-PSU RVM Roadside Vegetation Management Research

– 2013 Report

Report # PA-2014-009-PSU RVM Roadside Vegetation Management Research

– 2014 Report

Report # PA-2015-010-PSU RVM Roadside Vegetation Management Research

– 2015 Report

Report # PA-2016-011-PSU RVM Roadside Vegetation Management Research

– 2016 Report

Report # PA-2017-012-PSU RVM Roadside Vegetation Management Research

– 2017 Report

Report # PA-2018-013-PSU RVM Roadside Vegetation Management Research

– 2018 Report

Report # PA-2019-014-PSU RVM Roadside Vegetation Management Research

– 2019 Report

Report # PA-2020-015-PSU RVM Roadside Vegetation Management Research – 2020 Report

Report # PA-2021-016-PSU RVM Roadside Vegetation Management Research – 2021 Report

Report # PA-2022-017-PSU RVM Roadside Vegetation Management Research – 2022 Report

Report # PA-2023-018-PSU RVM Roadside Vegetation Management Research – 2023 Report

These reports are available by request from the authors and are available online in portable document format (PDF) at https://plantscience.psu.edu/research/projects/vegetation-management/annual-reports.

Use of Statistics in This Report

Many of the individual reports in this document make use of statistical analysis, particularly techniques involved in the analysis of variance. The use of these techniques allows for the establishment of criteria for significance. Numbers are said to be significantly different when the differences between them are most likely due to the different treatments, rather than chance. We have relied almost exclusively on the commonly used probability level of 0.05. When a treatment effect is significant at the 0.05 level, this indicates that there is only a five percent chance that the differences are due to chance alone. Once this level of certainty is reached with the analysis of variance, Tukey's HSD separation test is employed to separate the treatments into groups that are significantly different from each other. In many of our results tables, there is/are a letter or series of letters following each number and a notation which states, 'within each column, numbers followed by the same letter are not significantly different at the 0.05 level'. In addition, absence of letters within a column or the notation 'n.s.' indicates that the numbers in that column are not significantly different from each other at the 0.05 level.

This report includes information from studies relating to roadside brush control, herbaceous weed control, plant growth regulators, native species establishment, low maintenance groundcovers, and total vegetation control. Herbicides are referred to as product names for ease of reading. The herbicides used are listed on the following page by product name, active ingredients, formulation, and manufacturer.

Product Information Referenced in This Report

The following details additional information for products referred to in this report. DF = dry flowable, DG = dispersible granules, L = liquid, EC = emulsifiable concentrate, ME = microencapsulated, RTU = ready to use, S = water soluble, SC = soluble concentrate, SG = soluble granule, SL = soluble liquid, WDG=water-dispersible granules, WE= water emulsion, XP= Extruded Paste.

Trade Name	Active Ingredients	Formulation	Manufacturer
Accord XRT II	glyphosate	4 S	Corteva Agriscience
Arsenal Powerline	imazapyr	2 S	BASF Corp.
Assure II	quizalofop-P	0.88 EC	DuPont
Echelon 4SC	sulfentratzone + prodiamine	4 SC	FMC Corporation
Escort XP	metsulfuron methyl	60 DF	Bayer Environmental Science
Esplanade 200 SC	indaziflam	1.67 SC	Bayer Environmental Science
Esplanade Sure	indaziflam + rimsulfuron	24.3 + 16.7 WDG	Bayer Environmental Science
Freelexx	2,4-D choline	3.8 S	Corteva Agriscience
Fusilade II	fluazifop-P-butyl	2 EC	Syngenta
Hyvar XL	bromacil	2 SL	Bayer Environmental Science
MSM 60	metsulfuron methyl	60 DF	Alligare LLC
Method 240SL	aminocyclopyrachlor	2 SL	Bayer Environmental Science
Oust Extra	sulfometuron + metsulfuron	56.25 + 15 WDG	Bayer Environmental Science
Outrider	sulfosulfuron	75 WDG	Valent USA LLC
Pendulum Aquacap	pendimethalin	3.8 ME	BASF Corp.
Piper EZ	flumioxazin + pyroxasulfone	33.5 + 42.5 WDG	Valent USA LLC
Plateau	imazapic	2 S	BASF Corp.
Prodiamine 65 WDG	prodiamine	65 WDG	Control Solutions Inc.
Promenade WDG	flumioxazin	51 WDG	Alligare LLC
RoundUp Pro Concentrate	glyphosate	3.7 S	Bayer CropScience
Segment II	sethoxydim	1.5 EC	BASF
TerraVue	aminopyralid+florpyrauxifen-benzyl	71 + 6 WDG	Corteva Agriscience
Triplet LO	2,4-D+mecoprop-p+dicamba	2.38+0.63+0.22 S	NuFarm Inc.
Vastlan	triclopyr choline	4 S	Corteva Agriscience
Vanquish	dicamba	4 S	NuFarm Inc.

EVALUATION OF FOLIAR APPLICATIONS TO CALLERY PEAR 3RD YEAR

Herbicide trade and common names: TerraVue (*aminopyralid + florpyrauxifen-benzyl*), Accord XRT II (*glyphosate*), Freelexx (*2, 4-D choline*), Method 240SL (*aminocyclopyrachlor*), MSM 60 (*metsulfuron-methyl*), Vastlan (*triclopyr choline*)

Plant common and scientific name: Callery pear (*Pyrus calleryana*)

ABSTRACT

Callery pear has been identified in many states as an invasive species and populations have increased dramatically along Pennsylvania roadsides. In November 2021, Callery pear was added to Pennsylvania's class B noxious weed list. A class B noxious weed is a plant that is widely established in Pennsylvania and cannot feasibly be eradicated. An experiment was conducted at the I-99 northbound Atherton Street interchange in State College, PA to evaluate the efficacy of foliar herbicide applications to Callery pear trees. The herbicide treatments included TerraVue at 2.85 oz/ac; Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac; Freelexx at 128 oz/ac; Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac; Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac; MSM 60 at 1 oz/ac; Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac; and an untreated check. By 62 days after treatment, all treatments except for Terra Vue at 2.85 oz/ac provided a minimum of 99% injury to Callery pear. One year after treatment MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac resulted in 0% living leaf canopy of Callery pear. Additional noteworthy treatments include Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac with 0.2% living leaf canopy and Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac with 3.5% living leaf canopy. By the conclusion of the experiment, 2 years after treatment, MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac resulted in 0% living leaf canopy of Callery pear. Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac resulted in 4% living leaf canopy. A common brush herbicide mix used by PennDOT, Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac resulted in 12.8% living leaf canopy.

INTRODUCTION

Native to Asia, Callery pear (*Pyrus calleryana*) was originally introduced into the United States in the early 1900's as a potential fire blight resistant root stock for common pear. In the 1960's based on its beautiful white flowers, disease resistance and outstanding fall leaf color several varieties of Callery pear were propagated, sold, and planted in managed landscapes and used as street trees. Callery pear was originally considered self-sterile when introduced in the United States; however, the introduction of other varieties have resulted in the opportunity for cross pollination between the different varieties and the production of viable seed. This viability combined with its fruit being attractive to birds and mammals has resulted in the rapid spread along roadside corridors and field edges. *Pyrus calleryana* is a small tree reaching 40 feet in height and can be found naturalizing along the edges of fields, forests, and roadsides[1]. In November 2021, Callery pear was added to Pennsylvania's class B noxious weed list. A class B

[1] Penn State Extension 2020. Invasive Plant Fact Sheet, Callery Pear *(Pyrus calleryana)*. Available at https://extension.psu.edu/callery-pear Accessed August 23, 2023.

noxious weed is a plant that is widely established in Pennsylvania and cannot be feasibly eradicated. With this designation, Callery pear may no longer be sold, propagated, or cultivated in Pennsylvania as of February 2024.

The goal of this experiment was to compare seven common brush herbicide treatments to determine their efficacy as a foliar application thoroughly applied throughout the canopy to injure and ultimately control Callery pear as determined by percent living leaf canopy.

MATERIALS AND METHODS

The experiment was established near the interchange of I-99 northbound at North Atherton Street in State College, Pennsylvania. With ten trees per replication, each tree was measured to determine the canopy area. The formula used to calculate canopy areas was the surface area of a cylinder ((2 x pi x radius x height) + (2 x pi x radius^2)) (Appendix Table 1). The herbicide application amounts were based on the calculated canopy area. The experiment evaluated eight treatments: TerraVue at 2.85 oz/ac; Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac; Freelexx at 128 oz/ac; Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac; Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac; MSM 60 at 1 oz/ac; Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac; and an untreated check. Methylated seed oil at 1% v/v was added to all herbicide mixes. The application was made at a carrier volume of 35 gallons per acre. All treatments were applied using a CO_2-powered backpack sprayer equipped with a 30 GunJet spray gun and one PPX 6 adjustable nozzle at 32 PSI (pounds per square inch). The weather at the time of application was sunny to partly cloudy with wind speeds of 5-10 mph, 60% relative humidity, and air temperatures of 85° F. The treatments were applied on July 7, 2021.

Treatments were visually rated for percent injury where 0 = no injury – 100 = complete injury on August 5, 2021, 29 days after treatment (DAT) and on September 7, 2021, 62 DAT, and percent living leaf canopy where 0= 0% living leaf canopy – 100 = 100% living leaf canopy on July 7, 2022, 365 DAT and July 7, 2023, 730 DAT. All data were subjected to analysis of variance, and when treatment effect F-tests were significant ($p \leq 0.05$), treatment means were compared using Tukey's HSD separation test.

RESULTS AND DISCUSSION

Injury to Callery pear from all herbicide treatments ranged from 74.6 to 100%, while the untreated check exhibited natural leaf damage of 9.5% on August 5, 2021, 29 DAT (Table 1). By 62 DAT, a similar percent injury range of 71% to 100% was observed amongst herbicide treatments while the untreated check recorded 8.1% injury. Treatments resulting in 100% injury were Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac; Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac; MSM 60 at 1 oz/ac; and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac. Freelexx alone at 128 oz/ac resulted in 99.8% injury, while Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac resulted 99.7% injury. TerraVue at 2.85 oz/ac resulted in the lowest injury with 71%.

On July 7, 2022, 365 DAT, the percent living leaf canopy ranged from 98.5% for the untreated check to 0% for two different herbicide treatments. MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac resulted in 0% living leaf canopy. Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac resulted in 0.2% living leaf canopy while Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac resulted in 3.5% living leaf canopy. Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac resulted in 10% living leaf canopy, Freelexx at 128 oz/ac resulted in 15% canopy reduction and TerraVue at 2.85 oz/ac resulted in 16.7% living leaf canopy.

By July 7, 2023, 730 DAT, the percent living leaf canopy ranged from 100% for the untreated plots to 0% for MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac. Accord XRT II at 96 oz/ac + Vastlan at 48 oz/ac resulted in 4% living leaf canopy while Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac resulted in 12.8%. Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac resulted in 22% living leaf canopy, TerraVue at 2.85 oz/ac resulted in 29.8% and Freelexx at 128 oz/ac resulted in 33%.

CONCLUSIONS

By September 7, 2021, 62 DAT, all herbicide treatments resulted in injury of more than 99% except TerraVue at 2.85 oz/ac which showed a lower injury of 71%. Ultimately, only MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac resulted in 0% living leaf canopy over the subsequent one to two years after treatment.

The remaining treatments TerraVue at 2.85 oz/ac, Accord XRT II at 96 oz/ac +Vastlan at 48 oz/ac, Freelexx at 128 oz/ac, Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + MSM 60 at 0.5 oz/ac, and Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + MSM 60 at 0.5 oz/ac treatments showed percent living leaf canopy ranging from 4 to 33 percent 2 years after treatment. Callery pear treated with these products continued to grow thus requiring follow up treatments.

MANAGEMENT IMPLICATIONS

Based on the results of the experiment MSM 60 at 1 oz/ac and Method 240SL at 16 oz/ac + MSM 60 at 2 oz/ac are two treatments to consider as foliar applications to Callery pear. Caution should be exercised when using MSM 60 or any metsulfuron methyl product. Past work by the project indicates that rates of MSM 60 above 0.5 oz/ac may cause injury to a grass ground cover[2]. The Method 240SL label cautions that exceeding the rates of 8 oz/ac may result in unacceptable injury to desirable turfgrasses and the addition of MSO adjuvant may further increase turfgrass injury. In addition, caution must be taken with Method 240SL as it has the potential to injure desirable trees and plants when their roots extend into treated areas[3].

[2] Jon M Johnson et al 2014. Examining Potential Turf Phytotoxicity Caused by Escort XP, Krenite S and MAT 28. Roadside Vegetation Management Research –2014 Report. pp 23-26.
[3] Bayer CropScience LP. Method 240SL label. https://www.cdms.net/ldat/ldCFU019.pdf Internet September 22, 2023.

Table 1. Percent injury and living leaf canopy of Callery pear *(Pyrus calleryana)*. The experiment was visually rated for percent injury where 0 = no injury - 100 = complete injury on August 5, 2021, 29 days after treatment (DAT) & September 7, 2020, 62 DAT and percent living leaf canopy where 0 = 0% living leaf canopy – 100 = 100% living leaf canopy on July 7, 2022, 365 DAT and July 7, 2023, 730 DAT. Herbicides were applied on July 7, 2021. All treatments included methylated seed oil at 1% v/v. Each value is the mean of ten replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/ac	% Injury 8/5/21 29 DAT	% Injury 9/7/21 62 DAT	% Living Leaf Canopy 7/7/22 365 DAT	% Living Leaf Canopy 7/7/23 730 DAT
Untreated	--	9.5 a	8.1 a	98.5 b	100 c
TerraVue	2.85	74.6 b	71 b	16.7 a	29.8 ab
Accord XRT II Vastlan	96 48	99.6 c	99.7 c	0.2 a	4 ab
Freelexx	128	99.4 c	99.8 c	15 a	33 b
Freelexx Method 240SL MSM 60	96 16 0.5	99.8 c	100 c	10 a	22 ab
Freelexx Vastlan MSM 60	96 48 0.5	100 c	100 c	3.5 a	12.8 ab
MSM 60	1	99.7 c	100 c	0 a	0 a
Method 240SL MSM 60	16 2	100 c	100 c	0 a	0 a

EVALUATION OF FOLIAR APPLICATIONS TO EASTERN RED CEDAR *(Juniperus virginiana)*-1st Year

Herbicide trade and *common names*: Escort XP (*metsulfuron-methyl*), TerraVue (*aminopyralid + florpyrauxifen-benzyl*), Freelexx (*2, 4-D choline*), Method 240SL (*aminocyclopyrachlor*), Vastlan (*triclopyr choline*), Vanquish *(dicamba)*, *glyphosate (4 lb. ae/gal)*

Plant common and scientific name: eastern red cedar (*Juniperus virginiana*)

ABSTRACT

Eastern red cedar has become a problematic native species found in guiderail sites throughout the commonwealth where common bareground mixes applied and appear ineffective. The purpose of this experiment was to evaluate foliar applications to the entire canopy of eastern red cedar to determine injury and control based on percent living leaf canopy. The experiment evaluated eight herbicide treatments: Escort XP at 1oz/ac; Escort XP at 2 oz/ac; Escort XP at 3 oz/ac; TerraVue at 2.75 oz/ac + Escort XP at 1oz/ac; Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + Escort XP at 1 oz/ac; Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + Escort XP at 1 oz/ac; Vanquish at 32 oz/ac; glyphosate (4 lb. ae/gal) at 118 oz/ac; and an untreated check. Methylated seed oil at 1% v/v was added to all herbicide mixes. The application was made at a carrier volume of 35 gallons per acre on May 31, 2023. By July 27, 2023, 57 DAT, no treatment resulted in 100% injury. Percent injury of the Escort XP only treatments resulted in less injury (36-42%) than the other herbicide treatments (50-72%). Percent living leaf canopy evaluated on October 26, 2023, 148 DAT, resulted in no treatment with 0% living leaf canopy. Only two products resulted in less than 40% living leaf canopy. These included TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac with the lowest living leaf canopy at 31.5% and glyphosate (4 lb. ae/gal) at 118 oz/ac at 32.5%.

INTRODUCTION

Eastern red cedar, *Juniperus virginiana,* is native to Pennsylvania, and grows in a wide geographic range of sites and soils in the eastern half of the United States[4]. Soil conditions range from deep well drained soils associated with agricultural production areas to shallow, rocky outcrops common along roadsides with soils varying in pH from 4.7-7.8[1]. Eastern red cedar can reach a height of 40-50 feet and can grow as low as a small shrub. The bark is gray to reddish brown with peeling stripes. The needles are opposite scale-like in ranks of four[5], shiny smooth dark green and glandular on older foliage[6]. Young needles are linear, pointed, and prickly[3]. Eastern red cedar is a dioecious species reaching sexual maturity at about 10 years[1]. Male trees have yellow-brown cones near the tips, releasing yellow pollen[2] causing the tree to appear yellow brown during pollen release. Female trees produce fleshy bluish green to frosted blue cones ¼ inch in size[2] that are quite attractive producing 1-2 seeds per cone. Eastern red cedar produces some seed every year, however every 2-3 years seed production is quite heavy[1]. The cones do not open and stay on the tree through winter although many are eaten and dispersed by animals,

[4] https://www.srs.fs.usda.gov/pubs/misc/ag_654/table_of_contents.htm. Viewed Jan.23, 2024.
[5] Manual of Woody Landscape Plants. Michael A Dirr, 1990. Stipes Publishing Company Champaign, Illinois
[6] Important Trees of Eastern Forests. USDA Forest Service, R. W. Neelands 1974. Page28

specifically birds. The remaining cones are dispersed in February or March. Natural germination of the seed typically occurs in the spring of the second year after dispersal[7].

Recent observations have demonstrated that eastern red cedar is a growing concern in guiderail sites throughout the state. It appears that current herbicides and rates commonly used in bareground mixes are ineffective at controlling eastern red cedar. The purpose of this experiment was to evaluate foliar applications to the entire canopy of eastern red cedar to determine injury and control based on rating percent living leaf canopy. Our primary concern was to determine if an herbicide or herbicide mix can effectively control eastern red cedar in a guiderail setting. In the future, a much broader discussion and evaluation of bareground mixes should determine if current mixes are allowing eastern red cedar to germinate from seed, and if so, can we alter those bareground mixes to control eastern red cedar seedlings from germinating.

MATERIALS AND METHODS

The experiment was established along SR 22 approximately 2 miles west of Thompsontown, Pennsylvania exit. With ten trees per replication, each tree was measured to determine the canopy area. The formula used to calculate canopy areas was the surface area of a cylinder ((2 x pi x radius x height) + (2 x pi x radius^2)) (Appendix Table 1). The herbicide treatment quantities were based on the calculated canopy area. The experiment evaluated eight herbicide treatments: Escort XP at 1oz/ac; Escort XP at 2 oz/ac; Escort XP at 3 oz/ac; TerraVue at 2.75 oz/ac + Escort XP at 1oz/ac; Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + Escort XP at 1 oz/ac; Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + Escort XP at 1 oz/ac; Vanquish at 32 oz/ac; glyphosate (4 lb. ae/gal) at 118 oz/ac; and an untreated check. Methylated seed oil at 1% v/v was added to all herbicide mixes. The application was made at a carrier volume of 35 gallons per acre. All treatments were applied using a CO_2-powered backpack sprayer equipped with a 30 GunJet spray gun and one PPX 6 adjustable nozzle at 32 PSI (pounds per square inch). The weather at the time of application was sunny and clear with wind speeds of 5-10 mph, 40% relative humidity, and air temperatures of 85° F. The treatments were applied on May 31, 2023.

Treatments were visually rated for percent injury where 0 = no injury - 100 = complete injury on June 30, 2023, 30 days after treatment (DAT) & July 27, 2023, 57 DAT and percent living leaf canopy where 0 = 0% living leaf canopy – 100 = 100% living leaf canopy on October 26, 2023, 148 DAT. All data were subjected to analysis of variance, and when treatment effect F-tests were significant ($p \leq 0.05$), treatment means were compared using Tukey's HSD separation test.

RESULTS AND DISCUSSION

Injury to eastern red cedar from the herbicide treatments ranged from 6.4 to 70.5% while the untreated check showed 1.3% natural leaf damage on June 30, 2023, 30 DAT (Table 1). By 57 DAT, overall % injury increased ranging from 36 to 72%, while the untreated check was 1.5%. Only Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + Escort XP at 1 oz/ac showed a reduction in % injury (59.5%) compared to the 30 DAT mark. Herbicide treatments with 50% or less injury at 57 DAT included: Vanquish at 32 oz/ac (50%), Escort XP at 1 oz/ac (42%)

[7] USDA Agr. Handbook # 271. Eastern red cedar *(Juniperus virginiana)* pp 212-216.

Escort XP at 2 oz/ac (37.5%), and Escort XP at 3 oz/ac (36%). Herbicide treatments with greater than 50% injury included: Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + Escort XP at 1 oz/ac (59.5%), Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + Escort XP at 1 oz/ac (60.5%), glyphosate (4 lb. ae/gal) at 118 oz/ac (71%) and TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac (72%).

On October 26, 2023, 148 DAT, percent living leaf canopy ranged from 95.5% for the untreated check to 31.5% for TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac. Glyphosate (4 lb. ae/gal) at118 oz/ac resulted in 32.5% living leaf canopy while Escort XP at 2 oz/ac resulted in 38.8% living leaf canopy. Escort XP at 3 oz/ac resulted in 41% living leaf canopy while Freelexx at 96 oz/ac + Vastlan at 48 oz/ac + Escort XP at 1 oz/ac resulted in 43.5% living leaf canopy. Escort XP at 1 oz/ac resulted in 46.7% living leaf canopy while Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + Escort XP at 1 oz/ac resulted in 50.5% living leaf canopy and Vanquish at 32 oz/ac resulted in 73.5% living leaf canopy. All the herbicide treatments were statistically similar except Vanquish which was the only herbicide treatment statistically similar to the untreated check. Looking closer at Escort XP, it appears that increasing the rate from 1 oz/ac to 2 oz/ac decreased % living leaf canopy. However, increasing the rate from 2 oz/ac to 3 oz/ac did not reduce % living leaf canopy. Evaluating mixes that included Escort XP at 1 oz/ac to Escort XP at 1 oz/ac alone as a treatment, it appears that TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac reduced the percentage living leaf canopy compared to Escort XP at 1 oz/ac alone. In addition, Freelexx at 96 oz/ac + Method 240SL at 16 oz/ac + Escort XP at 1 oz/ac slightly reduced living leaf canopy compared to Escort XP at 1 oz/ac alone.

CONCLUSIONS

By July 27, 2023, 57 DAT, none of the treatments resulted in 100% injury. Percent injury of Escort XP only treatments resulted in less injury (36-42%) than the other herbicide treatments (50-72%). Percent living leaf canopy evaluated on October 26, 2023, 148 DAT, resulted in no treatment with 0% living leaf canopy. TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac resulted in the lowest living leaf canopy at 31.5% with glyphosate (4 lb. ae/gal) at 118 oz/ac at 32.5%. If using Escort XP alone, it appears at this point that Escort XP at 2 oz/ac is an appropriate rate for reducing living leaf canopy. Future research will include evaluating long-term damage to the treated plants with a spring 2024 rating. In addition, the question arises as to whether multiple treatments will be necessary to completely kill eastern red cedar. While the current concern is eastern red cedar in guiderail sites, future experiments should evaluate multiple foliar applications to eastern reed cedar, increasing the percent of MSO, and efficacy of soil applied herbicides.

MANAGEMENT IMPLICATIONS

Initial results suggest that eastern red cedar was not completely controlled with the herbicides evaluated for this experiment. Future experiments should evaluate multiple foliar applications to eastern red cedar as well as increasing the amount of MSO per treatment to determine efficacy. Two treatments to consider for spot treating eastern red cedar, in guiderail sites that typically are treated with a bareground mix, are TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac or glyphosate (4 lb. ae/gal) at 118 oz /ac. However, additional follow up treatments will

be required. If treating eastern red cedar in areas along roadsides where grass groundcovers should be maintained, TerraVue at 2.75 oz/ac + Escort XP at 1 oz/ac is recommended. Future data collection and analysis, one and two years after treatment will determine long-term living leaf canopy and future recommendations.

Table 1. Percent injury and living leaf canopy of eastern red cedar *(Juniperus virginiana)*. The experiment was visually rated for percent injury where 0 = no injury - 100 = complete injury on June 30, 2023, 30 days after treatment (DAT) & July 27, 2023, 57 DAT and percent living leaf canopy where 0 = 0% living leaf canopy – 100 = 100% living leaf canopy on October 26, 2023, 148 DAT. Herbicides were applied on May 31, 2023. All treatments included methylated seed oil at 1% v/v. Each value is the mean of ten replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/ac	% Injury 6/30/23 30 DAT	% Injury 7/27/23 57 DAT	% Living Leaf Canopy 10/26/23 148 DAT
Untreated	--	1.3 a	1.5 a	95.5 c
Escort XP	1	13.4 a	42 b	46.7 ab
Escort XP	2	10.9 a	37.5 b	38.8 a
Escort XP	3	6.4 a	36 b	41 a
TerraVue Escort XP	2.75 1	61 bc	72 d	31.5 a
Freelexx Method 240SL Escort XP	96 16 1	58 bc	60.5 cd	50.5 ab
Freelexx Vastlan Escort XP	96 48 1	65 c	59.5 cd	43.5 a
Vanquish	32	46 b	50 bc	73.5 bc
glyphosate (4lbs ae/gal)	118	70.5 c	71 d	32.5 a

EVALUATION OF NATIVE GRASS AND POLLINATOR SEED MIXES AND SEEDING METHODS FOR CONVERSION AND ESTABLISHMENT ALONG ROADSIDES-4th YEAR

Herbicide trade and common names: Accord XRT II (*glyphosate*), Triplet LO (*2, 4-D, mecoprop, dicamba*), Freelexx (*2, 4-D choline)*

Plant common and scientific names: hard fescue mixture (*Festuca longifolia*), creeping red fescue (*Fescue rubra*), little bluestem (*Andropogon scoparius*), Canada wildrye (*Elymus canadensis*), Virginia wildrye (*Elymus virginicus*), Indiangrass (*Sorghastrum nutans*), spring oats spp., winter wheat spp., annual ryegrass spp., black-eyed Susan (*Rudbeckia hirta*), New England aster (*Symphyotrichum novae-angliae*), oxeye sunflower (*Heliopsis helianthoides*), big bluestem (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), sheep fescue (*Festuca ovina L.*), creeping red fescue (*Festuca rubra*), chewing's fescue (*Festuca rubra subsp. commutata)*

ABSTRACT

Disturbances to the vegetation and soils along the roadside due to road construction and redevelopment continually impacts the roadside rights-of-way in Pennsylvania. Utilizing native grasses and pollinator species in roadside revegetation and new construction projects has gained momentum and is being promoted as a viable option. For this new revegetation program to be successful, soil stability, seed germination rate, speed of cover, vehicular safe site distance conditions, and ease of maintenance are all essential factors in which roadside managers must consider when selecting seed mixes. An experiment was established with two native seed mixes code named Formula N consisting of a mix of cool and warm season grasses and pollinator species (i.e., black-eyed Susan, New England Aster, and oxeye sunflower) and modified Formula N consisting solely of cool and warm season grasses. Both mixes were seeded at a pure live seed (PLS) rate and PennDOT's standard bulk rate. Once established, half of the site was subjected to standard maintenance practices whereas the other half was allowed to develop without maintenance. Over the three-year period of study, the Formula N mix started with a higher average plant count per four-foot subplots across the plots for both seeding rates compared to the modified Formula N mix. Black-eyed Susan was the greatest component at both seeding rates, followed by Indiangrass and the fine fescue. During the second season the unmaintained bulk seeded Formula N plots had a higher count of fine fescue, little bluestem, and black-eyed Susan than the maintained plots for both seeding rates as well as the PLS rate of the unmaintained Formula N plots. Switchgrass was most prominent in the modified Formula N bulk rate seeded and maintained plots followed by Indiangrass and little bluestem. By the end of the third growing season, plant counts changed with the unmaintained Formula N plots diverging between the two seeding rates. The PLS plots showed less fine fescue and black eyed Susan while the bulk rate plots also showed less fine fescue but greater black eyed Susan plant counts. The maintained Formula N plots at both seeding rates showed a greater number of fine fescue and black-eyed Susan while the bulk rate showed an increase in black-eyed Susan and a decrease in presence of little bluestem. The maintained modified Formula N plots seeded at the bulk rate resulted in

fewer fine fescue and switchgrass plants but an increase in big bluestem. The unmaintained PLS plots showed an increase of fine fescue while the bulk rate unmaintained plots resulted in fewer little bluestem by year three. Broadleaf and grass weeds increased from year to year within all plots. Three years after seeding, overall, the plots have poor stand density of the seeded species in both formula N and modified formula N.

INTRODUCTION

Native grasses and pollinator species offer greater diversity in providing a more natural ecosystem that is more appealing to wildlife including pollinating insects[8]. Pennsylvania's grasslands and field habitats have been steadily declining over the past decades, partially due to development and succession, a process where fields naturally grow back into forests[9]. These circumstances have increased concerns for the survival needs of wildlife species and soil erosion[10]. With a growing call to employ native species along the PennDOT right-of-way while continuing to consider adaptability to site conditions and maintain soil stability during establishment, traveler safety, and ease of future maintenance, we evaluated alternative grass and pollinator species within a previously created PennDOT native seed mix (PennDOT Formula N). Formula N created in 2009, included native warm-season grasses (WSG) and was designed as an alternative to the PennDOT Formula C seed mix containing crownvetch and used for rocky, shallow soil, difficult to mow areas near road cuts and embankments. Crownvetch has been classified as a "situational invasive" by the PA DCNR due to its potential to spread away from the roadside right-of-way[11].

The current Formula N (Table 1) seed mix consists of little bluestem and Indiangrass, which, once established, adapts well to poor soil conditions, provides sufficient groundcover, and prevents erosion. These two grasses are tall bunch-type grass species with deep roots. The seed mix's hard and creeping red fescue components germinate within 2-3 weeks of seeding and provide early cover, thus reducing weed pressure and erosion caused by heavy spring precipitation. The oats and wildrye also provide early cover and erosion protection. To support native wildlife food resources, the black-eyed Susan, oxeye sunflower, and New England aster are nectar sources for foraging bees, butterflies, and insects, and seeds for birds. However, the slow establishment was the main drawback with Formula N due to the WSG component, which generally requires three to four seasons to provide satisfactory groundcover. It thus increased opportunities for erosion and weed pressure. This slow establishment may be partially due to

[8] Meadows and Prairies : Wild-life Friendly Alternatives to Lawns Penn State Extension. https://extension.psu.edu/downloadable/download/sample_id/224/

[9] Warm Season Grasses and Wildlife. Penn State Extension. https://extension.psu.edu/warm-season-grasses-and-wildlife

[10] Warm Season Grasses and Wildlife. Penn State Extension. https://extension.psu.edu/warm-season-grasses-and-wildlife

[11] Johnson et. al. 2014. Evaluation of Native Seed Mixes for Roadside Application – Year Three. Roadside Vegetation Management Research-2014 Report. pp. 27-28.

seed dormancy constraints requiring natural cold stratification to germinate and the variation in dormancy levels within seed lots.

The creation of a modified Formula N (Table 2) was intended to enhance the WSG component of the seed mix to better adapt to heat, drought, variable pH levels, low fertility, and salt buildup[12] while assuring a better stand of WSG. The Canada and Virginia wildrye, black-eyed Susan, oxeye sunflower, and New England aster were replaced with big bluestem and switchgrass to help achieve a better stand of WSG. In addition, the cool-season grass (CSG) component was enhanced by adding sheep and chewing's red fescue to provide better gap coverage for several seasons allowing the WSG time to establish while reducing weed pressure and possible soil erosion. The modified Formula N seed mix components were chosen based on grass type, site conditions, and concerns around standard broadleaf weed management procedures applied during seedling establishment and in future maintenance. In addition, seeds were selected based on availability and applicability to the site.

A secondary goal of this experiment was to compare the effectiveness and potential cost saving of seeding the plots based on label bulk weight seed rates to PLS rates. Traditionally, PennDOT has seeded new and revegetated sites using bulk weight seed rates. However, the current view by forage, field production, and natural area seed industry professionals is that PLS seeding rates are more effective and assure better quality stand development and seedling survival. The decision to compare these two seeding rates resulted from discussions within PennDOT on the economics and potential overall success of plant establishment on newly seeded sites with native seed mixes. For this reason, Formula N and modified Formula N were seeded at PennDOT's standard bulk rate versus a standardized PLS rate.

The final goal of this experiment was to determine how implementing maintenance practices early in the establishment process would impact seedling success in plot establishment. The seeded plots were subdivided into standard maintenance implemented one year after seeding and no maintenance to determine the effect on the establishment. This paper represents third-year observations of the seeding process.

MATERIALS AND METHODS

A site was established along Park Avenue on the back slope under the interchange of I-99 and SR 322. The site had a slight slope with poor soil conditions. Several cool-season grass species were onsite, including fine fescue, tall fescue, Kentucky bluegrass, and reed canary grass, along with several broadleaf weed species. Four 60' x 160' replicate plots were created and arranged in a randomized block design. Each replicate plot was split into four treatment plots of 30' x 40' and arranged in a complete randomized block design. Each treatment plot was then divided into 30' x 20' subplots to compare maintenance vs. non-maintenance. Plants were counted within four subplots that were 2' x 2' in size and were arranged on a diagonal line

[12] Johnson et. al. 2014. Evaluation of Native Seed Mixes For Roadside Application – Year Three. Roadside Vegetation Management Research-2014 Report. pp. 27-28.

running along the center of each treatment replication to measure the performance. On June 1, 2020, all plots were sprayed with Accord XRT II at 64 oz/ac in a carrier volume of 50 gallons per acre with a pressure of 35 pounds per square inch (PSI) using a CO2-powered backpack sprayer with a six-foot boom equipped with four 8004VS nozzles to eliminate vegetation. A surfactant, CWC 90, was added to all treatments at 0.25% v/v. The weather at the time of application consisted of sunny skies, wind speeds of 5-10 mph, air temperature of 74° F, and 20% relative humidity. Soil temperatures at the surface, 1-inch and 3-inch depths, were 71° F, 71°F, and 71° F, respectively. Following this application, on June 22 and 23, 2020, the soil was cultivated with a disc harrow pulled by a Kubota L2500 tractor.

Seeds were purchased from native seed nurseries and stored until planting. Seeds were weighed and bagged for each plot separately. The seeding rates were calculated for each species using pure live seed (PLS), standardizing the overall seeding rate among the mix at 430 PLS seeds per square meter based on a recent research report on seeding native forb and grasses to assure accuracy in seeding rates, seed purity, and acceptable cover. Eight plots were broadcast seeded, four with a PennDOT standard rate per acre and four with a rate based on PLS per acre. Specifically, Formula N was seeded at PennDOT's bulk rate of 105.1 lbs./acre and at the PLS rate of 4.91 lbs./acre. Modified Formula N was seeded at a bulk rate of 40 lbs./acre and at the PLS rate of 50.4 lbs./acre. A quick cover of oats was seeded over the top at 30 lbs./acre to protect the seed and prevent erosion. Plots were fertilized with 10-6-4 at 1 lb. N per 1000 sq. ft. and covered with erosion control straw blankets on June 25, 2020. Local rain events occurred on June 27, July 1, and 3, 2020, measuring 0.52", 0.01", and 0.09", respectively, according to http://newa.cornell.edu. The nearest weather station was located at Rock Springs, PA.

During the second growing season, on June 25, 2021, the plots included in the maintenance program were sprayed with Triplet LO at 64 oz/ac in a carrier volume of 35 gallons per acre with a pressure of 33 PSI using a CO2 powered backpack sprayer with a six-foot boom equipped with four 8004VS nozzles to eliminate broadleaf weeds. In addition, a surfactant, Induce, was added to all treatments at 0.25% v/v.

At the time of application, weed pressure was significantly high. The weather at the time of application consisted of clear skies, wind speeds of 0-5 mph, air temperature of 72° F, and 52% relative humidity. Soil temperatures at the surface, 1-inch, 3-inch, and 6-inch depths, were 78° F, 80° F, 74°, and 69° F, respectively. On August 3, 2021, all plots receiving maintenance were mowed using a Kubota with a mower attachment at the height of 6 inches to prevent further infestation of weeds, including thistle and several grass weeds.

Later during the second growing season, on October 19, 2021, the plots included in the maintenance program were sprayed with Freelexx at 64 oz/ac in a carrier volume of 35 gallons per acre with a pressure of 33 PSI using a CO2 powered backpack sprayer with a six-foot boom equipped with four 8004VS nozzles to eliminate broadleaf weeds. In addition, a surfactant, Induce, was added to all treatments at 0.25% v/v. At the time of application, weed pressure was significantly high. The weather at the time of application consisted of clear skies, wind speeds of 10-12 mph, air temperature of 71° F, and 35% relative humidity. Soil temperatures at the surface, 1-inch, 3-inch, and 6-inch depths, were 60° F, 60° F, 59°, and 59° F, respectively. Local rain

events occurred on October 22, 25, and 27, 2021, measuring 0.17”, 0.26”, and 0.17”, respectively, according to http://newa.cornell.edu. The nearest weather station was located at Rock Springs, PA. No further maintenance (i.e., mowing and broadleaf weed control were applied in 2022.

All data were subjected to analysis of variance, and when treatment effect F-tests were significant ($p \leq 0.05$), treatment means were compared using Tukey’s HSD separation test.

RESULTS AND DISCUSSION

Seeding Rate and Seedling Development

The experimental site was seeded after the typical spring seeding window, and the growing season did not include a significant amount of precipitation immediately after seeding. The 2020 growing season was generally considered a drought season with little precipitation. The dry conditions likely inhibited seed germination and represent what may happen in roadside plantings where supplemental irrigation is not available or financially justified. All treatments (Tables 3 & 4) showed the presence of broadleaf and grass weeds, and oats at the end of the first growing season.

At the end of the first growing season, 97 DAS (days after seeding), Formula N produced the highest plant count, with black-eyed Susan being the most prominent species present among the PennDOT bulk seed rate plots across maintenance regimes ranging on average from 3.38 in maintained plots and 4.13 unmaintained plots based on 4-square foot subsampling units per plot (Table 3).

In contrast, black-eyed Susan among the PLS seeded Formula N plots averaged 0.06 and 0.19 in maintained and unmaintained plots, respectively. Among the WSG seedlings counted, Indiangrass was highest at 0.19 seedlings per subplot at the bulk seed rate compared to 0.06 in the PLS plots under the maintenance regime with no Indiangrass in the unmaintained plots for both seeding rates. Fine fescue was the next prominent species with the bulk seeded plots producing on average more seedlings at 1.88 and 0.44 based on maintenance regimes compared to the PLS rates of 0.19 and 0.13. Little bluestem was only found in the bulk seed rate plots. All other WSG and flowers were absent. There was no significant difference among the Formula N plots at either seeding rate for broadleaf and grass weeds.

Within the bulk rate of the modified Formula N seed mix, the species present included big bluestem, little bluestem, and switchgrass, while the PLS seed rate plots had fine fescue and switchgrass, all in small amounts ranging from 0.06 to 0.38 seedlings per subplots (Table 4). Little bluestem was most prominent at 0.31 and 0.38 plants per subplot, followed by switchgrass and big bluestem. Fine fescue was the most prominent among the PLS plots at 0.13 and 0.31.

At the end of the second growing season, 474 DAS (days after seeding), Formula N produced the highest plant count, with black-eyed Susan being the most prominent, followed by fine fescue and little bluestem (Table 5). However, compared to the first-year data, the total

average presence of black eyed Susan was reduced and only found in the no maintenance plots, with an average of 2.0 seedlings per subplot found in the bulk rate plots and 0.19 seedlings in the PLS plots. Reduced seedling numbers were also found with little bluestem in the second year among the bulk rate plots compared to the first year, with 0.13 under the maintenance regime and 0.06 under no maintenance compared to 0.25 and 0.88, respectively, in the first year (Table 3). Fine fescue also dropped average seedling numbers compared to first-year data under the bulk and PLS seedings maintenance regime. The unmaintained plots averaged the same number of seedlings as the first year at 1.88 and 0.13, respectively, for seeding rates. No other WSG or flowers were found in the plots. The number drops may be due to the damage caused by the maintenance program on black-eyed Susan; however, the unmaintained plots also saw a decline in plant count. The weather may have also been a factor and may have affected little bluestem and fine fescue counts, at least under the maintenance regime.

Within the modified Formula N seed mix, the seedlings present changed with an increase in fine fescue across the treatment plots, with all plots recording fine fescue seedlings compared to the first year, where only the PLS seeding produced plants (Table 6). Big bluestem was not found in any of the subplots across seeding rates and maintenance regimes. The amount of little bluestem was reduced on average from 0.38 plants to 0.19 in the bulk rate planting under maintenance and from 0.31 to 0.13 in the PLS seeding under no maintenance. Switchgrass increased between the bulk rate-maintained plots compared to the bulk rate unmaintained subplots and the PLS rate-maintained plots. The unmaintained bulk rate plots saw a decrease in the average number of plants, of 0.06, compared to the first-year data of 0.31 (Tables 4 & 6). In addition, a small amount of Indiangrass was found among the bulk rate maintained plots for the first time.

Overall, the percent cover across the whole experiment was low during the second year. In past experiments with WSG seedings, we have found that the establishment can take more than two years. One consideration for the low percent cover may be due to the time of year the plots were seeded, after the typical spring seeding window. Furthermore, the growing season did not include significant precipitation immediately after seeding, creating dry conditions for seed germination. A 2009 study evaluating the ability of native WSG species to establish at four different seeding dates throughout the year showed significantly different results. In that experiment, seeding occurred in February, April, July, and August. Three years later, results showed the plots seeded in February produced the highest percent cover (25%), followed by plots seeded in April (20%), and then by plots seeded in July and August (1%). The soil moisture conditions and temperatures of the late winter through early spring season were most favorable in establishing that WSG cover. Results of the 2009 study are comparable to this experiment two years later in that the late seeding inhibited reasonable cover and showed a low percent cover.

By the end of the third growing season, in general Formula N produced a significantly higher plant count. Black-eyed Susan was the most prominent, followed by fine fescue, Canada wildrye, and little bluestem (Table 7). On average black-eyed Susan increased in the plots receiving maintenance with 9.19 seedlings per subplot at the bulk seed rate and 0.75 seedlings per subplot at the PLS rate. The total average presence of black-eyed Susan in the unmaintained

plots increased on average to 14.25 seedlings per subplot at the bulk seed rate but decreased to no seedlings per subplot at the PLS rate. The total average presence of fine fescue in the plots receiving maintenance increased to an average of 1.75 seedlings per subplot at the bulk seed rate and 0.81 seedlings per subplot at the PLS rate but decreased to 0.81 seedlings per subplot at the bulk rate, and to no seedlings per subplot at the PLS rate. The total average presence of Canada wildrye in the plots receiving maintenance increased with an average of 0.25 seedlings per subplot at the bulk seed rate. And finally, the total average presence of little bluestem in the plots receiving maintenance decreased to no seedlings per subplot at the bulk seed rate. No other WSG or forbs were found in the plots. Over the three-year period oxeye sunflower and New England aster failed to appear in the plots. Two questions arise as to whether this is an environment issue or seed dormancy issue? The dry seasons may have played a role, but equally important is the three-month cold stratification requirement for the germination of oxeye sunflower and New England aster. Both pollinator species makeup less than 10% of both seeding rates. Such a low percent and potential predation may have played a role in failure to germinate. These two pollinator species suffer the same slow to establish potential as the warm season grasses found in the mix. It may be helpful to increase their percentage in the mix to enhance the potential for establishment. Finally, a question remains as to whether maintenance or lack of maintenance and weed pressure were factors in the lack of identifiable New England aster and oxeye sunflower in the plots.

Among the modified Formula N plots, fine fescue was more prevalent in both the maintained and non-maintained PLS plots. While big bluestem in the maintained bulk rate plots was more prevalent (Table 8). Counts of fine fescue and switchgrass in the maintained bulk seed rate plots were less. Whereas in the unmaintained bulk rate plots little bluestem numbers were also reduced. Among the maintained PLS plots, fine fescue increased by an average of 1.69 seedlings per subplot while the unmaintained plots produce 1 seedling per subplot. A very low number of big bluestem (0.06 seedlings per subplot) were found in the maintained and non-maintained plots. Overall, fine fescue increased in the PLS plots and decreased in the bulk seeded plots. Switchgrass decreased with an average 0.06 seedlings per subplot even with maintenance. Lastly, in the unmaintained bulk rate plots, the total average presence of little bluestem decreased to 0.06 seedlings per subplot. No other WSGs were found in the plots.

In the fourth growing season, the plots were visually rated on September 22, 2023, for percent cover of the species seeded in formula N (Table 9) and modified formula N (Table 10). For the maintenance plots, formula N seeded at 105.1 lbs./ac showed fine fescue at 35.4%, little bluestem at 0.3%, Canada wildrye at 0.1%, Virginia wildrye at 0.6%, and black-eyed Susan at 0.06%, while formula N seeded at 4.91 lbs./ac showed fine fescue at 31.3%, and Virginia wildrye at 0.3% cover. Formula N seeded at 105.1 lbs./ac with no maintenance showed fine fescue at 5.4%, little bluestem at 0.1%, Virginia wildrye at 0.06%, black-eyed Susan at 0.6%, New England aster at 0.06%, and oxeye sunflower at 0.6%, while Formula N seeded at 4.91 lbs./ac with no maintenance showed fine fescue at 1.8%. Modified formula N seeded at 40 lbs./ac and receiving maintenance showed fine fescue at 22.5%, switchgrass at 3.5%, little bluestem at 2.3 %, big bluestem at 1.5%, and Indiangrass at 0.06%. Modified formula N seeded at 5.04 lbs./ac and receiving maintenance showed fine fescue at 25.6%, switchgrass at 0.8%,

little bluestem at 0.8%, big bluestem at 0.6%, and Indiangrass at 0.06%. Modified formula N seeded at 40 lbs./ac with no maintenance showed fine fescue at 1.9%, switchgrass at 0.6%, little bluestem at 0.1%, and big bluestem at 0.3%, while modified formula N seeded at 5.04 lbs./ac with no maintenance showed fine fescue at 0.5%.

Weed Competition and Maintenance Impact

After the first year, the broadleaf weeds in the Formula N plots ranged on average from 7.06 to 14.16 (Table 3) in the maintained and unmaintained plots and varied widely between PLS and bulk seeded plots with no apparent trend. Similarly, the modified Formula N plots ranged on average from 5.94 to 16.88 plants (Table 4) in the subplots. In both cases there were no significant difference between plots, seeding rates, and maintenance regimes. For the grassy weeds, a significant difference was found among the seeding rates for the modified Formula N plots (Table 4) with a higher weed count found in the PLS subplots compared to the bulk seeded plots. In contrast, there was no significant difference found among the Formula N plots across seeding rates and maintenance regimes (Table 3).

The broadleaf and grassy weed counts greatly increased from year one to year two, with nearly a three-fold total increase in broadleaf weeds across all counted subplots and nearly a four-fold increase in grass weeds. There was no significant difference among the Formula N and modified Formula N plots at both seeding rates for both broadleaf and grass weeds in the second year nor was there an obvious trend in weed count between the maintenance regimes (Table 5). Broadleaf and grass weed pressure was obviously high across all subplots by the end of the third year and no plant count was taken due to the overabundance of weeds in the subplots. It appears obvious that a single season of herbicide application early and again late in the second growing year is not enough to reduce weed pressure to allow either seeding mix or rate to take hold. In the future, a different approach to weed management will need to be devised.

The concern that a standard broadleaf weed management strategy would harm the herbaceous broadleaf forbs or flower components within the Formula N seed mix also proved true. One question that arises is what impact did mowing in August of the second year prior to the October Freelexx application have on both seed mix performance and weed control? Overall, the Formula N plots that received maintenance during the second growing season showed an overall decrease in plant count for black eyed Susan (Table 5). Was this decrease due to reduction in the weed canopy cover allowing more of the herbicide to reach the black-eyed Susan? The fact that all seeding rates and maintenance regimes showed a general reduction in black-eyed Susan coverage compared to the first growing season, except for the PLS rate with no maintenance, which showed a slight increase suggests that the mowing was not a factor in the drop in seedling numbers. By the end of the third growing season, Formula N plots seeded at the bulk rate under both maintenance regimes showed an obvious increase in black-eye Susan plants. The increase in the third year in maintained and unmaintained bulk rate plots also suggests that the mowing and herbicide application in October was not drastically detrimental to black-eyed

Susan numbers but may have had a slight effect on the black-eyed susan numbers in the maintained plot compared to the unmaintained plots. The maintained Formula N PLS plots showed a very slight increase while the unmaintained PLS plots produced no black-eyed Susan (Table 7).

The increase in black-eyed Susan in the third year (Table 7) is a positive outcome; however, the weed pressure also increased in plots which demonstrates that a weed control program still needs to be defined and weed control may be required beyond a single growing season to assure the plots survive and thrive. The success of a pollinator friendly seeding program may hinge of the development of an effective weed control program. A further refining of a weed management plan will be important in the success of a pollinator friendly seeding program. Conversely, applying the pollinator seeding program to new construction or roadside redevelopment projects rather than trying to retrofit it into established roadside landscapes may reduce the immediate weed pressure and seed bank that would compete with the seeding programs success.

Table 11 represents the final data tally for the fourth growing season showing percent coverage of seeded species (formula N or modified formula N), broadleaf weed , annual grass weed, as well as cover by several perennial grass species-bromegrass, Kentucky bluegrass, tall fescue, and reed canarygrass. Regardless of formula or seeding rate the maintenance plots showed higher percent seeded species cover and less broadleaf weeds compared to the no maintenance plots. It appears maintenance activities (mowing and broadleaf herbicide applications) aided in the establishment of some of the seeded species. The forb species in Formula N would have been controlled with the broadleaf weed herbicide applications. If a goal is to combine forbs and grasses in a mix, then spot treatment of broadleaf weeds will be necessary in order to maintain the desired forb species. This will increase the costs of maintenance operations. Another result of the maintenance activities appeared to impact the amount of bromegrass and reed canarygrass cover. In the maintenance plots, bromegrass and reed canarygrass spread after broadleaf weed herbicide applications and showed more cover compared to the no maintenance plots. After the September rating, it was very apparent that the overall stand was not acceptable. The decision was made to mow all plots, including the “no maintenance” plots in order to regain some level of control. Evaluations next year will determine if the seeded species are able to recover.

CONCLUSIONS

The establishment and cover of the species seeded in formula N and modified formula N was poor. Several factors influence stand density including site preparation, seeding rate and time, seeding method, rainfall after seeding and maintenance activities during the first few growing season. Two different seeding rates were evaluated, a standard rate and 430 pure live seeds per square meter (PLS) rate. The standard rate was more effective than the PLS rate for formula N and modified formula N. This experiment site was prepared, and hand seeded in June

and based on the results seeded too late. The late season establishment and low precipitation are possible factors to the low germination and establishment results and increased weed pressure. Common recommendations[13] suggest spraying a non-selective herbicide like glyphosate, prepare soil, and plant a groundcover like oats or winter rye depending on time of year. The following season spray site again with glyphosate and seed warm season grasses in late winter[6] to April, maybe into early May[14] depending on species. After seeding, it is crucial to manage weeds either through mowing or spot treatment of weeds. Fine fescue was the most common species found. Several species, bromegrass, Kentucky bluegrass, and reed canarygrass, were present at the site spread into some plots. This experiment has provided a clearer view of the difficulties of establishing native warm season grasses combined with cool season grasses and forbs in a roadside setting. It is apparent that the seeding timing of late June was less than ideal. This experiment will further be evaluated to determine stand composition and density four years after establishment.

MANAGEMENT IMPLICATIONS

Establishing warm season grasses, cool season grasses and forbs provide unique challenges. Seeding cool season grasses is best in late summer while warm season grasses and forbs are best seeded in late winter through early spring. Sites should be evaluated to determine suitability of seeding warm season and cool season grasses and forbs in mixes. Sites with existing groundcover should be sprayed with a non-selective herbicide and seeded with an annual cover crop. The following season the site should be again prayed with a non-selective herbicide and seeded. Seeding time will depend on the mix. Cool season grasses are best seeded in fall but can be seeded in the spring. Warm season grasses are best seeded in late winter through early spring. Forbs can be seeded at various times of the year depending on species. Annual forbs can be seeded in the spring while perennial forbs can be seeded in spring or fall. Since the experiment started, PennDOT has adopted several different seed mixes (Pub 408) that include warm season grasses, cool season grasses, sedges and various forbs and pollinator plants. Regardless of seed mix, sites must be prepared in a way to minimize weeds present, prepare soils to be seeded, and most importantly be seeded at the proper time of year with the proper seeding technique. The most reliable seeding method is a no till drill. Broadcast seeding maybe another option but must ensure good seed to soil contact by lightly rolling the site after seeding. Once sites are established, weed control is of utmost importance. Remember, establishing warm season grasses takes up to three years to be fully established, extending the weed control window. The weed control goal is to reduce competition from annual grass weeds and broadleaf weed, not eliminate all weeds. Weed control strategies may include mowing weeds above newly emerging seedlings to be sure they don't get too tall and shade out desirable species or it may be spot spraying broadleaf weed species.

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[13] Establishing Native Grasses. USDA Natural Resource Conservation Service. https://static1.squarespace.com/static/5889438b893fc0576c2911de/t/61c0f35ffda6b94321fa26e5/1640035168008/Establishing+Native+Grasses.pdf

[14] Warm Season Grasses. Penn State Extension. https://extension.psu.edu/warm-season-grasses

Table 1: Formula N: Species included in Formula N seed mix at PennDOT's rate of 105.1 lbs./acre and at a PLS rate of 4.91 lbs./acre.

Common name	Scientific name	PennDOT Rate lbs./ac	430 PLS/m^2 Rate lbs./ac
Hard fescue	*Festuca longifolia*	43.56	2.03
Creeping red fescue	*Fescue rubra*	21.78	1.02
Little bluestem	*Schizachyrium scoparius*	5.81	0.27
Indiangrass	*Sorghastrum nutans*	4.36	0.02
Canada wildrye	*Elymus canadensis*	8.71	0.41
Virginia wildrye	*Elymus virginicus*	2	0.09
Black-eyed Susan	*Rudbeckia hirta*	7.26	0.34
New England Aster	*Symphyotrichum novae-angeliae*	4.36	0.2
Oxeye Sunflower	*Heliopsis helianthoides*	7.26	0.34
Total		**105.1**	**4.91**

Table 2: Modified Formula N: Species included in Modified Formula N seed mix at Penn State Roadside Project recommended rate of 40 lbs./acre and at a PLS rate of 5.04 lbs./acre.

Common name	Scientific name	PSU Rate lbs./ac	430 PLS/m^2 Rate lbs./ac
Big bluestem	*Andropogon gerardii*	6	0.76
Little bluestem	*Schizachyrium scoparius*	6	0.76
Indiangrass	*Sorghastrum nutans*	6	0.76
Switchgrass	*Panicum virgatum*	2	0.25
Hard fescue	*Festuca longifolia*	5	0.63
Sheep fescue	*Festuca ovina L.*	5	0.63
Creeping red fescue	*Festuca rubra*	5	0.63
Chewing's fescue	*Festuca rubra subsp. commutata*	5	0.63
Total		**40**	**5.04**

Table 3: Formula N 1st Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots were sprayed with Accord XRT II at 64 oz/ac on June 1, 2020. The soil was cultivated with a disc harrow on June 22 and 23, 2020. All plots were broadcast seeded with the specified seed mix shown below and oats at a rate of 30 lbs./acre, fertilized with 10-6-4 at 1 lb. N per 1000 sq. ft., and covered with erosion control straw blankets on June 25, 2020. Four plots were seeded with Formula N at PennDOT's rate of 105.1 lbs./acre and at a PLS rate of 4.91 lbs./acre. Each value is a mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 9/20	Little Bluestem Count 9/20	Indiangrass Count 9/20	Canada Wildrye Count 9/20	Virginia wildrye Count 9/20	Black-eyed Susan Count 9/20	New England aster Count 9/20	Ox-eye Sunflower Count 9/20	Broadleaf Weeds Count 9/20	Grass Weeds Count 9/20	Oats Count 9/20
Formula N- Maint.	105.10	0.44	.25ab	0.19	0	0	3.38	0	0	7.06	3.38	5.38
Formula N- Maint.	4.91	0.19	0a	0.06	0	0	0.19	0	0	12.00	3.50	5.88
Formula N- No maint.	105.10	1.88	.88b	0	0	0	4.13	0	0	14.16	3.81	2.94
Formula N- No maint.	4.91	0.13	0a	0	0	0	0.06	0	0	5.88	3.19	5.38
		n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 4: Modified Formula N 1st Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots were sprayed with Accord XRT II at 64 oz/ac on June 1, 2020. The soil was cultivated with a disc harrow on June 22 and 23, 2020. All plots were broadcast seeded with the specified seed mix shown below and 30 lbs./acre, fertilized with 10-6-4 at 1 lb. N per 1000 sq. ft., and covered with erosion control straw blankets on June 25, 2020. Four plots were seeded with Modified Formula N at a rate of 40 lbs./acre and at a PLS rate of 5.04 lbs./acre. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 9/20	Big bluestem Count 9/20	Little bluestem Count 9/20	Indiangrass Count 9/20	Switchgrass Count 9/20	Broadleaf Weeds Count 9/20	Grass Weed Count 9/20	Oat Count 9/20
Modified Formula N- Maint.	40.00	0	0.19	0.38	0	0.19	5.94	1.81a	5.19
Modified Formula N- Maint.	5.04	0.13	0	0	0	0.06	7.25	5.81b	4.13
Modified Formula N- No maint.	40.00	0	0.25	0.31	0	0.31	14.81	2.81ab	3.88
Modified Formula N- No maint.	5.04	0.31	0	0	0	0	16.88	4.19ab	2.88
		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.

Table 5: Formula N 2nd Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots receiving maintenance were sprayed with Triplet LO at 64 oz/ac on June 25, 2021. Four plots were seeded with Formula N at PennDOT's rate of 105.1 lbs./acre and at a PLS rate of 4.91 lbs./acre. Each value is a mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 10/21	Little Bluestem Count 10/21	Indiangrass Count 10/21	Canada wildrye Count 10/21	Virginia wildrye Count 10/21	Black-eyed Susan Count 10/21	New England aster Count 10/21	Ox-eye sunflower Count 10/21	Broadleaf Weeds Count 10/21	Grass Weeds Count 10/21	Oats Count 10/21
Formula N- Maint.	105.10	0.25	0.13	0	0	0	0.00	0	0	42.56	16.25	0
Formula N- Maint.	4.91	0.13	0.00	0	0	0	0.00	0	0	22.44	16.25	0
Formula N- No maint.	105.10	1.88	0.06	0	0	0	2.00	0	0	27.50	15.81	0
Formula N- No maint.	4.91	0.13	0.00	0	0	0	0.19	0	0	29.81	11.25	0
		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 6: Modified Formula N 2nd Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots receiving maintenance were sprayed with Triplet LO at 64 oz/ac on June 25, 2021. Four plots were seeded with Modified Formula N at a rate of 40 lbs./acre and at a PLS rate of 5.04 lbs./acre. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 10/21	Big bluestem Count 10/21	Little bluestem Count 10/21	Indiangrass Count 10/21	Switchgrass Count 10/21	Broadleaf weed Count 10/21	Grass weed Count 10/21	Oat Count 10/21
Modified Formula N- Maint.	40.00	0.125	0	0.19	0.06	0.31b	28.75	12.38	0.00
Modified Formula N- Maint.	5.04	0.38	0	0	0	0.06ab	30.25	21.13b	0.06
Modified Formula N- No maint.	40.00	0.25	0	0.13	0	0.06ab	22.38	8.88	0.00
Modified Formula N- No maint.	5.04	0.44	0	0	0	0a	27.75	12.13	0.00
		n.s.	n.s.	n.s.	n.s.		n.s.		n.s.

Table 7: Formula N 3rd Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots receiving maintenance were sprayed with Freelexx at 64 oz/ac on October 19, 2021. Four plots were seeded with Formula N at PennDOT's rate of 105.1 lbs./acre and at a PLS rate of 4.91 lbs./acre. Each value is a mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 10/21	Little Bluestem Count 10/21	Indiangrass Count 10/21	Canada wildrye Count 10/21	Virginia wildrye Count 10/21	Black-eyed susans Count 10/21	New England aster Count 10/21	Ox-eye sunflower Count 10/21
Formula N- Maint.	105.10	1.75	0	0	0.25	0	9.19	0	0
Formula N- Maint.	4.91	0.81	0	0	0	0	0.75	0	0
Formula N- No maint.	105.10	0.81	0.06	0	0	0	14.25	0	0
Formula N- No maint.	4.91	0	0	0	0	0	0	0	0
		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 8: Modified Formula N 3rd Year: Plant counts were conducted using four permanent sub plot samples per plot that were 2 x 2' in size. All plots receiving maintenance were sprayed with Freelexx at 64 oz/ac on October 19, 2021. Four plots were seeded with Modified Formula N at a rate of 40 lbs./acre and at a PLS rate of 5.04 lbs./acre. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Seed Mix	Seed Rate lbs./ac	Fine fescue Count 10/21	Big bluestem Count 10/21	Little bluestem Count 10/21	Indiangrass Count 10/21	Switchgrass Count 10/21
Modified Formula N- Maint.	40.00	0.25	0.06	0.19	0	0.06
Modified Formula N- Maint.	5.04	1.69	0	0	0	0
Modified Formula N- No maint.	40.00	0.25	0	0.06	0	0
Modified Formula N- No maint.	5.04	1	0	0	0	0
		n.s.	n.s.	n.s.	n.s.	n.s.

Table 9 Formula N Fourth Year Percent seeded species cover visually rated on September 22, 2023. Each value is the mean of four replications. Column means followed by the same letter are not significantly different. Statical analyses were combined for Table 9 and Table 10.

	Seed Rate lbs./ac	% Fine Fescue Cover	% Little Bluestem Cover	% Indiangrass Cover	% Canada Wildrye Cover	% Virginia Wildrye Cover	% Black Eyed Susan Cover	% New England Aster Cover	% Oxeye Sunflower Cover
Formula N- maint.	105.1	35.4 c	0.3 a	0	0.1	0.6	0.06	0	0
Formula N- maint.	4.91	31.3 bc	0 a	0	0	0.3	0	0	0
Formula N- no maint.	105.1	5.4 ab	0.1 a	0	0	0.06	0.6	0.06	0.1
Formula N- no maint.	4.91	1.8 a	0 a	0	0	0	0	0	0
				n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 10 Modified formula N Fourth Year Percent seeded species cover visually rated on September 22, 2023. Each value is the mean of four replications. Column means followed by the same letter are not significantly different. Statical analyses were combined for Table 9 and Table 10.

Seed mix	Seed Rate lbs./ac	% Fine Fescue Cover	% Switchgrass Cover	% Little Bluestem Cover	% Big Bluestem Cover	% Indiangrass Cover
Modified Formula N- maint.	40	22.5 abc	3.5	2.3 b	1.5 b	0.06
Modified Formula N- maint.	5.04	25.6 abc	0.8	0.8 a	0.6 ab	0.06
Modified Formula N-no maint.	40	1.9 a	0.6	0.1 a	0.3 a	0
Modified Formula N-no maint.	5.04	0.5 a	0	0 a	0a	0
			n.s.			n.s.

Table 11. Formula N & Modified Formula N Fourth Year Percent seed species, broadleaf weed, annual grass, bromegrass, Kentucky bluegrass, and tall fescue cover. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Seed mix	Seed Rate lbs./ac	% Total Seeded Species Cover	% BLW Cover	% Annual Grass Cover	% Bromegrass Cover	% Kentucky Bluegrass Cover	% Tall Fescue Cover	% Reed Canarygrass Cover
Formula N- maint.	105.1	36.7 c	16.1 a	0.5	17	2.5	0	27.2
Modified Formula N- maint.	40	29.9 bc	13.9 a	2.5	25.3	1.5	0.6	26.1
Formula N- maint.	4.91	31.5 bc	14.3 a	5	11.3	3.8	3.5	28.3
Modified Formula N- maint.	5.04	27.9 abc	15 a	3.7	20.1	5.5	1.3	26.5
Formula N- no maint.	105.1	6.3 ab	81.3 b	1.8	0	1.6	0	9.1
Modified Formula N-no maint.	40	2.3 a	81.2 b	0.3	2.4	1.3	0	12.5
Formula N- no maint.	4.91	1.8 a	94.2 b	0	0	0	0	4
Modified Formula N-no maint.	5.04	0.5 a	85.2 b	0	0	0	0	14.3
				n.s.	n.s.	n.s.	n.s.	n.s.

HERBICIDE EFFICACY ON JOHNSONGRASS *(Sorghum halepense* (L.) Pers.*)*

Herbicide trade and common names: Outrider *(sulfosulfuron*), Segment II *(sethoxydim)*, Arsenal Powerline *(imazapyr*), *glyphosate (3.7 lb. ae/gal),* Assure II *(quizalofop-P)*, Fusilade II *(fluaziflop-P)*

Plant common and scientific name: Johnsongrass *(Sorghum halepense* (L.) Pers.*)*

ABSTRACT

Johnsongrass, a class B noxious weed in Pennsylvania, is a frequent problem species found along roadsides and thus threatens adjacent farmland. This experiment evaluated nine herbicide treatments: Outrider at 0.75 oz/ac; Outrider at 1 oz/ac; Segment II at 24 oz/ac; Segment II at 40 oz/ac; Arsenal Powerline at 32 oz/ac; glyphosate (3.7 lb. ae/gal) at 128 oz/ac; Assure II at 12 oz/ac; Fusilade II at 16 oz/ac; Fusilade II at 24 oz/ac; and an untreated check. A non-ionic surfactant at 0.25% v/v was added to all herbicide treatments, except Segment II treatments where methylated seed oil at 1% v/v was recommended per label directions. The herbicide treatments were applied on July 11, 2023. Initial percent Johnsongrass cover ranged from 16.75 to 25 with no significant difference among treatments. On July 25, 14 DAT, percent injury to Johnsongrass ranged from 71.25 to 91.25 with the untreated at 3.75. By the last rating on October 10, 91 DAT, percent Johnsongrass cover was similar to the 63 DAT rating. Treatments with less than 10% Johnsongrass cover included Assure II at 12 oz/ac (8.25%), Fusilade II at 16 oz/ac (4.5%), Fusilade II at 24 oz/ac (4.5%), Outrider at 0.75 oz/ac (4.13%), Arsenal Powerline at 32 oz/ac (1.88%), and Outrider at 1 oz/ac (1.63%). Johnsongrass cover for the remaining treatments included Segment II at 40 oz/ac (14.5%), Segment II at 24 oz/ac (28.75%), glyphosate (3.7 lb. ae/gal) at 128 oz/ac (41.25%) and the untreated check (33%). Two herbicide options to consider include Outrider at 1 oz/ac, which reduced Johnsongrass cover by 93% and grass cover by 27% and Fusilade II at 24 oz/ac, which reduced Johnsongrass cover by 80% and grass cover by 31%.

INTRODUCTION

Johnsongrass *(Sorghum halepense* (L.) Pers.*)* is a stout perennial grass that reaches heights of 2-7 feet and propagates from thick, aggressive rhizomes and seeds. It will emerge from rhizomes in early May and from seed in late May[15]. Johnsongrass leaves are up to 20 inches long with a prominent white midvein, the ligule is membranous with a fringe of hairs on top, and flowers are present June through July with the seed head being an open, purplish panicle[16]. Due to its size and ability to outcompete naturalized or native plantings, Johnsongrass can be a problematic species found along roadside. Several maintenance strategies that may be employed includes mowing, a selective herbicide application or a nonselective herbicide application. Mowing may be a temporary strategy to reduces its size; however, a more appropriate strategy is to selectively remove Johnsongrass while maintaining a competitive grass groundcover. Certain situations may occur where a competitive grass cover doesn't exist or is of

[15] https://extension.psu.edu/Johnsongrass-and-shattercane-control-an-integrated-approach viewed Jan. 25, 2024
[16] Neal, JC.; Uva, RH; DiTomaso, JM; & DiTommaso, A 2023. Weeds of the Northeast Second Edition. Ithaca: Cornell University Press

poor quality, so a nonselective herbicide may be acceptable to use followed by seeding a low growing grass cover. The purpose of is this study was to determine if commonly used herbicides for Johnsongrass control could be applied once while minimizing damage to desirable grass species. Common desirable grass species found along roadsides in Pennsylvania includes tall fescue, the fine fescues-sheep, hard, Chewing's and creeping red, and Kentucky bluegrass to name a few.

MATERIALS AND METHODS

The experiment was established near the intersection of SR 222 and SR 61 approximately 1 mile north of Reading, Pennsylvania. The experiment evaluated nine herbicide treatments: Outrider at 0.75 oz/ac; Outrider at 1 oz/ac; Segment II at 24 oz/ac; Segment II at 40 oz/ac; Arsenal Powerline at 32 oz/ac; glyphosate (3.7 lb. ae/gal) at 128 oz/ac; Assure II at 12 oz/ac; Fusilade II at 16 oz/ac; Fusilade II at 24 oz/ac; and an untreated check. A non-ionic surfactant at 0.25% v/v was added to all herbicide treatments, except Segment II treatments which recommended methylated seed oil at 1% v/v per label directions. Plots were 18 feet by 6 feet in size with four replications per treatment. The application was made at a carrier volume of 35 gallons per acre. All treatments were applied using a CO_2-powered backpack sprayer equipped with a 6-foot boom with four 8004 nozzles at 31 PSI (pounds per square inch). The weather at the time of application was sunny with clouds, wind speeds of 0-5 mph, 52% relative humidity, and air temperatures of 82° F. The herbicide treatments were applied on July 11, 2023.

Initial percent Johnsongrass cover was visually rated July 11, 2023, prior to treatment and designated as 0 DAT (days after treatment) prior to herbicide treatment. Percent Johnsongrass injury was visually rated on July 18, 2023, 7 DAT and July 25, 2023, 14 DAT and percent cover where 0 = 0% cover – 100 = 100% cover on July 11, 2023, 0 DAT, September 12, 2023, 63 DAT and October 10, 2023, 91 DAT. All data were subjected to analysis of variance, and when treatment effect F-tests were significant ($p \leq 0.05$), treatment means were compared using Tukey's HSD separation test.

RESULTS AND DISCUSSION

Initial percent Johnsongrass cover was visually rated July 11, 2023, 0 DAT, prior to herbicide treatment, ranged from 16.75 to 25 with no significant difference among treatments (Table 1). By 7 DAT, injury ranged from 62.5-98.75% for the herbicide treatments and the untreated at 5%. On July 25, 14 DAT, percent injury ranged from 71.25 to 91.25 with the untreated at 3.75. Segment II at 40 oz/ac and glyphosate (3.7 lb ae/gal) at 128 oz/ac resulted in over 90% injury to Johnsongrass. Percent Johnsongrass cover was rated on September 12, 63 DAT. Herbicide treatments ranged from 2.56% to 33.75% while the untreated check was 37.5%. Treatments with less than 10% Johnsongrass cover included Assure II at 12 oz/ac (7.75%), Fusilade II at 16 oz/ac (5.13%), Outrider at 0.75 oz/ac (4.13%), Fusilade II at 24 oz/ac (4%), Arsenal Powerline at 32 oz/ac (2.63%), and Outrider at 1 oz/ac (2.56%). By the last rating on October 10, 91 DAT, percent Johnsongrass cover was similar to the 63 DAT rating. Treatments with less than 10% Johnsongrass cover included Assure II at 12 oz/ac (8.25%), Fusilade II at 16 oz/ac (4.5%), Fusilade II at 24 oz/ac (4.5%), Outrider at 0.75 oz/ac (4.13%), Arsenal Powerline at 32 oz/ac (1.88%), and Outrider at 1 oz/ac (1.63%). Johnsongrass cover for the remaining

treatments included Segment II at 40 oz/ac (14.5%), Segment II at 24 oz/ac (28.75%), glyphosate (3.7 lb ae/gal) at 128 oz/ac (41.25%) and the untreated check (33%). Table 2 shows percent Johnsongrass cover, percent grass cover as all grasses except Johnsongrass, and percent broadleaf weed (BLW) cover prior to herbicide treatments, 0 DAT and 91 DAT. In general, by 91 DAT, percent grass cover was less than the 0 DAT rating, while percent BLW cover varied by treatment. Arsenal Powerline and glyphosate treatments would have activity on broadleaf plants. Percent change in Johnsongrass cover (Table 3) helps determine which treatments were most effective when comparing the initial Johnsongrass cover before herbicide treatments to the last rating on October 10, 91 DAT. For instance, the untreated plots showed a 55% increase in Johnsongrass cover whereas Arsenal Powerline at 32 oz/ac had a 99% decrease in Johnsongrass cover. Other treatments with good reduction in Johnsongrass cover included Outrider at 1 oz/ac (-93%), Outrider at 0.75 oz/ac (-81%), Fusilade II at 24 oz/ac (-80%), and Fusilade II at 16 oz/ac (-73%). Additional treatments with reduced Johnsongrass cover included Assure II at 12 oz/ac (-63%) and Segment II at 40 (-36%). Interesting, Segment II at 24 oz/ac and glyphosate at 128 oz/ac showed an increase in Johnsongrass cover, +6% and +65% respectively. An additional evaluation to consider is percent grass cover. Table 4 presents the percent change in grass cover based on treatment. For the untreated check by 91 DAT, grass cover showed a reduction by 28%. Several factors may have influenced this reduction including summer annual grasses that may have senesced and simply were not present in October even though no frost occurred by the last rating. For the Outrider treatments, Outrider at 0.75 oz/ac had a 7% reduction, and Outrider at 1 oz/ac had a 27% reduction. Segment II at 24 oz/ac had a 5% reduction while Segment II at 40 oz/ac had a 50% reduction. Assure II at 12 oz/ac had 58% reduction. Fusilade II at 16 oz/ac had a 40% reduction while Fusilade II at 24 oz/ac had a 31% reduction. Arsenal Powerline at 32 oz/ac reduced grass cover by 99% and glyphosate (3.7 lb ae/gal) at 128 oz/ac reduced grass cover by 98%.

CONCLUSIONS

All herbicide treatments resulted in at least 70 percent injury to Johnsongrass on July 25, 14 DAT. No herbicide treatment resulted in 0% Johnsongrass cover by October 10, 91 DAT. The following treatments resulted in less than 5% Johnsongrass cover: Fusilade II at 16 oz/ac; Fusilade II at 24 oz/ac; Outrider 0.75 oz/ac; Arsenal Powerline at 32 oz/ac; and Outrider at 1 oz/ac. Arsenal Powerline at 32 oz/ac reduced Johnsongrass cover by 99% and grass cover by 99% making this an acceptable option where maintaining a desirable grass ground cover is not necessary. Acceptable selective herbicide options to consider included Outrider at 1 oz/ac, which reduced Johnsongrass cover by 93% and grass cover by 27% and Fusilade II at 24 oz/ac, which reduced Johnsongrass cover by 80% and grass cover by 31%. Future experiments should evaluate multiple herbicide treatments during the same season for control of Johnsongrass. Ultimately the question is whether multiple applications to Johnsongrass during one season will control it or will Johnsongrass need multiple treatments over multiple years to exhaust the root system.

MANAGEMENT IMPLICATIONS

Depending on the site and roadside vegetation management objective, several herbicide options are available for managing Johnsongrass. We found that a single application will not

completely control Johnsongrass, this technique will reduce Johnsongrass cover, ultimately requiring follow up treatments. On sites where no or very little desirable grass groundcover exist, Arsenal Powerline at 32 oz/ac is one option to consider. While this product is effective on Johnsongrass it is also effective on desirable species as well, including grasses. Caution should be exercised when using Arsenal Powerline, as the label contains a statement warning of potential injury to trees and desirable plants with root systems extending into the treatment zone[17]. Assure II at 12 oz/ac and Segment II at 40 oz/ac both marginally reduced Johnsongrass cover and reduced grass cover to unacceptable levels (more than 50% reduction). Outrider at 1 oz/ac and Fusilade II at 24 oz/ac both provided acceptable Johnsongrass reduction and showed some decline in desirable grass cover. At this point, Outrider at 1 oz/ac would be recommended to selectively control Johnsongrass. The prudent approach would be to strive to minimize damage to desirable grass groundcovers while controlling unwanted species, in this case Johnsongrass. Where grass groundcovers exist and are damaged by herbicide applications, seeding a competitive grass ground cover with formula L is recommended.

Table 1. Percent injury and cover of Johnsongrass (SORHA) *(Sorghum halepense* (L.) Pers*)*. The experiment was visually rated for percent injury where 0 = no injury - 100 = complete injury on July 18, 2023, 7 days after treatment (DAT) & July 25, 2023, 14 DAT and percent cover where 0 = 0% cover – 100 = 100% cover on July 11, 2023, 0 DAT, September 12, 2023, 63 DAT and October 10, 2023, 91 DAT. Herbicides were applied on July 11, 2023. All treatments included 0.25%v/v non-ionic surfactant except Segment II which included methylated seed oil at 1% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/acre	% SORHA COVER 07/11/23 0 DAT	% SORHA INJURY 07/18/23 7 DAT	% SORHA INJURY 07/25/23 14 DAT	% SORHA COVER 9/12/23 63 DAT	% SORHA COVER 10/10/23 91 DAT
Untreated	--	21.25	5 a	3.75 a	37.5 c	33 bc
Outrider	0.75	22.25	72.5 bc	80 bc	4.13 a	4.13 a
Outrider	1	23.75	62.5 b	71.25 b	2.56 a	1.63 a
Segment II	24	27	77.5 bc	80 bc	31.25 bc	28.75 bc
Segment II	40	22.5	90 cd	91.25 c	15.25 ab	14.5 ab
Arsenal Powerline	32	16.75	76.25 bc	86.25 bc	2.63 a	1.88 a
glyphosate (3.7 lb ae/gal)	128	25	98.75 d	95 c	33.75 bc	41.25 c
Assure II	12	22.5	76.25 bc	83.75 bc	7.75 a	8.25 a
Fusilade II	16	16.75	87.5 cd	87.5 c	5.13 a	4.5 a
Fusilade II	24	22.5	83.75 cd	85 bc	4 a	4.5 a
		n.s.				

[17] BASF. Corporation. Arsenal Powerline label. https://www.cdms.net/ldat/ld86K002.pdf

Table 2. Percent Johnsongrass (SORHA) *(Sorghum halepense* (L.) Pers*)*, grass and broadleaf weed (BLW) cover. The experiment was visually rated for percent cover where 0 = 0% cover – 100 = 100% cover on July 11, 2023, 0 DAT and October 10, 2023, 91 DAT. Herbicides were applied on July 11, 2023. All treatments included 0.25%v/v non-ionic surfactant except Segment II which included methylated seed oil at 1% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/acre	% SORHA COVER 07/11/23 0 DAT	% GRASS COVER 7/11/23 0 DAT	% BLW COVER 07/11/23 0 DAT	% SORHA COVER 10/10/23 91 DAT	% GRASS COVER 10/10/23 91 DAT	% BLW COVER 10/10/23 91 DAT
Untreated	--	21.25	36.25	42.5	33 bc	26.25	37.5
Outrider	0.75	22.25	40.25	37.5	4.13 a	37.63	55
Outrider	1	23.75	27.5	48.75	1.63 a	20	73.5
Segment II	24	27	35.5	37.5	28.75 bc	33.75	36.25
Segment II	40	22.5	32.5	45	14.5 ab	16.25	65
Arsenal Powerline	32	16.75	50.75	32.5	1.88 a	0.13	17.5
glyphosate (3.7 lb ae/gal)	128	25	41.25	33.75	41.25 c	0.75	26.25
Assure II	12	22.5	47.5	30	8.25 a	20	61.25
Fusilade II	16	16.75	48.25	35	4.5 a	28.75	61.25
Fusilade II	24	22.5	41.25	36.25	4.5 a	28	65
		n.s.	n.s.	n.s.		n.s.	n.s.

Table 3. Percent Johnsongrass (SORHA) *(Sorghum halepense* (L.) Pers*)* cover and percent change Johnsongrass cover. The experiment was visually rated for percent cover where 0 = 0% cover – 100 = 100% cover on July 11, 2023, 0 DAT and October 10, 2023, 91 DAT. Herbicides were applied on July 11, 2023. (+ = an increase and **-** = a decrease in percent change Johnsongrass cover). All treatments included 0.25%v/v non-ionic surfactant except Segment II which included methylated seed oil at 1% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/acre	% SORHA COVER 07/11/23 0 DAT	% SORHA COVER 10/10/23 91 DAT	% Change SORHA COVER
Untreated	--	21.25	33 bc	+ 55
Outrider	0.75	22.25	4.13 a	-81
Outrider	1	23.75	1.63 a	-93
Segment II	24	27	28.75 bc	+6
Segment II	40	22.5	14.5 ab	-36
Arsenal Powerline	32	16.75	1.88 a	-99
glyphosate (3.7 lb ae/gal)	128	25	41.25 c	+65
Assure II	12	22.5	8.25 a	-63
Fusilade II	16	16.75	4.5 a	-73
Fusilade II	24	22.5	4.5 a	-80
		n.s.		

Table 4. Percent grass cover and percent change in grass cover. The experiment was visually rated for percent cover where 0 = 0% cover – 100 = 100% cover on July 11, 2023, 0 DAT and October 10, 2023, 91 DAT. (+ = an increase and - = a decrease in percent change grass cover). Herbicides were applied on July 11, 2023. All treatments included 0.25%v/v non-ionic surfactant except Segment II which included methylated seed oil at 1% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different at $p \leq 0.05$.

Product	Rate oz/acre	% GRASS COVER 7/11/23 0 DAT	% GRASS COVER 10/10/23 91 DAT	% Change GRASS COVER
Untreated	--	36.25	26.25	-28
Outrider	0.75	40.25	37.63	-7
Outrider	1	27.5	20	-27
Segment II	24	35.5	33.75	-5
Segment II	40	32.5	16.25	-50
Arsenal Powerline	32	50.75	0.13	-99
glyphosate (3.7 lb ae/gal)	128	41.25	0.75	-98
Assure II	12	47.5	20	-58
Fusilade II	16	48.25	28.75	-40
Fusilade II	24	41.25	28	-31
		n.s.	n.s.	

DEMONSTRATION OF THREE BAREGROUND PROGRAMS WITH ALTERNATIVE SITE OF ACTION-YEAR ONE

Herbicide trade and common names: Method 240SL *(aminocyclopyrachlor)*, Esplanade 200 SC *(indaziflam)*, Arsenal Powerline *(imazapyr)*, RoundUp Pro Concentrate *(glyphosate*), TerraVue *(aminopyralid + florpyrauxifen-benzyl)*, Fusilade II *(fluaziflop-P)*, Prodiamine 65 WDG *(prodiamine*), Hyvar XL (*bromacil*), Pendulum Aquacap (*pendimethalin*), Piper EZ *(flumioxazin + pyroxasulfone)*, Plateau *(imazapic)*, Esplanade Sure *(indaziflam + rimsulfuron)*, Segment II *(sethoxydim)*, Oust Extra *(sulfometuron-methyl + metsulfuron-methyl)*

INTRODUCTION

Bareground weed control is a priority roadside vegetation management program to assure safe roads and travel corridors allowing water runoff during rainstorms and safe emergency stopping throughout Pennsylvania. Most districts apply bareground mixes yearly on numbered routes and secondary roads, however some may treat secondary roads every other year. A bareground mix has three components: a pre-emergence herbicide, a broad-spectrum residual herbicide, and a post emergence herbicide. Pre-emergence herbicides control weeds growing from seed. Broad-spectrum residual herbicides provide control of existing vegetation, as well as soil residual activity. Post emergence herbicides are effective at controlling actively growing weeds that are already established. The repeated use of the same bareground mix may lead to an inability to control weeds that were once controlled leading to the potential for development of herbicide resistant weed species. One strategy to manage resistance and maintain a large arsenal of herbicides for use, is to rotate the site of action of the pre-emergence, broad-spectrum residual, and post emergence herbicides of a bareground mix. Over the past few years, experiments have evaluated alternative bareground mixes that rotate the site of action (SOA) [18,19,20]. Using results from previous experiments, alternative bareground mixes that rotate site of action can be utilized along with a standard bareground mix. The goal of this demonstration is to initiate a four-year rotation program of bareground mixes on a site to determine the efficacy of rotating different SOAs on the weeds of the site.

MATERIALS AND METHODS

The demonstration was established as a randomized design beneath a guiderail site along SR 350 near Bald Eagle, PA. Treatments include Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + Fusilade II at 24 oz/ac; Method 240SL at 16 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; and an untreated check. Induce, a non-ionic surfactant, was added to all herbicide treatments at 0.25% v/v. Plots were 80 by 4 feet in size.

[18] Jodon et.al 2022. Evaluation of Alternative Bareground Herbicide Mixes. Roadside Vegetation Management Research-2022 Report pp 31-41.
[19] Jodon et.al 2023. Evaluation of Alternative Bareground Herbicide Mixes. Roadside Vegetation Management Research-2023 Report pp 43-52.
[20] Jodon et.al 2023. Evaluation of Bareground Herbicide Mixes without Glyphosate. Roadside Vegetation Management Research-2023 Report pp 53-63.

The herbicide treatments were applied on May 10, 2023. Treatments were pre-measured, mixed, and applied, using a CO_2 powered backpack sprayer equipped with one OC-06 nozzle at 31 PSI (pounds per square inch), and delivered at 50 gallons per acre. Weather at the time of application consisted of sunny skies, winds at 0-5 MPH, 23% relative humidity, air temperature of 62°F and soil temperatures of 68°F, 62°F, 62°F, and 60°F, at 0-, 1-, 3-, and 6-inch depths, respectively. Local rain events occurred on May 14, 21, June 10, and 13, 2023, with 0.07", 0.11", 0.05, and 1.09", respectively, according to https://www.weather.gov/wrh/Climate?wfo=ctp. The nearest weather station was in Tyrone, PA. Table 1 lists bareground program mixes in use in years 1, 2, 3, and 4. Program 1 is untreated, and rotations begin with Program 2 in which the SOA rotates for each component over four years. Programs 3 and 4 rotate the SOA of each component over 3 years. It is also very important to remember to rotate out of herbicides such as Method 240SL or TerraVue used as foliar applied with soil residual activity with the same SOA, in this case SOA 4.

The experiment was visually rated for percent total vegetative cover on June 15, July 10, September 20, and October 10, 2023, 36, 61, 133 and 153 days after treatment (DAT). On October 31, 2023, a killing frost occurred at the guiderail site effectively ending the experiment.

RESULTS AND DISCUSSION

Prior to the initiation of this demonstration the guiderail site was treated yearly with a standard bareground mix (Method 240SL + Esplanade 200SC + Arsenal Powerline + RoundUp Pro Concentrate). The guiderail site was quite clean with minimal weed pressure. Herbicide treatments were applied May 10, 2023. By June 15, 36 DAT percent total cover (Table 2) ranged from 0% for TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac to 0.1% for Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac and Method 240SL at 16 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac. The untreated plot showed 35% total cover. Percent total cover remained the same by 61 DAT while the untreated plot increased to 40%. By the last rating on October 10, 153 DAT, TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0% total cover, Method 240SL at 16 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0.1% total cover, and Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 3% total cover. The untreated plots showed 60% total cover. Percent grass cover (Table 3) by October 10, 153 DAT showed the untreated plot at 40%, Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac at 2.9%, Method 240SL at 16 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac 0.1%, and TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0%. Percent broadleaf weed cover (Table 4) by 153 DAT for the untreated plot showed 20%, Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0.1%, while both Method 240SL at 16 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro

Concentrate at 64 oz/ac and TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0%.

CONCLUSIONS

TerraVue at 5 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac resulted in zero total cover and provided season long bareground control. Based on a threshold of 5% or less total vegetative cover, both Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac and Method 240SL at 12 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac were acceptable mixes. Future work will continue to evaluate alternative bareground mixes as outlined in bareground programs 2, 3, and 4 to determine effectiveness of the programs to a site over time.

Table 1. Bareground Program 2, 3, & 4. Mixes that rotate SOA each year. Program 1 is untreated.

Program	Product	Rate oz/ac	SOA
2	Method 240SL	12	4
1st year	Esplanade 200 SC	5	29
	Arsenal Powerline	8	2
	RoundUp Pro Concentrate	64	9
2	Method 240SL	16	4
2nd year	Pendulum Aquacap	128	3
	Arsenal Powerline	8	2
	RoundUp Pro Concentrate	64	9
2	Prodiamine 65 WDG	32	3
3rd year	Hyvar XL	128	5
	RoundUp Pro Concentrate	64	9
2	TerraVue	5	4+4
4th year	Esplanade 200 SC	5	29
	Arsenal Powerline	8	2
	Fusilade II	24	1

Program	Product	Rate oz/ac	SOA
3	TerraVue	5	4+4
1st year	Esplanade 200 SC	5	29
	Arsenal Powerline	8	2
	Fusilade II	24	1
3	Method 240SL	12	4
2nd year	Piper EZ	20	14+15
	Arsenal Powerline	8	2
	RoundUp Pro Concentrate	64	9
3	Pendulum Aquacap	128	3
3rd year	Hyvar XL	128	5
	RoundUp Pro Concentrate	64	9

Program	Product	Rate oz/ac	SOA
4	Method 240SL	16	4
1st year	Prodiamine 65 WDG	32	3
	Arsenal Powerline	8	2
	RoundUp Pro Concentrate	64	9
4	Piper EZ	20	14+15
2nd year	Hyvar XL	64	5
	RoundUp Pro Concentrate	64	9
	Plateau	12	2
4	Esplanade Sure	5	29+2
3rd year	Oust Extra	4	2+2
	Segment II	32	1

Table 2. Effectiveness of treatments based on percent total vegetative cover at 36, 61, 133, & 153 days after treatment (DAT). The site was visually rated on June 15, July 10, September 20, & October 10, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treat-ment	Product	Rate oz/acre	% Total Cover 6/15/23 36 DAT	% Total Cover 7/10/23 61 DAT	% Total Cover 9/20/23 133 DAT	% Total Cover 10/10/23 153 DAT
1	untreated	--	35	40	60	60
2	Method 240SL	12	0.1	0.1	3	3
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				
3	TerraVue	5	0	0	0	0
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	Fusilade II	24				
4	Method 240SL	16	0.1	0.1	0.1	0.1
1st year	Prodiamine 65 WDG	32				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				

Table 3. Effectiveness of treatments based on percent grass cover at 36, 61, 133, & 153 days after treatment (DAT). The site was visually rated on June 15, July 10, September 20, & October 10, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treat-ment	Product	Rate oz/acre	% Grass Cover 6/15/23 36 DAT	% Grass Cover 7/10/23 61 DAT	% Grass Cover 9/20/23 133 DAT	% Grass Cover 10/10/23 153 DAT
1	untreated	--	30	35	40	40
2	Method 240SL	12	0.1	0.1	2.9	2.9
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				
3	TerraVue	5	0	0	0	0
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	Fusilade II	24				
4	Method 240SL	16	0.1	0.1	0.1	0.1
1st year	Prodiamine 65 WDG	32				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				

Table 4. Effectiveness of treatments based on percent broadleaf weed cover at 36, 61, 133, & 153 days after treatment (DAT). The site was visually rated on June 15, July 10, September 20, & October 10, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treat-ment	Product	Rate oz/acre	% BLW Cover 6/15/23 36 DAT	% BLW Cover 7/10/23 61 DAT	% BLW Cover 9/20/23 133 DAT	% BLW Cover 10/10/23 153 DAT
1	untreated	--	5	5	20	20
2	Method 240SL	12	0	0	0.1	0.1
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				
3	TerraVue	5	0	0	0	0
1st year	Esplanade 200 SC	5				
	Arsenal Powerline	8				
	Fusilade II	24				
4	Method 240SL	16	0	0	0	0
1st year	Prodiamine 65 WDG	32				
	Arsenal Powerline	8				
	RoundUp Pro Concentrate	64				

EVALUATION OF ALTERNATIVE BAREGROUND HERBICIDE MIXES

Herbicide trade and common names: Method 240SL *(aminocyclopyrachlor)*, Esplanade 200 SC *(indaziflam)*, Arsenal Powerline *(imazapyr)*, RoundUp Pro Concentrate *(glyphosate*), Echelon 4 SC *(sulfentrazone + prodiamine)*, Oust Extra *(sulfometuron-methyl + metsulfuron-methyl)*, Fusilade II *(fluaziflop-P)*, Pendulum Aquacap (*pendimethalin*), Hyvar XL (*bromacil*), Plateau *(imazapic)*, Esplanade Sure *(indaziflam + rimsulfuron)*, Segment II *(sethoxydim)*, TerraVue *(aminopyralid + florpyrauxifen-benzyl)*, Prodiamine 65 WDG *(prodiamine*), Piper EZ *(flumioxazin + pyroxasulfone)*, Promenade WDG *(flumioxazin)*

Plant common and scientific names: mugwort *(Artemisia vulgaris)*, field horsetail *(Equisetum arvense),* poverty dropseed *(Sporobolus vaginiflorus),* tufted lovegrass *(Eragrostis pectinacea),* tall fescue *(Schedonorus arundinaceus),* prostrate knotweed *(Polygonum aviculare),* witchgrass *(Panicum capillare),* purpletop *(Tridens flavus)*

ABSTRACT

Roadside areas, in particular around signs and under guiderails require season long bareground weed control. While developing a bareground weed control program, roadside vegetation managers should implement alternative mixes that rotate sites of action (SOA) of the various components of a bareground herbicide mix. This experiment evaluated herbicide mixes with alternative bareground pre-emergence, broad-spectrum residual herbicides and mixes that did not utilize RoundUp Pro (*glyphosate*). Treatments include Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusilade II at 24 oz/ac; Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Pendulum Aquacap at 128 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac + Oust Extra at 4 oz/ac + Segment II at 32 oz/ac; TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + Fusilade II at 24 oz/ac; Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; TerraVue at 5 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac; Method 240SL at 12 oz/ac + Piper EZ at 20 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; and an untreated check. In addition, one treatment was a split application in time containing different mixes Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in April followed by Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in July. By October 23, the last rating, four treatments were significantly different from the untreated plots. While no treatment resulted in 0% total cover, the treatment with the lowest % total vegetative cover, 0.7%, was Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64. The following treatments showed less than 2% total vegetative cover: Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac

(1.5%); Pendulum Aquacap at 128 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.8%) and the split application (1.8%).

INTRODUCTION

Bareground weed control is an essential part of a roadside vegetation management program and include signs, under guiderails, concrete barriers, and traffic islands, as well as other fixed structures. Areas maintained free of vegetation allow for proper surface water movement from the roadway, ease of maintenance operations, increased sight distance, and an overall clean and safe aesthetic. Bareground or total vegetation control mixes are comprised of three components: a post emergence herbicide, broad-spectrum residual herbicide, and a pre-emergence herbicide. Post emergence herbicides are effective at controlling actively growing and established weeds. Broad-spectrum residual herbicides provide control of existing weeds and soil residual activity to prevent emergence of weeds prior to activation of the pre-emergence herbicide. Pre-emergence herbicides prevent the establishment of weeds from seed. Roadside vegetation managers select herbicides for bareground applications based on costs, availability, function, and site of action. Site of action (SOA) of herbicides are very important to consider in developing a bareground program. Depending on the component within a bareground mix, it is necessary to rotate the SOA of each component to minimize herbicide resistant weeds. This technique will allow for current technology to be utilized longer. The repeated use of the same bareground mix with the same SOA for bareground applications used year after year will lead to herbicide resistance in targeted weed species. A bareground mix is what is used for a particular year. A program involves bareground mixes used over several years in sequence that rotates SOA of pre-emergence, broad-spectrum residual, and post emergence herbicides. In a continuing effort to develop alternative bareground mixes that rotate SOA, this experiment evaluated mixes that utilize different pre-emergence, broad-spectrum residual and post emergence herbicides including mixes that do not contain *glyphosate*.

MATERIALS AND METHODS

The experiment was established as a randomized complete design with four replications beneath a guiderail site along SR 764 near Pinecroft, PA. Treatments include Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusilade II at 24 oz/ac; Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Pendulum Aquacap at 128 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac + Oust Extra at 4 oz/ac + Segment II at 32 oz/ac; TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + Fusilade II at 24 oz/ac; Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; TerraVue at 5 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac; Method 240SL at 12 oz/ac + Piper EZ at 20 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 oz/ac; ; a split dual application: Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac

applied in April and Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in July; and an untreated check. Induce, a non-ionic surfactant, was added to all herbicide treatments at 0.25% v/v. Plots were 20 by 4 feet in size. The first nine herbicide treatments including the split dual app were applied on April 25, 2023, or while the remaining three treatments were applied on May 8, 2023, due to a delay in receiving products. Treatments were pre-measured, mixed, and applied, using a CO_2 powered backpack sprayer equipped with one OC-04 nozzle at 32 PSI (pounds per square inch), and delivered at 50 gallons per acre. Weather at the time of application on April 25 consisted of sunny skies, winds at 5-10 MPH, 22.4% relative humidity, air temperature of 54°F and soil temperatures of 54°F, 54°F, 53°F, and 53°F, at 0-, 1-, 3-, and 6-inch depths, respectively. Local rain events occurred on April 28, 29, 30 and May 1, 2, 2023, with 0.81", 0.09", 1.06", 0.13"and 0.12" respectively, according to http://newa.cornell.edu. Weather at the time of application on May 8 consisted of mostly cloudy skies, winds at 5-10 MPH, 46.6% relative humidity, air temperature of 70°F and soil temperatures of 66°F, 62°F, 61°F, and 60°F, at 0-, 1-, 3-, and 6-inch depths, respectively. Local rain events occurred on May 9, 13, 20 and June 12, 13, 14, 2023, with 0.03", 0.26", 0.14", 0.68", 0.14" and 0.42" respectively, according to http://newa.cornell.edu. The nearest weather station was the airport in Martinsburg, PA.

The experiment was visually rated for percent total vegetative cover on April 25, May 24, June 28, July 26, September 27, and October 23, 2023, 0, 29, 64, 92, 155 and 181 days after treatment (DAT) for treatments applied on April 25. For treatments applied on May 8, percent total vegetative cover was visually rated on May 8, May 24, June 28, July 26, September 27, and October 23, 2023, 0, 16, 51, 79, 143 and 155 DAT for treatments. Additionally, percent broadleaf weed cover and grass cover were visually rated on June 28, July 26, September 27, and October 23, 2023. On October 31, 2023, a killing frost occurred at the guiderail site effectively ending the experiment. All data were subjected to analysis of variance and when treatment F-tests were significant ($p \leq 0.05$), treatment means were compared using Tukey's HSD separation test. Despite different application times for several treatments (11-13), statistics analysis was analyzed together for percent total vegetative cover, percent grass cover, and percent broadleaf and presented for instance, as percent total vegetative cover Table 1 and Table 1a, to differentiate application date.

RESULTS AND DISCUSSIONS

Prior to treatment application, the plots were rated on April 25 and ranged from 1 to 2.6% total cover with no significance between treatments (Table 1 & 1a). Total cover ranged from 0.1 to 9.3% for the herbicide treatments and 12% for the untreated check on May 24, 29/16 DAT. Percent total cover varied amongst herbicide treatments through July 26, 92/79 DAT, with only two treatments resulting in less than 1% total cover. The treatments included the dual application: Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied April 25 and Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied July 5 and Promenade WDG + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 oz/ac. So, by the July 26 rating the dual application would have had both treatments applied to the plots. On September 27, 155/143 DAT, treatments ranged from 0.7 to 19.2 % total vegetative cover for the herbicide treatments, while the untreated check was 26.4 %.

While herbicide treatments were statistically similar, these treatments were significantly different when compared to the untreated check. Common species identified in the four untreated plots included mugwort (3 of 4), field horsetail (2 of 4), poverty dropseed (4 of 4), tufted lovegrass (3 of 4), tall fescue (2 of 4), prostrate knotweed (2 of 4), witchgrass (2 of 4), and purpletop (1 of 4). Across all experiment plots, poverty dropseed was identified in 44% of the plots and field horsetail was identified in 38% of plots. Interestingly, purpletop was identified in only one untreated plot but was identified in 37% of the plots. The last rating, October 23 181/168 DAT, showed four treatments were significantly different from the untreated plots. While no treatments resulted in 0% total cover, the treatment with the lowest % total vegetative cover, 0.7%, was Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64. The following treatments showed less than 2% total vegetative cover: Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.5%); the split dual application: Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in April and Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in July (1.8%) and Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.8%). Treatments with less than 10% total vegetative cover included: Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (5.9%), TerraVue at 5 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac (6.6%), Method 240SL at 12 oz/ac + Piper EZ at 20 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (6.6%), Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac + Oust Extra at 4 oz/ac + Segment II at 32 oz/ac (6.9%), Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (7.9%) and TerraVue at 5oz/ac + Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + Fusilade II at 24 oz/ac (8.3%). Pendulum Aquacap at 128 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 10.1% total cover while Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusilade II at 24 oz/ac showed 19.1% total cover. Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusilade II at 24 oz/ac mix may have done poorly in this experiment due the use of a very low rate of Echelon 4SC. Echelon 4SC label directs use rates at 24-36 oz/ac and future work will utilize those rates.

Grass cover between the herbicide treatments ranged from 0 to 7.2% while the untreated check showed 6.9% on June 28, 64/51 DAT (Table 2 & 2a). By October 23 181/168 DAT, several treatments resulted in less than 3% grass cover: the split dual application: Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in April and Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in July (0%), Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 (0.1%), Pendulum Aquacap at 128 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.3%), Method 240SL at 12 oz/ac + Piper EZ at 20 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.6%), Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.9%), Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.4%), Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.4%), Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac +

Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (1.9%) and TerraVue at 5 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac (2.7%). Two treatments were around 5% grass cover: Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac + Oust Extra at 4 oz/ac + Segment II at 32 oz/ac (5.3%) and TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + Fusilade II at 24 oz/ac (5.1%).

Broadleaf weed cover ranged from 0 to 12.4% for the herbicide treatments and the untreated check showed 7.5% on June 28, 64/51 DAT (Table 3 & 3a). By October 23 181/168 DAT, nine treatments showed 5% or less broadleaf weed cover: Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.1%), Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.4%), Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (0.5%), Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusilade II at 24 oz/ac (0.8%), Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac + Oust Extra at 4 oz/ac + Segment II at 32 oz/ac (1.4%), the split dual application: Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in April and Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac applied in July (1.8%), TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + Fusilade II at 24 oz/ac (3.2%), TerraVue at 5 oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac (3.8%) and Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac (5%).

Several treatments require further discussion. Treatment 10 was a split application in late April of Method 240SL at 7 oz/ac + Esplanade 200 SC at 3 oz/ac + Oust Extra at 2 oz/ac + Plateau at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac followed by a second application in early July of Method 240SL at 9 oz/ac + Esplanade 200 SC at 3 oz/ac + Arsenal Powerline at 6 oz/ac + RoundUp Pro Concentrate at 48 oz/ac. While this treatment provided acceptable percent total vegetative cover by the end of the season (1.8%), this technique of two applications will increase costs compared to a standard one application per year.

In our effort to identify and effective bareground mix without glyphosate as a post emergence herbicide component, three mixes were included in this experiment; treatment 6 (Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac+ Oust Extra at 4 oz/ac + Segment II) treatment 7 (TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust extra at 2 oz/ac + Fusilade II at 24 oz/ac) and treatment 9 (TerraVue at 5oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac). . In general, a bareground mix includes a product (e.g., Method 240SL, Milestone, or TerraVue) with postemergence activity on broadleaf weeds. Without *glyphosate* in the mix, a grass post emergence herbicide must be included. Unfortunately, there is a potential for antagonism to occur in mixing a grass herbicide and a broadleaf weed herbicide[21]. Please read and follow all label instructions. Ideally a decline in % total cover should be observed at 30 DAT, only treatment 7 (TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust extra at 2 oz/ac + Fusilade II at 24 oz/ac) showed a decline in total cover. June 28 was the first rating that showed a difference in percent grass and broadleaf weed

[21] Holshouser DL, Coble HD. Compatibility of Sethoxydim with Five Postemergence Broadleaf Herbicides. *Weed Technology*. 1990;4(1):128-133. doi:10.1017/S0890037X00025112

cover per plot. Treatment 9 (TerraVue at 5oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac) showed the lowest % grass cover (0.3%) by 64 DAT. At this point it was expected that the grass herbicide would have controlled the existing grass and the pre-emergence herbicide would have controlled the grassy weeds that germinated. By the last rating October 23, 181 DAT, treatment 9 (TerraVue at 5oz/ac + Prodiamine 65 WDG at 32 oz/ac + Arsenal Powerline at 8 oz/ac + Segment II at 32 oz/ac) showed 2.7% grass cover, treatment 7 (TerraVue at 5 oz/ac + Pendulum Aquacap at 128 oz/ac + Oust extra at 2 oz/ac + Fusilade II at 24 oz/ac) showed 5.1% grass cover, and treatment 6 (Plateau at 12 oz/ac + Esplanade Sure at 5 oz/ac+ Oust Extra at 4 oz/ac + Segment II) showed 5.3% grass cover. Interestingly, all treatments that contained *glyphosate* plus a pre-emergence herbicide, including those in treatments 6, 7, & 9, *pendimethalin*, *prodiamine*, and *indaziflam* showed less percent grass cover than treatments 6, 7, & 9 at the last rating. A possibly explaination is antagonism between grass herbicide and broadleaf herbicide in treatment 6,7, & 9 resulting in less grass control or simply the treatments that contained *glyphosate* plus similar pre-emergence herbicides better controlled grass species.

Among treatments with similar preemergence herbicides but with different broad spectrum residual herbicides plus *glyphosate* there were distinct differences in total percent vegetative cover. Pendulum Aquacap at 128 oz/ac + Oust Extra at 2 oz/ac + RoundUp Pro Concentrate at 64 oz/ac resulted in 1.8% total vegetative cover by 181 DAT while Pendulum Aquacap at 128 oz/ac + Hyvar at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 10.1% total vegetative cover. Whereas a similar mix containing Prodiamine 65 WDG at 32 oz/ac + Hyvar XL at 64 oz/ac + RoundUp Pro Concentrate at 64 oz/ac resulted in 5.9% total vegetative cover by the last rating.

Several products contained *flumioxazin* as the preemergence component including Piper EZ a combination product (*flumioxazin* + *pyroxasulfone*) and Promenade WDG. Piper EZ at 20 oz/ac contained 3.35 oz active ingredient *flumioxazin* and Promenade WDG at 12 oz/ac contained 6.12 oz active ingredient *flumioxazin*. By the end of the experiment, 168 DAT, Method 240SL at 12 oz/ac + Piper EZ at 20 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 6.6% total vegetative cover while Method 240SL at 12 oz/ac + Promenade WDG at 12 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac resulted in 1.5% total vegetative cover. Additionally, Promenade WDG at 12 oz/ac + Oust Extra at 4 oz/ac + RoundUp Pro Concentrate at 64 oz/ac showed 0.7% total vegetative cover by the last rating.

The guiderail site selected for this experiment was not treated the previous year. This site provided an opportunity to evaluate the effectiveness of alternative bareground mixes to areas that may not receive yearly bareground applications and therefore have established weed populations. Based on the results, all herbicide treatments except Echelon 4 SC at 5 oz/ac + Oust Extra at 4 oz/ac + Fusillade II at 24 oz/ac could be used as alternative bareground mixe in rotation from a standard PennDOT mix. A common standard PennDOT mix is Method 240SL at 12 oz/ac + Esplanade 200 SC at 5 oz/ac + Arsenal Powerline at 8 oz/ac + RoundUp Pro Concentrate at 64 oz/ac, which was evaluated in this experiment as treatment 2. If considering rotation of herbicides with different sites of action for each component a baseline or standard mix needs to be established and then herbicide rotations can be determined.

Table 4 outlines each bareground mix describing the common name of herbicides, site of action, and how each product is used in the mix. For example, Pendulum Aquacap, *pendimethalin* is a pre-emergence herbicide and *SOA 3*. The Weed Science Society of America WSSA groups herbicides based on site of action of each herbicide. This can be used to easily rotate herbicides based on SOA as a tool to manage herbicide resistance.

CONCLUSIONS

No herbicide treatments provided complete season-long bareground weed control by the end of the experiment. If 5% total vegetative cover is an acceptable threshold by the end of the growing season, several herbicide mixes evaluated may be considered as options to use in a bareground program. This experiment demonstrates the effectiveness of alternative bareground mixes used within a program that rotates SOA of pre-emergence, broad-spectrum residual herbicides as well as alternative mixes without *glyphosate* as the nonselective post emergence herbicide to manage herbicide resistance. Future work should continue to evaluate combinations and rates that can used to replace standard pre-emergence, broad-spectrum residual, and post emergence products in bareground mixes. Additionally, future research should evaluate a site over several years with an intentional SOA rotation based on this and previous research. Data collection over several years would build historical data and confidence with future recommendations.

MANAGEMENT IMPLICATIONS

A goal of the project is to develop bareground mixes that can be used to rotate the SOA of all of the herbicide components. It is important to remember that a bareground mix is what is used in a particular year, while a bareground program involves bareground mixes used over several years in sequence that rotates SOA of pre-emergence, broad-spectrum residual, and post emergence herbicides. Based on this experiment and previous work, *prodiamine*, *pendimethalin or flumioxazin* are pre-emergence herbicides that can be used as a rotation for *indaziflam*. Additionally, *bromacil* a broad-spectrum residual that can be used in place of *imazapyr* or *sulfometuron-methyl* in certain situations. Be careful of the use rate of *bromacil* due to its tendency to move offsite. We recommend 128 oz/ac of Hyvar XL at this point, however Hyvar XL at 64 oz/ac will continue to be evaluated for efficacy. This experiment combined with the past experiments (AR 2020-2023) on herbicide mix SOA rotation recommendations for *glyphosate* can be helpful in choosing alternative bareground mixes. Most bareground mixes and some specific components (e.g., Method 240SL[22], TerraVue[23], Arsenal Powerline[24] and Hyvar XL[25] labels) have the potential to do unintended damage to non-target plant root systems that extend into treated areas and caution in choice and use is advised. Products containing *sulfometuron-methyl* such as Oust XP or Oust Extra and *bromacil,* Hyvar XL, also have the potential of moving offsite after application. A careful evaluation of the site must be made to determine if soil texture, slope, and drainage patterns may cause offsite movement by wind or

[22] Bayer CropScience LP. Method 240SL label. http://www.cdms.net/ldat/ldCFU019.pdf
[23] Corteva Agriscience. Dow Agrosciences LLC TerraVue label. http://www.cdms.net/ldat/ld2IB008.pdf
[24] BASF Corporation. Arsenal Powerline label. http://www.cdms.net/ldat/ld86K002.pdf
[25] Bayer CropScience LP. Hyvar X-L label. https://www.cdms.net/ldat/ldCFT000.pdf

water erosion[26]. The use of these herbicide combinations may be considered for use on interstate or limited access routes with wide right of ways to minimize potential offsite damage. In developing a bareground program the following would rotate herbicide SOA for each component. Over a 3-year period, the mixes may include: 1) Method 240SL + Esplanade 200 SC + Arsenal Powerline + RoundUp Pro 2) Pendulum Aquacap + Hyvar XL + RoundUp Pro 3) Method 240SL + Esplanade 200 SC + Arsenal Powerline + Fusilade II. This is one possible scenario and other herbicides can be used in place of one's listed with similar SOA. For example, TerraVue could be used instead of Method 240SL, Prodiamine 65 WDG can be used instead of Pendulum Aquacap and Oust XP can be used instead of Arsenal. As mentioned above some herbicides have potential to move off site so the roadside specialist needs to exercise care to be sure bareground treatments are not creating additional bareground than necessary. This issue may be the key focus once herbicide SOA rotations are developed.

[26] Bayer CropScience LP. Oust Extra label. https://www.cdms.net/ldat/ldCJ3001.pdf

Table 1. Effectiveness of treatments based on percent total vegetative cover at 0, 29, 64, 92, 155, & 181 days after treatment (DAT). The site was visually rated on April 25, May 24, June 28, July 26, September 27, & October 23, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% Total Cover 4/25/23 0 DAT	% Total Cover 5/24/23 29 DAT	% Total Cover 6/28/23 64 DAT	% Total Cover 7/26/23 92 DAT	% Total Cover 9/27/23 155 DAT	% Total Cover 10/23/23 181 DAT
1	Untreated	--	2.5	12 b	14.4	17.8	26.4 b	26.4 b
2	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	12 5 8 64	1	1.8 ab	4.1	7.2	7.8 ab	7.9 ab
3	Echelon 4 SC Oust Extra Fusilade II	5 4 24	2.6	3.4 ab	8.1	13.1	19.2 ab	19.2 ab
4	Pendulum Aquacap Oust Extra RoundUp Pro Concentrate	128 2 64	2.5	2 ab	2.7	2	1.8 ab	1.8 a
5	Pendulum Aquacap Hyvar XL RoundUp Pro Concentrate	128 64 64	2.1	9.3 ab	12.5	12.4	10.1 ab	10.1 ab
6	Plateau Esplanade Sure Oust Extra Segment II	12 5 4 32	1.4	2.3 ab	5.1	5.7	6.9 ab	6.9 ab
7	TerraVue Pendulum Aquacap Oust Extra Fusilade II	5 128 2 24	2.6	0.9 ab	2.9	6.6	8.3 ab	8.3 ab
8	Prodiamine 65 WDG Hyvar XL RoundUp Pro Concentrate	32 64 64	2.4	6.3 ab	8.1	8.3	5.8 ab	5.9 ab
9	TerraVue Prodiamine 65 WDG Arsenal Powerline Segment II	5 32 8 32	1.4	4.2 ab	5.8	6.9	6.6 ab	6.6 ab
10 Dual App 1st App April	Method 240SL Esplanade 200 SC Oust Extra Plateau RoundUp Pro Concentrate	7 3 2 6 48	1	0.25 a	0.9	0.3	1.8 ab	1.8 a
10 Dual App 2nd App July	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	9 3 6 48						
			n.s.		n.s.	n.s.		

Table 1a. Effectiveness of treatments based on percent total vegetative cover at 0, 16, 51, 79, 143, & 168 days after treatment (DAT). The site was visually rated on May 8, May 24, June 28, July 26, September 27, & October 23, 2023. Treatments were applied May 8, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% Total Cover 5/8/23 0 DAT	% Total Cover 5/24/23 16 DAT	% Total Cover 6/28/23 51 DAT	% Total Cover 7/26/23 79 DAT	% Total Cover 9/27/23 143 DAT	% Total Cover 10/23/23 168 DAT
1	Untreated	--	2.5	12 b	14.4	17.8	26.4 b	26.4 b
11	Method 240SL Piper EZ Arsenal Powerline RoundUp Pro Concentrate	12 20 8 64	1.5	0.5 ab	1.6	7.1	6.6 ab	6.6 ab
12	Method 240SL Promenade WDG Arsenal Powerline RoundUp Pro Concentrate	12 12 8 64	1.2	0.1 a	0.5	1.3	1.4 a	1.5 a
13	Promenade WDG Oust Extra RoundUp Pro Concentrate	12 4 64	2.4	1.6 ab	1.9	0.9	0.7 a	0.7 a
			n.s.		n.s.	n.s.		

Table 2. Effectiveness of treatments based on percent grass cover at 64, 92, 155 & 181 days after treatment (DAT). The site was visually rated on June 28, July 26, September 27, & October 23, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% Grass Cover 6/28/23 64 DAT	% Grass Cover 7/26/23 92 DAT	% Grass Cover 9/27/23 155 DAT	% Grass Cover 10/23/23 181 DAT
1	Untreated	--	6.9	9.9	15.3	17.8
2	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	12 5 8 64	0.6	1.7	1.9	1.9
3	Echelon 4 SC Oust Extra Fusilade II	5 4 24	7.2	12.7	18.4	18.4
4	Pendulum Aquacap Oust Extra RoundUp Pro Concentrate	128 2 64	0.2	0.9	1.4	1.4
5	Pendulum Aquacap Hyvar XL RoundUp Pro Concentrate	128 64 64	0.1	0.2	0.3	0.3
6	Plateau Esplanade Sure Oust Extra Segment II	12 5 4 32	3.1	5.1	5.3	5.3
7	TerraVue Pendulum Aquacap Oust Extra Fusilade II	5 128 2 24	1.2	3.4	5.1	5.1
8	Prodiamine 65 WDG Hyvar XL RoundUp Pro Concentrate	32 64 64	0.2	0.6	0.9	0.9
9	TerraVue Prodiamine 65 WDG Arsenal Powerline Segment II	5 32 8 32	0.3	0.4	2.7	2.7
10 Dual App 1st App April	Method 240SL Esplanade 200 SC Oust Extra Plateau RoundUp Pro Concentrate	7 3 2 6 48	0.1	0	0	0
10 Dual App 2nd App July	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	9 3 6 48				
			n.s.	n.s.	n.s.	n.s.

Table 2a. Effectiveness of treatments based on percent grass cover at 51, 79, 143, & 168 days after treatment (DAT). The site was visually rated on June 28, July 26, September 27, & October 23, 2023. Treatments were applied May 8, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% Grass Cover 6/28/23 51 DAT	% Grass Cover 7/26/23 79 DAT	% Grass Cover 9/27/23 143 DAT	% Grass Cover 10/23/23 168 DAT
1	Untreated	--	6.9	9.9	15.3	17.8
11	Method 240SL Piper EZ Arsenal Powerline RoundUp Pro Concentrate	12 20 8 64	0.1	0.3	0.6	0.6
12	Method 240SL Promenade WDG Arsenal Powerline RoundUp Pro Concentrate	12 12 8 64	0.5	1.3	1.4	1.4
13	Promenade WDG Oust Extra RoundUp Pro Concentrate	12 4 64	0	0.1	0.1	0.1
			n.s.	n.s.	n.s.	n.s.

Table 3. Effectiveness of treatments based on percent total broadleaf weed (BLW) cover at 64, 92, 155 & 181 days after treatment (DAT). The site was visually rated on June 28, July 26, September 27, & October 23, 2023. Treatments were applied April 25, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% BLW Cover 6/28/23 64 DAT	% BLW Cover 7/26/23 92 DAT	% BLW Cover 9/27/23 155 DAT	% BLW Cover 10/23/23 181 DAT
1	Untreated	--	7.5	7.9	11.1	8.7
2	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	12 5 8 64	3.5	5.5	6	6
3	Echelon 4 SC Oust Extra Fusilade II	5 4 24	0.9	0.4	0.8	0.8
4	Pendulum Aquacap Oust Extra RoundUp Pro Concentrate	128 2 64	2.5	1.1	0.3	0.4
5	Pendulum Aquacap Hyvar XL RoundUp Pro Concentrate	128 64 64	12.4	12.2	9.8	9.8
6	Plateau Esplanade Sure Oust Extra Segment II	12 5 4 32	2	0.6	1.4	1.4
7	TerraVue Pendulum Aquacap Oust Extra Fusilade II	5 128 2 24	1.7	3.2	3.2	3.2
8	Prodiamine 65 WDG Hyvar XL RoundUp Pro Concentrate	32 64 64	7.9	7.7	5	5
9	TerraVue Prodiamine 65 WDG Arsenal Powerline Segment II	5 32 8 32	5.5	6.5	3.8	3.8
10 Dual App 1st App April	Method 240SL Esplanade 200 SC Oust Extra Plateau RoundUp Pro Concentrate	7 3 2 6 48	0.8	0.3	1.8	1.8
10 Dual App 2nd App July	Method 240SL Esplanade 200 SC Arsenal Powerline RoundUp Pro Concentrate	9 3 6 48				
			n.s.	n.s.	n.s.	n.s.

Table 3a. Effectiveness of treatments based on percent broadleaf weed (BLW) cover at 51, 79, 143, & 168 days after treatment (DAT). The site was visually rated on June 28, July 26, September 27, & October 23, 2023. Treatments were applied May 8, 2023. A non-ionic surfactant was added to all treatments at 0.25% v/v. Each value is the mean of four replications. Column means followed by the same letter are not significantly different.

Treatment	Product	Rate oz/acre	% BLW Cover 6/28/23 51 DAT	% BLW Cover 7/26/23 79 DAT	% BLW Cover 9/27/23 143 DAT	% BLW Cover 10/23/23 168 DAT
1	Untreated	--	7.5	7.9	11.1	8.7
11	Method 240SL Piper EZ Arsenal Powerline RoundUp Pro Concentrate	12 20 8 64	1.5	6.8	6.1	6.1
12	Method 240SL Promenade WDG Arsenal Powerline RoundUp Pro Concentrate	12 12 8 64	0	0	0.1	0.1
13	Promenade WDG Oust Extra RoundUp Pro Concentrate	12 4 64	1.9	0.8	0.5	0.5
			n.s.	n.s.	n.s.	n.s.

Table 4. Bareground herbicide mixes listed by product name, rate, common name, Weed Science Society of America (WSSA) site of action (SOA) group, and component within a bareground mix: pre-emergence herbicide (pre); post emergence (post) (post + residual) (post grass); and broad-spectrum residual (bsr).

Treatment	Product	Rate oz/acre	Common Name	WSSA SOA	
1	untreated	--			
2	Method 240SL	12	*aminocyclopyrachlor*	4	post+residual
	Esplanade 200 SC	5	*indaziflam*	29	pre
	Arsenal Powerline	8	*imazapyr*	2	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
3	Echelon 4 SC	5	*sulfentrazone+prodiamine*	14+3	pre
	Oust Extra	4	*sulfometuron+metsulfuron*	2+2	bsr
	Fusilade II	24	*fluazifop-P-butyl*	1	post grass
4	Pendulum Aquacap	128	*pendimethalin*	3	pre
	Oust Extra	2	*sulfometuron+metsulfuron*	2+2	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
5	Pendulum Aquacap	128	*pendimethalin*	3	pre
	Hyvar XL	64	*bromacil*	5	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
6	Plateau	12	*imazapic*	2	pre+post
	Esplanade Sure	5	*indaziflam+rimsulfuron*	29	pre+post
	Oust Extra	4	*sulfometuron+metsulfuron*	2+2	bsr
	Segment II	32	*sethoxydim*	1	post grass
7	TerraVue	5	*aminopyralid+florpyrauxifen*	4+4	post+residual
	Pendulum Aquacap	128	*pendimethalin*	3	pre
	Oust Extra	2	*sulfometuron+metsulfuron*	2+2	bsr
	Fusilade II	24	*fluazifop-P-butyl*	1	post grass
8	Prodiamine 65 WDG	32	*prodiamine*	3	pre
	Hyvar XL	64	*bromacil*	5	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
9	TerraVue	5	*aminopyralid+florpyrauxifen*	4+4	post+residual
	Prodiamine 65 WDG	32	*prodiamine*	3	pre
	Arsenal Powerline	8	*imazapyr*	2	bsr
	Segment II	32	*sethoxydim*	1	post grass

Table 4 (continued). Bareground herbicide mixes listed by product name, rate, common name, Weed Science Society of America (WSSA) site of action (SOA) group, and component within a bareground mix: pre-emergence herbicide (pre); post emergence (post) (post + residual) (post grass); and broad-spectrum residual (bsr).

Treatment	Product	Rate oz/acre	Common Name	WSSA SOA	
10	Method 240SL	7	*aminocyclopyrachlor*	4	post+residual
Dual App	Esplanade 200 SC	3	*indaziflam*	29	pre
1st App	Oust Extra	2	*sulfometuron+metsulfuron*	2+2	bsr
April	Plateau	6	*imazapic*	2	pre+post
	RoundUp Pro Concentrate	48	*glyphosate*	9	post
10	Method 240SL	9	*aminocyclopyrachlor*	4	post+residual
Dual App	Esplanade 200 SC	3	*indaziflam*	29	pre
2nd App	Arsenal Powerline	6	*imazapyr*	2	bsr
July	RoundUp Pro Concentrate	48	*glyphosate*	9	post
11	Method 240SL	12	*aminocyclopyrachlor*	4	post+residual
	Piper EZ	20	*flumioxazin+pyroxasulfone*	14+15	pre+post
	Arsenal Powerline	8	*imazapyr*	2	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
12	Method 240SL	12	*aminocyclopyrachlor*	4	post+residual
	Promenade WDG	12	*flumioxazin*	14	pre
	Arsenal Powerline	8	*imazapyr*	2	bsr
	RoundUp Pro Concentrate	64	*glyphosate*	9	post
13	Promenade WDG	12	*flumioxazin*	14	pre
	Oust Extra	4	*sulfometuron+metsulfuron*	2+2	bsr+post
	RoundUp Pro Concentrate	64	*glyphosate*	9	post

APPENDIX

Appendix Table 1. Canopy area of each plant. The experiment evaluated 8 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant	Treatment	Radius (in.)	Height (in.)	Area ($ft.^2$)	Dosage (ml.)
1	4	42	108	274.89	836
2	1	24	60	87.96	268
3	8	38	80	195.65	595
4	2	49	108	335.67	1021
5	5	22	48	67.20	204
6	7	32	102	187.10	569
7	6	18	50	53.41	162
8	3	46	94	281.00	855
9	4	13	45	32.90	100
10	1	12	45	29.85	91
11	5	32	109	196.87	599
12	2	11	82	44.64	136
13	8	13	55	38.57	117
14	7	22	70	88.31	269
15	6	32	108	195.48	594
16	3	30	96	164.93	502
17	7	33	102	194.39	591
18	3	45	109	302.38	920
19	4	32	60	128.46	391
20	5	28	60	107.51	327
21	8	36	102	216.77	659
22	1	16	60	53.06	161
23	2	16	89	73.30	223
24	6	36	128	257.61	783
25	2	24	60	87.96	268
26	8	36	89	196.35	597
27	7	26	80	120.25	366
28	5	44	112	299.50	911
29	4	16	51	46.77	142
30	6	11	45	26.88	82
31	1	20	43	54.98	167
32	3	12	60	37.70	115
33	8	24	73	101.58	309
34	2	17	50	49.70	151
35	1	13	47	34.03	104
36	5	17	62	58.60	178

Appendix Table 1 (continued). Canopy area of each plant. The experiment evaluated 8 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant	Treatment	Radius (in.)	Height (in.)	Area ($ft.^2$)	Dosage (ml.)
37	6	24	87	116.24	354
38	3	18	50	53.41	162
39	7	36	120	245.04	745
40	4	36	122	248.19	755
41	8	18	40	45.55	139
42	3	12	50	32.46	99
43	7	15	64	51.71	157
44	4	22	72	90.23	274
45	6	19	60	65.49	199
46	5	10	52	27.05	82
47	2	18	68	67.54	205
48	1	30	62	120.43	366
49	6	56	76	322.54	981
50	7	24	82	111.00	338
51	8	30	110	183.26	557
52	2	9	69	30.63	93
53	3	12	77	46.60	142
54	5	35	88	187.84	571
55	1	26	78	117.98	359
56	4	42	82	227.24	691
57	5	22	50	69.12	210
58	2	12	59	37.18	113
59	4	30	65	124.35	378
60	1	18	91	85.61	260
61	8	30	70	130.90	398
62	3	24	62	90.06	274
63	7	39	77	197.40	600
64	6	34	102	201.76	614
65	6	12	46	30.37	92
66	7	26	55	91.89	279
67	8	30	64	123.05	374
68	3	32	60	128.46	391
69	1	26	72	111.18	338
70	4	36	110	229.34	697
71	5	40	96	237.36	722
72	2	36	103	218.34	664

Appendix Table 1 (continued). Canopy area of each plant. The experiment evaluated 8 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant	Treatment	Radius (in.)	Height (in.)	Area ($ft.^2$)	Dosage (ml.)
73	5	30	70	130.90	398
74	8	40	92	230.38	701
75	1	40	94	233.87	711
76	6	48	106	322.54	981
77	4	24	73	101.58	309
78	7	32	53	118.68	361
79	3	55	107	388.77	1182
80	2	30	54	109.96	334

Appendix Table 2. Canopy area of each plant. The experiment evaluated 9 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant #	Treatment	Radius (in.)	Height (in.)	Area (ft. sq.)	Dosage (ml.)
1	2	23	72	95.34	290
2	6	16	48	44.68	136
3	9	10.5	42	24.05	73
4	1	6.5	40	13.19	40
5	3	10	42	22.69	69
6	4	18	50	53.41	162
7	7	9	49	22.78	69
8	8	20	64	73.30	223
9	5	15	56	46.47	141
10	8	12	40	27.23	83
11	1	21.5	62	78.33	238
12	3	14.5	55	43.97	134
13	9	5	26	6.76	21
14	4	5.5	25	7.32	22
15	7	22	70	88.31	269
16	6	21	50	65.06	198
17	2	15	46	39.92	121
18	5	7	31	11.61	35
19	7	14	50	39.10	119
20	9	5	22	5.89	18
21	3	10	25	15.27	46
22	6	14.5	51	41.44	126
23	4	13.5	48	36.23	110
24	2	7.5	42	16.20	49
25	1	14.5	45	37.64	114
26	8	7	35	12.83	39
27	5	15	40	36.00	109
28	3	11.5	40	25.84	79
29	8	12	37	25.66	78
30	9	7.5	29	11.94	36
31	6	16.5	42	42.12	128
32	7	12	42	28.27	86
33	5	15.5	47	42.27	129
34	1	19	55	61.35	187
35	4	15	52	43.85	133

Appendix Table 2 (continued). Canopy area of each plant. The experiment evaluated 9 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant #	Treatment	Radius (in.)	Height (in.)	Area (ft. sq.)	Dosage (ml.)
36	2	12	40	27.23	83
37	6	11.5	28	19.82	60
38	8	11.5	45	28.35	86
39	5	17	52	51.18	156
40	7	13	46	33.47	102
41	3	15	46	39.92	121
42	1	17	63	59.34	180
43	2	15.5	57	49.03	149
44	9	9	35	17.28	53
45	4	15	40	36.00	109
46	8	10	33	18.76	57
47	3	11	48	28.32	86
48	7	18	55	57.33	174
49	1	15	37	34.03	104
50	9	6	29	9.16	28
51	4	7	23	9.16	28
52	6	9.5	43	21.76	66
53	2	10	35	19.63	60
54	5	8	25	11.52	35
55	4	5	20	5.45	17
56	5	4.5	21	5.01	15
57	2	21.5	56	72.70	221
58	9	20	34	47.12	143
59	7	10	27	16.14	49
60	8	12.5	19	17.18	52
61	3	12	25	19.37	59
62	6	5	13	3.93	12
63	1	5	17	4.80	15
64	2	9	24	12.96	39
65	6	12.5	48	33.00	100
66	1	15.5	38	36.18	110
67	3	5	19	5.24	16
68	5	5.5	18	5.64	17
69	7	11.5	18	14.80	45
70	4	13	58	40.27	122

Appendix Table 2 (continued). Canopy area of each plant. The experiment evaluated 9 treatments. Each plant is an individual replication with 10 replications per treatment.

Plant #	Treatment	Radius (in.)	Height (in.)	Area (ft. sq.)	Dosage (ml.)
71	8	13	42	31.20	95
72	9	8.5	39	17.62	54
73	1	14	43	34.82	106
74	7	14	54	41.54	126
75	4	15	50	42.54	129
76	3	16	48	44.68	136
77	2	7.5	28	11.62	35
78	9	9	23	12.57	38
79	5	13.5	50	37.40	114
80	6	13.5	43	33.28	101
81	8	16.5	48	46.44	141
82	4	7	30	11.30	34
83	7	7	27	10.38	32
84	5	12	48	31.42	96
85	9	12	53	34.03	104
86	3	14	55	42.15	128
87	1	6	22	7.33	22
88	2	13	32	25.53	78
89	8	6.5	20	7.52	23
90	6	14	62	46.43	141