FINAL PERFORMANCE REPORT

Project Title	Debating Glyphosate, Understanding the Prominence of Herbicide Resistance and Residuals in Nurseries: Specialty Crops Matter!			
Recipient Organization Name:	Michigan Nursery & Landscape Association			
Period of Performance:	**Start Date:**	10/1/2020	**End Date:**	8/31/2022

PERFORMANCE NARRATIVE

PROJECT BACKGROUND

Provide enough information for the reader to understand the importance or context of the project. This section may draw from the background and justification contained in the approved project proposal.

Lack of knowledge of the susceptibility of specialty crops to agronomic crop drift is evident with frequency of drift complaints and succeeding court claims filed. It is imperative to increase the i knowledge of the injurious impacts of herbicide drift from neighboring farms and even their own Little is published regarding the correlation of the herbicides being applied to the ppm determina in analyte tests, and to the damage, symptomology and progression. Obtaining this information agronomic producers and nursery growers. Additionally, there are carry-over issues regarding nursery plants and in soils that many growers do not recognize. Growers need to know these c problems can continue to impact their nursery stock for years after the application. Because of a weed resistant to a variety of herbicides, more toxic sprayer tank mixes are being used in row-c research conducted in this grant is fundamental to the long-term viability of the nursery industry

ACTIVITIES PERFORMED

OBJECTIVES

Provide the approved project's objectives.

#	Objective	Completed?	
		Yes	No*
1	Objective 1 is evaluation of corn herbicide drift on a nursery deciduous tree species, herbaceous perennial, and conifer.	100%	
2	Objective 2 is evaluation of soybean herbicide drift on a nursery deciduous tree species, herbaceous perennial, and conifer.	100%	

3	Objective 3 evaluate glyphosate on five species of weeds applied post at two times in the year at various rates to determine susceptibility.	100%	
4	Objective 4, the pre-study and post study of residual herbicides in three plant type-nurseries and further exceeding the objective evaluations of soil resides.	100%	
5	Objective 5 evaluate the growth rates mortality of three plant types non-applied and applied.	100%	

**If no is selected for any of the listed objectives, you must expand upon this in the challenges and lessons learned sections.*

ACCOMPLISHMENTS

List your accomplishments for the project's period of performance, including the impact they had on the project's beneficiaries, and indicate how these accomplishments assist in the fulfillment of your project's objective(s), outcome(s), and/or indicator(s).

#	Accomplishment or Impact	Relevance to Objective, Outcome, and/or Indicator
1	Roundup Power Max® (EPA Reg. No. 524-549) [Glyphosate, N-(phosphonomethyl) glycine as a potassium salt 48.7% (4.5 pounds a.e. per gallon) (Monsanto Co., St. Louis, MO) was applied to three species of trees. Power Max is an EPSP synthase inhibitor WSSA group 9 mode of action (MoA), and chemical family Organophosphorus was applied to simulate drift at 0 and 6% of a 32 oz/ac or 1.13 lb a.e./acre application. Warrant® (EPA Reg. No. 524-591) Acetochlor 33.0%) (Monsanto Co., St. Louis, MO) Group 15 herbicide replaced Harness Max the herbicide originally specified in objective 1 of this grant. Harness Max was unavailable for study in 2021. All products were donated to Dr. Mathers, directly from the manufacturer, and were required to be on that companies' research list to study. Warrant is a Class 15- VLCFA inhibitor and chemical family chloroacetamide (the same family as one component of Harness). Warrant was applied at 6% to stimulate drift of a 1.25 qt/ac or 40 oz/ac spray event. Roundup Power Max® + Warrant® were applied in combination: Power Max 6% + Warrant 6%.	Completed objective 1 and 2. Objective 1 is evaluation of corn herbicide drift on a nursery deciduous tree species, herbaceous perennial, and two conifers. Objective 2 is evaluation of soybean herbicide drift on two species of deciduous shrubs. Objective 5 100% complete, effects of herbicides used on growth rates and mortality. Exceeding objective 1, 2 and 5 by conducting evaluations 13 month after application on deciduous trees to see long-term impact and carry-over effects on caliper and height. *Syringa* height was reduced, and symptoms were still evident after 13 months with the Power Max + Warrant application (Fig. 3C). *Malus* caliper was reduced, and visual symptoms were still present after 13 months. Since deciduous trees are sold by caliper and aesthetics the impact of Power Max + Warrant on *Malus* caliper and the impact on both species with increased visual symptoms are significant to the industry (Table 1). Additionally, there was a profound impact on lack of rooting in with the *Malus* combo treatment versus the control. This effect on rooting needs to be explored further in future projects. Exceeding objective 1, 2 and 5 by conducting evaluations 13 months after application on coniferous and broadleaf evergreen shrubs, to see long-term impact

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		and carry-over impact on height and caliper (Table 1). *Buxus* 'Green Velvet' had no long-term impacts on height, caliper, or visual symptoms (phytotoxicity) (Table 2) (Fig. 5). However, *Taxus X media* 'Densiformis' had reduced caliper, height and increased phytotoxicity as distinct chlorosis even after 13 MAT with the combination treatment. (Table 2 and Fig. 6). This was a very interesting finding as the effect on Taxus was not evident at 60 DAT but was at 13 MAT. Evaluations of height and caliper and GI one various species within the year of application, i.e., 60 DAT showed only marginal changes in growth measures, but symptomology related to herbicide injury for *Syringa* and *Malu*s. However, the evaluations at 13 months AT showed the carry-over action of the Glyphosate in the *Malus* (Table 1) and *Taxus* (Table 2) significantly reducing caliper (Malus), height and GI (*Taxus*). The rates of drift in these evaluations were low, only 6%; thus, illustrating the severity of the drift issue, a year after and that symptomology not seen in the year of application can be pronounced in the second year with a coniferous shrub (Fig. 6). Generally, the impact of decreasing plant growth (GI) was greater with both species (Weigela and Rhamnus) than on height [(GI) (Fig. 8), height (Fig. 7)]. *Wiegela* height was decreased by all treatments including 10% glyphosate (PM), 10% dicamba (Vanquish), 10% Acetochlor (Warrant), 10% PM + 10% Warrant versus the control (Fig. 7). Only Warrant 10% significantly reduced height less than PM and Vanquish but not PM + Warrant. (Fig. 7). *Rhamnus* height was not significantly reduce versus the control with the PM (Fig. 7). However, Warrant 10% and PM + Warrant significantly reduced height more than Vanquish (dicamba) or PM (Fig. 7). Only Warrant caused significantly less
	Further exceeding objectives 1, 2 and 5 additional experiments were conducted on two deciduous shrubs, i.e., *Weigela* and *Rhamnus frangula* 'Aspenfolia.'	

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		height versus the control (Fig. 7). *Weigela* GI was significantly reduced by the Vanquish, Warrant and Combo treatment versus the control but not by the glyphosate (Fig. 8). All other treatment were significantly less than the control but not significantly different from each other (Fig. 8). With *Rhamnus* the PM did not reduce the GI but all other treatments did (Fig. 8). The Warrant and the two-way combo reduced GI the most and significantly versus the Vanquish (Fig. 8). The lack or impact on Height and GI on Rhamnus and GI on Weigela by the glyphosate, and the increased impact on growth when the glyphosate is combined with another product has been seen before in trees, but this is the first report on deciduous shrubs.
2	Soil and foliar samples were collected over four replications post-spraying, per species of deciduous trees, to represent the individual treatments and rates for a total of 6 samples for *Magnolia* 'Yellow Bird', *Syringa reticulata* and *Malus* 'Robinson Dark Pink.' Samples were submitted to the South Dakota Agricultural Laboratory (SDAL) for analyte testing and results have been obtained at a cost of $1124.00 and to meet pre-study, Objective 4 at a cost of $8468.00 (Table 3). Contractual staff of Mathers Environmental Science Services (MESS) paid the $9592.00 worth of analyte testing (out-of-pocket) in this reporting period. Only ~$2158.00 was spent on post-survey testing as MESS business line of credit which it used to carry the debit of sampling before expired in early 2022. Leaving MESS with no ability to carry debit over $2,000 in sampling for this project. Additionally, there was a 5% overage of expenses from the original grant proposal that was required in salary and fringe and 8% for contractual and 0.04% for travel to complete all the reporting required.	Exceeded objectives 1, 2, and 4 which specify evaluation and analyses of foliar samples only; however, soil samples were also collected. (See Table 1 and 3). $9592.00 of the $17,600.00 originally budgeted for analyte testing had been in pre-study evaluations. For the post-study analyte tests, 9 samples were submitted looking for various chemicals (Table 3 – see post-study). The pre-study tests indicated there were significant issues with residues of herbicides impacting nursery stock and potentially weed resistance. Specific herbicides of concern were 2,4-D, atrazine, metolachlor, dicamba, MCPP and clopyralid (Table 3 pre-study). The post-survey samples contained no samples 2,4-D, atrazine, dicamba, MCPP and clopyralid but metolachlor was present in 6 of 9 samples submitted (Table 3 post-study) and soil residual glyphosate was detected at one deciduous tree site (Table 3 post-study, Fig. 10). The change was reflected in the survey results (Fig. 9). Both glyphosate and S-metolachlor are used in nursery production. 56% of participant showed an interest in detecting drift from their own staff versus 70% from their neighbor's (Fig. 9, questions 2 and 3,

#	Accomplishment or Impact	Relevance to Objective, Outcome, and/or Indicator
		respectively). Obviously, the project has had an impact on increasing awareness of drift from neighboring operations but awareness lags about their own applications. Further studies should focus on drift in nurseries from nursery applications.
3	Post survey of the impact of this SCBG regarding drift awareness was completed with over a 50% return rate from the audience.	The survey results (Fig. 9) are used indicate 100% of the outcome indicators are meet.
4	Two greenhouse experiments were conducted at the Horticulture Teaching and Research Center (HRTC), Michigan State University, East Lansing to complete objective 3. Objective 3 was changed due to lack of nurseries willing to participate in herbicide treatments that would dramatically damage and even kill their stock. Instead of glyphosate was applied on five species of weeds to see any possible glyphosate resistant issues with these species and how timing of application impacted response. This change to objective 3 was conducted as weed resistance was an issue and a topic specified in the title of the SCBG additional more knowledge of glyphosate use in nurseries was central to the grant. The five species chosen to evaluate were barnyardgrass (*Echinochloa cruss-galli*) (Table 4) (Fig. 9), large crabgrass (*Digitaria sanguinalis*) (Table 5), smooth pigweed (*Amaranthus hybridus*) (Table 6), field pennycress (*Thlaspi arvense*) (Table 7), and velvetleaf (*Abutilon theophrasti*) (Table 8). Barnyard grass was the species with the most resistance with nine SoA's (i.e., eight SoA's + Group 9). The glyphosate dose response used in this study was used to see what resistance problems exist in MI.	Increasing rates of glyphosate provided excellent (100%) control to the flowering mature stage of barnyardgrass. For all the doses, 100% control was achieved at 4 WAT that continued till 8 WAT. But in case of the young 4-5 leaves stage of barnyardgrass, rates of 2X and 4X were required to achieve satisfactory control after 4 WAT (Table 4). For unexplained reasons rates above 4X did not improve control (Table 4) (Fig. 10). These results may suggest some resistance to glyphosate could be assumed when applying to young plants but not to flowering plants. In case of large crabgrass (Table 5), the three rates of glyphosate have shown a very good control for both the stages. For the young (4-5 leaf stage), the weed control percentage varied from 97.5% to 100% at 8 WAT and at the mature flowering stage, all the rates provided a complete control at the 8 weeks (Table 5). For smooth pigweed, 0.5X rate provided 100% control during the young (4-5 leaf) stage (Table 6). But when applied during the flowering stage, 0.5X rate has provided only 67.5% control (Table 6), potentially indicating some level of resistance exists in smooth pigweed. Overall, as the rates of the glyphosate were increased, the smooth crabgrass was totally controlled at 8 weeks after treatment (Table 6). Field Pennycress was controlled at (2X and 4X) and showed better control during its young (4-5 leaf) stage in comparison to the

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		mature stage (flowering) (Table 7). The rates of 2X and 4X have provided a 100% control at stage 1 but they have provided 92% and 98% control respectively in the flowering stage, at 8 weeks (Table 7). The results may indicate herbicide resistance exist in field pennycress. In case of velvetleaf, most of the glyphosate rates worked well at the mature flowering stage (Table 8). But not in the young 4-5 leaf stage (Table 8). The 1X, 2X, 4X, 8X, and 16X rates have provided velvetleaf control ranging from 92.5% to 100% during the mature stage (Table 6). Whereas rates above 2X were required for control above 58.7% in the tiller stage. There was no further significant increase in control beyond 2X, indicating glyphosate resistance maybe becoming an issue.

CHALLENGES AND DEVELOPMENTS

Provide any challenges to the completion of your project or any positive developments outside of the project's original intent that you experienced during this project. Also, provide the corrective actions you took to address these issues. If you did not attain an approved objective, outcome(s), and/or indicator(s), provide an explanation in the Corrective Actions column.

#	Challenge or Development	Corrective Action or Project Change
1	The objectives 1, 2 and 5 of the grants, were to increase the industries' knowledge of drift susceptibility of major nursery crops and correlate that level of susceptibility to the herbicides being applied, the ppm determinations of those applications, with damage occurrence, symptomology and progression. To meet these objectives some of original grant methodology was changed. However, objectives 1, 2 and 5 were meet for deciduous trees, a herbaceous perennial, one broadleaf evergreen, two conifers and two deciduous shrubs (not required in the original grant. We were also able to evaluate the trees, broadleaf evergreen and one conifer into one year after treatment, exceeding original expectations.	Originally, three rates drift + control application per year were prescribed; however, this was changed to one rate in 2021 due to lack of available plant material. Additionally, 1 rate was chosen this first season of study on a larger array of species i.e., 7 vs the original 3 to reduce plant lose. This allowed for evaluations of the three tree species, one conifer and one broadleaf evergreen to continue to one year after for surviving plants. Many MI growers were unwilling to sacrifice the number of plants required to complete the original objectives. This has meant some protocols were delayed until more plants were acquired over the 2021 season from MI nurseries to study in the 2022 season at one site. In 2022, we found one grower willing to provide two species of deciduous shrubs for potential destruction. We then conducted the applications used for soybeans such as dicamba (Vanquish),

#	Challenge or Development	Corrective Action or Project Change
		Warrant, compared to glyphosate, a combo of glyphosate and Warrant, and a control in a fully replicated trial with subsampling within reps. Table 1 and 2 present the results of studies conducted to fulfill Objectives 1, 2 and 5.
2	Regarding, objective 4, the pre-study evaluations of three plant type-nurseries. The evaluations in the pre-study at five nursery sites indicated more herbicide residues and injuries than expected. More money was spent in pre-study residual sampling, to fulfill the study this outcome than originally planned. The increased expenditures; however, paid-off, indicating significantly higher background levels for a larger variety of herbicides than initial anticipated. Of five sites 3 showed background levels of herbicides from seven herbicides applied to agricultural crops (Table 3). Post-study sampling was limited as Mathers Environmental Science Services' (MESS) line of credit expired. This prevent carrying the debit of sampling in 2022. The point of objective 4 was to determine the scope of the issue, we felt increased testing was warranted to meet the objective. In addition, objective 5 required knowledge of whether residues were contributing to nursery injuries in conjunction with a normal nursery herbicide program; therefore, testing of some common nursery herbicides was conducted. Table 1 shows the levels of foliar residual found at the five MI Nursery sites, pre-study. We had no problems finding growers to participate in the pre-study analyte testing all sites wanted to keep the results anonymous.	Five nursery sites, with nine plant species/genera (Table 3) were sampled in 2021. The increased expenditures in the pre-study (2021) cut the amount of sampling in the study itself.. Even with the loss of MESS's line of credit; several sites, species, and chemicals were analyzed with the analyte testing MESS conducted. Also 5% of the salary and fringe, 0.4% of travel and 8% of contractual was required as overage to complete the objective and reporting requirements of the grant. These overages covered the money not spent in the other line item (i.e., analyte testing). The post-survey sampling indicated MI growers had more issues post-study with drift from their own application versus neighboring growers. Objective 4 was meet.. Results are present fulfilling objective 4 in Table 3.
3	Objective 3, had to be modified due to lack of cooperates willing to sacrifice their nursery stock. We believe this was due in part to the large demand for nursery stock after the pandemic.	Objective 3 was changed from applications to nursery stock of glyphosate to application on nursery weeds with glyphosate. This may have been a fortuitous change as it allowed examination of goals indicated in the title of the grant, such as evaluations of weed resistance;

#	Challenge or Development	Corrective Action or Project Change
		that were not specified in the objectives, until this change was made. Table 4-8 show the results of this change.

LESSONS LEARNED

Provide recommendations or advice that others may use to improve their performance in implementing similar projects.

It is very hard to predict what sales will be in the nursery industry two and three years in advance. A drift study is best suited to period of surplus nursery stock. Fortunately for the industry but unfortunate this grant, we hit a period of great demand. In other studies, not in MI, growers were very generous with tree materials; however, only in this MI study were we able to study impact on plants into the second year and on field produced deciduous shrubs.

CONTINUATION AND DISSEMINATION OF RESULTS (IF APPLICABLE)

Describe your plans for continuing the project (sustainability; capacity building) and/or disseminating the project results.

One more article will be written for the MNLA nursery magazine to summarize the results achieved in this grant. The grant results are of particularly interest with the pre-and post-study sampling. These results will be shared throughout the industry to show background levels of various herbicides in nursery.

BENEFICIARIES

Number of project beneficiaries: 10,000

OUTCOME(S) AND INDICTATOR(S)/SUB-INDICATOR(S)

Provide the results of the project outcome(s) and indicator(s) as approved in your application and project proposal. The results of the outcome(s) and indicator(s) will be used to evaluate the performance of the Program on a national level.

OUTCOME MEASURE(S)

Select the Outcome Measure(s) that were approved for your project.

- ☐ **Outcome 1**: Enhance the competitiveness of specialty crops through increased sales.
- ☐ **Outcome 2**: Enhance the competitiveness of specialty crops through increased consumption
- ☑ **Outcome 3**: Enhance the competitiveness of specialty crops through increased access
- ☑ **Outcome 4**: Enhance the competitiveness of specialty crops though greater capacity of sustainable practices of specialty crop production resulting in increased yield, reduced inputs, increased efficiency, increased economic return, and/or conservation of resources
- ☑ **Outcome 5**: Enhance the competitiveness of specialty crops through more sustainable, diverse, and resilient specialty crop systems
- ☐ **Outcome 6**: Enhance the competitiveness of specialty crops through increasing the number of viable technologies to improve food safety.
- ☐ **Outcome 7**: Enhance the competitiveness of specialty crops through increased understanding of the ecology of threats to food safety from microbial and chemical sources
- ☑ **Outcome 8**: Enhance the competitiveness of specialty crops through enhancing or improving the economy as a result of specialty crop development

OUTCOME INDICATOR(S)

Provide the indicator approved for your project and the related quantifiable result. If you have multiple outcomes and/or indicators, repeat this for each outcome/indicator (add more rows as needed).

#	Outcome and Indicator	Quantifiable Results
1	Outcome 3. Indicator 1a. – reach 300 consumers. Outcome 3, indicator 1a – reach 95 consumers	One articles about drift was written in the MNLA magazine reaching a circulation of >12,000. Two presentations were conducted to audiences in MI regarding drift. In the two talks a total of 75 people were reached. The talk at GLTE was subsequently posted on-line with another 20 people viewing. Total 95. A survey of the audience was conducted after the two talks to determine that number of new practices learned and and whether the presentations increased their knowledge.
2	Outcome 4, indicator 2	More than 25 individuals adopted best management practices and technologies resulting in increased yields and reduced stock losses due to drift. According to our survey responses to questions 11 and 12 and using weighted averages to calculate the median, people learned 3.6 new things about drift prevention and injury avoidance.
3	Outcome 4, indicator 3	Based on survey results the value of one thing learned regarding drift management would save participants $9260.87 in crop damages per yr., or $185.00 per ac. With 50 acres being the average nursery size.
4	Outcome 4, indicator 4	Therefore, the value of 3.6 new drift management tools gained was worth $27,782.61 per person reached in pesticide reduction costs.
4	Outcome 4, indicator 2d	Gardens Alive nursery alone has over 500 acres in production in MI; so, with their adoption of best management practices and four other sites for the additional 500 we exceeded this outcome and indicator of 1000 acres
	Outcome 5, indicator 2	75 people indicated adoptions of more than 6 new innovations..
5	Outcome 5, indicator 6	50 attendees to the GLTE event were the first responders trained in early detection and rapid response to drift. Over 82% of survey respondent were concerned about herbicide drift 70% about residues on their sites; whereas, before this program, they were unaware of the issues.

6	Outcome 5, indicator 8	1095 growers/producers gained knowledge of science-based tools.
7	Outcome 8, indicator 5	Survey respondents indicated they had learned practices that would increase their revenue by $9260.87, exceeding $5,000.00 indicated in the grant application.

DATA COLLECTION FOR OUTCOMES AND INDICATORS LISTED ABOVE:

Fig. 9. Indicates how the information was collected, i.e., via a survey at the end of the study. The questions asked are listed and the responses to the survey are indicated (yes response = blue bars) and (no response = dark red line).

DATA COLLECTION

Table 1. Three species of deciduous trees studied with three replicates with the chemicals applied at 6% to simulate drift, ratings were collected at initiation on 08/01/2021 or pre-sprays, 7 days after treatment 7 (DAT) 08/08/2021, 60 DAT 09/30/2021. Evaluations were continued at 10 months after treatment (10 MAT) (05/30/2022), and 13 MAT (09/05/2022) for the combination treatment versus the control (Bold Text). Foliar glyphosate and 2,4-D were detected in the Syringa and *Malus* controls, respectively.

Species	Treatment	Rate	Start Rating	Start Foliar Glyph. ppm	Start foliar MCPP. ppm	Start foliar 2,4-D ppm	Starting height (Ht) (in) 08/01/21	Starting caliper (Cal) (in) 08/01/21	Ending Ht. 60 DAT	Ending Cal. 60 DAT	13 MAT Ht. (in)	13 MAT Cal. (in)	Delta Cal. (start to end)	7 DAT Rating	7 DAT ppm Foliar ppm	60 DAT Rating	10 MAT Rating	13 MAT Rating
***Magnolia* 'Yellow Bird'**	Roundup Power Max® (32 oz/ac)	6%	2	0	0	0	68	0.63	68	0.63	.	.		6b		6b	,	.
	Warrant® (40 oz/ac)	6%	2	0	0	0	56	0.6	56	0.62	.	.		6b		6b	.	.
	PowerMax + Warrant	**6% +6%**	**2**	**0**	**0**	**0**	**48**	**0.6**	**48**	**0.6**	**dead**	**dead**		**6b**	**3.46 PM**	**8a**	**9.3**	**10**
	Control		**2**	**0**	**0**	**0**	**43**	**0.61**	**43**	**0.64**	**29**	**0.69**	**0.08**	**1a**	**-**	**5b**	**9.0**	**9.8**
	Sp. Av.		2.0			--											9.2	9.9
Syringa reticulata	Roundup Power Max® (32 oz/ac)	6%	1		0	0	92	0.89	92	0.93	.	.		6c		6a	.	.
	Warrant® (40 oz/ac)	6%	1		0	0	96	0.70	97.5	0.93	.	.		4b		4b	.	.
	PowerMax + Warrant	**6% +6%**	**1**		**0**	**0**	**92**	**0.73**	**94**	**0.77**	**101**	**0.88**	**0.10**	**4b**	**0.51 PM**	**4b**	**0**	**2**
	Control		**2**	**0.134**	**0**	**0**	**77**	**0.81**	**80**	**0.81**	**81**	**0.96**	**0.15**	**1a**	**--**	**1c**	**0**	**0**
	Tmt. Av.		1.0			--											0	1
***Malus* 'Robinson Dark Pink'**	Roundup Power Max® (32 oz/ac)	6%	1	0	0	0.0093	70	0.84	70	0.84				6a		6.0		
	Warrant® (40 oz/ac)	6%	1	0	0	0.0093	89	0.79	90	0.86				5a		6.0b		
	PowerMax + Warrant	**6% +6%**	**1**	**0**	**0**	**0.0093**	**84**	**0.82**	**79**	**0.77**	**86.5**	**0.83**	**0.01***	**6a**	**1.26 PM**	**8.5b**	**4**	**8**
	Control		**0**	**0**	**0.00638**	**0**	**82.5**	**0.81**	**78.5**	**0.81**	**81**	**0.89**	**0.08**	**0a**		**0c**	**0**	**3**
	Tmt. Av.		1.0														2	5.5

Note: Phytotoxicity rating is on a 0-10 scale, where 10 is dead and $\leq$ 3 is commercially acceptable. The herbicides studied are not registered for the species listed; however, all are all known contributors to drift events in nursery production from row crop production. 0 ppm = non-detected, Glyph. = glyphosate. PM= PowerMax, W= Warrant.

Table 2. Means for two conifers (*Taxus cuspidata* and *Taxus* X *media* 'Densiformis'), one herbaceous perennial species (*Echinacea purpurea)* and one broadleaf evergreen (*Buxus* 'Green Velvet') studied are listed with the chemicals applied and their respective rates to simulate drift, with phytotoxicity ratings collected at initiation on 08/01/2021 or pre-sprays, 7 days after treatment 7 (DAT) 08/08/2021 and 60 DAT (09/30/2021. Evaluations were continued for 10 months (MAT) (May 30 2022) and 13 MAT (09/04/2022) for *Buxus* and the *Taxus X media* with the combo treatment versus the control (Bold text). Foliar analytes were not collected, as no visible symptoms of the treatments were ever identified. Growth measures of height (Ht), two widths (w1 and w2) and growth index (GI) at the initiation of the study on 08/01/2021 and 60 DAT on 09/30/2021 and 13 MAT, along with the delta Ht and Delta GI are presented. Letters of significance and GI measures are described in notes at the bottom of the table.

Species	Treatment	Rate	Start Rating	Starting height (Ht) (in) 08/01/21	Starting GI $(in)^3$ 08/01/21	13 MAT HT	13 MAT GI	Delta HT	Delta GI	7 DAT Rating	60 DAT Rating	10 MAT Rating	13 MAT Rating
***Buxus* 'Green Velvet'**	Roundup Power Max® (32 oz/ac)	6%	0	13	1021.02					0	0		
	Warrant® (40 oz/ac)	6%	0	14	1454.16					0	0		
	PowerMax + Warrant	**6% +6%**	**0**	**14**	**1696.46**	**17.0**	**3139.89**	**2.3**	**1361.1a**	**0**	**0**	**0a**	**0a**
	Control		**0**	**8.6**	**1055.86**	**15.3**	**2252.39**	**2.3**	**1067.1a**	**0**	**0**	**1.5a**	**1.5 a**
Taxus cuspidata	Roundup Power Max® (32 oz/ac)	6%	0	12	1039.1			.	.	0	0		
	Warrant® (40 oz/ac)	6%	0	7	445.3			.	.	0	0		
	PowerMax + Warrant	6% +6%	0	7	727.1			.	.	0	0		
	Control		0	8.7	900.0			.	.	0	0		
Echinacea purpurea	Roundup Power Max® (32 oz/ac)	6%	0	17	3418.1			.	.	0	0		
	Warrant® (40 oz/ac)	6%	0	22	4754.80			.	.	0	0		
	PowerMax + Warrant	6% +6%	0	23	5852.8			.	.	0	0		
	Control		0	19	4420.0			.	.	0			
***Taxus* X *media* 'Densiformis'**	Roundup Power Max® (32 oz/ac)	6%	0	12	1472.6					0	0		
	Warrant® (40 oz/ac)	6%	0	12	1592.8					0	0		
	PowerMax + Warrant	**6% +6%**	**0**	**12.7**	**2209.3**	**14.7a**	**5089.1**	**2.0**	**2879.8a**	**0**	**0**	**4.3b**	**4.0b**
	Control		**0**	**15.3**	**2938.6**	**17.3b**	**8056.7**	**2.3**	**5118.1b**	**0**	**0**	**1.3a**	**0.0a**

Note for Table 2: Phytotoxicity is rated on a 0-10 scale, where 10 is dead and ≤ 3 is commercially acceptable. The herbicides listed are not registered for the species listed; however, all are all known contributors to drift events in nursery production from row crop production. 0 ppm = non-detected, Glyph. = glyphosate. PM= PowerMax, W= Warrant. LS means for rated scores at 7 and 60 DAT, 10 months AT and 13 MAT delta eight (Ht) and delta caliper (cal.); Means with the same letter are not significantly different from each other. Growth index (in^3) and was calculated as GI=Pi (Ht)(r2), where Ht. (in) was the starting or final height, respectively, r was half of the average of W1+W2 (two perpendicular measurements taken of plant crown diameter (in)) and Pi was "π". The GI provides a volume measure of the plant crown which helps with quality determinations not necessarily evident by heights and widths alone or by visual observations by rating.

Table 3. The table is divided into **A.** Pre-study foliar sampling at five different nurseries (scatter over the state) and nine species and **B.** Post-study foliar, and soil results. The nurseries in the pre-study were Lincoln Nursery (Grand Rapids, MI), Ray Wiegand's Nursery (Lenox, MI), Halton House and Farm (Olivet, MI), Walter's Gardens (Zeeland, MI) and Gardens Alive (West Olive, MI). The post-survey results were collected at two completely anonymous sites. The five sites in the pre-study wished to remain anonymous; therefore, we have randomized the location number and the species sampled to bear no correspondence to the order presented in the table. The two sites in the post study did not wish to be identified at all. South Dakota Ag Laboratories, Brookings, SD. conducted analyte testing. The species in the pre-study were *Euonymus alata*, *Acer rubrum*, *Quercus rubra*, *Hibiscus*, *Asclepias tuberosa*, *Acer saccharum*, *Geranium*, *Malus* sp., and *Quercus palustris*. In the post-study the species were *Hemerocallis*, and *Quercus rubra* and *Quercus alba*. Table 1 analytes are converted to ppm, in this table they are ppb. Post-study herbaceous species and two deciduous species were analyzed.

A. Pre-study

Location	Genus/ Species	2,4-D (ppb)	Atrazine (ppb)	Metolachlor (ppb)	Dicamba (ppb)	Dimethamid (ppb)	Clopyralid (ppb)	MCPP
1	1	7.43	47.7	61.6	ND	ND	ND	ND
2	2	8.56	<10	54.7	ND	ND	ND	ND
2	3	10.3	15.9	21	2.93	<5	ND	ND
3	4	ND	ND	ND	ND	ND	ND	ND
3	5	ND	ND	ND	ND	ND	ND	ND
4	6	ND	ND	ND	ND	ND	ND	ND
4	3	ND	ND	ND	ND	ND	ND	ND
5	7	ND	ND	ND	ND	12.4	ND	6.33
5	8	ND	29.4	16	ND	ND	9.2	ND
5	9	25.4	105	14.7	2.73	ND	ND	ND
Total		**4**	**5**	**5**	**2**	**2**	**1**	**1**

Post-study

Location	Genus/ Species	2,4-D (ppb)	Atrazine (ppb)	Metolachlor (ppb)	Dicamba (ppb)	Glyphosate	Glyphosate (soil)
6	11	ND	ND	45.8	ND	ND	.
6	11	ND	<16	76.0	ND	ND	.
6	3	ND	ND	124	ND	ND	.
6	3	ND	ND	13.9	ND	ND	.
6	11	ND	ND	9.09	ND	ND	.
7	3	ND	ND	35.6	ND	ND	.
7	3	ND	15.5	ND	ND	ND	.
8	10	ND	ND	ND	ND	ND	.
8	10	ND	ND	ND	ND	ND	246
Total		**0**	**2**	**6**	**0**	**0**	**1**

Tables 4-8: Two sets of plants were produced to achieve evaluations at two different growth stages. For both sets nursery containers of 1.5 quart were filled with suremix (peat: perlite) substrate and amended with Osmocote controlled release fertilizer [17-5-11 (8 to 9 months)] were subjected to 0.5 inches of irrigation for one day. Then after one day, twenty-five seeds of either barnyardgrass (*Echinochloa cruss-galli*), large crabgrass (*Digitaria sanguinalis*), smooth pigweed (*Amaranthus hybridus*), field pennycress (*Thlaspi arvense*), and velvetleaf (*Abutilon theophrasti*) were sown into each container. All containers were kept inside the greenhouse under daily irrigation of 0.5 inches via overhead sprinkler till the seeds germinated and the seedlings reached 4-5 leaves stage (young plants). After attainting 4-5 leaves stage, all plants were moved outside to treat with the different glyphosate doses. With the second set of plants seedlings were kept until reaching flowering stage (mature plants). After attainting flowering stage, all plants were moved outside to treat with the different glyphosate doses. The different glyphosate doses were applied to both sets to five different weed species (Table 4-8). All herbicides were applied in liquid formulation with a CO_2 backpack sprayer at 30 psi and 22 gallons/acre output rate. After the herbicides were applied to the weed species, they were brought back inside the greenhouse and maintained till 8 weeks after treatment (WAT). Data collection included visual estimation of weed control ratings at a scale ranging from 0 to 100% where 0 % meaning no control and 100% meaning complete death of the plant. Data were collected at 2, 4, 6, and 8 weeks after treatment (WAT).

Barnyardgrass:

Table 4. Weed control percentages of Barnyardgrass at different doses of glyphosate

Weed Species	Glyphosate dose	Weed control percentage (Visual estimation)			
		2 WAT*	4 WAT	6WAT	8WAT
Barnyard grass					
Stage 1 (4-5 leaves)	0 (Control)	0a**	0a	0a	0a
	0.125X	45bc	62.2c	72.5c	93.7d
	0.25X	23.7ab	51.2bc	72.5c	762c
	0.5X	52.5bc	77.5cd	91.2cd	93.7d
	1X***	35b	48.7bc	56.2bc	70c
	2X	67.5c	83.7cd	95d	100d
	4X	78.7d	88.7d	92.5cd	100d
	8X	38.7bc	42.5b	47.5b	56.2b
	16X	50bc	73.7cd	82.5cd	85c

	32X	63.7bc	88.7d	95d	100d
Barnyard grass					
Stage 2 (Flowering)	0 (Control)	0a	0a	0a	0a
	0.125X	25b	100b	100b	100b
	0.25X	56.2c	100b	100b	100b
	0.5X	6.2ab	100b	100b	100b
	1X	77.5cd	100b	100b	100b
	2X	90cd	100b	100b	100b
	4X	60cd	100b	100b	100b
	8X	92.5d	100b	100b	100b
	16X	82.5cd	100b	100b	100b
	32X	85cd	100b	100b	100b

*WAT represents Weeks after treatment

**Same letter within the column represents no statistical difference

***1X represents label rate of glyphosate

Large Crabgrass

Table 5. Weed control percentages of large crabgrass at different doses of glyphosate

Weed Species	Glyphosate dose	Weed control percentage (Visual estimation)			
		2 WAT*	4 WAT	6WAT	8WAT
Large crabgrass					
Stage 1 (4-5 leaves)	0 (Control)	0a**	0a	0a	0a
	1X***	40b	70b	90b	97.5b
	2X	87.5c	93.7c	100b	100b
	4X	90c	97.5c	100b	100b
Large crabgrass					

Stage 2 (Flowering)	0 (Control)	0a	0a	0a	0a
	1X	38.7b	100b	100b	100b
	2X	50c	100b	100b	100b
	4X	55c	100b	100b	100b

*WAT represents Weeks after treatment

**Same letter within the column represents no statistical difference

***1X represents label rate of glyphosate

Smooth pigweed:

Table 6. Weed control percentages of Smooth pigweed at different doses of glyphosate

Weed Species	Glyphosate dose	Weed control percentage (Visual estimation)			
		2 WAT*	4 WAT	6WAT	8WAT
Smooth pigweed					
Stage 1 (4-5 leaves)	0 (Control)	0a**	0a	0a	0a
	0.25X	95c	96.2c	96.2c	96.2c
	0.5X	93.7c	100c	100c	100c
	1X***	78.7b	86.2b	86.2b	87.5b
	2X	98.7c	100c	100c	100c
	4X	98.7c	100c	100c	100c
	8X	98.7c	100c	100c	100c
	16X	98.7c	100c	100c	100c
	32X	96.2c	100c	100c	100c
Smooth pigweed					
Stage 2 (Flowering)	0 (Control)	0a	0a	0a	0a
	0.25X	22.5b	77.5c	82.5c	92.5c

0.5X	16.2ab	45b	57.5b	67.5b
1X	53.7c	925d	97.5d	100c
2X	22.5b	87.5c	96.2d	98.7c
4X	90d	100d	100d	100c
8X	90d	100d	100d	100c
16X	90d	100d	100d	100c
32X	92.5d	100d	100d	100c

*WAT represents Weeks after treatment

**Same letter within the column represents no statistical difference

***1X represents label rate of glyphosate

Field pennycress

Table 7. Weed control percentages of Field pennycress at different doses of glyphosate

Weed Species	Glyphosate dose	Weed control percentage (Visual estimation)			
		2 WAT*	4 WAT	6WAT	8WAT
Field pennycress					
Stage 1 (4-5 leaves)	0 (Control)	0a**	0a	0a	0a
	1X***	12.5b	10b	11.2b	15b
	2X	57.5c	92.5c	97.5c	100c
	4X	77.5d	97.5c	100c	100c
Field pennycress					
Stage 2 (Flowering)	0 (Control)	0a	0a	0a	0a
	1X	22.5b	60b	76.2b	86b

	2X	21.2b	80c	90c	92.5b
_	4X	22.5b	95c	975c	98.7b
*WAT represents Weeks after treatment					
**Same letter within the column represents no statistical difference					
***1X represents label rate of glyphosate					

Velvetleaf:

Table 8. Weed control percentages of Velvetleaf at different doses of glyphosate

Weed Species	Glyphosate dose	Weed control percentage (Visual estimation)			
		2 WAT*	4 WAT	6WAT	8WAT
Velvetleaf					
Stage 1 (4-5 leaves)	0 (Control)	0a**	0a	0a	0a
	0.5X	68.7c	73.7c	75c	95c
	1X***	15b	35b	32.5b	58.7b
	2X	87.5d	92.5d	92.5d	92.5c
	4X	77.5d	100d	100d	100c
	8X	77.2d	100d	100d	100c
	16X	88.7d	98.7d	100d	100c
Velvetleaf					
Stage 2 (Flowering)	0 (Control)	0a	0a	0a	0a
	0.5X	26.2b	50b	53.7b	58.7b
	1X	60c	86.c	90c	92.5c
	2X	60c	90c	90c	92.5c
	4X	66.2c	98.7c	100c	100c
	8X	56.2c	91.2c	95c	95c
	16X	88.7d	98.7c	100c	100c

*WAT represents Weeks after treatment

**Same letter within the column represents no statistical difference

***1X represents label rate of glyphosate

Fig. 1. *Malus* sp., June 14, 2021, showing clustering of growth along the stems. Analyte testing found positive levels atrazine, metolachlor. New leaves are rolled and in various stages of chlorosis. This malus tree was one of the plants sampled pre-study and sent to South Dakota Ag. Lab for testing. This nursery is surround by agricultural fields. Picture by: H. Mathers.

Fig. 2. *Quercus rubra*., June 14, 2021, showing clustering of growth, areas of blank wood and loss of apical dominance. Analyte testing found positive levels 2,4-D, atrazine, metolachlor and dicamba. New leaves are malformed with areas of chlorosis and necrosis. This oak tree was one of the plants sampled pre-study and sent to South Dakota Ag. Lab for testing. This nursery site has agricultural fields on three sides. Picture by: Dr. H. Mathers.

Fig. 3. A. and B. A. (Left) *Malus* 'Robinson Dark Pink', 7DAT August 8, 2021, showing injury to the terminal including necrosis and loss of turgor. Analyte testing found positive levels glyphosate and 2,4-D. This tree is one of the glyphosate + Warrant treated replicates shown in Table 2. No residue of acetochlor was detected. **B. (Below)** The same tree 60DAT showing complete pre-mature defoliation on the main stem. Pictures by: Dr. H. Mathers.

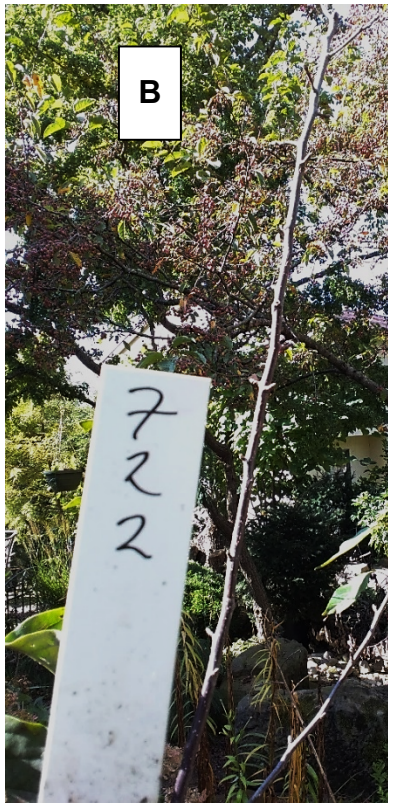


Fig 4. and B. A (Left) *Magnolia* 'Yellow Bird', 60 DAT Sept. 30, 2021. On the left is one of the replicates treated with glyphosate and acetochlor, showing chlorosis and necrosis of leaves and defoliation. On the right is the (cohort) control tree showing no injury. Analyte testing on the left (treated tree) found positive levels glyphosate, whereas the control tree showed no glyphosate residue (Table 2). B. (Below) *Syringa reticulata* treated with glyphosate and acetochlor 60 DAT (623). No residue of acetochlor was detected in *Magnolia* or *Syringa* treated trees, but glyphosate was found in both. The *Syringa* injury is less pronounced showing only as leaf curling, rolling and some deformation. However, in photo C (below). We see the visual impact still occurring 13 MAT on the *Syringa* and in Height reduction (Table 1). Photos by: H. Mathers

Fig. 5. *Buxus* at 60 DAT three reps of the controls are on the left of the photos and three replicates of the treated plants are on the right as shown in Table 2 no significant differences in growth or symptoms of injury were evident. Picture by: Dr. H. Mathers.

Fig. 6. *Taxus X media* at 13 MAT three reps of the plants were treated (right in Photo) with glyphosate (PowerMaxx) at 6% + Warrant (acetholor) at 6%, shown is replicate one. Shown on the left of the photo is replicate 2 of the untreated plants (control). Like the Buxus in Fig, 5 (above) there was no effect of the treatment at 60 DAT on height, GI or visible injury; however, after over a year since application the effects on the treated plants were significant in reducing height and growth index and increasing visible injury. In Table 2 we can see the significant differences in growth and symptoms at 13 MAT. Picture by: Dr. H. Mathers

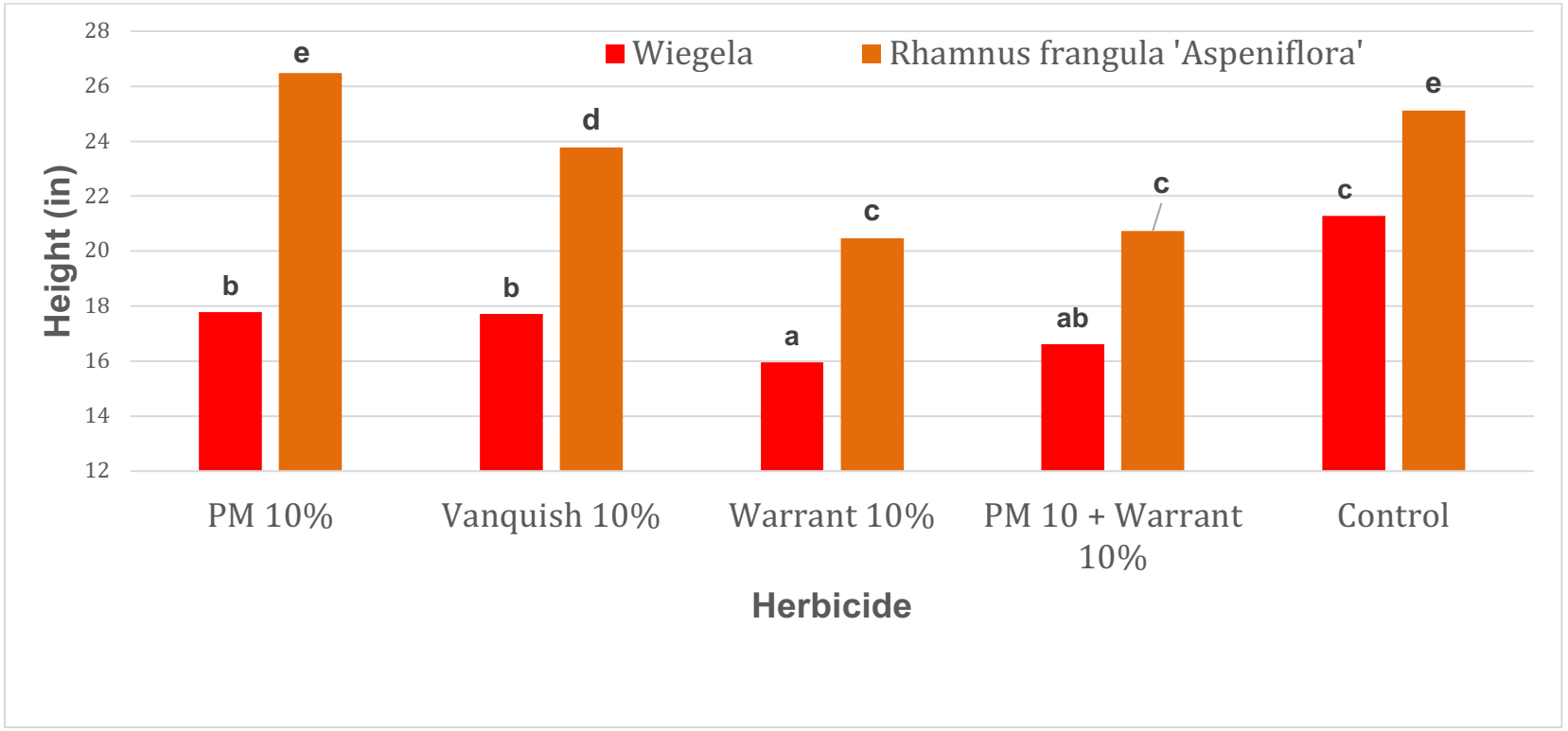
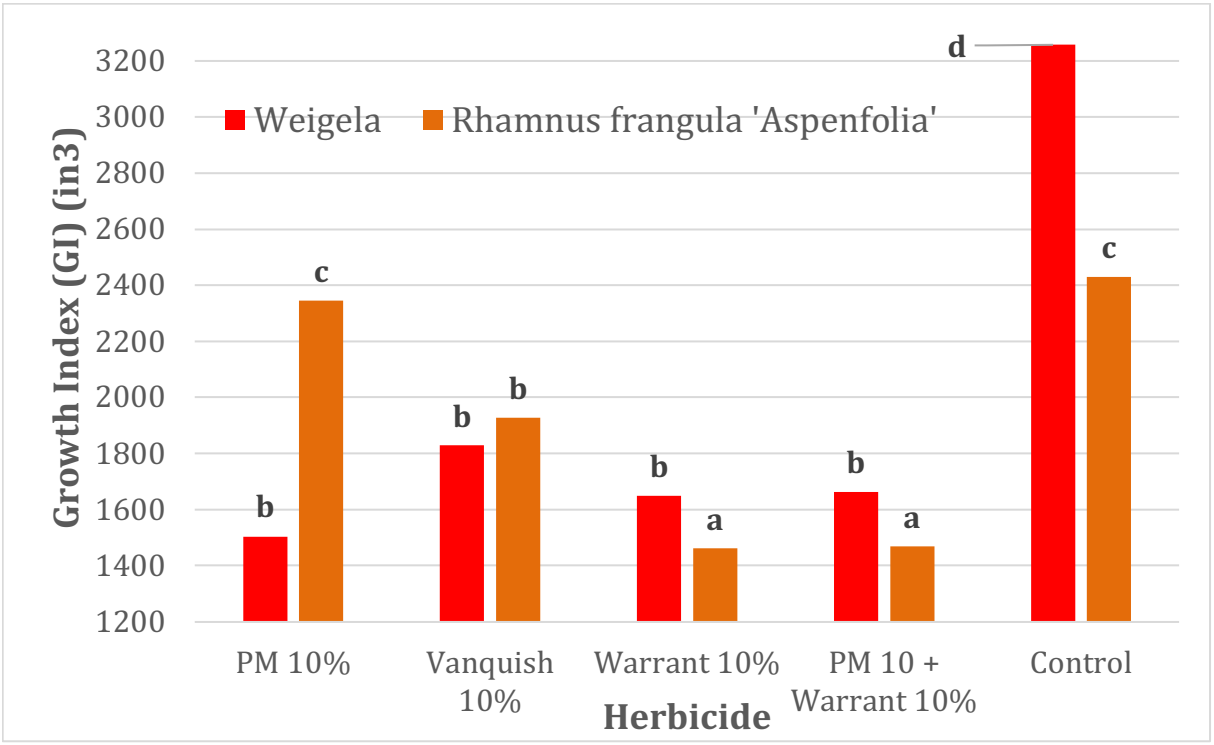


Fig. 7. The impact on height growth from applications of Roundup Power Max® (EPA Reg. No. 524-549) [Glyphosate, N-(phosphonomethyl) glycine as a potassium salt 48.7% (4.5 pounds a.e. per gallon) (Monsanto Co., St. Louis, MO) was applied to two species of deciduous shrubs. Power Max is an EPSP synthase inhibitor WSSA group 9 mode of action (MoA), and chemical family Organophosphorus was applied to simulate drift at 0 and 10% of a 32 oz/ac or 1.13 lb a.e./acre application. Warrant® (EPA Reg. No. 524-591) (Acetochlor 33.0%) (Monsanto Co., St. Louis, MO) Group 15 herbicide replaced Harness Max the herbicide originally specified in objective 1 of this grant. Harness Max was unavailable for study in 2021. All products were donated to Dr. Mathers, directly from the manufacturer, and were required to be on that companies' research list to study. Warrant is a Class 15-VLCFA inhibitor and chemical family chloroacetamide (the same family as one component of Harness). Warrant was applied at 6% to stimulate drift of a 1.25 qt/ac or 40 oz/ac spray event. Roundup Power Max® + Warrant® were applied in combination: Power Max 10% + Warrant 10%. Vanquish which contains dicamba was also applied at a 10% rate. The sprays were initiated on May 19, 2022, and final measures were conducted on August 2, 2022 (11 weeks after treatment).



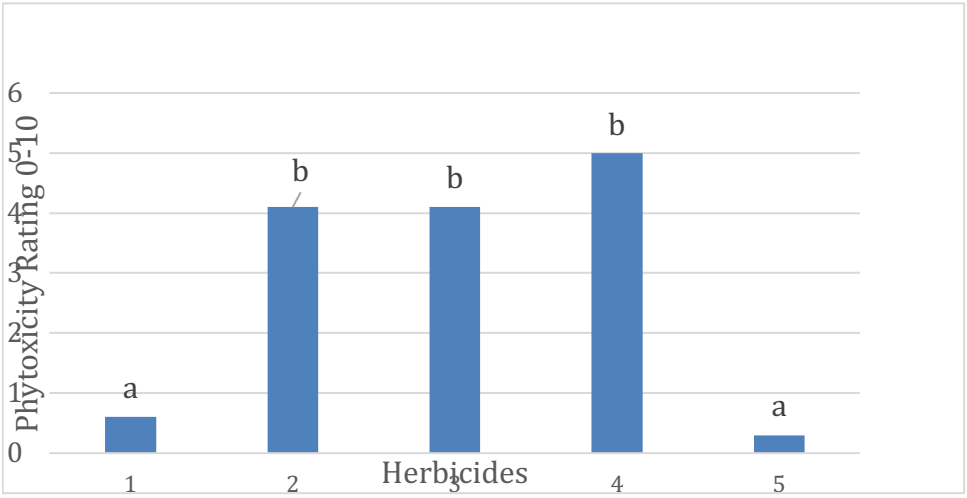


Fig. 8. A. and B. A. The impact on height growth from applications of Roundup Power Max® (EPA Reg. No. 524-549) [Glyphosate, N-(phosphonomethyl) glycine as a potassium salt 48.7% (4.5 pounds a.e. per gallon) (Monsanto Co., St. Louis, MO) was applied to two species of deciduous shrubs. Power Max is an EPSP synthase inhibitor WSSA group 9 mode of action (MoA), and chemical family Organophosphorus was applied to simulate drift at 0 and 10% of a 32 oz/ac or 1.13 lb a.e./acre application. Warrant® (EPA Reg. No. 524-591) (Acetochlor 33.0%) (Monsanto Co., St. Louis, MO) Group 15 herbicide replaced Harness Max the herbicide originally specified in objective 1 of this grant. Harness Max was unavailable for study in 2021. All products were donated to Dr. Mathers, directly from the manufacturer, and were required to be on that companies' research list to study. Warrant is a Class 15- VLCFA inhibitor and chemical family chloroacetamide (the same family as one component of Harness). Warrant was applied at 6% to stimulate drift of a 1.25 qt/ac or 40 oz/ac spray event. Roundup Power Max® + Warrant® were applied in combination: Power Max 10% + Warrant 10%. Vanquish which contains dicamba was also applied at a 10% rate. The sprays were initiated on May 19, 2022, and final measures were conducted on August 2, 2022 (11 weeks after treatment). **B.** Phytotoxicity ratings correlate well with the impact on height and GI with Rhamnus(shown) and Weigela (not shown).

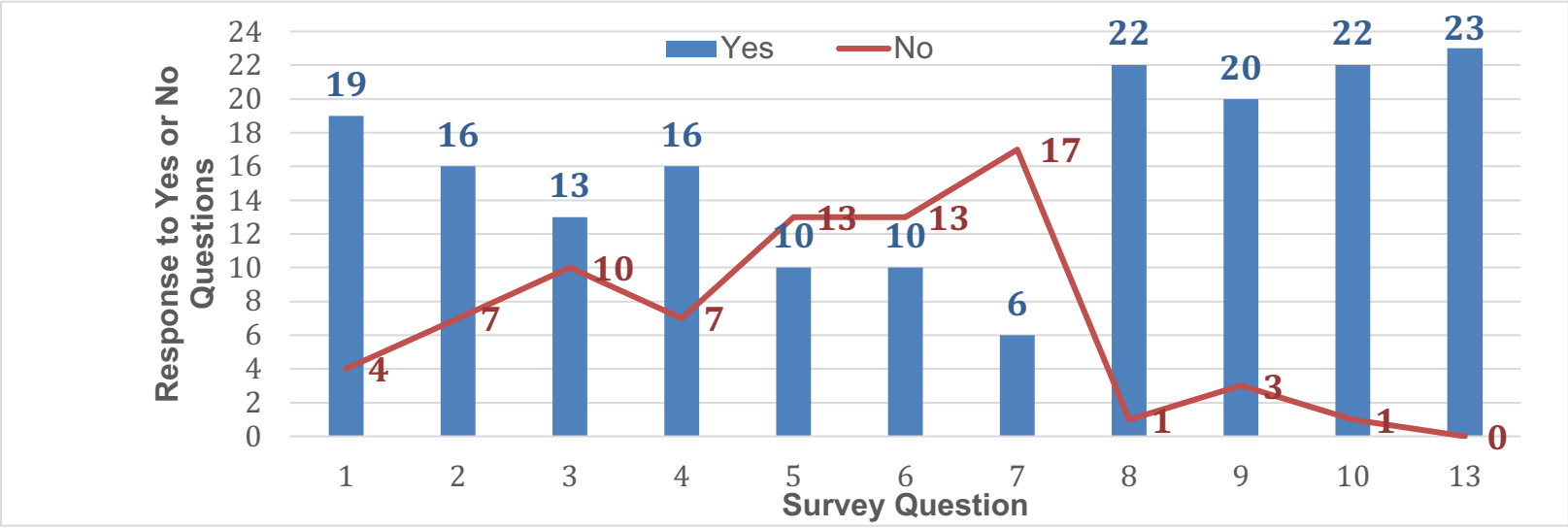


Fig. 9. (Above) Survey responses of Yes or no, to the drift survey delivered on 01/25/2022 at GLTE. The survey tools questions are listed below. (Questions 1 to 13). Dr. Hannah Mathers designed, administered, and evaluated the survey.

1. Are you concerned about herbicide drift on your site(s)? Yes No (Circle your answer)
2. Have your site(s) ever been the recipient of herbicide drift by you or your staff? Yes No (Circle your answer)
3. Have your site(s) ever been the recipient of herbicide drift from a neighbor's property? Yes No
4. Are you concerned about herbicide residues on you site(s)? Yes No (Circle your answer)
5. Are you concerned about herbicide residues in your irrigation water? Yes No
6. Do you know if your site(s) have herbicide residues from your applications? Yes No
7. Do you know if your site(s) have herbicide residues from a neighbor's application Yes No
8. Do you think what you learned today could help you produce better plants? Yes No (Circle your answer)
9. Do you think what you learned today could increase your economic returns? Yes No (Circle your answer)
10. Do you think what you learned today will help you reduce plant damage in your operation? Yes No
11. How many things did you learn from this program?
    a) 1=2
    b) 3-4
    c) 5-6
12. How much money do you think learning one thing about the issue of drift or how to decrease drift could save you/your boss in your/their business? A) $1,000 – 3,000; B) $4,000 – 8,000; C) $9,000 – 12,000; D) $13,000 – 26,000; E) > $27,000
13. Do you think what you learned will help increase revenue for your company?

Fig. 10. Barnyardgrass (flowering stage) responses at different glyphosate doses at week 8 after treatment. From right to left are rates 0.125, 0.25, 0.5, 1 and 2X rates. Background are treatments applied at 4-5 tiller stage and foreground are treatments applied at flowering stage. There were no issues with control in the flowering stage but were in the tillering stage. Photo credits: Debalina Saha (Dept. of Horticulture, MSU).

Fig. 11. Destruction in the crown of *Quercus rubra* in July 2022. The oak soil tested positive for 246 ppb of glyphosate. No glyphosate had been applied on this site for two years. Therefore, the original level of glyphosate, if it had been tested, would have been extremely high. The test for glyphosate was done to potentially illustrate the original rate of glyphosate applied was far in excess of normal. Picture by: Dr. H. Mathers.

ADDITIONAL INFORMATION

Mathers, H.M. 2022. Herbicide Drift and Carry Over. Presented at Great Lakes Trade Exposition (GLTE) by the Michigan Nursery and Landscape Association to 60 industry members. Lansing, MI. (January 25).

Mathers, H.M. 2022. Herbicide Drift and Carry Over. MI St. Clair Co, Pesticide Recertification Program. Port Huron, MI. (Feb. 16, 2022).

Mathers, H.M. 2022. Let's be Pragmatic: Marengo G as an OTT dormant application. Michigan Landscape: 65(4):55-59.