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Importance of cover crops in alleviating negative effects of reduced soil tillage and promoting soil fertility in a winter wheat cropping system

Lucie Büchi[a,*], Marina Wendling[a,b], Camille Amossé[a], Magdalena Necpalova[c], Raphaël Charles[a,b]

[a] Plant Production Systems, Agroscope, Nyon, Switzerland
[b] Research Institute of Organic Agriculture FiBL, Lausanne, Switzerland
[c] Sustainable Agroecosystems Group, Department of Environmental Systems Science, Swiss Federal Institute of Technology, ETH Zurich, Switzerland

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A B S T R A C T

Reduction of soil tillage is of paramount importance for agricultural soil preservation. However, it is often accompanied by yield reduction and weed management problems. In this perspective, cover crops could play an important role to alleviate weed infestation and sustain yield. In this study, the results from a three-year experiment of cover crop cultivation in different soil tillage treatments is presented, together with results from DayCent simulations on the long term evolution of soil organic carbon and total nitrogen. Eight cover crop treatments were set up as subtreatments in a long term experiment in Switzerland. Cover crops were cultivated for a short two-month period between two winter wheats. Substantial differences in cover crop growth were observed depending on cover crop species. In all tillage treatments, high cover crop biomass production allowed to supress weed biomass compared to the no cover crop control. Wheat grain yield was higher in the minimum tillage than in the plough treatment. In the no till treatment, wheat yield was notably low, except in the field pea treatments, where wheat yield reached values similar to that observed in the plough and minimum tillage treatments. In addition, these differences in biomass production translated into important differences in nutrient inputs, and even in soil nutrient concentration in some cases. Long term simulations showed that cover crop cultivation could increase drastically soil organic carbon and total nitrogen, especially in reduced tillage treatments. Altogether, these results demonstrated that the presence of a well-developed cover crop, even for only two months, allows to sustain wheat yield in a no till treatment. It impacts also soil fertility and nutrient cycling. This study shows that an accurate use and management of cover crops, in interaction with tillage reduction, could maintain yield and improve soil fertility in the long term.

1. Introduction

In order to limit the environmental impact of agriculture, alternatives to traditional systems have been proposed. Conservation agriculture is one of these alternatives, which is more and more adopted worldwide (Holland, 2004). It is based on three fundamental principles: 1. diversification of crop rotation, 2. reduction of soil tillage and 3. permanent soil cover (FAO, 2017). Compared to classical plough tillage, reduced tillage has several advantages, such as reduction of fuel costs, decreased disturbance for soil organisms, preservation of soil fertility, higher soil macroporosity, better water retention (Holland, 2004; Lienhard et al., 2013; Mazzoncini et al., 2011; Murugan et al., 2014; Palm et al., 2014; Sapkota et al., 2012; Soane et al., 2012). In contrast, detrimental effects, such as increased soil density, reduction of mineralisation or slowing of soil warming, could be observed in reduced tillage systems, especially with direct seeding (Soane et al., 2012). Reduced tillage also influences soil cover through a higher retention of crop residues at soil surface, compared to ploughing which incorporates residues in the soil. Another way to increase soil cover throughout the rotation is to integrate cover crops between two main cash crops. In temperate European regions, the long period running between summer harvest and the seeding of spring crops is obviously favourable for the implementation of cover crops. However, shorter periods such as the 2–3 months between summer harvest and the seeding of winter crops can also be suitable for the seeding of cover crops. Cover crops are expected to offer several services within the agroecosystems. In particular, they protect the soil against erosion, help to control weeds, and bring additional organic matter to the soil (Justes et al., 2012; Sainju et al., 2002; Thorup-Kristensen et al., 2003). They also accumulate large amounts of nutrients, and thus prevent their loss through lixiviation, and can improve the availability of nutrients for the next crop.

* Corresponding author. Present address: Natural Resources Institute, University of Greenwich, United Kingdom.
E-mail address: lucie.buchi@agroscope.admin.ch (L. Büchi).

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Table 1
Description of the eight cover crop subtreatments. The 'Standard targeted plant density' is the expected plant stand when cultivated as a monoculture, while 'Targeted plant density' is the density used in this experiment. '% density' is the relative density used in this experiment, compared to the standard one.

N°	Common name	Species	Botanical family	Cultivar	Standard targeted plant density (pl/m^2)	Targeted plant density (pl/m^2)	% density
1	Brown mustard	*Brassica juncea*	Brassicaceae	Vitasso	500	500	100
2	Daikon radish	*Raphanus sativus longipinnatus*	Brassicaceae	Structurator	80	80	100
3	Field pea	*Pisum sativum*	Fabaceae	Arkta	150	150	100
4	Black oat	*Avena strigosa*	Poaceae	Pratex	400	400	100
5	Niger	*Guizotia abyssinica*	Asteraceae	Azofix	300	300	100
6	Phacelia	*Phacelia tanacetifolia*	Hydrophyllaceae	Balo	500	500	100
7	11 species mixture						
		Sinapis alba	Brassicaceae	Albatros	300	19	6.25
		Raphanus sativus longipinnatus	Brassicaceae	Structurator	80	5	6.25
		Vicia faba	Fabaceae	Fuego	80	16	20
		Lens culinaris	Fabaceae	Lenti-fix	200	40	20
		Pisum sativum	Fabaceae	Arkta	150	15	10
		Setaria italica	Poaceae	Extenso	400	25	6.25
		Sorghum sudanense	Poaceae	Hay-king	200	13	6.25
		Helianthus annuus	Asteraceae	Iregi	80	5	6.25
		Phacelia tanacetifolia	Hydrophyllaceae	Balo	500	31	6.25
		Fagopyrum esculentum	Polygonaceae	Lilea	200	13	6.25
		Linum usitatissimum	Linaceae	Princess	500	31	6.25
8	control	non seeded					

However, the beneficial effect of cover crops in the whole system, and on the following crop, depends strongly on their management (e.g. choice of species, seeding and destruction time), and is not always easily demonstrated (Tonitto et al., 2006). An interaction with soil tillage could be expected for several reasons. Some cover crop species are particularly sensitive to seedbed preparation (e.g. phacelia) and are not expected to be well suited for direct seeding. Intensity of tillage before cover crop seeding could also influence mineralisation rate, or water availability, which could in turn affect cover crop emergence and growth. Therefore it is crucial to study the introduction of cover crops in agroecosystems in interaction with different tillage practices used on a long term.

The objectives were 1. to assess cover crop performance in interaction with soil tillage, and their effect on the yield of the following wheat, 2. to determine whether and which combination of treatments allows to exceed the yield of the classical system plough without cover crops, 3. to study the short term effects of three years of cover crops in terms of soil fertility and to evaluate the long term potential for soil fertility improvement through cover crop cultivation using DayCent simulations.

In the present study, eight different cover crop treatments were integrated in a long term experiment of soil tillage established in 1969. Three tillage treatments were used, going from classical plough tillage to minimum tillage and no till. As these tillage treatments had accumulated 44 years of differences when this specific experiment took place, they should be seen as different systems rather than classical factorial treatments. The standard crop rotation was interrupted to investigate the performance of cover crops in a short period of time, between two winter wheats. This sequence was repeated three times in order to also address cumulated effects.

2. Materials and methods

2.1. Long term experiment

The long term experiment was established in 1969 in Agroscope Changins (46°24′ N, 06°14′ E, 430 m above sea level), Switzerland. In this site, the mean annual temperature is 10.2 °C and the average total annual precipitation is 999 mm (30-year averages, 1981–2010). The experiment is set up on two different types of soil, a clay (48% clay-37% silt) and a loam (25% clay-44% silt) soil.

The experiment follows a randomized complete block design with three main treatments of soil tillage; conventional deep inversion tillage on one side, and two reduced tillage treatments on the other side (Büchi et al., 2017). Until 2007, the following treatments were applied: T1. deep inversion tillage (plough), T2. deep non inversion tillage, T3. minimum tillage. In 2007, the deep non inversion tillage treatment (T2) was converted into a no till treatment (last tillage: autumn 2006). Each treatment is replicated three times on the clay soil and four times on the loam soil.

The crop rotation is winter wheat, winter rapeseed, winter wheat, grain maize. In 2013, the standard rotation was interrupted to allow the setup of the present experiment, which took place between August 2013 and July 2016.

At that time, 44 years of differentiated tillage practices have modified soil properties in each treatment (Büchi et al., 2017). Though organic carbon (C) stocks were not significantly different between tillage treatments in 2013, the plough and deep non inversion tillage treatments showed a marked decrease of C concentration since the beginning of the experiment, while the minimum tillage treatment allowed to maintain C concentration. In addition, an important C and nutrient stratification with depth was observed in this treatment.

2.2. Experimental setup

In August 2013, after the harvest of a winter wheat (straw exported), each main plot was divided into eight subplots to integrate cover crops. The size of each subplot was 3 m × 8.75 m, which represented a surface of 26.25 m^2. Eight different treatments were considered: 1. brown mustard (*Brassica juncea*), 2. daikon radish (*Raphanus sativus longipinnatus*), 3. field pea (*Pisum sativum*), 4. black oat (*Avena strigosa*), 5. niger (*Guizotia abyssinica*), 6. phacelia (*Phacelia tanacetifolia*), 7. 11 species mixture (with 50% legumes), 8. control with no cover crop (Table 1). All species composing the 11-species mixture were studied in another experiment set up at the same site (Wendling et al., 2016). All the species used here are frost sensitive and would thus, in this region, typically die at the end of autumn (November–December).

The general management sequence was the following: cover crops were direct seeded, in all soil tillage treatments, at the beginning of August; their biomass was evaluated, together with weed biomass, at the beginning of October; tillage was then applied according to treatments, winter wheat was seeded at the end of October – beginning of November and then harvested between mid-July – beginning of August (Fig. 1). This sequence was repeated three times, in 2013–2014,