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Comparison of Glyphosate Formulations for Weed Control and Tolerance in Maize (*Zea mays* L.) and Soybean [*Glycine max* (L.) Merr.]

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Abstract

Twenty-two field experiments (six maize (*Zea mays* L.) and five soybean [*Glycine max* (L.) Merr.] using low glyphosate doses to assess weed control and six maize and five soybean using high glyphosate doses to assess tolerance) were conducted from 2010 to 2012 at two locations in southern Ontario, Canada to compare the commercially available glyphosate formulations of Roundup Weather MAX®, Clearout® 41 Plus, and Wise Up® (WeatherMAX, Clearout, and WiseUp, respectively). In maize and soybean, control of velvetleaf, pigweed species, common lambsquarters, and green foxtail 4 weeks after treatment (WAT) using 900 g·ae·ha^{-1} ranged from at least 85% to 99%, regardless of formulation. By 8 WAT with 900 g·ae·ha^{-1}, control of these weeds generally declined, but still ranged from 82% to 97% across all formulations. At harvest, maize yields were similar to the weed-free control for 900 g·ae·ha^{-1} of glyphosate as WeatherMAX and Clearout; however, reduced weed control with WiseUp resulted in an 8.8% yield loss. For soybean, yields were similar to the weed-free control, regardless of formulation or dose. In the tolerance experiments, 2.1% and 2.8% injury was observed 4 WAT for maize treated with 3600 g·ae·ha^{-1} of glyphosate as WeatherMAX and WiseUp, respectively. However, maize yields were unaffected by glyphosate formulation or dose. In soybean, visible injury of 8.5%, 4.5%, and 3.7% was observed 1 WAT with 5400 g·ae·ha^{-1} of glyphosate as WeatherMAX, WiseUp, and Clearout, respectively; by 8 WAT, visible injury was similar to the untreated control, regardless of formulation or dose. The early injury from 5400 g·ae·ha^{-1} of glyphosate resulted in 8.5%, 4.6%, and 5.5% yield loss for the WeatherMAX, WiseUp, and Clearout formulations, respectively.

Keywords

Maize, Soybean, Glyphosate, Dose, Injury, Yield

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1. Introduction

Within glyphosate-resistant maize and soybean production systems, glyphosate provides a broad spectrum of weed control, low crop phytotoxicity, and greater crop yields [1]. Glyphosate-resistant maize and soybean have also been extensively utilized [1] [2], because of the simplicity in weed management. Ontario maize and soybean growers typically use a one- or two-pass glyphosate program [3], which has spurred the demand for glyphosate or glyphosate-containing herbicides [4]. Furthermore, with the expiration of the patent on glyphosate, there has been a proliferation of glyphosate-containing herbicides available for growers [5]. Research has shown that most glyphosate herbicides provide an equivalent level of weed control and that herbicide selection could be based on cost, among other factors [4] [6]. While weed management programs that utilize glyphosate tend to be more profitable [7], continued economic pressures on Ontario maize and soybean growers have prompted interest in using low-cost glyphosate formulations sourced from China. However, the use of some of these low-cost alternatives has not been without controversy [8] [9].

Recently, research in Ontario has explored the tolerance of glyphosate-resistant maize and soybean to glyphosate formulated as Roundup WeatherMAX® [10] (hereafter referred to as WeatherMAX) at various growth stages [1] [11]. However, Ontario maize and soybean growers would like to be confident about the efficacy and crop safety of commercially available, low-cost glyphosate products as well. Therefore, the objectives of this research were to compare weed control and tolerance of glyphosate-resistant maize and soybean to three glyphosate formulations: WeatherMAX, Clearout® 41 Plus [12] (hereafter referred to as Clearout), and Wise Up® [13] (hereafter referred to as WiseUp). WeatherMAX is a commonly used glyphosate herbicide whereas Clearout and WiseUp are alternative glyphosate formulations originating from China.

2. Materials and Methods

2.1. Study Establishment

A total of twenty-two field experiments (six maize and five soybean using low glyphosate doses to assess weed control and six maize and five soybean using high glyphosate doses to assess tolerance) were conducted over a three-year period (2010 to 2012) at Ridgetown (42.4406˚N, 81.8842˚W) and Exeter (43.3500˚N, 81.4833˚W), Ontario, Canada. All experiments were designed as a randomized complete block, replicated four times. Treatments in the weed control and tolerance experiments conducted in both maize and soybean included glyphosate formulated as a potassium salt in WeatherMAX and glyphosate formulated as an isopropylamine salt in Clearout and WiseUp. In the weed control experiments, treatments included glyphosate applied at 225, 450, and 900 $g \cdot ae \cdot ha^{-1}$ in addition to weedy and weed-free controls. In the tolerance experiments conducted in maize, treatments included glyphosate applied at 1800 and 3600 $g \cdot ae \cdot ha^{-1}$ in addition to an untreated, weed-free control whereas in soybean, the glyphosate doses used were 2700 and 5400 $g \cdot ae \cdot ha^{-1}$. In maize, 1800 $g \cdot ae \cdot ha^{-1}$ represented the maximum single application glyphosate dose [3] whereas 2700 $g \cdot ae \cdot ha^{-1}$ used in soybean, while slightly more than the maximum allowed dose in a single application [10], represented the cumulative glyphosate dose (900 + 1800 $g \cdot ae \cdot ha^{-1}$) that could be received in sequential applications [3].

In both the weed control and tolerance experiments, each treatment plot was 2 m wide by 8 m (Ridgetown) to 10 m (Exeter) long. Glyphosate-resistant maize hybrids were seeded 4 to 5 cm deep at a rate of 80,000 $seeds \cdot ha^{-1}$ in rows spaced 0.75 m apart. Glyphosate-resistant soybean cultivars were seeded 3 to 4 cm deep at a rate of 370,000 to 480,000 $seeds \cdot ha^{-1}$ in rows spaced 0.75 m apart. In the weed control experiments, glyphosate treatments were applied to maize at the 7- to 9-leaf stage (approximately June 13) and to soybean at the 3rd trifoliate leaf stage (approximately July 2). In the tolerance experiments, glyphosate treatments were applied to maize to at the 9- to 11-leaf stage (approximately June 22) and to soybean at the flower initiation stage (approximately July 11); both application timings were generally later than recommended [3]. All glyphosate treatments were applied using a CO_2 pressurized backpack sprayer calibrated to deliver 200 $L \cdot ha^{-1}$ of water at 210 kPa through Ultra-Low Drift 120-02 nozzles (Hypro, New Brighton, MN). Plots within the tolerance experiments were maintained weed-free for the entire growing season using preemergence herbicides and hand weeding as needed.

2.2. Data Collection and Analysis

In the maize and soybean weed control experiments, visible crop injury and weed control were estimated visually on a scale of 0% (no injury/control) to 100% (complete plant death) relative to untreated control plants.

Maize and soybean injury was rated 1, 2, and 4 weeks after glyphosate application (WAT) whereas control of velvetleaf, pigweed species, common ragweed, common lambsquarters, and green foxtail was rated 4 and 8 WAT. In the maize and soybean tolerance experiments, visible crop injury was estimated visually on a scale of 0% (no injury) to 100% (complete plant death) relative to untreated control plants 1, 2, and 4 WAT in maize and 1, 2, 3, 4, and 8 WAT in soybean. At physiological maturity of maize, cob length was assessed by measuring ten fully exposed, randomly selected ears from end to end within each plot. The same cobs were rated for cob deformity on a scale from 1 (completely deformed) to 10 (no deformity) similar to methods used previously [1]. Both crops were harvested at maturity using a small plot combine and crop moisture and weight were recorded; final yields were adjusted to 15.5% and 13% moisture content for maize and soybean, respectively.

Maize and soybean injury and weed control data were analyzed separately by crop within the weed control and tolerance experiments using PROC MIXED (SAS Ver. 9.2, SAS Institute Inc., Cary, NC). In the individual analysis of the experiments, variances were divided into fixed (glyphosate treatment) and random effects [block; environment (*i.e*., year or location-year combinations); block nested within environment; and the herbicide treatment × environment interaction]. Significance of the fixed effect was tested using F-test and random effects were tested using a Z-test of the variance estimate. The herbicide treatment × environment interactions in maize and soybean experiments were not significant and the data for each set of experiments were pooled across environments within each crop for the weed control and tolerance experiments. PROC UNIVARIATE in SAS was used to test data for normality and homogeneity of variance. For all crop injury and weed control ratings, the untreated control treatment (assigned a value of zero) was excluded from the analyses. However, all values were compared independently to zero to evaluate treatment differences with the untreated control. To satisfy the assumptions of the variance analyses, data were transformed with the appropriate transformation as needed to improve normality. Means were separated using Fisher's Protected LSD at $P < 0.05$ and any data compared on the transformed scale were converted back to the original scale for presentation of results.

3. Results and Discussion

3.1. Weed Control Using Low Glyphosate Doses

For maize and soybean, no crop injury symptoms were noted at any of the observation timings, regardless of glyphosate formulation or dose (data not shown), consistent with previous research [4] [6] [14].

In general, weed control in maize increased with glyphosate dose at 4 and 8 WAT (**Table 1**, **Table 2**); however, the level of control varied by formulation and weed species. For example, velvetleaf control 4 WAT with 900 g·ae·ha^{-1} applied at the 7- to 9-leaf stage was similar to the weed-free control for all three of the formulations tested (**Table 1**). Control of pigweed species, common ragweed, common lambsquarters, and green foxtail 4 WAT using 900 g·ae·ha^{-1} ranged from 89% to 99%, regardless of glyphosate formulation (**Table 1**); however, in most instances, this level of control was not equivalent to the weed-free control. The exceptions to this were control of pigweed species using Clearout or WiseUp and control of green foxtail using WeatherMAX or WiseUp (**Table 1**). In the literature, glyphosate has been highly efficacious (e.g., greater than 90% control) on these weed species found in maize, but across years and/or locations this level of control still may not be equivalent to a weed-free control [7] [15] [16]. At 4 WAT, WeatherMAX, Clearout, and WiseUp provided equivalent control of all weed species with two exceptions: WiseUp provided better control of common ragweed than Clearout at 450 g·ae·ha^{-1} and WiseUp provided better control of common lambsquarters than Clearout at 225 g·ae·ha^{-1}. Similar to the velvetleaf control at 4 WAT, control 8 WAT using 900 g·ae·ha^{-1} was equivalent to the weed-free control for all formulations tested (**Table 2**). For the remaining weed species, especially common lambsquarters and green foxtail, the level of control 8 WAT using 900 g·ae·ha^{-1} ranged from 82% to 89% (**Table 2**), an overall decrease in control compared to observations 4 WAT (**Table 1**). There were no differences in control between using 450 or 900 g·ae·ha^{-1} for common lambsquarters and green foxtail for any of glyphosate formulations tested; furthermore, control of green foxtail was similar across all WiseUp doses (**Table 2**), indicative of the potential for a late-season weed escape [2] and for yield losses [3]. At 8 WAT, WeatherMAX, Clearout, and WiseUp provided equivalent control of all weed species with two exceptions: WiseUp provided better control of both velvetleaf and common ragweed than Clearout at 450 g·ae·ha^{-1}. At harvest, maize yields were statistically equivalent with WeatherMAX, Clearout, and WiseUp. Using 900 g·ae·ha^{-1} of glyphosate applied as WeatherMAX or Clearout, maize yield was equivalent to the weed-free control; but with WiseUp, maize yield was 8.8% less than the weed-free control (**Table 2**).

Table 1. Visual estimates of percent weed control 4 WAT with different glyphosate formulations applied postemergence in glyphosate-resistant maize at Exeter (2011-2012) and Ridgetown, Ontario, Canada (2010-2012)[ab].

		Weed Control				
Treatment	Dose	ABUTH	AMASS	AMBEL	CHEAL	SETVI
	$g \cdot ae \cdot ha^{-1}$	---%				
Weedy control		0 d	0 f	0 f	0 h	0 e
Weed-free control		100 a	100 a	100 a	100 a	100 a
WeatherMAX	225	6 d	69 e	59 e	44 fg	61 cd
WeatherMAX	450	50 c	91 cd	80 cd	80 cd	81 bc
WeatherMAX	900	84 ab	97 bc	92 b	93 bc	95 ab
Clearout	225	11 d	72 e	55 e	34 g	54 d
Clearout	450	45 c	89 d	76 d	71 de	67 cd
Clearout	900	86 ab	99 ab	92 b	89 bc	92 b
WiseUp[c]	225	12 d	70 e	61 e	56 ef	70 cd
WiseUp[c]	450	65 bc	91 cd	84 c	84 bcd	82 bc
WiseUp[c]	900	87 a	98 ab	94 b	95 b	95 ab

[a]Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lambsquarters; SETVI, green foxtail; WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Included N-Tank at 0.5% v/v.

Table 2. Visual estimates of percent weed control 8 WAT and crop yield with different glyphosate formulations applied postemergence in glyphosate-resistant maize at Exeter (2011-2012) and Ridgetown, Ontario, Canada (2010-2012)[ab].

		Weed control					
Treatment	Dose	ABUTH	AMASS	AMBEL	CHEAL	SETVI	Yield
	$g \cdot ae \cdot ha^{-1}$	---%					$T \cdot ha^{-1}$
Weedy control		0 e	0 f	0 f	0 f	0 e	7.6 e
Weed-free control		100 a	100 a	100 a	100 a	100 a	13.7 a
WeatherMAX	225	1 e	59 e	45 e	36 e	39 d	11.4 cd
WeatherMAX	450	46 cd	85 d	73 cd	78 bc	65 bcd	12.3 bcd
WeatherMAX	900	83 ab	95 bc	90 b	89 b	85 b	13.0 ab
Clearout	225	2 e	59 e	44 e	30 e	39 d	11.2 d
Clearout	450	33 d	87 cd	66 d	67 cd	60 bcd	12.5 bc
Clearout	900	83 ab	97 b	89 b	87 bc	82 bc	12.9 ab
WiseUp[c]	225	4 e	66 e	49 e	48 de	56 cd	11.9 bcd
WiseUp[c]	450	62 bc	87 cd	77 c	81 bc	71 bc	12.5 bc
WiseUp[c]	900	86 a	96 b	90 b	89 b	82 bc	12.5 bc

[a]Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; AMBEL, common ragweed; CHEAL, common lambsquarters; SETVI, green foxtail; WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Included N-Tank at 0.5% v/v.

For soybean, weed control increased with glyphosate dose and excellent control was observed 4 and 8 WAT when 900 g·ae·ha^{-1} was applied at the 3rd trifoliate leaf stage for nearly every weed species tested, regardless of glyphosate formulation (**Table 3**, **Table 4**). For example, control of velvetleaf, pigweed species, and green foxtail 4 WAT using 900 g·ae·ha^{-1} was similar to the weed-free control for all glyphosate formulations tested whereas control common lambsquarters ranged from 93% to 97% (**Table 3**). At 4 WAT, WeatherMAX, Clearout, and WiseUp provided equivalent control of all weed species with three exceptions: WiseUp provided better control of pigweed species than WeatherMAX at 225 g·ae·ha^{-1}, WiseUp provided better control of velvetleaf than Clearout at 450 g·ae·ha^{-1}, and both WeatherMAX and WiseUp provided better control of common lambsquarters than Clearout at 450 g·ae·ha^{-1}. By 8 WAT, control of velvetleaf, pigweed species, common lambsquarters, and green foxtail using 900 g·ae·ha^{-1} of glyphosate as WeatherMAX were all similar to the weed-free control (**Table 4**). For the Clearout and WiseUp formulations, control of velvetleaf, pigweed species, and green foxtail 8 WAT with 900 g·ae·ha^{-1} was also similar to the weed-free control; however, control of common lambsquarters, while rated at over 95%, differed from the weed-free control (**Table 4**). Control of common lambsquarters can be difficult as this species tends to respond better to glyphosate doses that are greater than 900 g·ae·ha^{-1} [17]. At 8 WAT, WeatherMAX, Clearout, and WiseUp provided equivalent control of all weed species with four exceptions at the 225 g·ae·ha^{-1} dose: WiseUp provided better control of pigweed species than WeatherMAX, WiseUp provided better control of velvetleaf than Clearout or WeatherMAX, and WiseUp provided better control of common lambsquarters than Clearout. At harvest, the excellent season-long control of the weeds present in this study, regardless of the glyphosate dose or formulation used, resulted in crop moisture levels and yields that were generally similar to the weed-free control (**Table 4**), consistent with the literature [5] [18]-[21].

3.2. Tolerance of High Glyphosate Doses

At all observation timings, visible injury levels of maize treated with 1800 g·ae·ha^{-1} of glyphosate applied at the 9- to 11-leaf stage were similar to the untreated control, regardless of formulation (**Table 5**). For the WeatherMAX and WiseUp glyphosate formulations however, visible injury tended to increase with dose, but decrease over time. Yet, 2.1% and 2.8% injury was still observed 4 WAT for maize treated with 3600 g·ae·ha^{-1} of glyphosate

Table 3. Visual estimates of percent weed control 4 WAT with different glyphosate formulations applied postemergence in glyphosate-resistant soybean at Exeter (2011) and Ridgetown, Ontario, Canada (2010-2011)[ab].

		Weed Control			
Treatment	Dose	ABUTH	AMASS	CHEAL	SETVI
	g·ae·ha^{-1}	--%--			
Weedy control		0 f	0 e	0 f	0 e
Weed-free control		100 a	100 a	100 a	100 a
WeatherMAX	225	28 ef	72 d	58 de	83 d
WeatherMAX	450	52 cd	95 b	90 bc	95 bc
WeatherMAX	900	85 ab	100 a	97 b	99 ab
Clearout	225	28 ef	79 cd	51 e	82 d
Clearout	450	41 de	94 b	68 d	94 bc
Clearout	900	89 ab	100 a	93 bc	98 ab
WiseUp[c]	225	36 de	84 c	62 de	86 cd
WiseUp[c]	450	69 bc	98 ab	88 c	97 ab
WiseUp[c]	900	93 a	100 a	96 bc	99 ab

[a]Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; CHEAL, common lambsquarters; SETVI, green foxtail; WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Included N-Tank at 0.5% v/v.

Table 4. Visual estimates of percent weed control 8 WAT, crop moisture, and crop yield with different glyphosate formulations applied postemergence in glyphosate-resistant soybean at Exeter (2011) and Ridgetown, Ontario, Canada (2010-2011)[ab].

		Weed Control					
Treatment	Dose	ABUTH	AMASS	CHEAL	SETVI	Moisture	Yield
	g·ae·ha^{-1}	----------------------	----------------------	%	----------------------	----------------------	T·ha^{-1}
Weedy control		0 f	0 f	0 e	0 e	17.0 c	2.70 c
Weed-free control		100 a	100 a	100 a	100 a	14.6 a	4.00 ab
WeatherMAX	225	30 ef	79 e	63 cd	84 d	15.8 b	3.84 b
WeatherMAX	450	60 cd	98 ab	91 b	95 bc	15.0 a	4.01 ab
WeatherMAX	900	89 ab	100 a	97 ab	99 ab	14.7 a	3.96 ab
Clearout	225	31 ef	83 de	52 d	85 cd	15.3 ab	3.84 b
Clearout	450	48 de	96 bc	69 cd	95 bc	15.3 ab	3.92 ab
Clearout	900	90 ab	100 a	95 b	99 ab	15.0 a	3.98 ab
WiseUp[c]	225	46 de	90 cd	70 c	88 cd	15.0 a	3.95 ab
WiseUp[c]	450	74 bc	98 ab	90 b	97 ab	14.8 a	4.04 a
WiseUp[c]	900	94 ab	100 a	96 b	99 ab	14.6 a	4.04 a

[a]Abbreviations: ABUTH, velvetleaf; AMASS, pigweed species; CHEAL, common lambsquarters; SETVI, green foxtail; WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Included N-Tank at 0.5% v/v.

Table 5. Percent visible injury 1, 2, and 4, WAT, cob length and deformity, and crop yield of glyphosate-resistantmaize treated with different glyphosate formulations applied postemergence at Exeter (2011-2012) and Ridgetown, Ontario, Canada (2010-2012)[ab].

		Visible Crop Injury[c]					
Treatment	Dose	1 WAT	2 WAT	4 WAT	Cob Length	Cob Deformity	Yield
	g·ae·ha^{-1}	------------	%	------------	cm		T·ha^{-1}
Untreated		0 a	0 a	0 a	19.6 a	10.0 a	14.4 a
WeatherMAX	1800	0.3 a	0.2 a	0 a	19.8 a	9.8 ab	14.4 a
WeatherMAX	3600	2.3 bc	1.7 b	2.1 b	19.8 a	9.3 cd	14.2 a
Clearout	1800	0.1 a	0 a	0 a	19.6 a	9.8 ab	14.6 a
Clearout	3600	0.4 a	0.2 a	0.1 a	19.8 a	9.4 bcd	14.6 a
WiseUp[d]	1800	1.0 ab	0.7 ab	0.1 a	19.8 a	9.7 abc	14.4 a
WiseUp[e]	3600	3.8 c	3.7 c	2.8 b	19.3 a	9.1 d	13.8 a

[a]Abbreviation: WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Ridgetown 2011 (4 WAT) and Exeter 2012 (1, 2, and 4 WAT) injury data were not included in the analysis as no injury was detected. [d]N-Tank at 0.5% v/v. [e]N-Tank at 1.0% v/v.

as WeatherMAX and WiseUp, respectively (**Table 5**). Maize injury levels and symptoms were similar with previous research [1] [22], such as chlorosis, degradation of the leaves present in the whorl at the time of application, wrapped leaves, and overall reduced growth compared to the untreated control. Similar to visible injury, cob deformity tended to increase with glyphosate dose, especially for maize treated with WeatherMAX and WiseUp (**Table 5**). However, maize demonstrated excellent tolerance as cob length and final yields were unaffected by glyphosate dose or formulation (**Table 5**), consistent with prior studies [1] [6] [14] [22].

For soybean, visible injury 1 WAT with 2700 g·ae·ha^{-1} of glyphosate applied at the flower initiation stage was 3.2%, 1.4%, and 1.0% for WeatherMAX, WiseUp, and Clearout formulations, respectively (**Table 6**). Visible soybean injury increased more than two-fold as 8.5%, 4.5%, and 3.7% injury was observed 1 WAT with 5400 g·ae·ha^{-1} of glyphosate formulated as WeatherMAX, WiseUp, and Clearout, respectively (**Table 6**). The WeatherMAX label warns of short term yellowing in spray overlap areas if soybean is treated with 2522 g·ae·ha^{-1}, but according to the label this injury should not influence yield [10]. In the literature, significant injury to soybean has been reported when glyphosate was applied at doses greater than 2000 g·ae·ha^{-1} [23]-[26]. Using similarly high doses to those in the current study, other research demonstrated that an isopropylamine salt formulation was more injurious than a potassium salt formulation [27] and was equally injurious as a trimethylsulfonium salt formulation [28]. Conversely, related research in Ontario reported no injury in soybean treated with 3600 g·ae·ha^{-1} of glyphosate formulated as WeatherMAX [11], contrary to the results of the current study (**Table 6**). Yet, visible soybean injury was transient. For example, by 4 WAT, visible injury of soybean treated with 2700 g·ae·ha^{-1} of glyphosate as WeatherMAX and WiseUp was similar to the untreated control while visible injury of soybean treated with glyphosate as Clearout was similar to the untreated regardless of dose; by 8 WAT, visible injury was similar to the untreated control, regardless of formulation or dose (**Table 6**). At harvest, yield of soybean treated with 2700 g·ae·ha^{-1} of glyphosate, regardless of formulation, was similar to the untreated control (**Table 6**), consistent with other research which used doses ranging from 2240 to 4480 g·ae·ha^{-1} [28]. Unfortunately, the persistent observations of injury from 5400 g·ae·ha^{-1} of glyphosate resulted in 8.5%, 4.6%, and 5.5% yield loss for WeatherMAX, WiseUp, and Clearout formulations, respectively (**Table 6**).

4. Conclusion

With the proliferation of glyphosate-containing herbicides available since the expiration of the glyphosate patent [5], Ontario maize and soybean growers have been particularly interested in using low-cost glyphosate formulations sourced from China (e.g., Clearout and WiseUp). In both maize and soybean, this research clearly demonstrates that when using the recommended 900 g·ae·ha^{-1} dose [3], the WeatherMAX, Clearout, and WiseUp formulations of glyphosate resulted in statistically equivalent control of all weed species at 4 and 8 WAT and equivalent maize and soybean yield. Yet, slight differences in weed control were observed at below label doses. For maize and soybean growers, where a spray overlap occured, this research showed that these crops differed in tolerance to the formulations tested. For example in maize, there was slightly more visible injury at 1, 2, and 4 WAT with WeatherMAX and WiseUp than Clearout, but this increased visible injury was transient with no differences among formulations with respect to cob length, cob deformity, or yield. Furthermore, consistent with a comparable study [1], Ontario maize growers can be confident that observations of injury after a late-season application should have little to no impact on yield, regardless of glyphosate formulation. Conversely in soybean, the WeatherMAX formulation at 5400 g·ae·ha^{-1} resulted in greater visible injury at 1, 2, 3, and 4 WAT than

Table 6. Percent visible injury 1, 2, 3, 4, and 8 WAT, crop moisture, and crop yield of glyphosate-resistant soybean treated with different glyphosate formulations applied postemergence at Exeter (2011) and Ridgetown, Ontario, Canada (2010-2011)[ab].

		Visible Crop Injury						
Treatment	Dose	1 WAT	2 WAT	3 WAT	4 WAT	8 WAT	Moisture	Yield
	g·ae·ha^{-1}	---%---						T·ha^{-1}
Untreated		0 a	0 a	0 a	0 a	0 a	14.3 ab	4.33 a
WeatherMAX	2700	3.2 c	2.5 c	1.2 cd	0.1 a	0.4 a	14.3 ab	4.23 ab
WeatherMAX	5400	8.5 e	7.5 d	4.9 e	1.9 c	0.8 a	14.5 b	3.96 c
Clearout	2700	1.4 b	0.6 b	0.3 b	0 a	0 a	14.2 a	4.30 a
Clearout	5400	4.5 d	3.6 c	1.8 d	0.5 ab	0.6 a	14.3 ab	4.13 b
WiseUp[c]	2700	1.0 b	0.9 b	0.5 bc	0.3 a	0.3 a	14.2 a	4.36 a
WiseUp[d]	5400	3.7 cd	3.1 c	1.8 d	0.9 b	0.6 a	14.4 b	4.09 bc

[a]Abbreviation: WAT, weeks after glyphosate treatment. [b]Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P < 0.05$). [c]Included N-Tank at 0.5% v/v. [d]Included N-Tank at 1.0% v/v.

Clearout and WiseUp and the application of WeatherMAX resulted in a greater yield loss than Clearout. For the WiseUp and Clearout formulations, less injury was observed which translated into lower yield reductions compared to the WeatherMAX formulation.

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Abbreviation

WAT, weeks after treatment.