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Response of soil biological activity to common herbicide strategies in sugar beet cultivation

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ABSTRACT

Agricultural intensification is strongly related to the application of pesticides which may substantially affect agroecosystems. It is recognized that the effect of pesticides on agroecosystems is associated with the application of multi-component mixtures rather than from individual pesticides. In sugar beet (*Beta vulgaris* L.) cultivation, the most used pesticides are herbicides. Herbicides are commonly applied with varying intensities depending on their amount of active ingredients and dosages to coincide with weed species-specific occurrence. Research on their ecotoxicological effects on functional attributes of agroecosystems has not received adequate attention. This study aims to determine the impact of three common sugar beet herbicide strategies (HS) on the biological activity of the edaphic community, proposed as a functional indicator for potential decomposition capability. The strategies compared were: HS1: two herbicides, 100% of authorized application rate; HS2: three herbicides, <50% of authorized application rate; HS3: six herbicides, ≤35% of authorized application rate. To discern anticipated small differences, different tillage intensities (ploughing and mulching) and comprehensive field trials at 19 environments (site × year) distributed throughout Germany were compared. Feeding activity on bait substrate and the mass loss of wheat straw were measured to quantify the effect of HS on the decomposition activity of the edaphic community.

Overall, this study demonstrated that no consistent significant differences in biological activity were found among herbicides strategies. Environment and tillage intensity were the main factors influencing the biological activity of the edaphic community. Biological activity was highly variable among environments and was reduced by differences in tillage. Furthermore, temperature was observed to be an important factor for the biological activity. Moreover, soil parameters resulting from reduced tillage intensity in the mulching system enhanced biological activity. In conclusion, clear and direct effects of changing herbicide strategies on the functional integrity of the edaphic community could not be discerned. These results were quantified for the first time through considering multiple influencing factors *in situ*.

1. Introduction

Ecosystem services can be defined as 'the benefits that people obtain from an ecosystem' (MEA, 2005). In agriculture, the soil ecosystem provides benefits in many areas, *inter alia*, in soil formation, detoxification, disease control, and nutrient cycling that support crop yield and thereby income (Barrios, 2007). The value of this service is driven by many essential natural functions of the edaphic community and its biological activity. One of the most important soil processes is nutrient cycling, which is strongly associated with the breakdown of organic matter (Swift et al., 1979; Gongalsky et al., 2008). Furthermore, this process contributes to soil fertility, which is closely related to cropping productivity (Diacono and Montemurro, 2010).

Decomposition of organic matter is partly based on the biological activity of the multitrophic edaphic community and its complex interactions (Murphy et al., 1998; Bardgett and Chan, 1999; Edwards, 2002). While soil macrofauna (e.g., earthworms, enchytraeidae, springtails) are primarily responsible for the breakdown of structural tissue, the microflora (bacteria and fungi) predominantly perform biochemical transformations and thereby nutrient releases (Lavelle, 1997). Abiotic factors, like water and temperature, may limit decomposition (Strickland et al., 2009). Otherwise, the biological activity as a functional parameter is a sensitive ecological indicator in relation to agricultural management intensities (Burrows and Edwards, 2002; Lupwayi et al., 2004; Marinari et al., 2006). The intensity markedly influences the biological activity of soil organisms, potentially causing variation

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in ecosystem services (Postma-Blaauw et al., 2010). In particular, pesticide application and tillage operations are used with considerable variation in intensity and may substantially affect the activity of soil organisms (Riley et al., 2008). The magnitude of response of soil organisms to these management-induced impacts is species-specific, which may result in impairment.

Sugar beet (*Beta vulgaris* L.) is extremely sensitive to weed competition during the initial growth stages, so effective weed control is critical (Mittler et al., 2002; Märländer et al., 2003). Herbicides are an essential tool in weed management. They are commonly applied using site-specific strategies reflecting local weed population. In general, the activity of the edaphic community is indirectly affected when a strong reduction of weed density results in food limitation and shelter loss (Edwards, 1984; Marshall et al., 2003). Most of the herbicides used usually are not directly toxic to the soil fauna (Lee, 1985; Freemark and Boutin, 1995; Bamford, 1997) compared to the direct effect of fungicides and insecticides (Edwards and Bohlen, 1992). This non-toxicity was assessed by investigating the effect on diverse soil organisms of the edaphic community using single herbicidal active ingredients (e.g., Wardle et al., 1999; Farenhorst et al., 2003; Pereira et al., 2009) or combinations (e.g., House et al., 1987; Lupwayi et al., 2009) without considering intensity-oriented approaches. Direct toxic effects of herbicides on soil organisms have mainly been demonstrated in laboratory assays (e.g., Novais et al., 2010; Haque et al., 2011). However, results of laboratory tests cannot be extrapolated to the complexity of an *in situ* field situation where different environmental properties influence the effect and conversion of substances (Amorim et al., 2005).

Tillage is another tool used for weed control. In sugar beet cultivation, conservation tillage is also quite common (Buhre et al., 2011) to reduce runoff and erosion (Koch et al., 2003) and to stabilize income (Märländer et al., 2003). It is well known that reduced tillage compared to ploughing benefits the edaphic activity due to food retention at the soil surface and to decreased physical disruption of soil (Holland, 2004). In this context, the response of biological activity to the intensity of weed management in sugar beet cultivation has not yet been the subject of system-oriented investigations quantitatively measured *in situ*.

The objective of this study was to elucidate the response of the biological activity within the edaphic community to the application of three herbicide strategies differing in application rates and amounts of active ingredients. The performance of decomposition was measured as mass loss of wheat straw and feeding activity on artificial bait substrate using the mini-container test (Eisenbeis, 1993) and the bait-lamina assay (von Törne, 1990). In order to discern anticipated minor significance among herbicide strategies, and anticipating potential interactions within herbicide–tillage systems, multifactorial research project was conducted in 2008 and 2009: two tillage intensities and comprehensive field trials at 19 broad-scaled environments (site × year) distributed throughout Germany.

2. Materials and methods

2.1. Sites and cultivation

The experiments were carried out at 19 sites in Germany, nine in 2008 (A–I) and 10 in 2009 (J–S) (Table 1). The sites reflect large variation in soil and weather parameters and represent highly productive farming conditions for sugar beet production in Central Europe. Details of environmental conditions at sites are given in Table 1. Soil parameters of each site were obtained by representative soil samples taken by a gouge auger and soil profile pits. Meteorological data were gathered from adjacent weather stations.

Prior to sugar beet sowing in March or April, all fields were planted with yellow mustard (*Sinapis alba* L.) as a catch crop. The preceding crop was either winter wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.). Fields of long-term conservation tillage were chosen and divided in half for the assignment of tillage treatments. One half of the field was mouldboard ploughed in autumn to 0.25–0.30 m depth (hereinafter referred to as ploughing system). Consequently, residues of the catch crop were incorporated into the soil. The other half was managed by reduced tillage with a rotary cultivator for stubble cultivation of the catch crop which mixed soil down to 0.05–0.17 m depth. This treatment is hereinafter referred to as mulching system since a cover of yellow mustard residues remained on the soil surface. In both tillage systems either rototiller or harrow were used for overall seedbed preparation and agricultural means were carried out site-specifically in accordance to local extension service.

The three herbicide strategies combined different numbers of active ingredients (a.i.) and application rates (Table 2) involving

Table 1
Pedological and meteorological conditions of the field trial sites, Germany 2008/2009.

Site (coordinates)	Soil type	Texture	Soil valuation index[a]	pH value[b]	Temperature[c] (⌀ °C)	Precipitation[d] (Σ mm)	Organic carbon content[b] (%)
A (51°5.571′N 12°9.896′E)	Luvic Phaeozem	Clay silt	84	6.5	9.8	615	1.8
B (49°38.310′N 10°9.714′E)	Haplic Luvisol	Clay silt	78	6.9	9.8	607	1.0
C (49°36.602′N 8°4.710′E)	Calcic Luvisol	Clay silt	78	7.3	10.5	436	1.4
D (48°52.385′N 9°1.209′E)	Luvisol	Clay silt	72	6.9	10.4	690	1.2
E (50°51.554′N 6°36.503′E)	Luvisol	Clay silt	75	6.6	10.7	650	0.9
F (52°16.255′N 10°27.382′E)	Stagnic Cambisol	Sandy loam	55	7.0	10.3	621	1.5
G (53°5.154′N 10°28.481′E)	Luvisol	Sandy loamy silt	65	6.6	9.8	768	1.1
H (51°36.841′N 11°53.575′E)	Chernozem	Clay silt	96	7.0	10.4	470	1.8
I (51°28.386′N 9°54.934′E)	Luvisol	Clay silt	80	6.2	9.7	575	1.1
J (49°38.439′N 10°7.615′E)	Haplic Luvisol	Clay silt	72	6.7	10.5	630	1.3
K (49°35.792′N 8°5.302′E)	Calcic Regosol	Loamy silt	75	7.4	9.9	639	2.3
L (51°35.876′N 9°51.956′E)	Gleyic Chernozem	Clay silt	77	7.2	8.9	617	1.8
M (48°52.209′N 9°0.802′E)	Luvisol	Clay silt	78	7.2	11.3	931	1.5
N (50°51.627′N 6°36.503′E)	Luvisol	Clay silt	75	6.7	9.5	650	1.0
O (51°4.406′N 12°14.575′E)	Stagnic Phaeozem	Silty loam	72	6.9	9.1	520	2.6
P (51°37.156′N 11°52.967′E)	Gleyic Phaeozem	Clay silt	85	7.0	9.1	469	1.4
Q (51°29.051′N 9°56.107′E)	Luvic Phaeozem	Clay silt	83	6.8	8.9	617	1.3
R (52°17.032′N 10°29.178′E)	Stagnic Cambisol	Loamy sand	56	6.7	8.8	618	1.5
S (53°40.560′N 13°19.134′E)	Luvisol	Sandy loam	48	6.3	8.4	540	1.5

[a] German index to classify soil quality (max = 100).
[b] Topsoil layer (Ap-horizon), values were averaged over the ploughing system and the mulching system.
[c] Mean annual temperature.
[d] Total annual precipitation.