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Comparison of a premix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor with other preemergence herbicides for weed control and corn yield in no-tillage and reduced-tillage production systems in Nebraska, USA

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ABSTRACT

A premix of atrazine, bicyclopyrone, mesotrione, and *S*-metolachlor (ABMS) has recently been registered for broad-spectrum weed control in corn (*Zea mays* L.) in the USA. The objectives of this study were to compare the efficacy of ABMS applied preemergence (PRE) with other commonly used PRE herbicides for weed control, corn injury, and yield in no-tillage (no-till) and reduced-tillage (reduced-till) corn production systems, and to determine the biologically effective doses of ABMS for controlling Palmer amaranth (*Amaranthus palmeri* S. Wats.) in field conditions. Field experiments were conducted in 2015 and 2016 at South Central Agricultural Laboratory, Clay Center, Nebraska, USA. ABMS applied at the labeled dose (2.89 kg ai ha^{-1}) resulted in 92–99% Palmer amaranth control in both tillage systems. A similar level of Palmer amaranth control (86–99%) was observed with mesotrione plus rimsulfuron in the no-till system; however, the control was higher with ABMS than with other premixes in the reduced-till system at 42 days after treatment (DAT) and at harvest. Applications of ABMS at 2.89 kg ai ha^{-1} provided 99 and 81% control of velvetleaf (*Abutilon theophrasti* Medik.) and foxtail (*Setaria* spp.), respectively, in the no-till system at 28 DAT, whereas control was ≥93% in the reduced-till system. ABMS applied at 2.89 kg ai ha^{-1} resulted in 3% corn injury at 14 DAT regardless of the tillage system, whereas 15% corn injury was observed with acetochlor plus clopyralid plus flumetsulam, and dimethenamid-P plus saflufenacil in the reduced-till. ABMS or mesotrione plus rimsulfuron at labeled doses resulted in 16.0–16.3 t ha^{-1} corn yield, comparable to the weed-free control (16.4 t ha^{-1}). The biologically effective doses of ABMS to provide 90% control (ED_{90}) of Palmer amaranth at 42 DAT were 2.44 and 2.81 kg ai ha^{-1} in no-till and reduced-till systems, respectively. The efficacy of ABMS for broadleaf weed control and early-season grass weed control, and corn yield was the same or sometimes better than most of the PRE herbicides tested in this study; therefore, ABMS can be considered as an additional option for management of problem weeds, including Palmer amaranth in corn in the USA.

1. Introduction

The shift from conventional tillage to conservation tillage, including no-tillage (no-till) and reduced-tillage (reduced-till) production systems, had an impact on agricultural practices, specifically on weed management in corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] cropping systems in the Midwestern United States (Buhler, 1995; Price et al., 2011). Pre-plant conventional tillage aided in higher crop production by minimizing weed interference (Barnes et al., 2017; Ganie et al., 2017); however, the introduction of residual herbicides such as atrazine promoted conservation tillage in the early 1960s (Triplett et al., 1964). Conservation tillage has several environmental and crop production benefits over conventional tillage, including timely establishing crops (Hobbs and Giri, 1997), supplying moisture and nutrients for crop growth (Triplett and Dick, 2008), reducing soil erosion and runoff by dissipating rain drop energy (Gicheru et al., 2004; Zhang et al., 2007), increasing soil aggregate formation and stability, and increasing soil organic matter near the soil surface (Beare et al., 1994; Six et al., 1999). Conservation tillage also requires less fuel and energy input compared to conventional tillage (Frye, 1984). Widespread adoption of conservation tillage began in the United States during the 1980s and was later adopted in Australia, Canada, and several South American countries (Triplett and Dick, 2008). The introduction of glyphosate-resistant crops in 1996 dramatically changed weed control practices: a survey conducted by Givens et al. (2009) in six states including Nebraska reported that after the adoption of

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Table 1
Details of herbicide treatments and doses applied preemergence for broadleaf and grass weed control in glyphosate-resistant corn in field experiments conducted in Nebraska.

Treatment	Dose kg ai ha^{-1}	Trade Name	Manufacturer
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	0.96	Acuron	Syngenta Crop Protection, Inc., Greensboro, NC 27419
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	1.93	Acuron	Syngenta Crop Protec., Inc.
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	2.89	Acuron	Syngenta Crop Protec., Inc.
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	3.86	Acuron	Syngenta Crop Protec., Inc.
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	4.82	Acuron	Syngenta Crop Protec., Inc.
Atrazine + bicyclopyrone + mesotrione + *S*-metolachlor	5.78	Acuron	Syngenta Crop Protec., Inc.
Atrazine + fluthiacet-methyl + pyroxasulfone	1.26	Anthem ATZ	FMC Corporation, Philadelphia, PA 19103
Atrazine + isoxaflutole + thiencarbazone-methyl	0.50 + 0.10	AAtrex 4L + Corvus	Syngenta Crop Protec., Inc. Bayer CropScience LP, Research Triangle Park, NC 27709
Mesotrione + rimsulfuron	0.19	Instigate	E. I. du Pont de Nemours and Company, Wilmington, DE 19805
Acetochlor + clopyralid + flumetsulam	1.19	Surestart II	Dow AgroSciences LLC, Indianapolis, IN 46268
Dimethenamid-P + saflufenacil	0.78	Verdict	BASF Corporation, Research Triangle Park, NC 27709

glyphosate-resistant crops, 25% and 31% of producers transitioned from conventional tillage to no-till and reduced-till, respectively. By 2015, more than 156 million ha agricultural land was in conservation tillage throughout the world, with the United States as the leading country (70 million ha including no-till area) followed by Brazil and Argentina (FAOSTAT, 2017, USDA-NASS,2012). Nebraska has the second largest area (after Kansas) in no-till crop production of any state in the United States (USDA-NASS, 2012).

Tillage affects the distribution of the weed seedbank, which overall impacts weed emergence. Yenish et al. (1992) noted that no-till and reduced-till (chisel plowing) left 60% and 30% of weed seeds in the upper 1 cm soil layer, respectively, compared with conventional tillage, where seeds were distributed uniformly throughout the top 19 cm. Different types of tillage practices, including no-till, can alter the dynamics of the weed population (Buhler, 1995); Clements et al. (1994) described that the changes in tillage operations influenced weed species diversity. Widespread adoption of no-till and reduced-till systems aided in the weed population shift towards small-seeded broadleaves [such as common waterhemp (*Amaranthus rudis* Sauer) and Palmer amaranth (*Amaranthus palmeri* S. Wats.)], grasses [such as foxtail (*Setaria* spp.)], and perennial weeds such as Canada thistle [*Cirsium arvense* (L.) Scop.], dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers), and field bindweed (*Convolvulus arvensis* L.) (Buhler, 1995; Costea et al., 2005; Felix and Owen, 1999; Price et al., 2011; Shrestha et al., 2006).

Palmer amaranth is a summer annual weed native to the Southwestern United States (Sauer, 1957). A recent survey by the Weed Science Society of America listed Palmer amaranth as the topmost troublesome weed in the United States (Van Wychen, 2016). Palmer amaranth is also considered the most problematic weed in cotton (*Gossypium hirsutum* L.), corn, and soybean in the southern United States (Price et al., 2011; Prince et al., 2012), and the infestation is becoming more common in Midwestern states, including Nebraska (Chahal et al., 2015; Jhala et al., 2014b). It is a highly competitive weed and can compete with crops for resources such as light, water, and nutrients (Massinga et al., 2003). Massinga et al. (2001) reported that Palmer amaranth emerging with corn reduced yield 91% at a density of 8 plants m^{-1} row. It is an erect plant growing up to 2 m tall, and a single female plant can produce 200,000–600,000 seeds, resulting in the quick establishment of a soil seed bank (Keeley et al., 1987; Legleiter and Johnson, 2013).

The widespread adoption of glyphosate-resistant crops and subsequent multiple applications of glyphosate resulted in high selection pressure, promoting the rapid evolution of glyphosate-resistant weeds. Glyphosate-resistant Palmer amaranth has been reported in 27 states in the United States, along with several cases of multiple herbicide resistance (Heap, 2017). Palmer amaranth has also evolved resistance to five other modes of action, including acetolactate synthase (ALS)-, microtubule-, photosystem (PS) II-, protoporphyrinogen oxidase (PPO)-, and 4-hydroxyphenylpyruvate dioxygenase (HPPD)-inhibitors (Chahal et al., 2015; Heap, 2017). Palmer amaranth resistant to HPPD, PS-II, and glyphosate has already been confirmed in Nebraska with two discrete population showing multiple resistance (Chahal et al., 2017; Jhala et al., 2014b).

Herbicides play a significant role in weed management in conservation tillage systems. Acuron® (Syngenta Crop Protection, LLC, Greensboro, NC 27419) is a new herbicide premix labeled for controlling broadleaf and grass weed species in corn in the United States (Anonymous, 2016). It contains four active ingredients from three modes of action [atrazine (PS II-), bicyclopyrone (HPPD-), mesotrione (HPPD-), and *S*-metolachlor (very long-chain fatty acid-inhibitor)] plus a crop safener, benoxacor; thereafter abbreviated as "ABMS". This is the first bicyclopyrone-containing herbicide available in the marketplace. Previously, several premixes containing at least two of the following components: atrazine, mesotrione, and *S*-metolachlor, have been studied to determine their weed-control efficacy in corn (Dobbels and Kapusta, 1993; Ferrell and Witt, 2002; Johnson et al., 2002; Taylor-Lovell and Wax, 2001); however, limited literature is available on the efficacy of a premix containing the aforementioned three components and bicyclopyrone (Kohrt and Sprague, 2017; Sarangi and Jhala, 2017a). Herbicide active ingredients from a new mode of action have not been commercialized in corn since the 1990s (Duke, 2012); therefore, the use of herbicide premixes, combining existing active ingredients are becoming important tool for the weed control in no-till and reduced-till production systems (Beckie, 2006; Beckie and Reboud, 2009; Owen, 2016).

Although the application of the preemergence (PRE) herbicides (especially atrazine and/or HPPD inhibitor) is common in corn (USDA-NASS, 2015), it is important to compare the efficacy of newly commercialized herbicide premixtures with commonly used PRE herbicides in corn for broad-spectrum weed management. In this study, the efficacy of ABMS was compared with five commonly used PRE herbicides by Nebraska corn growers (Table 1). The duration of residual activities of PRE herbicides can be altered by soil disturbances, or by plant residue present on the soil surface (Bauman and Ross, 1983; Curran et al., 1992; Johnson et al., 1989). Scientific literature is not available on the efficacy of ABMS compared with commonly used PRE herbicides in no-till and reduced-till corn production systems. Additionally, Devlin et al. (1991) mentioned that the recommended doses of herbicides are usually set high, or sometimes within a range so they will work on a broad range of weed species in different environmental conditions. As this premix is new for the corn growers, it is also important to determine the biologically effective doses to control problem weeds such as Palmer amaranth. The objectives of this research were to 1) evaluate the efficacy of ABMS for control of broadleaf and grass weeds in no-till and reduced-till production systems compared with commonly used corn herbicides applied PRE, along with their effect on corn injury and yield, and 2) determine the biologically effective doses of ABMS applied PRE for Palmer amaranth control in field conditions.