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Intercropping strategies of white clover with organic wheat to improve the trade-off between wheat yield, protein content and the provision of ecological services by white clover

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ABSTRACT

Nitrogen (N) deficiency and weed infestation are the main factors limiting the yield and quality of organic soft winter wheat (*Triticum aestivum* L.). If forage legumes are associated with wheat, simultaneously or successively, they can help to reduce the impact of limiting factors through the ecological services they provide. The aim of this study was to evaluate two intercropping strategies to increase soft winter wheat yield and protein content and improve the provided ecological services (mainly N provisioning and weed control) by white clover (*Trifolium repens* L.).

White clover (*Trifolium repens* L. cv Aberdaï) was intercropped with soft winter wheat (*Triticum aestivum* L. cv Renan) under organic conditions. Two strategies were compared, simultaneous intercropping versus relay intercropping using three field experiments. A control treatment with sole wheat crop was included in the three field experiments. Fertilization management on organic wheat was also tested (0 versus 100 kg N applied at spring time) to evaluate its incidence on cash and cover crop yields and protein content.

White clover shoot dry matter (DM) was significantly higher in simultaneous intercropping compared to relay intercropping at wheat harvest (2.2 vs. 0.1 Mg DM ha^{-1}) and at cover destruction (4.5 vs. 3.1 Mg DM ha^{-1}). Wheat grain yield was not affected by the intercropping strategy while the protein content was significantly lower under simultaneous intercropping system (9.1% of the grain DM) compared to relay intercropping or in wheat as sole crop (10.0% of the grain DM). At cover destruction, both simultaneous and relay intercropped white clover significantly decreased weed shoot DM compared to sole wheat crop (-1.4 Mg DM ha^{-1} for relay intercropping and -1.8 Mg DM ha^{-1} for simultaneous intercropping). In comparison to relay intercropping strategy, N accumulation in white clover shoot DM was higher under simultaneous intercropping strategy at wheat harvest (52 vs. 2 kg N ha^{-1}) and at cover destruction (123 vs. 83 kg N ha^{-1}).

In conclusion, our study has highlighted the positive effect of combining a simultaneous intercropping strategy with high N availability to guarantee a sufficient level of legume shoot DM as rapidly as possible to increase both N accumulation and weed control services, thus reducing the risk of impairing winter wheat yield and protein content.

1. Introduction

High variability of grain yield is common in stockless organic grain systems (Brainard et al., 2011; David et al., 2005), mainly because of weed competition (Rajcan and Swanton, 2001) and nutrient deficiency in soils (Poudel et al., 2002; Doltra et al., 2011). Forage legumes may be inserted in the crop rotation to limit weed infestation (Carof et al., 2007; Amossé et al., 2013a) and provide additional nitrogen (N) fixed from the atmosphere to the subsequent cash crops (Malézieux et al., 2008). In Southern France, climate conditions are generally dry during summer. As a result, a low success rate is generally observed in establishing a legume crop. Intercropping, defined by Willey (1979) as

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Table 1
Soil and climatic conditions of the field experiments. (a) values in brackets are climatic deficit which corresponds to the difference between ETP and rainfall (mm) (b) values in brackets indicates thermal time (in °C d).

Sites		Site 1	Site 2	Site 3
Soil texture		Clay loam	Sandy	Clay loam
Sol mineral nitrogen (kg ha^{-1})		30,8	16,5	39,9
Initial weed biomass (kg ha^{-1})		372	46	58
Cumulative rainfall (mm) and climatic deficit (a) up to wheat harvest (mm)	Simultaneous intercropping [irrigation]	563	776 [40]	573
		(−98)	(−163)	(−80)
	Relay intercropping [irrigation]	191	219 [40]	216
		(−298)	(−220)	(−283)
Cumulative temperature from legume sowing up to wheat harvest (b)	Simultaneous intercropping	2512	2466	2676
	Relay intercropping	1666	1539	1812
Cumulative rainfall and climatic deficit (a) between wheat harvest and final legume harvesting (mm)		214	288	201
		(−91)	(−271)	(−304)
Cumulative temperature between wheat harvest and final legume harvesting (b)		1344	2663	2341

growing two (or more) crops simultaneously on the same plot of land, could provide a better option for inserting forage legume into the crop rotation. Then, intercropping wheat as cash crop and forage legume as cover crop may extend the growing period of the legumes, increase produced DM and N fixation. The level of forage legume DM has been shown as a key-factor for weed control (Bergkvist et al., 2011; Blaser et al., 2011; Mutch et al., 2003; Amossé et al., 2013a) and determines the amount of N fixed by legumes (Peoples et al., 2001; Vrignon-Brenas et al., 2016b).

Simultaneous intercropping is defined as “growing two or more crops simultaneously where one or more crops are planted in rows” while relay intercropping is defined as “growing two or more crops on the same field during part of the life of each” (Andrews and Kassam, 1976; Vandermeer, 1989). Simultaneous and relay intercropping are selected for different objectives and management strategies. In the case of a simultaneous intercropping strategy, the growing period for the legume, as cover crop, is longer to provide a high amount of fixed N and potential ground cover to compete with weeds. However, the legumes might also compete with wheat during cereal growth. By contrast, in a relay intercropping strategy, mechanical weeding is possible until the beginning of spring, the objective being to insert the forage legume before summer without impairing wheat yield and protein content. When the cash crop is harvested, the legume is used as green manure to avoid bare soil. Most studies conducted in temperate climate conditions demonstrated that the intercropping of a forage legume as cover crop with a cereal increases the yield and protein content of the subsequent crop (Hesterman et al., 1992; Vyn et al., 2000) through (i) N availability from N fixation by legumes, (ii) limitation of N leaching during the fall period when forage legumes cover the soil, and (iii) mitigation of weed competition following the intercropping period (Askegaard and Eriksen, 2008; Bergkvist et al., 2011; Garand et al., 2001; Almeida et al., 2000; Huss-Danell et al., 2007). Although forage legume cover was largely expected to contribute to reducing the risk of leaching, the incorporation of legumes may also cause nitrate leaching, in particular during the fall period due to N release from roots and nodules. In grain systems production, when forage legume is used as cover crop, an additive design is employed: the standard density of wheat is used to maintain the yield potential and forage legume is undersown at low density to limit the risk of competition.

In organic grain production, spring fertilization is also generally applied to improve cereal yield and protein content. Previous studies with clover and lucerne (*Medicago sativa* L.) generally highlighted that both relay and simultaneous intercropping systems had no significant effect on wheat yield (Olesen et al., 2009; Amossé et al., 2013b; Mpairwe et al., 2002). By contrast, some authors have shown that a simultaneous intercropping system might limit the cereal yield in case of high growth of the cover crop and the resulting competition for nutrient resources and light (Mysliwiec et al., 2014). Even with a relay intercropping strategy, competition between the cereal and the cover crop may occur and impact negatively on the grain protein content (Amossé et al., 2013a). In order to limit the risk of lower yield and protein content in winter wheat, farmers mostly choose to apply spring fertilization to their intercropping system. This practice potentially increases weed DM (Blackshaw, 2004) and competition between winter wheat and the forage legume at the expense of the latter. As the forage legume is less able to compete for resource acquisition (Corre-Hellou et al., 2006), their DM is negatively impacted by higher N availability under conventional or organic conditions (Vrignon-Brenas et al., 2016a; Gaudin et al., 2014).

The objective of this study, conducted in organic conditions, was to compare the effects of simultaneous *vs*. relay intercropping strategies of white clover (*Trifolium repens* L.) and soft wheat. More specifically, we assessed the impact of such strategies on the ability of white clover to provide expected services (mainly weed mitigation and N provision) and on wheat grain yield and grain protein content. As spring fertilization is also expected to change the trade-off between the wheat yield and protein content and the services provided by forage legumes, we also investigated the effect of spring fertilization in the two different intercropping systems.

2. Material and methods

2.1. Experimental sites and design

Three field experiments were conducted during two climatic years on organic farms in south-eastern France (44°37′ to 45°41′ N and 4°49′ to 5°32′ E) (Table 1). Daily precipitation and mean air temperatures were recorded at local weather stations. One field (site 1) was monitored in cropping season 2013-14 and the two other fields (sites 2 and 3) in cropping season 2014–15. Precipitation was similar for sites 1 and 3 even though the cropping sites and years are different, whereas site 2 was characterized by higher rainfalls but also temporary water deficit (Table 1). This field (site 2) was irrigated once (40 mm) in April 2015 (during wheat growth stage Z23 (Zadoks et al., 1974)), to avoid intense water deficit.

The intercropping experiments were established in the fall after soybean (*Glycine max*, L) and were carried out from wheat sowing to cover destruction, during the following fall period. A complete and randomized experiment was performed on each field with three blocks per field and incorporating two factors: an intercropping strategy and a fertilization rate. The two factors were randomly assigned; each plot measured 12 × 15 m in size. In each experimental site, relay intercropping (ReIC) consisted of sowing white clover (*Trifolium repens* L. cv. Aberdaï) in mid-March at the end of wheat tillering (Z29). Simultaneous intercropping (SiIC) consisted of sowing the same cultivar of white clover at the same time as winter wheat. In both simultaneous intercropping and relay intercropping, clover seeds were broadcast using a manual centrifugal seed drill at a density of 800 seeds m^{-2}.