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Identification of weed community traits response to conservation agriculture

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ABSTRACT

Conservation agriculture is designed to deliver more sustainable cropping systems by preserving agricultural soils with tillage abandonment. However, knowledge on the impacts of Conservation agriculture adoption on weed infestation level and potential shifts in the composition of weed communities appears low and contradictory. We used a trait-based approach to investigate whether there are shifts in values of a set of traits within weed communities following the adoption of Direct Drilling with cover-crop (DD) which is one of the Conservation Agriculture practices. Weed surveys were conducted across a range of times since conversion to DD in 52 winter wheat fields located in north-eastern France. A three-table ordination method (RLQ analysis) was performed to relate environmental data to species traits data using weed community composition data. We found a shift in the weed community toward perennial and monocotyledon species with increasing time since conversion to DD. Weeds tended to invest more in maintaining their roots system than in seed production as time since conversion increased. Thus, weeds developing in DD systems tended to be more persistent, and this poses a challenge for management with current practices.

1. Introduction

The main challenge for agricultural scientists in the coming decades will be to identify alternative cropping systems that can both ensure sufficient levels of food production, maintain ecosystem integrity (Robertson and Swinton, 2005; Pretty, 2008) and deliver multiple ecosystem services simultaneously (Firbank et al., 2013). Adopting alternative land management, whether for environmental reasons or to increase crop production can lead to important shifts in the composition of communities living in agroecosystems: as has been documented for plants and animals (Bengtsson et al., 2005; Geiger et al., 2010), including groups delivering key ecosystem services such as pollinators or pest natural enemies (Tscharntke et al., 2005). Recent studies have demonstrated that the concept of the "functional trait" (Violle et al., 2009) can give powerful insights into the interpretation of community changes in agroecosystems. In particular, trait-based approaches have the potential to identify both the management practices that drive community shifts and the expected impacts of community shifts on the properties of the agroecosystem (Garnier and Navas, 2012).

Among management systems likely to deliver a more sustainable agriculture, conservation agriculture (CA) has been promoted in recent years as a method for preserving agricultural soils and their structure (Holland, 2004). CA is defined as a cultivation system that combines avoidance or minimization of soil disturbance with a permanent residue for soil cover and crop diversification (FAO, 2012). A major limitation to CA adoption is that it may lead to less effective weed control. Weed control in conventional systems is mostly carried out through soil tillage and chemical weeding that both prevent weed emergence and control weed growth during crop development. In CA, soil tillage is proscribed, leading to a reduction in disturbance of perennial weed roots (Bullied et al., 2003). In addition, the presence of crop residues has been suggested to reduce the efficacy of root-applied-herbicides (Chauhan et al., 2012). Minimizing soil disturbance may also lead to changes in soil environmental properties, properties that can in turn affect the composition of weed communities (Zanin et al., 1997). Among existing CA systems, Direct Drilling with cover–crop (DD) associates no till with a cover crop either during the crop or intercrop period. This cover, which is generally set up to improve nitrogen management, may also suppress weeds by increasing competition for light (Carr et al., 2012) and provide habitat for organisms that consume weeds, such as granivorous carabid beetles (Trichard et al., 2013). Thus, despite existing experimental monitoring of weed communities under contrasted tillage regimes (Streit et al.,

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2002; Dorado and Lopez-Fando, 2006; Murphy et al., 2006; Légère et al., 2008), current knowledge on the impacts of DD adoption on weed infestation level and potential shifts in the composition of communities appears low and contradictory.

Trait-based approaches have been successfully applied to understand how weed communities assemble or change in response to filters imposed by agricultural management. Examples include weed functional response to crop type and rotation (Fried et al., 2009; Gunton et al., 2011), to levels of fertilizers and herbicide inputs (Storkey et al., 2010; Fried et al., 2012). Soil tillage effects on weed communities have also indicated a functional split between weed communities under spring tillage and communities under autumn tillage (Smith, 2006). However, the effect of tillage intensity on weed traits was somewhat limited, although there is evidence that tillage affects the representation of weeds in terms of life form, with perennial species favored under minimal and no-till systems (Streit et al., 2002; Fried et al., 2012). In the case of a total tillage ban, one could hypothesize a gradual shift in weed communities that would be comparable to changes in natural vegetation communities during ecological succession (Garnier et al., 2004; Raevel et al., 2012). Reduced soil disturbance has indeed been shown to promote, initially, a pioneer community with a predominance of annual species and, subsequently, a shift towards a more mature community comparable to that of woodland edges, with more perennial species and shrubs (Zanin et al., 1997). In our case, weed community shifts might also include changes in the representation of additional traits such as seed size, as larger seeds usually exhibit a higher ability to germinate on undisturbed soil surface and to emerge under a cover.

In this study, a RLQ approach was used to investigate whether or not 13 selected traits shift in their representation within weed communities over a gradient of time since conversion to DD using weed data collected within 52 winter-wheat fields located in north-eastern France. Traits were selected according to two key stages in the life-cycle of plant species: establishment and persistence. It is hypothesized here that species that are more persistent and long-term established would be favored as time since conversion to DD increased, mimicking changes in communities observed after land abandonment. It is also hypothesized that conversion to DD may alter the representation of reproduction strategies in the community.

2. Materials and methods

The study area was set within a 50 km radius around the city of Dijon in the Côte d'Or department (47°19′18″N, 5°02′29″E). The area is dominated by shallow calcareous soils with loam, clay loam and silky clay loam soils and the major local crop rotation is winter oilseed rape-winter wheat-spring barley. In this study area, a network of farmers started to implement DD systems a few years ago. Within this network, 52 winter-wheat DD fields were selected in order to encompass: (i) a gradient of age, i.e. number of years under no-till management (1 to 13 years) and (ii) a diversity of crop management practices and environmental conditions of DD. Overall, 12 replicate fields for each year since conversion (1, 2, 3, 4 years) and 4 fields with longer duration under DD systems (from 5 up to 13 years) were sampled. The average area of surveyed field was 12.7 ha with field size ranging from 1 to 43 ha. The duration of intercropping was 2.5 months (between July and September) and farmers sowed different mixes of annual species belonging mostly to the cruciferous and legums families.

2.1. Weed data collection

In each field, weed communities were surveyed in 2011 within a plot of 50 × 40 m located 50 m away from a field boundary to avoid field edge effects. As the DD system is a new cropping system in this part of France and the associated weed flora is not well documented, weed data were collected at three periods during the study: the cropping period in late-March 2011 (before foliar herbicide treatment), before harvest in mid-June 2011 (flowering time—potential seed production) and during the cover cropping period in mid-September 2011. The sampling protocol was similar at the three dates and consisted of recording species occurring within the 2000 m^2 area by walking according a "W" in the plot.

Table 1
Environmental variables retained for the 52 fields.

Environmental variables	Abb.	Min	Max	Mean	Std dev.
No-tillage duration (number of years)	*Age*	1.00	13.00	2.96	2.14
Broad leaf active ingredients	*DiH*	0.00	4.00	1.58	1.36
Broad spectrum active ingredients	*BSH*	0.00	6.00	3.17	1.17
Organic matter (g/kg)*	*OM*	28.00	72.20	48.66	11.09
pH*	*pH*	6.90	8.42	8.14	0.23
Cation exchange capacity (cmol+/kg)*	*CEC*	10.80	30.40	20.65	4.28
Stones (g/kg)**	*Stones*	4.97	748.00	255.07	179.99

* From the 6–20 cm soil horizon.
** From the 0–5 cm soil horizon.

The abundance of each species was estimated using the Barralis' scale, described in Fried et al. (2009): "+": found once in the 2000 m^2 area; "1" less than 1; "2" 1–2; "3" 3–20; "4" 21–50 and "5" more than 50 individuals m^{-2}. Abundance classes were transformed into weed density by using the median value of the abundance classes. Plants were identified following Jauzein (1995) except for a few taxa that, because of small seedling size and the absence of reproductive parts, were identified at genus level (*Bromus* spp., *Valerianella* spp. and *Lolium* sp.).

A total of 121 weed taxa were identified; taxa recorded only once in the survey were excluded so that analyses were carried out on a dataset that included 93 weed taxa. Weed composition was computed as the average density per species, per field over the three surveys.

2.2. Environmental variables

Seven environmental variables were collected that were related to: (i) cultivation practices through farmers' interviews and (ii) soil properties through soil sampling and subsequent physico-chemical analyses (Table 1). The variable *Age* represented the number of years since conversion to DD and varied from 1 to 13 years; *DiH* was computed as the number of active ingredients of broadleaf herbicides and *BSH*, the number of active ingredients of broad spectrum herbicides applied from the previous harvest date until the date of latter flora survey in September. As only two fields received specific grass-weed herbicide treatments, this variable was excluded from the analysis. Four soil parameters were measured. Soil samples from below the litter layer were collected with a hand-auger in each plot at the end of November 2011 (0–5 cm and 6–20 cm). Each sample consisted of 14 cores for each horizon, evenly distributed around the center of each vegetation plot and bulked to make a composite sample representative of the plot. All soil samples were analyzed by the "Laboratoire d'Analyses des Sols" of the National Institute for Agronomic Research (INRA, Arras, France) using standard procedures. Overall parameters were measured in 0–5 cm and 6–20 cm and variables retained in the final data analysis were *Stones* (kg of rocks >0.5 cm/kg of soil) amount in the 0–5 cm soil horizon and physical–chemical parameters measured in the 6–20 cm soil