Turkish Journal of FIELD CROPS

Turkish Journal of
Field Crops
2013, 18(2), 174-178

EFFECT OF NITROGEN FERTILIZERS AND OIL ADJUVANTS ON NICOSULFURON EFFICACY

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Received: 23.01.2013

ABSTRACT

Effect of oil adjuvants and nitrogen fertilizers on weed control with nicosulfuron was investigated at two locations in the years 2006 – 2008. Treatments included nicosulfuron at 60 g ha^{-1} without adjuvant and at 30 g ha^{-1} with or without methylated seed oil (MSO) and petroleum (PO) and additionally with and without ammonium nitrate (AMN), urea (U) or urea – ammonium nitrate liquid fertilizer (UAN). Reduction of nicosulfuron rate from 60 to 30 g ha^{-1}, except *Echinochloa crus-galli*, significantly decreased *Chenopodium album*, *Viola arvensis*, *Polygonum convolvulus*, and *Polygonum aviculare* control. *E. crusgalli* control ranged from 93 to 99% regardless of herbicide and adjuvant treatment. However, addition of oil adjuvants, especially MSO strongly increased weed control, especially when used with AMN and UAN nitrogen fertilizers. Reduction of nicosulfuron rate from 60 to 30 g ha^{-1} strongly reduced grain yield of maize. However, addition of PO and MSO oil adjuvants, especially MSO applied in a mixture with AMN or UAN nitrogen fertilizers completely overcome this effect and allowed to obtain comparable grain yield of maize as obtained after application of recommended nicosulfuron rate (60 g ha^{-1}).

Key words: Methylated seed oil, mineral adjuvant, sulfonylurea herbicide, weed control.

INTRODUCTION

During the first weeks after sowing, maize (*Zea mays* L.) plants are particularly exposed to weed competition (Gosheh et al., 1996; Evans et al., 2003), including such persistent species as *Chenopodium album* L. and *Echinochloa crus-galli* (L.) Pal. Beauv. The presence of weeds during this period may result in considerable maize yield loss. According to Wilson and Westra (1991), the occurrence of *Panicum dihotomiflorum* Michx. in a maize field during the first two weeks after sowing, caused a 10% decrease in the crop yield.

Poor maize competitiveness with weeds makes human intervention necessary. The use of herbicides is the most effective method of weed control in maize fields. In the 1970s, sulphonylurea herbicides were discovered and introduced into the market. They soon became very popular as they control numerous persistent weed species, were safe for cultivated plants and the environment, and were characterised by low toxicity to mammals (Russell et. al., 2002).

Nicosulfuron belonging to sulfonylurea derivatives is an acetolactate synthase ALS inhibitor (EFSA, 2012; HRAC, 2012), which blocks the production of amino acids, such as valine, leucine and isoleucine, and, as a result, it interferes with the formation of proteins and other functional plant components. This herbicide was registered to post-emergent applications to control grass and some dicot weeds in maize. When used in recommended rates, nicosulfuron is safe for both maize plants and the environment. Nicosulfuron-containing herbicides are available in solid (Greek and Hale, 2005) and liquid formulations (Waligora and Szpurka, 2009). Nicosulfuron is a weak acid with the dissociation constant pK_a at a level of 4.3 (Greek and Hale, 2005; Regitano and Koskinen, 2008). Therefore, sulfonylurea herbicides are weakly absorbed by soil, especially with pH > pK_a (Martins and Mermoud, 1999). Nicosulfuron may be used together with non-ionic surfactants, petroleum oils, methylated ester of plant oils, often (with addition of urea ammonium nitrate (UAN) or ammonium nitrate fertilizer (AMS)) or basic (high pH) blend adjuvants for postemergence weed control (EXTOXNET, 2010).

Adjuvants added to spraying liquid are used to improve the effectiveness of foliage-applied herbicidal treatment (Hazen, 2000; Penner, 2000). This improvement mostly occurs when these preparations are used at reduced rates and in disadvantageous environment conditions (Praczyk and Adamczewski, 1996). The action of adjuvants consists mainly in increasing the retention of spray droplets, plant surface wetability and absorption of herbicide from spray deposit on plant surface into their cells (Sanyal et al., 2006).

The objective of this study was to determine the effectiveness of different oil and nitrogen fertilizer adjuvants on efficacy of nicosulfuron applied at reduced rate and to determine this effect on maize grain yield.

MATERIALS AND METHODS

Field trials were conducted during the 2006, 2007 and 2008 growing seasons at Brody and Zlotniki, located near Poznan, Poland. Experimental fields were prepared according to good experimental practice – moldboard plowed in the fall, and shallow cultivated in the spring prior to planting. Mineral fertilization was adjusted to the plants' needs, taking into account the nutrient content in the soil. Phosphorus and potassium were applied in both locations prior to plowing in the fall at 60 and 117 kg ha^{-1}, respectively. A broadcast application of nitrogen fertilizers in Brody and Zlotniki, was at 140 kg ha and 160 kg ha^{-1}, respectively. Each year maize was planted in the first 10 days period of May. Soil texture, soil organic matter content, soil pH, corn hybrid, seeding date, seeding rate and herbicide application dates are presented in Table 1.

Table 1. Soil characteristics, corn hybryd, seeding date, seeding rate and spray dates for experiments conducted in Brody and Zlotniki, PL, in 2006 – 2008

Year	Location	Soil texture	Soil organic matter (%)	Soil pH	Corn hybrid	Seeding date	Seeding rate (seeds ha)	Spraying date
2006	Brody	sandy loam	1.5	6.1	Fido	April 20	75,000	May 17
	Zlotniki	sandy loam	1.1	5.3	Claryca	April 28	84,000	May 22
2007	Brody	sandy loam	1.5	6.0	PR39T45	April 17	80,000	May 21
	Zlotniki	sandy loam	1.1	5.3	Claryca	April 13	84,000	May 11
2008	Brody	sandy loam	1.2	6.1	PR39B56	April 18	80,000	May 16
	Zlotniki	sandy loam	1.0	5.8	PR39K	April 15	84,000	May 15

Field experiments at each localization were established as a randomized complete block design with 4 replication, on 2.5 x 10 m plots, consisting of 4 rows of plants with 70 cm spacing. Seeds were planted at a depth of 4 cm, with 19.5 cm spacing in a row.

Treatments included an untreated check and nicosulfuron (Accent 75 WG, DuPont Poland) at 60 g ha^{-1} (recommended rate) and 30 g ha^{-1} (reduced rate). Reduced rate of nicosulfuron was applied alone and with two oil origin adjuvants: 1) MSO – methylated seed oil of rapeseed oil fatty acids with a build-in system buffering pH of the liquid spray liquid at the level of 7.3 – 7.8 plus emulsifier (Atpolan BIO 80 EC, ZPH AGROMIX, Niepolomice, Poland) and 2) PO – emulsified petroleum oil (Atpolan 80 EC by ZPH AGROMIX, Niepolomice, Poland), both at 1.5 L ha^{-1}. Oil origin adjuvants were applied alone or in a mixture with ammonium nitrate (AMN), urea (U), both at 30 g ha^{-1} and urea – ammonium nitrate liquid fertilizer (UAN) at 4 L ha^{-1}, at the 4-5-leaf stage of maize. Herbicide treatments in Brody were performed using a CO_2-pressurized plot sprayer equipped with flat fan nozzles Tee Jet DG 11002, delivering 230 L ha^{-1} of water at 220 kPa, and in Zlotniki with a CO_2-pressurized plot sprayer equipped with flat fan nozzles Tee Jet 11003 VP, calibrated to deliver 200 L ha^{-1} of water at 200 kPa. Herbicide application were made with a 2 m boom equipped with five nozzles spaced 50 cm apart. Application dates and environmental conditions at application (air temperature and humidity) for both locations are listed in Table 2.

Table 2. Herbicide application dates and environmental conditions at application

Year	Location	Application date	Air temperature at treatment ºC	Air humidity at treatment %	Mean air temperature 1 WAT* ºC	Rainfall 1 WAT* mm
2006	Brody	May 25	23.6	70	19.2	0.1
	Zlotniki	May 22	21.0	60	13.4	14.6
2007	Brody	May 17	21.7	58	14.7	7.6
	Zlotniki	May 11	21.0	75	13.7	42.8
2008	Brody	May 21	24.9	68	20.8	31.9
	Zlotniki	May 15	19.0	51	14.0	7.5

*first 7 days after treatment

Six weeks after treatment weeds were cut off at the soil surface from two 0.7 m^{-2} rectangle in each plot and biomass of each species was determined. Assessment of herbicidal efficacy based on the Henderson-Tilton formula. Estimation of crop injury was rated 2 and 4 weeks after treatment using 0 to 100% scale (0% = no injury and 100% = plant death). Yield was measured at crop maturity by harvesting cobs from two middle rows of each plot and the weight and seed moisture content were recorded. Maize grain yield was expressed at 15% moisture level.

An analysis of variance was conducted on all data. Data were analyzed using procedures in ARM 8 (Agricultural Research Manager, Gylling Data Management, Inc.) manage and statistical summarize software. Variances were partitioned into the fixed effects of year and location, and the interaction of year and location by the fixed effect. Percent weed control data were transformed prior to analysis to correct for unequal variance and then back-trans-formed for presentation in the tables. Mean separation using Protected Tuckey`s Least Significance Difference was used to separate treatment means (P = 0.05).

RESULTS AND DISCUSSION

Air temperature at herbicide treatment, depending on years and locations, ranged from 19.0 to 24.9 °C, and relative humidity from 51 to 75% in Zlotniki and from 58 – 70% in Brody. The average temperature during the the first 7 days after application varied from 13.4 – 14.0 °C in Zlotniki and from 14.7 – 20.8 °C in Brody. The amount of rainfall during first week after treatment did not exceed 43 mm in Zlotniki and 32 mm in Brody (Table 2). Good absorption of the active ingredient of herbicides ensuring their efficacy takes place when physiological processes in weeds are sustained at a relatively high level. For most herbicides the optimal air temperature ranges from 10 to 25 ºC at appropriate humidity (Caseley, 1989; Joseph et al., 1996). Generally, the higher temperature the higher activity of herbicides is observed (Kells et al., 1984; Anderson et al., 1993). However, application of herbicide at too high temperatures may reduce their effectiveness due to wilting, closing of the stomata and quick drying of the spray liquid droplets, caused by limited herbicidal absorption (Ritter and Coble, 1981). However not only temperature and humidity influence herbicidal action, but also the weed. For example, development *Amaranthus rudis* Sauer and *Digitaria sanguinalis* L. Scop. was inhibited more effectively by mezotrion at 18 ºC than at 32 ºC, as opposed to, e.g. *Abutilon theophrasti* L. and *Xanthium strumarium* L. (Johnson and Young, 2002). Similar interactions are also pointed out by other authors (Kells et al., 1984). The weather conditions in all the years and in both location during application and several days after were favourable for the herbicidal action.

In total 20 weed species were identified at experimental plots. Weed community varied across locations and years and only weed species occurring during all years in both locations were analysed. There was no injury to corn with the herbicides and adjuvant evaluated (data not shown). The random effects of location, year and their interactions were not significant, therefore weed control and grain yield data were pooled only by treatment.

There were significant differences amongst treatments in herbicidal efficacy on prominent individual weed species based on their percent control by fresh mass reduction. Reduction of nicosulfuron rate from 60 to 30 g ha^{-1}, except *Echinochloa crus-galli,*' significantly decreased or tended to decrease *Chenopodium album*, *Viola arvensis* Murr., *Polygonum convolvulus* L., *Polygonum aviculare* L. and *Geranium pusillum* L. control. For example, nicosufuron at recommended rate of 60 g ha controlled the most occurring weed *Chenopodium album* merely in 80% and at reduced rate of 30 g ha^{-1} a strong decrease in efficacy (to 57%) was observed (Table 3). Nicosulfuron effectively limits the occurrence of monocot weeds, for example *Setaria* species, as well as *Agropyron repens* (L.) Pal. Beauv. or *E. crus-galli*, and some dicot weeds such as *Amaranthus retroflexus* L. and *Fagopyrum esculentum* Moench but it does not control *Chenopodium album* and *Solanum nigrum* L. at satisfactory level (NDWCG, 2010). Our results indicate that nicosulfuron applied alone at recommended or reduced rate even without adjuvants greatly controled only *Echinochloa crus-galli*, control ranged from 93 to 99% and was not modified by herbicide and herbicide-adjuvant treatment. Auskalniene and Auskalnis (2006) and GWC (2008) also confirmed high sensitivity of this species to nicosulfuron. In most cases, even a reduction of nicosulfuron rate, especially with adjuvants, does not limit its effectiveness in relation to other annual grass weed species (Nalewaja et al., 1998; Green and Hale, 2005).

All adjuvant treatments provided greater control of weeds compared to the use of nicosulfuron at 30 g ha^{-1} without adjuvant. However, there were no statistical differences observed among MSO, PO, and PO + U (efficacy 70, 64 and 66%, respectively). The addition of nitrogen fertilizers increased or tended to increase control of most weed species however the herbicide effectiveness depended on added nitrogen adjuvant to nicosulfuron with MSO or PO. The mixture of MSO or PO with AMN or UAN was more effective than with U. Generally nicosulfuron applied with MSO and AMN or UAN greater controlled most weed species than with PO.

Table 3. Weed control as influenced by oil and nitrogen fertilizer adjuvants with herbicide treatment (average from Zlotniki and Brody 2006 – 2008)

Nicosulfuron rate	Adjuvant*	CHEAL	VIOAR	POLAV	ECHCG	POLCO	GERPU
g a.i. ha		% control					
Untreated check	-	847 (g m^{-2})	183 (g m^{-2})	180 (g m^{-2})	140 (g m^{-2})	139 (g m^{-2})	77 (g m^{-2})
60	None	80	97	88	98	93	96
30	None	57	83	59	98	74	82
30	MSO	70	95	73	99	91	91
30	MSO + AMN	87	92	86	93	93	95
30	MSO + U	76	93	74	96	87	96
30	MSO + UAN	83	97	81	98	88	94
30	PO	64	92	73	99	86	88
30	PO + AMN	79	96	78	98	95	99
30	PO + U	66	90	69	99	90	93
30	PO + UAN	80	96	84	97	85	94
LSD 0.05		15.8	9.6	22.2	ns	17.0	13.1

Note. ns, not significant at P = 0.05 level; * MSO, methylated seed oil at 1.5 L ha^{-1}; PO, petroleum oil at 1.5 L ha^{-1}; AMN, ammonium nitrate at 3.3 kg ha^{-1}; U, urea at 2.5 kg ha^{-1}; UAN, 28% N urea-ammonium nitrate liquid fertilizer at 4.0 L ha^{-1}

GERPU – *Geranium pusillum*; ECHCG – *Echinochloa crus-galli*; VIOAR – *Viola arvensis*; CHEAL – *Chenopodium album*; POLCO – *Polygonum convolvulus*; POLAV – *Pologonum aviculare*

The data relating to the effect of the herbicide mixture with adjuvants on grain yield indicate significant differences among treatments. The lowest grain yield of 3.5 t ha was recorded with the untreated check that was at par (5.0 t ha^{-1}) with the application of nicosulfuron at reduced rate (Figure 1). Significantly higher grain yield was harvested from plots when nicosulfuron at 60 g ha^{-1} and at reduced rates with all adjuvants were applied. The grain yield from the plots where nicosulfuron was applied with PO and MSO was comparable to the yield obtained after the application of 60 g ha^{-1}. The addition of AMN or UAN to a spray liquid, led to a further yield increase, however this trend was not statistically confirmed. The results of the research make it possible to conclude that the effectiveness of treatment does not depend only on the rate of the herbicide but also on the appropriately selected adjuvant. The research also showed that only a mineral adjuvant appropriately selected in respect of the active ingredient increased the efficacy of the treatment. Greek and Cahill (2003) found that the addition of adjuvants with buffering properties (pH adjuster) were able to enhance nicosulfuron action by maintaining the alkaline reaction of the spray liquid, as sulfonylurea herbicides are highly water soluble in an alkaline environment and their activity increases, especially if they are used with crop oil concentrate, modified seed oil, and hydrophilic nonionic surfactants. The results of various experiments show that oil adjuvants, just as in the present author's study, differ in respect of their influence on the herbicidal effectiveness of nicosulfuron. Our results are confirmed by Nalewaja et al. (1995) who pointed out that nicosulfuron was the most effective in a mixture with MSO adjuvant, next, when combined with seed oils, and its effectiveness was the lowest with paraffin oil.

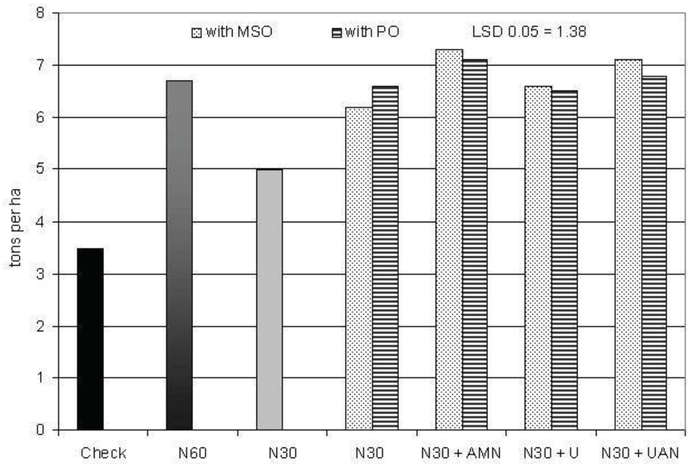

Figure 1. Grain yield of maize in correlation to herbicide treatments (average from Zlotniki and Brody 2006 – 2008) N60, nicosulfuron at 60 g ha^{-1}; N30, nicosulfuron at 30 g ha^{-1}; MSO, methylated seed oil at 1.5 L ha^{-1}; PO, petroleum oil at 1.5 L ha^{-1}; AMN, ammonium nitrate at 3.3 kg ha^{-1}; U, urea at 2.5 kg ha^{-1}; UAN, 28% N urea- ammonium nitrate liquid fertilizer at 4.0 L ha^{-1}

It is widely known that addition of nitrogen fertilizers to spray mixtures of certain foliar-applied herbicides enhances herbicide efficacy (Joost, 1998). The most commonly used are ammonium sulfate, ammonium nitrate and also urea – ammonium nitrate liquid fertilizer (Woznica, 2003). According to Gronwald at al. (1993) direct impact of mineral adjuvants may be cause by the effect of ammonium ions on the foliar penetration, and consequently the active transport of herbicides into plant cells. Many authors showed that more important is indirect effects of mineral adjuvants consisting of overcome any antagonism of Ca^{+2}, Mg^{+2}, Na^{+1} and other, often present in high concentrations in natural waters used for the preparation of liquid spray (Woznica, 1990; Nalewaja and Matysiak, 1993; Thelen at al., 1995).

According to Nandula et al. (1995) nicosulfuron applied with adjuvants has a positive effect on the grain yield of corn. In our study the effect of herbicide treatment on corn yield was variable. Adjuvants and nitrogen fertilizers, especially AMN and UAN, had rather consistent effect on grain yield increase. Grain yield was higher on plots treated with nicosulfuron with oil adjuvants and AMN or UAN as compared with U. Grain yield was always much higher in plots treated with herbicide and adjuvants than in untreated plots.

CONCLUSIONS

Effective weed control is guaranteed by nicosulfuron applied alone at the recommended rate, but also at reduced rate but with edition of properly chosen adjuvant or adjuvants. The presence of adjuvant in the spray liquid with different mechanisms of action, first of all MSO, especially with nitrogen fertilizer, preferably improve nicosulfuron activity. Higher weed control generally positively impact on the growth and yield of maize.

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