Soil Use and Management

Soil Use and Management, March 2010, **26**, 12–20 doi: 10.1111/j.1475-2743.2009.00253.x

Reduced tillage in temperate organic farming: implications for crop management and forage production

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Abstract

To promote conservation tillage in organic farming systems, weed control and ley removal within arable-ley rotations need to be optimized. A long-term field trial was thus established in Frick, Switzerland in 2002 on a clayey soil and with a mean precipitation of 1000 mm/year. The tillage experiment distinguished between conventional tillage with mouldboard ploughing (CT, 15 cm depth) and reduced tillage (RT), including a chisel plough (15 cm) and a stubble cleaner (5 cm). Results of a 2-year grass-clover ley (2006/2007) and silage maize (2008) are presented. Due to dry conditions, mean grass-clover yields were 25% higher in RT than in CT, indicating better water retention of RT soils. Clover cover and mineral contents of the fodder mixture were also higher in RT. The ley was successfully removed in autumn 2007 in RT plots, and a winter pea catch crop was sown before maize. In CT, ploughing took place in spring 2008. Maize yields were 34% higher in RT than in CT, despite a two- to three-fold higher but still tolerable weed infestation. Maize in RT plots benefited from an additional 61.5 kg of easily decomposable organic N/ha incorporated into the soil via the pea mulch. Measurement of arbuscular mycorrhizal colonization of maize roots indicated a similar mechanical disturbance of the topsoil through the reduced ley removal system compared with ploughing. It is suggested that RT is applicable in organic farming, even in arable-ley rotations, but long-term effects need further assessment.

Keywords: Crop rotation, grass-clover, ley removal, organic farming, reduced tillage, silage maize

Introduction

In view of the environmental challenges that are present today, the demand for more sustainable agricultural systems is growing. In recent reviews, traditional mouldboard ploughing was shown to cause soil erosion (Montgomery, 2007; Triplett & Dick, 2008) and loss of soil organic carbon (Lal *et al.*, 2007). Therefore, the development of no-till on a large scale is seen as the next agricultural revolution (Huggins & Reganold, 2008; Triplett & Dick, 2008). Between the two extremes of no-till (NT) and conventional tillage (plough, CT), various reduced tillage (RT) techniques were developed that work the soil less intensively. In this paper, NT and RT are summarized by the term 'conservation tillage'. In addition to tillage, the 'whole farm concept' needs to be changed to meet future requirements. FAO, for example, is promoting conservation agriculture which includes minimal soil disturbance, a permanent soil cover and crop rotations (Hobbs *et al.*, 2008). In organic farming, crop rotations are a fundamental part in arable cropping along with avoiding synthetic pesticides and mineral fertilizers (Lampkin, 1990). Integrating conservation tillage into organic farming would thus go beyond the FAO concept and would be an environmentally sound agricultural system. However, this combination is still rarely practised. This is because of several challenges, which are mainly related to increased weed infestation (Peigné *et al.*, 2007; Teasdale *et al.*, 2007). Weed control is far more difficult without herbicides, and continuous no-till is therefore probably not possible under organic farming conditions. Peigné *et al.* (2007) also state that pest and disease management could be more difficult under conservation tillage, but that further research is needed.

There are additional challenges in temperate climates. Carter (1994) states that conservation tillage under humid conditions promotes a dense plant cover. Along with the lack

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Received September 2009; accepted after revision November 2009

of soil mixing, aeration is reduced and soil warming and drying can be delayed in the spring. In addition to the resulting impact on soil workability, the mineralization of soil organic matter is slowed down compared to conventional tillage (Peigné *et al.*, 2007), which could result in a N shortage in the beginning of the growing season (Berner *et al.*, 2008).

In addition to those challenges, technical questions also need to be addressed. In organic agriculture, grass-clover leys play a crucial role within an arable crop rotation. They are an important source of N, improve the soil structure and help to control weeds and pests (Lampkin, 1990). Grass-clover leys are traditionally ploughed-out prior to seedbed preparation for the following crop. The incorporated organic matter mineralizes and N becomes available to the subsequent crops, especially in the first year (Davies *et al.*, 2001; Nevens & Reheul, 2002). A clean seedbed is achieved, thus reducing the risk of grass-clover and weed regrowth. However, Stockfisch *et al.* (1999) and Grandy *et al.* (2006) observed that soil organic matter accumulated by conservation tillage in the long-term was lost by ploughing even once. The storage and sequestration of carbon in the soil through conservation tillage would thus be offset. Given this, it is desirable to develop a method for removing grass-clover leys without ploughing, which guarantees a continuous low tillage intensity. A system that contains catch crops in addition to reduced tillage might be possible to meet weed control demands. Catch crops have been found to prevent soil erosion (Lu *et al.*, 2000; Rinnofner *et al.*, 2008), to suppress weeds (Liebman & Davis, 2000) and to take up soil nitrate after tillage (Hansen & Djurhuus, 1997). The additional operations, however, might cause a certain degree of soil disturbance in the short-term, possibly similar to ploughing. Effects on soil organisms like arbuscular mycorrhizal fungi that have a fragile extraradical hyphal network (Kabir *et al.*, 1997) might serve as an indicator for mechanical disturbance.

The objectives of this study were to assess the establishment and performance of a 2-year grass-clover ley, to launch a reduced tillage system for removing the ley and to quantify its impacts on soil properties as well as on the growth of the subsequent silage maize crop. The study compares data from the years 2006 to 2008 collected in an organic long-term tillage trial which started in autumn 2002 on a clayey soil in Switzerland.

Material and methods

Site conditions

The experimental site was at Frick, Switzerland (47°30′N, 8°01′E, 350 m). An oceanic climate prevails in this region with a mean annual precipitation and mean annual temperature of 1000 mm and 8.9 °C, respectively (Berner *et al.*, 2008). Monthly air temperature and precipitation from autumn 2005 to autumn 2008 are shown in Figure 1. The field trial was established in autumn 2002 on a heavy textured Stagnic Eutric Cambisol which was previously managed under conventional tillage. Analysis of the topsoil (0–10 cm) in 2008 revealed an organic carbon content of 2.2% in conventional tillage (CT) and 2.6% in reduced tillage (RT) plots. On average, the mineral fraction consisted of 22% sand, 33% silt and 45% clay. Averaged over all plots, an enrichment of ammonium-acetate-EDTA-extractable P (116 mg P/kg soil) and K (467 mg K/kg soil), and a pH (H_2O) of 7.5 were found. The nutrient accumulation was a result of intensive manuring before the farm was converted to organic standards (EEC No. 834/2007) in 1995. During winter and springtime the soil can be temporarily waterlogged.

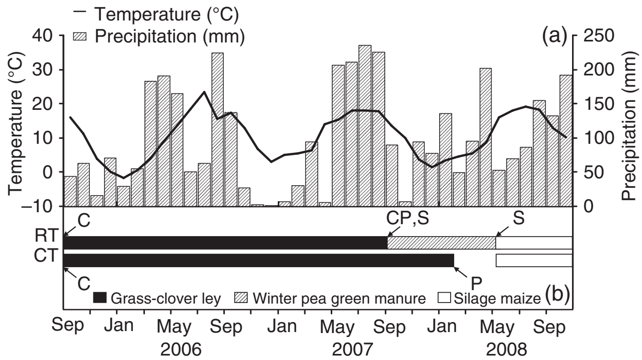

Figure 1 Climate data and crop management in 2005 to 2008. (a) Monthly averages of air temperature (°C) and precipitation (mm). (b) Primary tillage operations and crop rotations of the reduced tillage (RT) and conventional tillage (CT) treatments. Timing and types of tillage operations are indicated by arrows, as follows: cultivator (C) 5 cm, chisel plough (CP) 15 cm, stubble cleaner (S) 5 cm and mouldboard plough (P) 15 cm.

Crop rotation and management

The six course crop rotation consisted of winter wheat (*Triticum aestivum* L. cv. 'Titlis', 2003), an oat-clover intercrop (*Trifolium alexandrinum* L. and *Avena sativa* L., 2003/2004), sunflower (*Helianthus annuus* L., cv. 'Sanluca', 2004), spelt (*Triticum spelta* L., cv. 'Ostro', 2005), a 2-year grass-clover ley (mixture of *Trifolium campestre* L., *T. repens* L., *Dactylis glomerata* L., *Festuca pratensis* Huds., *Phleum pratense* L., *Lolium perenne* L., 2006 and 2007) and a winter pea catch crop (*Pisum sativum* L., cv. 'EFB 33', 2007/2008) followed by silage maize (*Zea mays* L., cv. 'Amadeo', 2008). The winter pea catch crop was only grown in RT plots because grass-clover plants were cleared in the previous autumn. In contrast, the grass-clover crop was ploughed in spring in CT (details are explained in the discussion section). In 2008, silage maize marked the end of the first crop rotation period. The grass-clover mixture was seeded at a rate of 30 kg/ha, winter pea at a rate of 230 kg/ha and silage maize at a rate of 110 000 seeds/ha. All seeds were untreated.

Between 2006 and 2008, weeding was done only in maize. A rolling cultivator was used during the four-leaf stage. In the eight-leaf stage, each plot was weeded by hand at the rate of 15 h/ha. This corresponded to the Swiss production standards for organically grown maize as described in AGRIDEA & FiBL (2008).

Experimental design and management

Three factors – tillage, fertilization and biodynamic preparations – were tested in this long-term field trial. Each factor was characterized by two different treatments, which are summarized in Table 1. The corresponding eight treatment combinations were arranged in a split plot design with four replications. Subplot size was 12 × 12 m.

Conventional tillage (CT) was carried out using a mouldboard plough within the upper 15 cm. The reduced tillage treatment (RT) was a combination of chisel tillage ('WeCo-Dyn system'; EcoDyn company, D-77963 Schwanau, Germany) for loosening the soil within 15 cm depth and a stubble cleaner ('Stoppelhobel', Zobel company, D-74585 Rot am See, Germany). This tool is similar to a shallow plough, but undercuts and mixes only the upper soil layer (5 cm) to remove rhizomatous weeds. The primary tillage operations of 2005 to 2008 are illustrated in Figure 1. For all crops, seedbed preparation and seeding was done simultaneously in all plots with a horizontally rotating harrow ('Rototiller'; Rau company, D-73235 Weilheim, Germany, 5 cm). The grass-clover ley was established after spelt on 12/13 August 2005. The soil crust was superficially disrupted (5 cm) by a cultivator with wide goose sweeps, equalling one or two passes for CT or RT plots, respectively.

To remove the ley in 2007/2008, two different approaches for CT and RT were applied. In CT, the ley was ploughed-out on 25 February 2008, leaving a bare soil surface until maize establishment. For RT plots, a new method was tested. The grass-clover sward was superficially incorporated using the stubble cleaner and the soil loosened with the chisel plough on 14/15 September 2007 (Figure 1). This meant a loss of the last grass-clover cut in 2007 in the RT treatment. The grass-clover mulch successfully dried within a month, and a winter pea green manure crop was directly sown on 11 October 2007. The 7 May 2008 peas were mulched and superficially incorporated with the stubble cleaner. Afterwards, maize was drilled into the fresh mulch on 12 May 2008.

Table 1 Experimental factors

Tillage	Conventional tillage (CT); Reduced tillage (RT)
Fertilization	Slurry (SL); Manure compost/slurry (MC)
Biodynamic preparations	Without preparations; With field and compost preparations

Table 2 Amount of total and mineral N applied to manure compost (MC) and slurry plots (SL) in 2006 to 2008

	Applied N (kg N/ha)			
	Slurry (SL)		Manure compost/slurry (MC)	
	N_{tot}	N_{min}	N_{tot}	N_{min}
2006	160	79	104	49
2007	139	54	90	32
2008	29	13	48	18

N_{tot}, total nitrogen; N_{min}, mineral nitrogen (NO_3-N plus NH_4-N, contained in fertilizers).

Experimental plots were intended to be fertilized with cow manure at an annual average intensity corresponding to 1.4 livestock units (LU)/ha (Berner *et al.*, 2008). The manure compost treatment (MC) consisted of a mixture of manure compost and reduced amounts of slurry and the slurry treatment (SL) of slurry only. The amount of N applied from 2006 to 2008 is shown in Table 2. The preparation of slurry and manure compost was described in detail in Berner *et al.* (2008). Because of unfavourable weather conditions, a second slurry application was not possible in 2008. For this reason, SL plots received less fertilizer than MC plots in the maize season.

Field and laboratory analyses

The grass-clover sward was cut four times per year in May, July, August and October/November. Dry matter yields of each cut were recorded and the total annual yield subsequently calculated. Aliquots of each cut were mixed in order to adjust their amount of biomass to one bulk sample per plot. The dry matter biomass of winter peas and silage maize at harvest, as well as maize plant density were determined, and samples were taken. Grass-clover, pea and maize samples were analysed for nutrient concentrations. N was determined according to the Kjeldahl method. For measuring P, K, Mg and Ca, samples were incinerated at 600 °C and the ash was extracted with concentrated hydrochloric acid. N and P concentrations were determined photometrically and K, Mg and Ca concentrations were determined via atomic absorption spectrometry.

Weeds were assessed in 2008 at three maize stages (first-leaf, silking and at harvest), with special attention to clover and grass species. Weed density (plant/m^2) was estimated in the first-leaf stage before weeding. Thereafter, weed cover (%) was determined during silking and at harvest. Soil samples for analysing the colonization of maize roots with arbuscular mycorrhizal fungi (AMF) were taken at the four-leaf stage, silking and harvest of maize with a sampling auger (Ø = 4 cm) at depths of 0–10 cm and 10–20 cm. Roots were washed and fungal structures were stained according to the Swiss guidelines of ART & ACW (2004), which are based on Phillips & Hayman (1970). The percent AMF colonization of roots was determined with the gridline-intersect method suggested by Giovanetti & Mosse (1980).

Statistical analysis

All parameters were tested for normally distributed residuals (Shapiro-Wilk-test). Mean yields, nutrient concentrations and nutrient uptake were calculated with an ANOVA using the JMP 5.0.1 software (SAS, 2002). The three factors tillage, fertilizer and biodynamic preparations as well as their interactions and the effect of the replications were included in the analysis. For the binomially distributed parameters of clover cover, weed cover and arbuscular mycorrhizal colonization, the Wilcoxon test was used to test for significant differences.

Results

Results from the statistical analyses revealed no significant differences and interactions related to biodynamic preparations. Therefore, the results will neither be shown nor discussed. The data of the treatments with and without biodynamic preparations were consequently pooled.

Grass-clover

Total yields of grass-clover were 8.58 t dry matter (dm)/ha and 8.70 t dm/ha in 2006 and 2007, respectively. There were significant differences between RT and CT in both years. A surplus of 20–30% higher yields was achieved under RT management (Table 3). Also, slurry fertilization improved grass-clover growth relative to manure compost, resulting in 14% increased yields in 2006 but not in 2007. Examining the yields and the clover cover of each cut, differences between the years 2006 and 2007 were observed (Figure 2). In 2006, yields declined abruptly from the first to the second cut and remained consistently low thereafter. Clover growth was sparse, and finally reached a cover of 20% in RT and less than 5% in CT plots. In contrast, yields of each cut declined linearly in 2007 and clover growth increased logarithmically to more than 60% in RT and 50% in CT plots. Yields and clover cover were always significantly higher in RT than in CT. Significantly higher yields were observed in SL in 2006, and a greater clover cover was observed in MC in 2007.

On average, Ca concentrations of grass-clover samples taken in 2007 were nearly twice as high as in 2006. Except for P, plants in RT plots had from 4 to 31% higher nutrient

Table 3 Total yields of grass-clover and silage maize in 2006 to 2008

	2006 Grass-clover (t dm/ha)	2007 Grass-clover (t dm/ha)	2008 Silage maize (t dm/ha)
Tillage			
Conventional	7.51	7.79	12.27
Reduced	9.66	9.60	16.48
Reduced (100% = conventional) (%)	129	123	134
Fertilization			
Slurry	9.24	8.65	14.43
Manure compost	7.92	8.74	14.32
Manure compost (100% = slurry) (%)	86	101	99
ANOVA			
Tillage	***	***	***
Fertilization	***	ns	ns
Tillage × Fertilization	ns	ns	*

dm, dry matter; ns, not significant. ANOVA: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

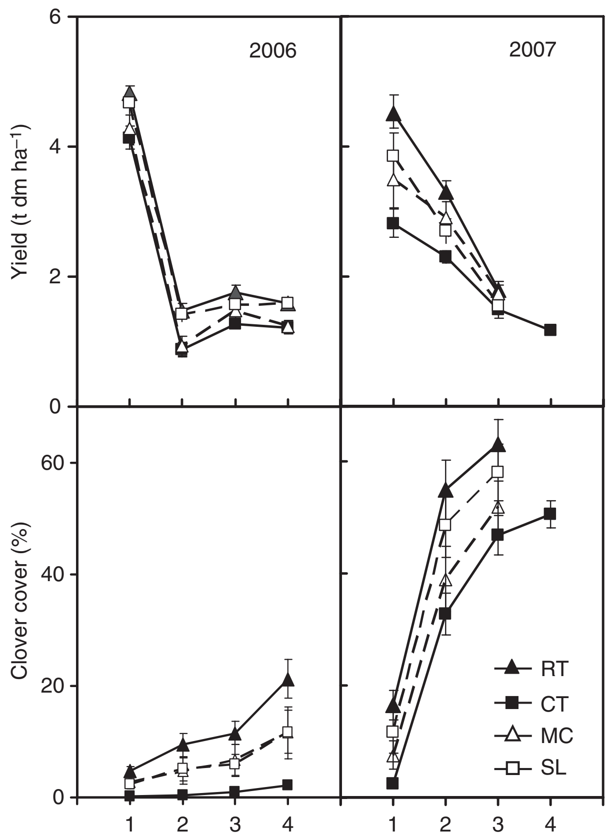

Figure 2 Grass-clover yields (t dm/ha) and clover cover (%) of four cuts in 2006 and 2007, respectively (±SEM). Data are provided for reduced tillage (RT), conventional tillage (CT), manure compost (MC) and slurry (SL) treatments.

concentrations than CT in 2006 and 2007 (Table 4). The effect was more apparent in 2006. Fertilizing the ley with slurry resulted in greater K and Mg concentrations in 2006, whereas N and Ca concentrations were higher with manure compost in 2007. In both years, nutrient uptake was 22 to 68% higher in RT than in CT plots (Table 5). Slurry application resulted in a consistently higher nutrient uptake of grass-clover in 2006, which was compensated for in 2007, and even reversed for N and Ca.

Winter pea green manure in RT plots

As a part of the new method for removal of the grass-clover ley without ploughing, a winter pea green manure was grown only in RT plots. Peas produced an average above-ground biomass of 1.9 t dm/ha which remained in the field. The amount of 61.5 kg N/ha was thus applied to RT plots via pea mulch.

Silage maize

Maize emergence was patchy in CT plots. This was clearly visible in the field and was indicated by a 7% lower maize density (not significant, data not shown). The average yield was 14 t dm/ha and was 34% higher in RT than in CT plots. The fertilizer types did not affect yields (Table 3). At harvest, N and Ca concentrations were 28 and 14% greater in RT plots, respectively, while plants in CT plots contained 15%

Table 4 Concentrations of N, P, K, Ca and Mg in grass-clover and silage maize in 2006 to 2008. Annual grass-clover samples were obtained by mixing all cuts according to their amount of biomass

	Grass-clover 2006 (mg/g)					Grass-clover 2007 (mg/g)					Maize 2008 (mg/g)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Tillage															
Conventional	19.2	3.61	23.77	5.92	2.07	18.1	3.20	25.22	10.68	2.73	9.03	2.01	8.18	1.36	1.39
Reduced	23.0	3.76	26.18	7.73	2.41	19.6	3.17	27.84	11.52	3.01	11.57	1.70	7.98	1.56	1.41
Reduced (100% = conventional) (%)	120	104	110	131	116	108	99	110	108	110	128	85	98	114	102
Fertilization															
Slurry	21.1	3.72	25.90	6.82	2.32	17.9	3.17	26.39	10.49	2.87	10.52	1.87	8.21	1.48	1.42
Manure compost	21.0	3.65	24.05	6.83	2.16	19.8	3.20	26.67	11.71	2.87	10.08	1.84	7.95	1.44	1.38
Manure compost (100% = slurry) (%)	100	98	93	100	93	111	101	101	112	100	96	98	97	97	98
ANOVA															
Tillage	***	**	***	***	***	*	ns	***	*	*	***	***	ns	**	ns
Fertilization	ns	ns	***	ns	**	**	ns	ns	***	ns	ns	ns	ns	ns	ns
Tillage × Fertilization	ns	ns	**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns, not significant. ANOVA: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

Table 5 Uptake of N, P, K, Ca and Mg in grass-clover and silage maize in 2006 to 2008. Annual grass-clover samples were obtained by mixing all cuts according to their amount of biomass

	Grass-clover 2006 (kg/ha)					Grass-clover 2007 (kg/ha)					Maize 2008 (kg/ha)				
	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Tillage															
Conventional	144	27.1	179	44.4	15.6	141	24.9	197	83.2	21.3	111	24.7	100	16.7	17.0
Reduced	222	36.3	253	74.6	23.2	188	30.4	267	111	28.9	191	28.0	131	25.7	23.2
Reduced (100% = conventional) (%)	154	134	142	168	149	134	122	136	133	136	171	113	131	154	136
Fertilization															
Slurry	195	34.4	239	63.0	21.4	155	27.4	228	90.7	24.8	154	26.8	119	21.5	20.4
Manure compost	167	28.9	191	54.1	17.1	173	27.9	233	102	25.1	148	25.9	113	20.8	19.8
Manure compost (100% = slurry) (%)	85	84	80	86	80	112	102	102	113	101	96	97	95	97	97
ANOVA															
Tillage	***	***	***	***	***	***	***	***	***	***	***	**	***	***	***
Fertilization	**	***	***	*	***	*	ns	ns	*	ns	ns	ns	ns	ns	ns
Tillage × Fertilization	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns, not significant. ANOVA: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

Table 6 Weed survey of maize at the first-leaf stage, at silking and at harvest in 2008

Maize stages: Weed survey:	First-leaf Density (plants/m²)	Silking Cover (%)	Harvest Cover (%)	Harvest Biomass (t dm/ha)
Tillage				
Conventional	33	9	21	0.27
Reduced	181	28	54	0.76
Reduced (100% = conventional) (%)	553	310	262	288
Fertilization				
Slurry	92	17	34	0.40
Manure compost	121	21	40	0.63
Manure compost (100% = slurry) (%)	131	125	116	160
Wilcoxon test				
Tillage	***	***	***	***
Fertilization	ns	ns	ns	*

dm = dry matter; ns, not significant. Wilcoxon test: ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

more P (Table 4). Nutrient uptake was 13 to 71% greater under RT relative to CT (Table 5). The different fertilizers had no effect on either nutrient concentrations or on nutrient uptake of maize.

The weed infestation (density, cover and biomass) was found to be two to five times higher in RT plots than in CT plots at the assessed maize stages (Table 6). Manure compost treatment tended to benefit weeds relative to SL as well. Convolvulus species (*Convolvulus arvensis* L., *Calystegia sepium* L. R.Br.) and *Chenopodium polyspermum* L. were dominant which covered the soil densely but had a low biomass. Regarding grass-clover species, only perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) were observed in negligible quantities (0.3 and 0.1% cover at maize harvest, respectively). Percent colonization of maize roots with arbuscular mycorrhizal fungi was slightly higher in CT plots at the four-leaf stage, silking and harvest of maize (Figure 3). At the 10–20 cm depth, the colonization followed a sigmoidal curve during the season. In contrast, different temporal patterns of AMF colonization in CT and RT were found in the first ten centimetres, starting at a low level and reaching the highest colonization at maize harvest.

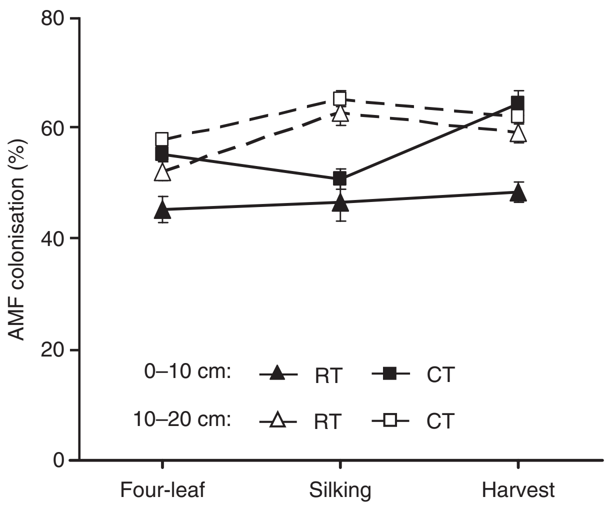

Figure 3 Percent arbuscular mycorrhizal fungi (AMF) colonization (±SEM) of maize roots in three maize stages and at two soil depths: 0–10 cm and 10–20 cm. Data are provided for reduced tillage (RT) and conventional tillage (CT) treatments.

Discussion

Grass-clover

Hot and dry conditions prevailed during seed germination in autumn 2005 which killed many seedlings and decelerated growth, especially in CT plots. The first cut of 2006 pretended a high yield due to regrowth of volunteer spelt. Spelt plants were killed during cutting, and the subsequent abruptly decreased yields represented grass-clover plants only. The yield in 2006 was ultimately lower than Swiss organic standards (AGRIDEA & FiBL, 2008) due to the dry summer. Grass-clover plants must have found more favourable conditions in the RT treatment. This was reflected in higher yields, a better nutrient supply and a greater clover cover compared to CT. Clover was able to grow in RT plots, but hardly at all in CT plots. Plants were consequently less stressed in the RT treatment, which was likely related to long-term changes in soil conditions, as the same tillage operations were carried out in all plots for establishing the grass-clover ley in 2005. Topsoils under conservation tillage have been found to retain water better than ploughed soils, particularly under dry conditions. This was reported mainly for no-till, but also for reduced tilled soils (Arshad *et al.*, 1999; Bescansa *et al.*, 2006) and seemed to be the result of a better soil structural stability. Under various climatic conditions, conservation tillage was found to increase aggregate size (Franzluebbers, 2002; Jacobs *et al*., 2009) and aggregate stability (Arshad *et al*., 1999; Emmerling, 2007) in topsoils. Correlations between aggregate stability and soil organic carbon content were shown in different tillage trials (McVay *et al*., 2006). The soil organic carbon content in the RT plots of our trial was already 7% higher after 3 years compared to CT plots (Berner *et al*., 2008), and increased to a relative difference of 17% (0–10 cm) in 2008. Thus, structural changes in the topsoil of the RT plots within the previous 4 years presumably helped to conserve water during the seasonal rainfall deficit periods of 2006 and alleviated water stress to grass-clover plants. Sufficient precipitation in summer 2007 partly normalized the growth situation. However, the effects of 2006 were still present, and higher yields as well as a greater clover cover in RT plots were recorded again.

The botanical composition of the ley changed from a grass-dominated ley in 2006 to a clover-dominated ley in 2007. This may have been caused by the dry weather conditions in 2006. A similar trend was also reported by Gutauskas *et al*. (2005). They found a shift to a grass sward in a long-term pasture after several dry years in succession. Fertilizer effects were also observed. The amount of applied N was 35% higher in SL versus MC plots in both years. An increased N fertilization was found to promote grass growth and to reduce the clover proportion in mixed swards (Steinshamn, 2001). This may explain why yields were higher in SL in 2006 where grasses dominated, and also why the clover cover was greater in MC plots in 2007, in which a clover cover of up to 60% was recorded.

Reduced ley removal system

As described in the introduction, we intended to remove the ley without ploughing in RT plots before sowing silage maize in springtime. This new method had to ensure that (i) grass-clover species did not regrow, (ii) the soil remained covered with plants or residues at all times and (iii) weeds were suppressed. We decided to eliminate the cut grass-clover plants by incorporation into the topsoil and desiccation in the autumn sun. A catch crop was considered to keep the soil covered during wintertime. We chose the same winter pea catch crop variety that Grass (2003) used as he reported increased yields of the subsequent maize crop. However, legume catch crops have been found to assimilate less soil nitrate than non-legume species after tillage (Fageria *et al*., 2005). The effect of our reduced ley removal system and the role of the pea catch crop in nitrate leaching and in other soil chemical features therefore need further attention. As an indicator of mechanical soil disturbance, we assessed the colonization of maize roots with arbuscular mycorrhizal fungi (AMF). The findings of Kabir *et al*. (1997) indicated that the external net of hyphae was more affected by ploughing than by RT and no-till particularly, in the upper horizon. They also found a correlation between the AMF hyphal length and the AMF colonization of maize roots, which was thus lower in CT throughout the season. Negative effects of ploughing on AMF colonization of maize roots in field experiments were also reported by McGonigle & Miller (1996), Mozafar *et al*. (2000), Galvez *et al*. (2001), and no differences were reported by Gavito & Miller (1998). Contrary to these expectations, we found a slightly higher AMF colonization in CT than in RT at both depths (0–10 cm, 10–20 cm) at three maize stages (four-leaf, silking, harvest). In the lower soil horizon, AMF colonization followed plant root growth, which was consistent with the findings of Kabir *et al*. (1997). In the topsoil (0–10 cm), however, it seemed that the AMF were disturbed in the beginning and recovered towards the end of the season, regardless of the tillage treatment. The short-term effect of soil disturbance might have been slightly higher following the RT compared to the CT ley removal system. Its long-term effects on soil organisms and other soil properties need further observation.

Silage maize

Silage maize grown on RT plots did benefit from the described ley removal system, particularly from the additional N provided by the pea catch crop. Yields were 34% higher in RT than in CT and also higher than the Swiss organic standard (AGRIDEA & FiBL, 2008). In contrast to CT, N was not likely to have been the limiting factor for plant growth in RT plots, which resulted in a dilution of other nutrients in maize plants, especially P. The high yield level in RT plots was achieved despite a two to three-fold more serious weed infestation throughout the season. The weed problem of conservation tillage in organic farming is well known (Kainz *et al*., 2003; Hampl, 2005; Schmidt *et al*., 2006). In our trial, the weed level was still acceptable in RT plots after 6 years, but its further development must be monitored.

Weeds were also favoured in MC compared to SL plots, possibly due to weed seeds introduced with the manure compost. Such a contamination might occur when weed seed viability is not fully destroyed, for example, because of incomplete composting (Larney & Blackshaw, 2003). Also, a slower crop emergence in the beginning of the season could have facilitated weed growth in MC plots, as manure compost contained less available N than slurry. Regarding volunteer grass-clover species, only negligible amounts of *Trifolium repens* L. and *Lolium perenne* L. were observed, which showed that the RT removal method was successful.

Conclusions

Long-term and short-term effects of reduced tillage were found to positively influence crop performance. It is suggested that a better soil structure retained soil moisture and reduced the water stress on grass-clover plants under dry conditions. Higher yields were reported consequently. The new reduced approach of removing the grass-clover ley included a green manure. The consequently better N supply increased yields of the subsequent silage maize despite a higher weed infestation. However, a slightly lower colonization of maize roots with arbuscular mycorrhizal fungi indicated that the reduced ley removal technique disturbed the upper soil layer similar to conventional ploughing. Reviewing the entire first crop period, reduced tillage was applicable under organic farming conditions. Overall, higher yields compared to ploughing were recorded, and weed infestation was still acceptable.

Acknowledgements

We sincerely thank the farmers involved in the project, especially Pius Allemann, Rainer Sax and Daniel Böhler. For technical assistance we are grateful to Robert Frei and Bruno Nietlisbach. Thanks also to Fredi Strasser and Monika Messmer. This study was funded by the Swiss Federal Office for Agriculture and various foundations: Dutch BD-Vereniging (NL), Stiftung zur Pflege von Mensch, Mitwelt und Erde (CH), Sampo Verein (CH), Software AG Stiftung (DE) and Evidenzgesellschaft (CH).

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