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Effects of no-tillage and non-inversion tillage on weed community diversity and crop yield over nine years in a Mediterranean cereal-legume cropland

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ABSTRACT

Both no-tillage and non-inversion tillage systems have been proposed within the context of 'conservation agriculture' as alternatives to conventional tillage for weed management and soil conservation. However, little information is available regarding their influence on weed community diversity and crop yield in Mediterranean cereal steppelands. Type of tillage represents a crop abiotic factor that largely influences the environmental conditions at the field scale to which weed communities may respond. The present paper examines the effect of no-tillage, subsoil tillage and minimum tillage (the latter two being non-inversion systems), on arable weed community diversity and composition in a cereal-legume crop rotation over 9 years. Their effects on crop yield are also explored. Inter-annual environmental variability was found to be more important than the tillage system in determining weed species diversity and assembly. None of the studied tillage systems exerted consistent effects, neither on weed community diversity nor on crop yields. In addition, the effect of tillage system on weed community diversity was crop-type dependent. The main effects of tillage systems were related to the composition of weed communities. Less common species resulted particularly affected while core species were consistent across tillage systems.

1. Introduction

Agricultural practices strongly influence plant and animal diversity (Stoate et al., 2001) and impact ecosystem functioning and services (Power, 2010). Unfortunately, efforts to increase crop yields have often resulted in these services becoming difficult to maintain. For instance, arable weeds have traditionally been identified as one of the main factors behind declining crops yields, so ways to remove them, including tillage, have long been sought (Hobbs et al., 2008). Weed communities, however, may provide important ecosystem regulation services in arable steppe cropland. Weeds are known to serve as forage and refuge for pollinators and other beneficial arthropods (Isaacs et al., 2009); whereas granivorous bird species, ants and rodents also feed on weed seeds (Marshall et al., 2003). These services among others may be lost if weed diversity declines. Once the importance of well conserved weed communities was recognised (Seifert et al., 2015), a new priority of agricultural management emerged: ensuring crop productivity while maintaining weed diversity.

In the Mediterranean Basin, weed communities came to adapt to the traditional tillage systems that had been employed for centuries (Murphy and Lemerle, 2006; Neve et al., 2009). The development of more modern equipment, however, such as the mouldboard plough, allowed the mechanization of traditional practices, and the deep inversion of the soil profile. This type of soil management, now known as conventional tillage, affects the vertical distribution of weed seeds in the soil (Forcella et al., 2000; Colbach et al., 2014), and this has a profound influence on plant emergence, recruitment (Légère et al., 2011; Nichols et al., 2015; Singh et al., 2015), abundance, richness (Hernández-Plaza et al., 2011), other diversity indices, and on the composition of weed communities (Hyvönenen and Salonen, 2002; Légère et al., 2005; Dorado and López-Fando, 2006; Légère et al., 2011; Sans et al., 2011; Hernández-Plaza et al., 2015).

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Within the context of 'conservation agriculture' (Morris et al., 2010; González-Sánchez et al., 2015), new tillage practices have been proposed, including no-tillage (NT), which is based on the use of herbicides prior to sowing (Eslami, 2014), and non-inversion tillage. The latter includes subsoil tillage (ST), which entails ploughing with a vertical (non-soil-turning) blade to a depth of 30 cm before sowing, and minimum tillage (MT), which involves the same but only to a depth of 15 cm. Neither of these techniques invert the vertical soil profile, thus helping to avoid pernicious effects on the soil biota (Palm et al., 2014; Gronle et al., 2015; Henneron et al., 2015). The effects of non-inversion tillage systems on arable weed communities, however, remain unclear, with contradictory results being returned by studies performed in different geographical contexts (Fried et al., 2008; Hernández-Plaza et al., 2015). Most of the discrepancies regarding their effects on weed diversity are probably the consequence of the short duration of the field experiments. Thus, it is especially important to distinguish between short-term responses (evaluated with short-term experiments) and long-term directional changes (evaluated with long-term experiments). This concept may be particularly important when climatic inter-annual variability is high, as in the case of the Mediterranean Basin. In this and other climatically variable contexts only long term studies allow to characterise tillage practices in terms of their value to the conservation of arable weed communities (Moonen and Bàrberi, 2008). Furthermore, only results emerging from long term studies will allow recommendations to balancing crop yields with weed diversity-related ecosystem services (Storkey and Westbury, 2007).

In the Mediterranean Basin, this lack of information is especially notable with respect to extensive cereal-legume rotation croplands where biodiversity has been shaped by a long evolutionary and cultural history. In Spain, such croplands once represented the largest agricultural use of land, accounting for some 6,586,909 ha or about 50% of the country's arable landscape (FAOstat, 2014). The weed diversity of these agroecosystems was traditionally supported, at least in part, by the rotation of the crops (Ulber et al., 2009). Indeed, it is thought that extensive crop management could play a crucial role in the conservation of the threatened weed species. This in turn can have an effect on different consumer groups, such as birds, ants, rodents (Storkey et al., 2012). Unfortunately, the recent intensification of cropland management has led to a reduction in the area given over to legumes, which are now grown in rotation on just 5% of the above-mentioned area based on ESYRCE (2015). Recovering this type of rotation is important if agriculture is to become more sustainable, and knowing the best tillage techniques to use in this setting is important if the ecosystem services provided by weed communities are to be preserved.

The aim of the present work was to examine the effect of ST, MT and NT tillage systems on the arable weed communities of a cereal-legume cropland in Central Spain. The period examined was nine years - long enough to ensure that the results would be representative of the inter-annual variability. Particular emphasis was placed on determining whether the type of tillage practiced can explain differences in: (1) weed abundance and diversity (weed density, taxonomic richness (S), the inverse of the Simpson diversity index (D), and the Simpson evenness index (eD)) (Magurran, 2004); (2) weed community composition; and (3) crop yield.

Since tillage systems were developed in order to reduce the presence of weeds and enhance crop yields, it was hypothesized that 1) tillage depth would be inversely related to weed abundance and diversity (weed density, S, D and eD) in the pattern ST < MT < NT and positively related to crop yield in the manner ST > MT > NT; (2) that weed community composition would differ accordingly across the three tillage systems; and (3) that the strength of the effects of tillage on weeds might be more noticeable when the cereal, rather than the legume crop, was present because legumes compete less with arable weeds than do cereals, allowing for greater weed development (Lutman et al., 1994; Blackshaw et al., 2002). The long term observation of tillage system effects on weed communities and crop yields should allow to identify the system that better maintains weed diversity than other systems without compromising crop yields.

2. Materials and methods

2.1. Experimental site

The fieldwork for the present study was conducted at the El Encín Experimental Station (40°57.31′N; 3°17′W, altitude 610 m) in Alcalá de Henares, Madrid, Spain. This study was started in 2002, within the context of a 2-year cereal-legume rotation system. Before the beginning of the experiment the whole field was cultivated with the same crop rotation (cereal-legume) using a conventional tillage system. The soil at the study site is an Alfisol Xeralf with a loam texture (pH 7.8, 1.2% organic matter). The mean annual temperature during the nine year study period (October 2002–June 2011) was 13.4 °C, and the mean annual precipitation 444 ± 116 mm with large inter-annual fluctuations among the October to June growing seasons (Appendix A Fig. A1).

2.2. Tillage systems

The legumes sowed were pea (*Pisum sativum* L.) in 2002, 2004 and 2006 and vetch (*Vicia sativa* L.) in 2008 and 2010. Winter wheat (*Triticum aestivum* L.) was sown in 2003, 2005, 2007, 2009 and 2011. The crops were sown using a multi-purpose direct-drill with 17 cm row spacing. The time of sowing for the legume crop ranged from November 6th to January 19th. Fertilizers were applied at sowing (14 kg N, 14 kg P, 14 kg K ha^{-1}). Post emergence herbicide (diclofop-methyl 36%, 3 L active ingredient [a.i.] ha^{-1}) was applied during vegetative growth. The time of sowing for the cereal ranged from October 30th to December 19th. Fertilizers were applied at sowing (30 kg N, 30 kg P, 30 kg K ha^{-1}) and mid-tillering (53 kg N ha^{-1}). Post emergence herbicide (0.2 kg a.i. ha^{-1} ioxynil + 0.2 kg a.i. ha^{-1} bromoxynil + 1.012 kg a.i. ha^{-1} mecoprop) was applied at the tillering stage.

Three tillage systems were used, randomly assigned to 10 m × 40 m plots (24 plots in total, 8 plots per treatment): subsoil tillage (ST), minimum tillage (MT) and no-tillage (NT). ST involved at least one subsoil ploughing operation with a paraplow with slant shanks (it lifts and fractures the soil similar to the mouldboard plow but without soil inversion) to a depth of 30 cm; MT involved a primary cultivation with a chisel plough to a depth of 15 cm. Both MT and ST were followed by a secondary, superficial tillage with a field cultivator. NT involved the application of glyphosate© (0.9 L a.i. ha^{-1}) 4–6 days prior to crop planting.

2.3. Weed community survey and crop harvest

The number of weed species and their abundance (number of individuals per species) was recorded in 10 quadrats (30 cm × 33 cm) per plot every year—at stem elongation for the legume crop and at early tillering for the cereal crop. Weed surveys were always carried out before the application of the post-emergence herbicide. Sampling quadrats were located along an M-shaped itinerary, always at least 3 m away from the plot borders and at least 7 m away from each other. Data from the 10 quadrats were used to obtain weed density (as the total number of weed individuals found in the ten quadrats) and to compute