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Relay-intercropped forage legumes help to control weeds in organic grain production

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ABSTRACT

In organic grain production, weeds are one of the major limiting factors along with crop nitrogen deficiency. Relay intercropping of forage legume cover crops in an established winter cereal crop might be a viable option but is still not well documented, especially under organic conditions.

Four species of forage legumes (*Medicago lupulina*, *Medicago sativa*, *Trifolium pratense* and *Trifolium repens*) were undersown in six organic wheat fields. The density and aerial dry matter of wheat, relay-intercropped legumes and weeds were monitored during wheat-legume relay intercropping and after wheat harvest until late autumn, before the ploughing of cover crops.

Our results showed a large diversity of aerial growth of weeds depending on soil, climate and wheat development. The dynamics of the legume cover crops were highly different between species and cropping periods (during relay intercropping and after wheat harvest). For instance, *T. repens* was two times less developed than the other species during relay intercropping while obtaining the highest aerial dry matter in late autumn. During the relay intercropping period, forage legume cover crops were only efficient in controlling weed density in comparison with wheat sole crop. The control of the aerial dry matter of weeds at the end of the relay intercropping period was better explained considering both legumes and wheat biomasses instead of legumes alone. In late autumn, 24 weeks after wheat harvest, weed biomass was largely reduced by the cover crops. Weed density and biomass reductions were correlated with cover crop biomass at wheat harvest and in late autumn. The presence of a cover crop also exhibited another positive effect by decreasing the density of spring-germinating annual weeds during the relay intercropping period.

1. Introduction

In organic grain production, weeds are one of the main limiting factors (Bàrberi, 2002; Kruidhof et al., 2008) along with crop nitrogen deficiency (Casagrande et al., 2009). Weed density, biomass or ground cover are generally higher than in conventional systems (Cavigelli et al., 2008; Ryan et al., 2009; Teasdale and Cavigelli, 2010). Consequently, yields can suffer from competition for trophic resources, i.e. light, nutrients, and water (Cavigelli et al., 2009; Gherekhloo et al., 2010; Ryan et al., 2009). Weeds may compete with the cash crop for light interception (Corre-Hellou et al., 2011). Competition for soil nitrogen may also appear with some high nitrogen-competitive weed species (e.g. *Amaranthus retroflexus* L.) (Blackshaw and Brandt, 2008). Moreover, weeds are often more competitive than cereals for nitrogen nutrition coming from the soil (Bàrberi, 2002). In some cases, the allelopathic effect of weeds can be harmful to cereal crops as shown by Hamidi and Ghadiri (2011) with wild barley (*Hordeum spontaneum* Koch) to the detriment of wheat (*Triticum aestivum* L.).

In organic conditions, direct weed control, as listed by Wei et al. (2010), has to be combined with indirect and preventive methods like the diversification of the crop sequence or the use of cover crop (CC) among others (Bàrberi, 2002; Bond and Grundy, 2001; Wei et al., 2010). These techniques aim at tackling weed issues on a long-term strategy basis (Melander et al., 2005) by limiting weed infestation during the crop cycle and thereby reducing the weed seedbank over the following years.

The use of forage legume CCs could be an interesting option for limiting weed infestations. Previous research studied different options with CCs being grown between two cash crops (Kruidhof et al., 2008; Liebman and Davis, 2000; Teasdale et al., 2007) or CCs as living (Hiltbrunner et al., 2007) or dead mulches (Kumar et al.,

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2011). CCs interfere with weed emergence and growth through numerous mechanisms. They disturb seedling emergence insofar as they constitute a physical barrier (Teasdale and Mohler, 2000) and compete for light (Carof et al., 2007; Kruidhof et al., 2008; Teasdale et al., 2007). This barrier effect can also keep newly produced weed seeds from reaching the soil and thus replenish the soil seed bank (Doisy et al., 2012). Some forage legume species, like alfalfa (*Medicago sativa* L.), emit allelochemicals that are detrimental for weeds (Bhowmik and Inderjit, 2003; Weston and Inderjit, 2007; Xuan et al., 2003). The presence of a perennial CC also enhances seed predation by fauna (Meiss et al., 2010). Finally, forage legume CCs may contribute to the sustainability of the cropping system beyond natural weed control through several ecosystem services like biological nitrogen fixation or soil quality and biodiversity improvements (Scholberg et al., 2010; Sheaffer and Seguin, 2003).

The relay intercropping technique consists in "*growing two or more crops simultaneously during part of the life cycle of each*" (Vandermeer, 1989). In our case, it consisted in undersowing a CC in an already established winter cereal. This technique is expected to help organic grain producers in weed control. The relay intercropping of a forage legume (RIL) in a winter cereal is expected to guarantee the presence of the CC on the field by the time the cash crop is harvested and simultaneously enables mechanical weed control before undersowing, as suggested by Sjursen et al. (2011). The undersown CC is expected to be established on the field and be effective against weeds immediately after the cash crop has been harvested. This avoids the bare soil period, favourable to weed emergence, between the cash crop harvest and the full establishment of a CC, when it is sown between two cash crops.

The efficiency of RIL to control weeds has been given increasing attention in scientific literature in the last decade. Red clover (*Trifolium pratense* L.) is the most frequently studied species in RIL systems. It was shown that under conventional conditions, relay-intercropped red clover reduced weed development or density significantly (Bergkvist et al., 2011; Blaser et al., 2006, 2011; Mutch et al., 2003). Other species, like white clover (*Trifolium repens* L.) (Bergkvist et al., 2011; Hartl, 1989), alfalfa (Blackshaw et al., 2010; Blaser et al., 2011) or black medic (*Medicago lupulina* L.) (Hartl, 1989), were less frequently studied, but also appeared to potentially mitigate weed infestation in RIL conditions.

The different species of forage legumes, conducted as cash crops, do not demonstrate the same efficiency at controlling weeds depending on their morphological, phenological and physiological characteristics (Bilalis et al., 2009; Ross et al., 2001; Uchino et al., 2011). Moreover, the efficiency of the different species at controlling weeds in RIL varied according to the tested conditions, as Blackshaw et al. (2010) and Blaser et al. (2011) have shown in the case of red clover and alfalfa in RIL situations.

Previous results in RIL have shown that the CCs reduced weed biomass or weed density not only at wheat harvest, but also from 2 to 12 weeks after the end of the RIL period (Bergkvist et al., 2011; Blackshaw et al., 2010; Blaser et al., 2006, 2011; Mutch et al., 2003). Nevertheless, these studies mainly focused on a static evaluation of weeds at wheat harvest or just after, and did not study them all along the whole cycle of the undersown CC.

According to Teasdale (1996), the successful control of weeds also depends on the composition of the weed population. Subpopulations of weeds can react differently in the presence of a legume CC, as shown by Hiltbrunner et al. (2007) in their study of permanent living mulches. This subject has not been tackled in studies concerning RIL in winter wheat.

Finally, few of the previous experiments were performed in organic conditions (Hartl, 1989; Olesen et al., 2009). Despite the improvement of the non-chemical control techniques of weeds, they remain a prominent issue for organic grain producers (Bàrberi, 2002; Kolb and Gallandt, 2012). Temporary nitrogen deficiencies, observed in organic cropping systems, may also interfere in the interaction between CCs and weeds (Liebman and Davis, 2000) compared to systems where synthetic fertilizers are fulfilling the cash crop requirements. In the absence of synthetic herbicides, the success of CCs is also potentially compromised in a temperate climate (Hartl, 1989; Olesen et al., 2009) where forage legumes may establish slowly (Frame, 2005; Teasdale et al., 2007) especially when competing with wheat (Queen et al., 2009; Singer et al., 2006).

The aim of this paper was to evaluate the effect of various relay-intercropped legume CCs (black medic, alfalfa, red clover and white clover) in organic winter wheat on weed population. Weed density and biomass were monitored throughout the RIL period and after wheat harvest until wintertime, both with and without the presence of the CCs. We tested the nature of the CCs to control weeds efficiently in different climatic conditions as expressed by our experimental design.

2. Materials and methods

2.1. Experimental sites

A total of six field experiments (named as sites hereafter) were carried out over two crop seasons, two fields in 2008–2009 (A09 and B09) and four fields in 2009–2010 (C10, D10, E10 and F10) (Table 1). The field experiments were set up on organic farms without livestock located in south-eastern France over a large area of approximately 6000 km^2 (44°37′ to 45°41′ N and 4°49′ to 5°32′ E) representing various climatic conditions. Rainfall regimes were variable over years and sites. Cumulative precipitations, mean air temperatures and water balances, calculated as the difference between water input (precipitation and irrigation, in mm) and potential evapotranspiration (in mm), are given in Table 1 for three periods: between the sowing of CCs and wheat flowering, between wheat flowering and harvest and between wheat harvest and late autumn. Irrigation was carried out on sites B09 (70 mm), C10 (70 mm) and D10 (40 mm), according to the farmers' appraisal, with one or two applications from the beginning of April (wheat growth stage Z23, Zadoks et al., 1974) to the end of May (Z69). Irrigation was also performed after wheat harvest, at the beginning of August on site B09 (40 mm). The field experiments were characterized by various soil types (Jahn et al., 2006) (Table 1): two silt loam soils (D09 and F10), two sandy loam (B09 and C10), one clay loam soil with a stony-calcareous top soil layer (A09) and one silty clay soil (E10). In accordance with this grouping, we considered the main textural component of soil further in the study as silt for sites D09 and F10, sand for sites B09 and C10 and clay for sites A09 and E10.

2.2. Experimental design and treatments

Winter wheat (cv. Lona) was sown at a rate of 485 seeds m^{-2} (200 kg ha^{-1}) on fields previously cropped with winter wheat (A09), maize (*Zea mays* L.) (D10) or soybean (*Glycine max* (L.) Merr.) (B09, C10, E10 and F10). This wheat cultivar was one of the ten most used wheat cultivars for bread-making in French organic cereal production in 2010 (FranceAgriMer, 2011). This hard winter wheat cultivar is known to have a limited tillering capacity with a maximum height around 90 cm. The dates of wheat sowing and sums of temperatures from the sowing of wheat to, respectively, the undersowing of legumes and wheat harvest are given in Table 1.

Four different species of undersown legumes were compared. Black medic (cv. Virgo Pajberg), alfalfa (cv. Timbale), red clover (cv. Formica) and white clover (cv. Aberdaï) were broadcast sown (800 seeds m^{-2}) with a manual centrifugal seed drill late in March at the end of wheat tillering. These legume species were chosen