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Research paper

Split application of glyphosate in herbicide-tolerant maize provides efficient weed control and favors beneficial epigeic arthropods

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ABSTRACT

Wide deployment of genetically modified herbicide-tolerant (GMHT) maize may affect the efficiency of weed control methods and impair ecosystem functioning. We examined these potential threats using glyphosate-tolerant maize NK603 (Monsanto Technology LLC, St. Louis, MO, USA) planted in 54 randomly distributed plots in 2013 and 2014. Maize was grown in three herbicide treatments combined with six tillage regimes. Conventional, single post-emergence application of a selective herbicide MaisTer (Bayer CropScience GmbH, Frankfurt am Main, Germany; hereafter as MT) was compared with two herbicide strategies used in the glyphosate-tolerant crops: split application of Roundup Rapid (Monsanto Europe S.A./N.V., Brussels, Belgium; hereafter as RRRR) and application of this herbicide mixed with the soil residual herbicide Guardian Extra (Monsanto Europe S.A./N.V.; hereafter as RRGE). MT proved unreliable, whereas RRRR and especially RRGE provided efficient weed control and affected weed performance during the season. RRRR permitted restoration of weed cover during the latter half of the cultivation season. Conventional, reduced, and conservation (mulching with *Hordeum vulgare*, *Phacelia tanacetifolia*, *Sinapis alba*, and *Trifolium incarnatum*) tillage had minor effect on the weed performance. Carabids, staphylinids, and spiders were monitored to assess environmental impact of tested weed management practices. Carabid communities were not affected by the type of tillage but responded to the herbicide treatments. The plots treated with MT harbored the highest carabid activity abundance and species richness, followed by RRRR, and then by RRGE. RRRR and RRGE treatments also reduced the rise of staphylinid abundance and species richness after harvest, while conventional tillage negatively affected staphylinids at the start of the cultivation season. Spider and carabid activity abundance was similar, but spider species richness was highest in the RRRR plots. Neither herbicides nor tillage strongly affected arthropod species evenness. Multivariate analysis showed that weed species richness was significantly correlated with the species activity abundance of all three arthropod groups; weed coverage had a similar but smaller effect but the effect of herbicides and tillage was negligible. We concluded that herbicide treatments curbed weed performance which consequently influenced associated arthropods.

The RRRR herbicide treatment adequately regulates weeds and exerts restoration of weed cover later in growing season that is beneficial to the arthropods. Thus, GMHT crops have a potential to combine economic and environmental advantages for agroecosystem sustainability and can be recommended for implementation in European crop production systems.

1. Introduction

Tolerance to the herbicide glyphosate is the most common genetic modification (GM) in crops (ISAAA, 2016), reflecting the dominance of weed control as a challenge for modern agriculture (Ricroch et al., 2016). Prior to the development of genetically modified herbicide-tolerant (GMHT) crops, glyphosate application was restricted to pre-planting, pre-harvest, and post-harvest periods. However, glyphosate-

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tolerant crops can be treated throughout entire season whenever weed competition is particularly intense (Young, 2006). Currently, to reduce the selection of weed resistance, glyphosate is usually combined with other herbicides differing in mode of action. When using glyphosate alone, it is applied twice (usually referred as "split application") – early and late in the season relative to the cash crop growing season – because weeds emerging in different times.

The timing of glyphosate application affects seasonal changes in weed diversity and abundance (Duke and Powles, 2008; Soukup et al., 2008). Both living and dead weeds provide resources and heterogeneous habitat structure for a wide range of arthropods by supporting their growth and dispersion (Andow, 1991; Capinera, 2005; Norris and Kogan, 2000). By promoting interspecific competition, weeds contribute to agroecosystem resistance to the pest outbreaks (Jabbour et al., 2016).

Few studies have examined how GMHT crops affect arthropods. Existing research indicates that GMHT oilseed rape has no effect on chrysomelid, curculionid, and mirid pests (Cárcamo and Blackshaw, 2007). The insect-resistant GMHT maize also did not affect any of the examined arthropods (García et al., 2012; Pálinkás et al., 2016; Svobodová et al., 2013, 2016). More attention has been paid to the effects of GMHT crops on the weed management. The results tend to show that differences from the standard maize cultivation are indirect consequences of altered agricultural techniques rather than direct influence of the genetic modifications (Bourassa et al., 2010; Brooks et al., 2005; Graef et al., 2007; Hawes et al., 2003; Kolseth et al., 2015).

The commercial use of GMHT crops is often combined with reduced or conservation tillage (e.g., mulching). These agricultural practices have significant environmental benefits (Ladoni et al., 2016; Perego et al., 2016; Quintanilla-Tornel et al., 2016; Schipanski et al., 2014), but are also associated with crop management problems (Norris and Kogan, 2000; Shrestha and Parajulee, 2010). In this study, we compare the overall effects of three herbicide and six tillage regimes in plots planted with NK603, a GMHT maize commercially launched in 2000 that has more approvals for cultivation than any other GM crop (ISAAA, 2016). We monitored weed performance under the different treatments, and then examined how herbicides, tillage, and weed communities affected the abundance, species richness and evenness of carabid, staphylinid, and spider communities. These arthropod taxa were selected to represent a wide range of feeding behavior, from obligate zoophagy (predators) to obligate phytophagy (granivores, mycophages, algophages) or saprophagy. These beneficial epigeic arthropods are sensitive to ecological disturbances and therefore suitable as bioindicators of environmental changes, including different weed management practices in agroecosystems (Boháč, 1999; Marc et al., 1999; Saska et al., 2014). This data is important for environmental risk assessment of agronomic treatments, as well as for biodiversity conservation and sustainability in agroecosystems. Our results contribute to current European efforts aimed at reducing soil erosion (European Commission, 2016).

2. Material and methods

2.1. Field trial design

The field site was located close to Odřepsy village in Central Bohemia (50°09′12.5"N 15°11′58.5"E), a productive agricultural region with high weed species diversity and soil seed bank. The trial was established after winter wheat cultivation. We divided the area of 4.38 ha into three sectors with different herbicide treatments. In each herbicide treatment sector, six tillage treatments in three replications were randomized. The trial consisted of 54 plots (5.40 a each) isolated with 1.5-m strips of bare land and 6 m manipulation aisle between replications (Fig. 1). The isolation field margin was sown with eight rows of DKC 3399 (Dekalb c/o Monsanto Agrar Deutschland GmbH, Düsseldorf, Germany), a conventional maize variety that matures similarly to the experimental GMHT maize NK603 (MON-ØØ6Ø3-6, Roundup Ready™ 2 Maize, Monsanto Technology LLC, St. Louis, MO, USA). A 2-m strip of bare land separated the DKC 3399 buffer zone from the experimental plots. To avoid cross-pollination, all neighboring fields were seeded with cereals in 2013, then with oilseed rape and cereals in 2014.

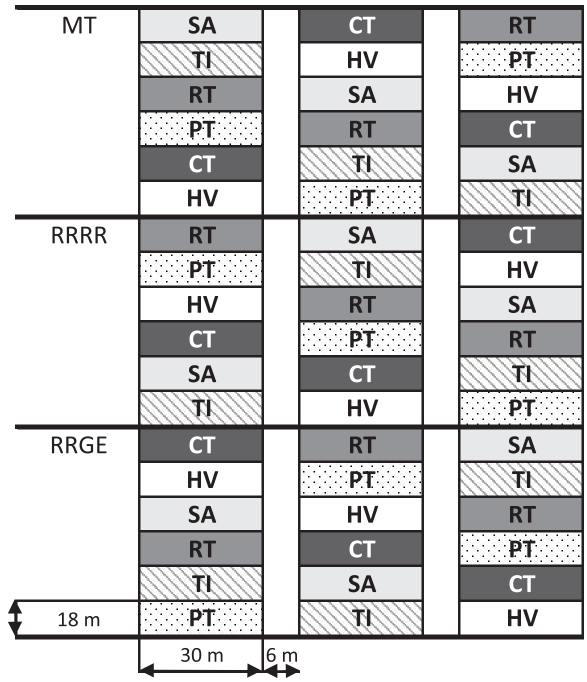

Fig. 1. Study plot distribution with herbicide and tillage regimes marked. Herbicide regimes: MT: MaisTer; RRRR: Roundup Rapid; RRGE: Roundup Rapid + Guardian Extra. Tillage regimes: CT: conventional tillage; RT: reduced tillage; HV: conservation tillage with *Hordeum vulgare*; PT: with *Phacelia tanacetifolia*; SA: with *Sinapis alba*; TI: with *Trifolium incarnatum*.

Variety NK603 was sown in all experimental plots at a density of 85-thousand kernels per hectare, and cultivated with standard agricultural practices. Crop was harvested by combine and after the weighing of grain, plant material was crashed and ploughed 25 cm deep into the soil (Table 1).

Interactive Map (Geospatial) data here

2.2. Herbicide regimes and soil tillage

Herbicides were applied in three regimes (treatments). The first was a conventional strategy, with widely used herbicide (MT) and other two herbicide strategies were a split application of glyphosate (RRRR) and combination of glyphosate with soil residual herbicide (RRGE), both intended for use in glyphosate-tolerant crops. Conventional post-emergence selective systemic herbicide MaisTer (MT; a.i. 30% foramsulfuron, 1% iodosulfuron-methyl-sodium, 30% isoxadifen-ethyl,

Table 1
Timeline for pitfall trap exposure, maize sowing, and harvest.

Sample collection		Maize growth stage	2013	2014
First			April 15	April 25
	sowing	BBCH 00[a]	May 15	May 14
Second		BBCH 09, VE[b]	May 23	June 5
Third		BBCH 16, V6	June 27	June 26
Fourth		BBCH 65, VT	August 8	August 8
Fifth		BBCH 87, R5	September 19	September 18
	harvest	BBCH 99	November 8	November 3
Sixth			November 14	November 6

[a] Staging according Lancashire et al. (1991).
[b] Staging according Ritchie et al. (1992).

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