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Evaluation of monocropped and intercropped grain legumes for cover cropping in no-tillage and reduced tillage organic agriculture

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ABSTRACT

Intensive tillage by means of mouldboard ploughing can be highly effective for weed control in organic farming, but it also carries an elevated risk for rapid humus decomposition and soil erosion. To develop organic systems that are less dependent on tillage, a two-year study at Reinhardtsgrimma and Köllitsch, Germany was conducted to determine whether certain legume cover crops could be equally successfully grown in a no-till compared with a reduced tillage system. The summer annual legumes faba bean (*Vicia faba* L.), normal leafed field pea (*Pisum sativum* L.), narrow-leafed lupin (*Lupinus angustifolius* L.), grass pea (*Lathyrus sativus* L.), and common vetch (*Vicia sativa* L.) were examined with and without sunflower (*Helianthus annuus* L.) as a companion crop for biomass and nitrogen accumulation, symbiotic nitrogen fixation (N_2 fixation) and weed suppression. Total cover crop biomass, shoot N accumulation and N_2 fixation differed with year, location, tillage system and species due to variations in weather, inorganic soil N resources and weed competition. Biomass production reached up to 1.65 and 2.19 Mg ha^{-1} (both intercropped field peas), and N_2 fixation up to 53.7 and 60.5 kg ha^{-1} (both common vetches) in the no-till and reduced tillage system, respectively. In the no-till system consistently low sunflower performance compared with the legumes prevented significant intercropping effects. Under central European conditions no-till cover cropping appears to be practicable if weed density is low at seeding. The interactions between year, location, tillage system and species demonstrate the difficulties in cover crop species selection for organic conservation tillage systems.

1. Introduction

Organic farming practices commonly include conventional mouldboard plough tillage with deep soil inversion as one of the most effective weed control methods (Gruber and Claupein, 2009). However, this labor- and energy-intensive technique reduces the soil's aggregate stability and organic matter content (Hermawan and Cameron, 1993; Schjønning and Rasmussen, 1989) leading to soil erosion. This contrasts the preservation of soil fertility, which is one basic principle of organic farming. No-till practices can diminish erosion to tolerable rates (Montgomery, 2007), stabilise soil aggregates and increase soil organic carbon close to the soil surface (Carter, 1992; He et al., 2009; Madari et al., 2005). Nonetheless, to date, organic no-till systems have not been widely adopted under temperate central European conditions.

The most prominent barrier to implement a no-till system is the yield reduction in the transition period (Reicosky and Saxton, 2007), due to poor crop emergence, increased weed infestation and reduced nitrogen (N) mineralization. Poor crop emergence is often a result of unfavorable seed placement, which leaves the seed exposed or embedded in hairpinned residue, resulting in reduced crop emergence in dry conditions due to poor seed–soil contact (Baker and Saxton, 2007). This can be avoided with the seeding technology of the inverted T-cross slot opener, which places the seed into horizontal slots below the residue covered soil surface, creating water vapor rich conditions that favorably affect germination (Baker, 2007; Wuest, 2002).

To control the weed infestation, the transition to the no-till system should be initiated after grain cash crop harvest in summer with the establishment of no-till seeded cover crops. This can reduce the weed competition for the cover crop because the available N resources for weeds have been depleted by the cash crop, whereas perennial weeds that are favored by the omission of tillage

Abbreviations: a.s.l, above sea level; cv, cultivar; DM, dry matter; DWD, Deutscher Wetterdienst (German meteorological service); IC, intercropped; KÖ, Köllitsch; MC, monocropped; RG, Reinhardtsgrimma.

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Table 1
Soil, experimental details and date of first daily mean below 0 °C (end of growing season by temperature definition).

Site	Reinhardtsgrimma (RG)		Köllitsch (KÖ)	
	2009	2010	2009	2010
Soil type (FAO classification)[a]	Dystric Cambisol (shallow)	Dystric Cambisol (shallow)	Arenic Fluvisol (deep)	Arenic Fluvisol (deep)
Soil texture	Loamy sand	Loamy sand	Loamy sand	Loamy sand
Field capacity (vol.%)[b]	34	34	32	32
Soil pH (0.01 M $CaCl_2$)	6.1	5.6	5.6	5.6
Soil P (CAL; mg kg^{-1})[c]	71	29	31	35
Soil K (CAL; mg kg^{-1})[c]	156	135	41	40
Soil Mg (0.01 M $CaCl^2$; mg kg^{-1})	88	84	159	131
Cover crop sowing dates	19 August 2009	24 August 2010	17 August 2009	15 August 2010
Biomass harvest I	18 September 2009	24 September 2010	18 September 2009	20 September 2010
Biomass harvest II	22 October 2009	25 October 2010	25 October 2009	27 October 2010
End of growing season[d]	31 October 2009	24 November 2010	13 December 2009	24 November 2010

[a] Soil type according to IUSS Working Group WRB (2006).
[b] Estimated according to DIN 4220 (DIN Deutsches Institut für Normung e.V., 2008).
[c] Calcium acetate lactate (CAL) extraction method after Schüller (1969).
[d] First daily mean temperature <0 °C, temperature indicator according to the Saxon climate impact monitor.

(Moonen and Barberi, 2004) were cut in the harvest process. The no-till seeding of cover crops can also reduce the annual weed population density as weed seeds are not incorporated into the soil and germination from the weed seed bank is not induced by tillage (Bilalis et al., 2001). During the cover cropping period, the weed growth will be reduced through cover crop-weed competition for light, water and nutrients.

Low inorganic soil N resources and N immobilization might impair the growth of non-legume cover crops, whereas legumes are able to compensate for the low N availability through N_2 fixation (Reiter et al., 2002). The N_2 fixation can be a competitive advantage over the weeds and increase the available N resources for the subsequent cash crop, which will be provided through decomposing legume residue (McVay et al., 1989). This could, to some extent, compensate for the decreased mineralization in the no-till system.

The faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), narrow-leafed lupin (*Lupinus angustifolius* L.), grass pea (*Lathyrus sativus* L.) and common vetch (*Vicia sativa* L.) are capable of N_2 fixation and have been tested as summer green manure (Biederbeck et al., 1993; Miller et al., 2011; Townley-Smith et al., 1993) and as winter annual cover crops (Hargrove, 1986; Holderbaum et al., 1990; Keeling et al., 1996). Only a few studies (Franczuk et al., 2010; Martens et al., 2001) have evaluated the use of large seeded legumes as late season cover crops that are terminated by frost. The cover crop termination by frost is an essential component in an organic no-till system approach because the termination by tillage or herbicides is not possible and alternative methods like mowing or rolling can delay the cash crop seeding and pose the risk of regrowth. The termination of cover crops during winter is also advantageous in dry years because it allows the soil water resources to be replenished over winter while frost resistant cover crops would continue their resource usage throughout spring, with possibly detrimental effects for the subsequent cash crop (Clark, 2007). Compared to cover crop termination in spring, the termination in winter offers the potential of early N mineralization which can improve the growth of the cash crop. In central European conditions, frost termination is ensured for the species used in this study and they might be better suited than other legumes for late season cover cropping due to their adaptation to dry late summer conditions (grass pea) or to biomass production and N_2 fixation under wet and cold late autumn conditions (faba bean, field pea) (Biederbeck et al., 1993; Power and Zachariassen, 1993).

Sown after the harvest of cereal grain crops such as winter wheat, the legume cover crops can function as a sink for nutrients and provide them to the spring cash crops, increase the easily decomposable organic matter and break the chain of infections (Clark, 2007). The cover crop residues can reduce erosion and limit the weed infestation in the early cash crop growing phases through light interception.

Growing a cover crop mixture of legumes and a non-legume, like rye (*Secale cereale* L.), can further deplete available soil N sources for weeds, reducing their growth and increasing the legume N_2 fixation efficiency (Brainard et al., 2012). The additional biomass production of the non-legume can increase the total intercropped biomass over the monocropped biomass production. The use of rye can be problematic in an organic no-till system when insufficient winter kill delays the cash crop seeding, because for the successful termination by the alternative use of a roller–crimper, rye has to reach anthesis (Mirsky et al., 2009). In the present study, sunflowers (*Helianthus annuus* L.) were used as an alternative. As a warm season crop they will be terminated by frost. Sunflowers are well suited as an intercrop partner due to the complementary characteristics to legumes, such as early ground shading. Successful conventional sunflower cropping in a well fertilized no-till system has shown their suitability for conservation tillage (Halvorson et al., 1999).

The objective of this study was to evaluate five large seeded legumes, both monocropped (MC) and intercropped (IC) with sunflowers as late season cover crops, all sown without tillage (no-till seeding) and after shallow soil inversion (reduced tillage), with a view to finding suitable species for organic no-till cover cropping.

2. Materials and methods

2.1. Experimental sites and setup

Field trials were conducted from August to October 2009 and 2010 at a long-term certified organic farm in Reinhardtsgrimma (50°53′N, 13°45′E, 350 m a.s.l.) and at the Teaching and Research Farm Köllitsch (51°30′N, 13°06′E, 84 m a.s.l.), Germany. Soil parameters are presented in Table 1. The sites Reinhardtsgrimma (RG), situated at the northern slope of the Eastern Ore Mountains and Köllitsch (KÖ), situated in the low land area of northwest Saxony, were chosen to represent the late season climate conditions at a submontane and planar location in central Europe, respectively.

The fields at both locations had been under conventional plough tillage up until the cash crop preceding the cover crops in 2009 and 2010. The cash crops were winter rye (2009) and oats (2010) at the RG location and winter wheat (2009 and 2010) at the KÖ location. Winter cash crops were sown during the autumn of the previous year and the oats was sown during the spring of the harvest year.