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EVALUATION OF THE EFFICACY OF MESOTRIONE PLUS NICOSULFURON WITH ADDITIVES AS TANK MIXTURES USED FOR WEED CONTROL IN MAIZE (*ZEA MAYS* L.)

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Abstract: The evaluation of the effects of grass and broadleaf weed control with different mixture rates of mesotrione plus nicosulfuron with methylated rapeseed oil and urea-ammonium nitrate liquid fertilizer (UAN) applied postemergence in maize was conducted in field experiments during the agricultural seasons of 2006, 2007 and 2008. Contact angle and surface tension were measured for all tank-mix solutions. There was no phytotoxicity observed on maize following the application of the herbicide-plus-additives treatment. Reduced rates of herbicide with additives provided similar control levels of *Echinochloa crus-galli* (L.) Beauv. as mesotrione used alone. The tank-mix of herbicides and adjuvants gave no antagonistic effect and it increased weed control. Plots treated with a reduced rate of tank-mix with additives, were always among the highest yielding as compared to untreated plots. Any reductions in cob and grain yield were associated with high weed fresh matter yields, indicating that it was the competition with weeds that led to a reduction in the maize grain yield and not the herbicide phytotoxicity.

Key words: weed control, tank-mix, mesotrione, nicosulfuron, additives, maize, *Zea mays*

INTRODUCTION

Weed control is an important management practice for maize production that should be carried out to ensure optimum grain yield (Skrzypczak and Pudełko 1993; Skrzypczak *et al.* 1995, 2005; Adamczewski *et al.* 1997).

Mesotrione is a new callistemone herbicide that inhibits the HPPD enzyme (p-hydroxyphenylpyruvate dioxygenase), a component of the biochemical pathway that converts tyrosine to plastoquinone and α-tocopherol (Lee *et al.* 1998; Cornes 2005). Following treatment in sensitive plants, carotenoid biosynthesis is disrupted in the chlorophyll pathway, resulting in a bleaching effect (Wichert *et al.* 1999). Mesotrione is a member of the benzoylcyclohexane-1,3-dione family of herbicides, which are chemically derived from a natural phytotoxin obtained from the *Callistemon citrinus* (Curtis) Skeels plants. Mesotrione has been shown to be effective for both pre- and postemergence control of weeds in maize (Sutton *et al.* 1999; Armel *et al.* 2003b). However, as it is a weak acid, mesotrione has been found to be highly absorbed by soil organic matter in acid soils, thus requiring higher rates when applied pre-emergent in these environments (Wichert *et al.* 1999). Mesotrione can be used to control weeds in conventional and no-till maize. It can also be used too control glyphosate tolerant weeds in glyphosate-resistant maize (Armel *et al.* 2003a, 2003c). Mesotrione, which provides control of major broad-leaved weeds, can be used in integrated weed management programmes, depending on the grower's preferred weed control strategy. With postemergence applications, mesotrione provides naturally selective control of key weed species that may show triazine resistance *e.g. Chenopodium album* L., *Amaranthus* spp., *Solanum nigrum* L., as well as weed species that show resistance to acetolactase synthase (ALS) inhibitors *e.g. Xanthium strumarium* L., and *Sonchus* spp. Thus, mestrione introduces a new naturally selective tool into weed management programmes for use in maize (Mitchell *et al.* 2001; Sutton *et al.* 2002). Maize is tolerant to mesotrione due to the slower uptake and selective metabolism of maize. In all cases, a grass herbicide is still needed in the weed control programme. Recently, mesotrione has been used as an effective tank-mix partner with pre-emergence or postemergence applications in maize for controlling broadleaf weeds and grasses (Mitchell *et al.* 2001). Weed control can be influenced by factors such as postemergence herbicide application rate, and timing, and use of additives. Since the activity of mesotrione in the soil is relatively short, optimum application methods and rates are essential for providing control of weeds that emerge before and after postemergence applications of mesotrione. Previous research has shown a synergistic activity between mesotrione and photosystem II inhibitors in the mixture, where herbicidal activity observed in the target

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plant was greater than expected (Sutton *et al*. 2002; Abendroth *et al.* 2006).

Nicosulfuron is a postemergence sulfonylurea herbicide that in low rates is able to control many difficult-to-manage monocotyledonous weeds, in maize. Nicosulfuron is safe for maize and the environment when used according to label recommendations. The water solubility of nicosulfuron and other sulfonylurea herbicides directly relates to the pH of the spray mixture and pKa of a hydrogen atom on the urea bridge. Some adjuvants called ''basic blends'', increase the pH of the spray mixture to increase solubility of weak acid herbicides and enhance biological activity (Green and Hale 2005). Tank-mixing of two or more herbicides is a practice which is becoming more common. Tank-mixing is done with most agronomic crops to control a wide spectrum of weeds, reduce production costs, and/or prevent the development of herbicide-resistant weeds (Zhang *et al*. 1995). Synergistic herbicidal activity has the potential to reduce application costs and amount of pesticides entering the environment (Streibig and Jensen 2000; Kudsk and Mathiassen 2004). Furthermore, the application of herbicides with independent modes of action in combination (tank-mix) rather than in rotation, has the potential to significantly delay the onset of herbicide resistance. Specific surfactants can alter the solubility of the leaf surface or perhaps the solubility of the herbicide, thereby increasing absorption. This allows polar herbicides to penetrate the nonpolar cuticle as well as enhance penetration through the slightly polar pectin portion of the leaf. The herbicide is available for cellular uptake, translocation, or action, but only after penetration through the cuticle, pectin, and cell wall. Activator adjuvants increase the activity of a given herbicide. The most common activator adjuvants are surfactants, which help with wetting, spreading, and dispersal. Surfactants either decrease phototransformation or increase absorption, or both (Penner 2000; Woźnica and Skrzypczak 1998).

Tank mixing of mesotrione and nicosulfuron is a common practice according to regulations of the European Union. In some cases these herbicides may replace the use of atrazine.

The objective of this research was to determine the influence of postemergence application rates of mesotrione plus nicosulfuron in combination with different additives on weed control and maize.

MATERIALS AND METHODS

Field trials were conducted using maize (cv. PR39B56) grown at the Brody Research and Education Station of Poznan University of Life Sciences, during the 2006–2008 agricultural seasons. The soil type was luvisoil with a pH ranging from 5.8 to 6.1. fertiliser and agronomic practices were applied according to State Soil Testing Laboratory recommendations. The experimental design was a randomised complete block with four replicates. The plot size was 2.8 m wide and 10 m long. Each plot contained four rows of maize planted at 70 cm row spacing. Mesotrione (Callisto 100 SC® – Syngenta®) and nicosulfuron (Milagro 040 SC® – supplied by Syngenta®) as the tank-mix were used at different rates [100+32 g/ha without additives, 75+30 g/ha and 50+20 g/ha both with MSO (methylated oilseed rape oil + buffer agent of 7.3–7.8 pH) at 1.5 l/ha, 75+30 and 50+20 g/ha both with UAN (urea-ammonium nitrate liquid fertilizer) at 4.0 l/ha and MSO at 1.5 l/ha, and 150 g/ha mesotrione only].

The parameters studied in the laboratory were surface tension and contact angles for all tanks-mix combinations. A drop of solution was used to measure the contact angle with optical tensiometer (Theta Lite) on a clean and dry Parafilm® surface. The instrument was calibrated. The calibration was confirmed using double-distilled water with a surface tension of 72.8 mN/m at 20°C.

Treatments were applied during the 4–6 leaf stage (BBCH 14–16) of maize growth using a bicycle mounted sprayer with fan nozzles of the Lurmark 02 110 type. The sprayer delivered 230 l/ha of spray solution at 220 kPa pressure.

Grass and broadleaf weed control as well as herbicide selectivity assessment to maize were evaluated 2 weeks after postemergence treatments using visual estimations (0 – no control and 100 complete controls). In July (8–10 weeks after planting), weeds were taken for fresh matter, and efficacy of weed treatments were calculated. Weed fresh matter was determined by cutting and collecting weeds at ground level in two middle rows, randomly selected from a 0.5 m^2 frame placed in each plot. The collected weeds were separated into grass and broadleaf species and then weighed. Cobs as well as grain yield were collected each year from the two adjacent middle rows in each plot. Maize grain, collected from each plot, was weighed and seed moisture was determined using a grain moisture tester. The seed yield was adjusted to 15.5% moisture. Weed control and yield of maize data were subjected to the analysis of variance, and treatment means were compared using the least significant difference test at 5% probability level.

RESULTS AND DISCUSSION

In conducted trials, maize plants showed good tolerance to mesotrione. No phytotoxic symptoms were observed in any of the mesotrione treatments alone or combinations with nicosulfuron and additives. These results agree with, James *et al.* (2006) and Sulewska *et al.* (2005), who indicated that maize plants showed good tolerance to mesotrione. The study conducted by Waligóra and Duhr (2004) showed no phytotoxicity to sweet maize in the cases where a mixture of mesotrione and atrazine were used.

The main weeds occurring on the untreated plots were: *E. cruss-galli*, *C. album*, *Viola arvensis* Murr., *Geranium pusillum* L., *Polygonum aviculare* and *P. convolvulus* L. (Table 1). Reduced rates of herbicide-with-additives provided similar levels of *E. crus-galii* control as mesotrione used alone. The addition of nicosulfuron to mesotrione or reduced rates in tank- mix with both herbicide and both additives, improved the control of broadleaf weeds. The addition of nicosulfuron to mesotrione improved the control of *P. convolvulus, P. aviculare, and V. arvensis*. Species like *G. pusillum*, were not adequately controlled by the mesotrione-treatment alone nor by tank-mix treatments.

Table 1. Weed control efficacy in applied treatments (2006–2008)

Treatment	Rate [g/ha]	Weed control efficacy [%]							
		visual broad-leaved	visual grasses	ECHCG	CHEAL	POLCO	POLAV	GERPU	VIOAR
Mesotrione	150	94 a	89 a	84	100	80	82	48	93
Mesotrione + nicosulfuron	100 + 32	94 a	92 a	88	100	86	97	20	98
Mesotrione + nicosulfuron + MSO*	75 + 30 +1.5 l/ha	95 a	94 a	86	100	73	47	0	100
Mesotrione + nicosulfuron + MSO* + UAN**	75 + 30 +1.5 l/ha +4.0 l/ha	97 a	95 a	88	100	88	76	84	98
Mesotrione + nicosulfuron + MSO*	50 + 20 +1.5 l/ha	94 a	94 a	85	100	44	56	0	95
Mesotrione + nicosulfuron + MSO* + UAN**	50 + 20 +1.5 l/ha +4.0 l/ha	93 a	93 a	80	100	80	65	54	95
Untreated (weeds g/m^2)	–	0 b	0 b	544	1145	57	13	37	13
LSD (0.05)	–	4.2	6.4	–	–	–	–	–	–

Values followed by a common letter in columns are not significantly different at $p < 0.05$
ECHCG – *Echinochloa crus-galli;* CHEAL – *Chenopo*dium *album;* POLCO – *Polygonum convolvulus;* POLAV – *Polygonum aviculare;* GERPU – *Geranium pusillum;* VIOAR – *Viola arvensis*
*MSO – methylated oilseed rape oil + buffer agent of 7.3–7.8 pH
**UAN – urea-ammonium nitrate liquid fertilizer

Table 2. Cob and grain yield of maize and some elements of yield structure as influenced by herbicide treatments (2006–2008)

Treatment	Rate [g/ha]	Yield [t/ha]		Weight of 1,000 grains [g]	Plant height [cm]
		cobs	grain		
Mesotrione	150	12.0 a	7.0 b	331.5 a	176 a
Mesotrione +nicosulfuron	100 + 32	13.0 a	8.5 a	334.0 a	182 a
Mesotrione + nicosulfuron + MSO	75 + 30 +1.5l /ha	12.7 a	8.5 a	333.6 a	183 a
Mesotrione + nicosulfuron + MSO + UAN	75 + 30 +1.5 l/ha +4.0 l/ha	12.4 a	8.2 ab	328.3 a	183 a
Mesotrione + nicosulfuron + MSO	50 + 20 + 1.5 l/ha	12.2 a	8.5 a	329.3 a	182 a
Mesotrione + nicosulfuron + MSO + UAN	50 + 20 +1.5 l/ha +4.0 l/ha	12.0 a	7.8 ab	328.8 a	180 a
Untreated	–	5.3 b	4.5 c	279.4 b	130 b
LSD (0.05)	–	2.04	1.31	17.22	19.3

Values followed by a common letter in columns are not significantly different at $p < 0.05$

However, the addition of urea-ammonium nitrate liquid fertilizer to reduced rates of herbicides always improved the control of the *G. pusillum* species. According to research conducted by Wichert and Pastushok (2000), the postemergence herbicide applications can be improved by adding 1% v/v crop-oil concentrate (COC) and 2.5% v/v urea ammonium nitrate (UAN). As a result, their addition to mesotrione, which inhibits carotenoid biosynthesis by inhibition of the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD), is complementary. Also, other research indicated that the addition of mesotrione plus atrazine to a sulfonylurea herbicide decreased herbicidal efficacy on *Setaria viridis* L., *Setaria glauca* L., and *Sorghum bicolor* L., compared with the sulfonylurea herbicide applied alone. In addition, increasing mesotrione application from 53 to 105 g/ha decreased efficacy of sulfonylurea herbicide in the tank-mix, on selected grass species (Schuster *et al.* 2008).

Also, Sulewska *et al.* (2005) reported that mesotrione needs an herbicide 'partner' to be more effective against *G. pusillum* control. The work of Lingenfelter *et al.* (2002) has shown that mesotrione applied postemergence provided > 90% control of *C. album, Abutilon theophrasti* Med. and *Amaranthus hybridus* L., but *Ambrosia artemisiifolia* L. and *P. convolvulus* control was improved by adding atrazine. Sulewska and Koziara (2006) also obtained better results of broadleaf weed control when mesotrione with atrazine was applied as a tank-mix. They observed complete weed control of such species as: *C. album, V. arvensis, Capsella bursa-pastoris* L., *Lamium purpureum* L. as well as *P. convolvulus*. James *et. al.* (2006) reported that all the broadleaf weeds present were significantly reduced by mesotrione, with the exception of *Portulaca oleracea* L. Portulaca was adequately controlled by atrazine, dicamba and nicosulfuron. Our presented results, and research work done by other authors are done with the new sustainable use directive of the European Union in mind. The new directive's preference is for the use of pesticides and other forms of intervention to be kept down to levels that are only necessary, *e.g.* by using reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and that intervention does not increase the risk for development of resistance in populations of harmful organisms (http://eur-lex.europa.eu).

Plots treated with mesotrione and mesotrione plus nicosulfuron with additives, were always among the highest yielding as compared to untreated plots. Any reductions in cob and grain yield were associated with high weed fresh matter yields, indicating that it was the weed competition that led to reduced yield and not herbicide phytotoxicity (Table 2).

Dynamic surface tension from the start was in the 29–44 mN/m range, but after 1 second, all measurements were stable at around 30 mN/m and did not influence efficacy (Fig. 1). All additives reduced contact angles of droplets on Parafilm® surface (Table 3). UAN may enhance herbicide absorption and translocation and deactivate antagonistic water salts. Oil additives increase herbicide absorption and spray retention. The water solubility limit of nicosulfuron increased after a buffer agent was added.

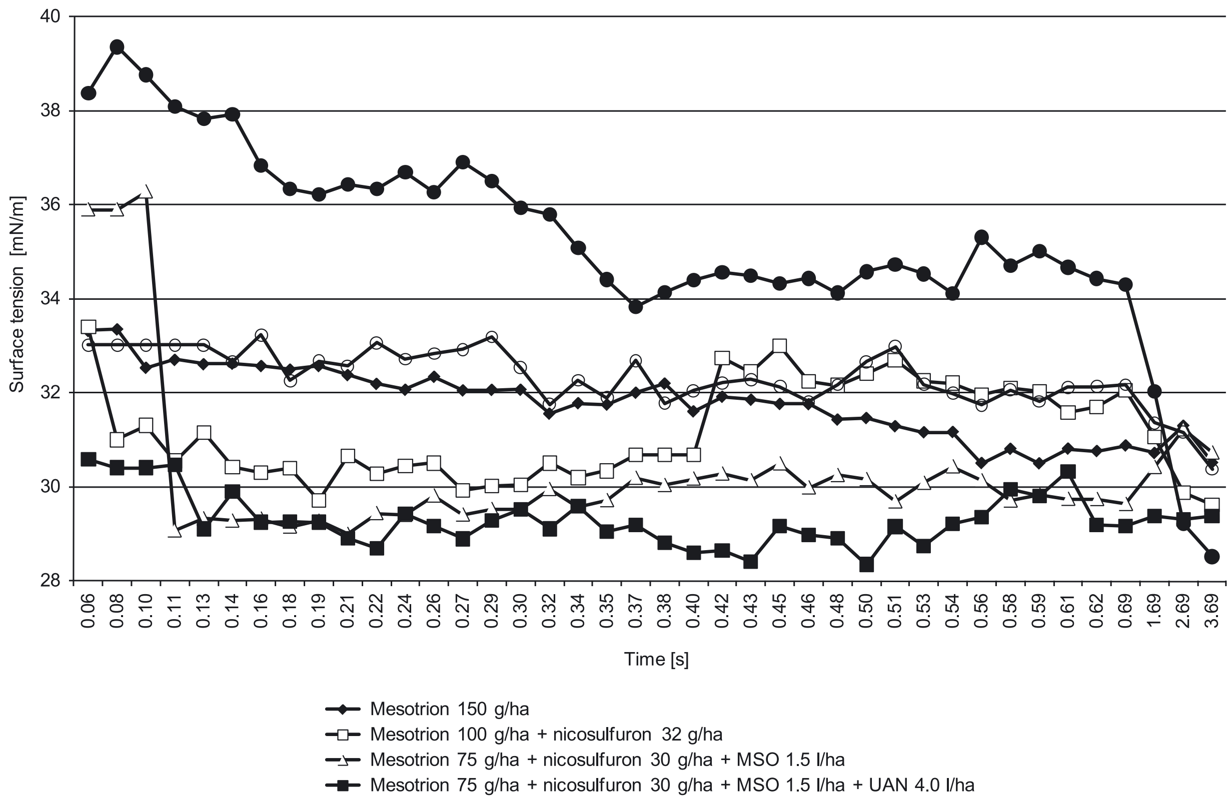

Fig. 1. Dynamic surface tension of all tank mix combinations

Table 3. Contact angle on the Parafilm® surface

Treatment	Rate [g/ha]	Contact angle [°]
Mesotrione	150	62.1
Mesotrione + nicosulfuron	100 + 32	60.0
Mesotrione + nicosulfuron + MSO	75 + 30 + 1.5 l/ha	55.1
Mesotrione + nicosulfuron + MSO + UAN	75 + 30 + 1.5 l/ha + 4.0 l/ha	50.2
Mesotrione + nicosulfuron + MSO	50 + 20 + 1.5 l/ha	53.0
Mesotrione + nicosulfuron + MSO + UAN	50 + 20 + 1.5 l/ha + 4.0 l/ha	55.9
Water	–	110.6

CONCLUSIONS

The presented results demonstrate that mesotrione was an effective herbicide for post-emergence control of weeds in maize, especially to broadleaf weeds. However, to ensure effective control of all weeds, mesotrione should be used in combination with an herbicide that has more activity on grass weeds (like a nicosulfuron). Using a combination of reduced rates of this postemergence herbicide with additives, overcomes many of the potential problems and also provides the best strategy for avoiding herbicide resistance. Selection will mainly depend on weed spectrum, cost, and use of restrictions.

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POLISH SUMMARY

OCENA MIESZANINY MEZOTRIONU I NIKOSULFURONU Z RÓŻNYMI WSPOMAGACZMI NA SKUTECZNOŚĆ ZWALCZANIA CHWASTÓW W KUKURYDZY (*ZEA MAYS* L.)

Po przeprowadzeniu badań polowych oceniono skuteczność zwalczania chwastów prosowatych i gatunków dwuliściennych w uprawie kukurydzy na ziarno, po zastosowaniu mieszaniny preparatów zawierających substancje aktywne: mezotrion i nikosulfuron. Stosowano je w obniżonych dawkach, z dodatkiem wspomagaczy zawierających ester metylowy oleju rzepakowego oraz płynny roztwór mocznika i saletry amonowej (RSM). Badania wykazały, że zastosowanie mieszaniny herbicydów w obniżonych dawkach wraz z ocenianymi wspomagaczami, pozwalało na uzyskanie podobnej skuteczności chwastobójczej, jak po zastosowaniu wyższych dawek herbicydów, lecz bez wspomagaczy. Ponadto stwierdzono, że zastosowane adiuwanty obniżały kąt przylegania kropli do powierzchni i szybko, po zabiegu, stabilizowały napięcie powierzchniowe cieczy użytkowej.

Dodatek nicosulfuronu do mezotrionu i zastosowanie niższych dawek tych herbicydów z adiuwantami, nie powodowało efektów antagonistycznych i obniżenia skuteczności zwalczania chwastów, a także nie miało fitotoksycznego wpływu na rośliny kukurydzy.