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ScienceDirect
Crop Protection 27 (2008) 452–458
Crop Protection
www.elsevier.com/locate/cropro

Annual weed control may be improved when AMS is added to below-label glyphosate doses in glyphosate-tolerant maize (*Zea mays* L.)

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Received 24 July 2007; accepted 25 July 2007

Abstract

In glyphosate-tolerant crops, weed control may be improved and glyphosate dose may be reduced when ammonium sulfate (AMS) is added to the spray mixture. Much research has investigated how AMS may reduce antagonism between salt ions present in the carrier water and glyphosate molecules, especially when hard water is used as the spray carrier. However, little information is available describing whether glyphosate dose may be reduced when soft water is used. Field trials were established at two Ontario and one Michigan location in 2003 and 2004 to evaluate control of several annual weeds when 0.25, 0.5, 0.75 and 1 × label doses of glyphosate ±2% AMS were applied in glyphosate-tolerant maize. The concentration of salt and metal ions in the spray water at Harrow and Ridgetown were low, and the concentrations at East Lansing were moderate. Crop tolerance was excellent in all treatment plots. The addition of AMS only improved weed control at the Ridgetown location. Control of *Abutilon theophrasti* was improved at the 0.25 and 0.5 × glyphosate doses; however, improvements in control did not exceed 65%. Percent weed control below 80% is generally considered unacceptable. Control of *Amaranthus retroflexus*, *Chenopodium album*, and several annual grasses was not improved by AMS addition at any glyphosate dose in comparison to the application of glyphosate alone. Overall, the addition of AMS to a soft water carrier improved control of some weed species only at below-label glyphosate doses. Nonetheless, because weed control was not improved beyond 70% when AMS was added, we continue to recommend that the full label dose of glyphosate be applied to reduce the necessity for additional glyphosate applications to maintain acceptable weed control.

Keywords: Ammonium sulfate; *Abutilon theophrasti*; *Amaranthus retroflexus*; *Chenopodium album*; Annual grasses

1. Introduction

Glyphosate-tolerant maize (*Zea mays* L.) was introduced in Canada in 2001. It is estimated that in 2007 greater than 60% of the maize seeded in Canada and the United States will be glyphosate-tolerant hybrids (Anonymous, 2007). *Chenopodium album*, *Amaranthus retroflexus*, *Abutilon theophrasti* and several annual grass species may cause economic losses in maize if left uncontrolled. The option to use glyphosate (*N*-phosphonomethyl glycine) in these systems is extremely valuable, because glyphosate is a broad-spectrum herbicide that provides excellent control of a wide range of weed species. However, due to natural tolerance, control of some species, especially *A. theophrasti*, may be less than satisfactory (Wiesbrook et al., 2001; Young et al., 2001), and this reduction in weed control may be exacerbated when hard water is used as the spray carrier. Hard water is defined as water containing greater than 500 ppm of Ca^{2+} and/or Mg^{2+} (Pratt et al., 2003). Nalewaja and Matysiak (1993) reported that 100 and 200 ppm of Ca^{2+} and Na^{2+}, respectively, reduced glyphosate phytotoxicity. These salts have a positive charge and antagonize or interfere with the activity of the negatively charged glyphosate molecules, leading to the formation of glyphosate–salt complexes with low solubility rather than glyphosate–isopropylamine complexes (Nalewaja and Matysiak, 1991; Thelen et al., 1995). The addition of

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doi:10.1016/j.cropro.2007.07.015

ammonium sulfate (AMS) to the carrier solution with glyphosate has been shown to reduce the antagonism caused by the ions found in hard water (Thelen et al., 1995). The presence of Fe^{2+} and Al^{3+} in carrier water may also be antagonistic (Stahlman and Phillips, 1979); however, the addition of AMS may be ineffective in preventing the formation of glyphosate–iron complexes (Nalewaja and Matysiak, 1991).

Several studies have shown that the addition of AMS to herbicides increases the control of *A. theophrasti* (Maschhoff et al., 2000; Young et al., 2003); however, control of other species such as *C. album* is not always improved (Maschhoff et al., 2000; Pline et al., 1999; Young et al., 2003).

Increased glyphosate efficacy results from the formation of glyphosate–ammonium salt complexes that are more readily absorbed by foliage than glyphosate–calcium or glyphosate–sodium complexes (Nalewaja et al., 1992). Thelen et al. (1995) concluded that the addition of AMS caused the calcium in the hard water to be tied up as $CaSO_4$, leaving the remaining ammonium from the AMS available to combine with glyphosate to form the glyphosate–ammonium salt. Satchivi et al. (2000) demonstrated that the addition of AMS to glyphosate improved glyphosate uptake through *A. theophrasti* and *Setaria faberi* foliage by 25% and 42%, respectively. In the United States, AMS is commonly used with glyphosate to minimize the risk of antagonism from hard water. The addition of AMS to glyphosate is not currently registered in Canada. It remains unclear what benefit AMS will provide when soft water is used as the carrier or when glyphosate dose is reduced. Hall et al. (2000) has previously reported that *A. theophrasti* contains calcium cations within and on the leaf tissue; it is possible that these cations may reduce the phytotoxicity of glyphosate even when soft water is used as the carrier. The increased uptake of glyphosate–ammonium complexes by the foliage of weeds offers an opportunity to reduce the dose of glyphosate required to achieve at least 80% control of economically important weed species.

Therefore, the objectives of this study were to determine whether (1) glyphosate dose can be reduced when AMS is added to the spray solution and (2) whether weed control can be maintained or improved at these lower glyphosate doses.

2. Materials and methods

Field studies were conducted at Agriculture and Agri-Food Canada, Harrow, Ontario; Michigan State University, East Lansing, Michigan; and at University of Guelph Ridgetown Campus, Ridgetown, Ontario, in 2003 and 2004. The soil at Harrow was a Fox sandy loam with 82.5% sand, 5% silt, 12.5% clay, 2.6% organic matter and pH of 6.0. The soil at East Lansing was a Capac sandy loam with 59% sand, 24% silt, 17% clay, 1.8% organic matter and pH of 6.2 in 2003 and a Capac sandy clay loam with 53% sand, 26% silt, 21% clay, 3.1% organic matter and pH of 6.9 in 2004. The soil at Ridgetown was a Watford-Brady sandy loam with 69% sand, 12% silt, 19% clay, 4.5% organic matter and pH of 7.2. Seedbed preparation at all sites consisted of autumn moldboard plowing, followed by two passes with a field cultivator in the spring.

The experiment was arranged as a randomized complete block design with 9 treatments and 4 replications. The first four treatments were glyphosate applied alone at 225 (0.25×), 450 (0.5×), 675 (0.75×) or 900 (1.0×) g ae/ha. Glyphosate was then applied at each dose with the addition of 2% w/v AMS. The final treatment was an untreated weedy control.

Each plot was 3.0 m wide and consisted of glyphosate-tolerant maize planted in rows 8 m long at Harrow and Ridgetown and 10 m long at East Lansing. Maize rows were spaced 0.75 m apart. Maize planting at all locations was done using a Max Emerge planter at a rate of 77,000 seeds/ha and a 4 cm depth on May 22, 2003 and May 17, 2004 at Harrow; May 14, 2003 and May 5, 2004 at East Lansing; and May 19, 2003 and May 30, 2004 at Ridgetown.

Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 100 L/ha aqueous solution at 210 kPa at Harrow, 100 L/ha at 172 kPa at East Lansing and 200 L/ha at 207 kPa at Ridgetown. Flat-fan 11001XR nozzles (Teejet Spraying Systems Co., Wheaton, IL), at a spacing of 0.5 m, were used at Harrow and 8015XR and 8002XR nozzles were used at East Lansing and Ridgetown, respectively. The herbicide glyphosate, formulated as a potassium salt, was applied post-emergence in one foliar broadcast application when weeds were 15–20 cm in height.

Visible injury of maize was assessed on a scale ranging from 0 (no visible injury) to 100 (total plant necrosis), 7, 14 and 28 days after application. The visual assessments of weed control, in comparison to the untreated weedy control, were made 28 and 56 days after herbicide application. At Harrow and Ridgetown, maize was mechanically harvested at physiological maturity and weights were adjusted to a 15% moisture level.

A recommended dose of AMS, for comparison with the AMS dose used in this study, was calculated using an equation developed by Nalewaja and Matysiak (1993):

$$\text{AMS g/100 L} = 0.6\,[\text{ppm Na}^{2+}] + 0.2\,[\text{ppm K}^{+}] + 1.0\,[\text{ppm Ca}^{2+}] + 1.7\,[\text{ppm Mg}^{2+}].$$

All data were subjected to analysis of variance (ANOVA) using SAS statistical software (Statistical Analysis Systems, 2000). The data were analyzed as a mixed model using the *Proc Mixed* procedure of SAS. The variances were partitioned into the fixed effects of herbicide treatment and into the random effects of year, location, year by location, their interactions with the fixed effect, and blocks nested within year by location. The assumptions of the variance analysis were tested by insuring that the