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The development of winter wheat and weeds under reduced tillage in organic farming.

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CONFIDENTIAL

Development of winter wheat and weeds in organic reduced tillage

Master thesis
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List of Abbreviations

AT - "After Tillering" stage

BT - "Before Tillering" stage

c - subplots cleaned from weeds (control)

CA - Conservation Agriculture

CT - Conventional Tillage system (mouldboard ploughing)

F - "Flowering" stage

H - "Harvest" stage

LUX - unit for illuminance

MsC - Manure compost/Slurry system

RT - Reduced Tillage system

S - Slurry system

SPAD - Soil Plant Analytical Development (Chlorophyll)

w - weed infested subplots

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1 Introduction

The loss of arable land by soil degradation is a problem worldwide. Within forty years almost one-third of the world's arable land has been lost due to degradation and continues to do so at a rate of 10 million hectares per year (Pimentel et al. 1995). Soil degradation has many forms, ranging from salinization, water logging, compaction, contamination, decline of soil structure and loss of fertility due to soil erosion by water and wind. However, among all of these serious forms of degradation, soil erosion is most widespread. With soil erosion losses from 10 up to 30 tons per hectare and year, and soil regeneration at a rate of 1 ton per hectare and year, top soils are eroded at a much higher rate than they are rebuilt (Gliessman 2007). Accelerated soil erosion has been a challenge since humanity started with agriculture and has been the rise and fall of early civilisations (Diamond 2005; Montgomery 2007) and thus is an undesirable and unsustainable trend. Intensive ploughing is one of the major causes of water and soil erosion especially in combination with monocultures and rotations where bare soil is exposed for a long time (Gliessman 2007; Lal et al. 2007; Montgomery 2007). Therefore to minimise the negative effect of tillage, more sustainable soil conservation methods should be implemented, for example Conservation Agriculture (CA).

1.1 Conservation Agriculture

Conservation Agriculture is an alternative cropping system based on three principals:

1. Minimising soil tillage: Ideally in this system, the soil should not be inverted and tilled as little as possible. The aim is to create stable soil aggregates, to decrease soil organic matter mineralisation and to promote soil life (Ball et al. 2005).

2. Protecting the soil surface with a permanent cover: In order to protect the soil against erosion, to maintain soil moisture, to suppress weeds and to provide shelter and food for soil biota, the soil should be covered at all times (Lal 1997). This can be achieved in arable farming by covering the soil with mulch, crop residues and/or cover crops in between the cultivation of cash crops.

3. Rotating and/or associating crops: The use of intercrops and diversified crop rotations helps to manage pests, diseases and weeds (Schmid and Obrist 2001).

How CA systems are applied is often determined by the local situation and can e.g. take the shape of zero- or no-tillage (NT) and reduced tillage (RT) that are often summarised with the term “conservation tillage”. According to Mäder and Berner (2012), reduced tillage is defined as any tillage that ‘operates at shallower depths or at lower intensity compared to customary ploughing in a given region’. Thus, reduced tillage can include a range between shallow ploughing (inversion) to non-inversion techniques like chisel ploughing or layer cultivation (Tebrügge and Düring 1999; Mäder and Berner 2012).

Next to soil and water conservation, reduced tillage has shown to have several additional benefits like increased soil organic matter sequestration (Six et al. 2002; Holland 2004; Berner et al. 2008), decreased runoff (Tebrügge and Düring 1999), soil biodiversity increase (Holland 2004) and an increase in earthworm abundance (Peigné et al. 2009; Kuntz et al. 2013). Beyond soil quality, there is also the potential of a decrease in labour demand (Davies and Finney 2002; Network 2005) and energy consumption (Holland 2004; Lal 2004). However, these benefits are debated in literature, balancing between beneficial and non-differential between the two systems (Carter 1994; Peigné et al. 2007; Mäder and Berner 2012).

Conservation tillage is increasingly applied worldwide and adopted especially as no-till farming since the last twenty years. In Brazil for example, no-till is applied in 50 % of all cropland (Derpsch et al. 2010; Scopel et al. 2013). The European Community as well as the FAO encourages European arable farmers to adopt CA like reduced and no-tillage as well. But the pedo-climatic conditions in Europe are different from the more semi-arid conditions in North and South America. The temperate climates are more humid, the annual temperatures lower. Beyond, European farms are smaller in size and often mixed farms with livestock using farmyard manure for nutrient recycling (Mäder and Berner 2012). Reduced tillage has shown to be more challenging in humid climates: the soil tends to stratify, aeration is reduced and soil warming can be delayed in spring altering seed germination (Ball et al. 2005; Peigné et al. 2007). Next to this, mineralisation of soil organic matter is slowed down (Peigné et al. 2007) which can result in an irregular and less controllable nitrogen supply especially in the beginning of the season (Berner et al. 2008). Additionally, with the soil cover being more dense, there are some technical difficulties in soil management for which farmers often need specific equipment (Ball et al. 2005).

1.2 Integration of Conservation Agriculture into Organic Farming

In terms of integration of CA systems like reduced tillage into an organic farming system, even more challenges arise. The main issue in this context is the increased weed infestation (Peigné et al. 2007). While conventional farmers change their weed management in CA by adapting herbicides, organic farmers need to find solutions within the organic regulations. One option is mechanical weeding, which is more difficult due to residues on the soil surface (Peigné et al. 2007). Perennial weeds like *Cirsium arvensis* and *Elytrigia repens* were found to increase (Gruber and Claupein 2009; Sans et al. 2011). They are more difficult to control by mechanical weed control and in some cases demand more hand weeding. Lastly, there is also the practical challenge of incorporating grass-clover leys that are important parts in organic crop rotations into the soil to prepare the seedbed. Grass-clover leys play a crucial role in soil fertility, pest and disease management, nitrogen acquisition and fodder production in the mostly mixed organic farms (Schmid and Obrist 2001). Also the fertilisation has an influence on the development of wheat and weeds in the field (Peigné et al. 2007). Where slurry contains more directly available nitrogen, which can be easily taken up by the crop but also by weeds, the slower release of nitrogen by solid farmyard manures appears to benefit weeds more than early nitrogen demanding crops (Berner et al. 2008). In addition, compost tends to contain relatively high numbers of weed seeds that can contribute to the soil weed seed bank (Blackshaw et al. 2005).

No-till is hardly adopted in organic farming systems due to the increase in weed pressure. As a practical compromise, reduced tillage is more common (Gruber and Claupein 2009; Soane et al. 2012). To successfully implement continuous reduced tillage and no-till in organic farming systems as a mean for erosion control, the weed challenge has to be solved. Thus, the weed infestation level and community composition should be under control in the short and long-term. This implies new weeding machines and strategies like the above mentioned adjusted crop rotation including cover crops.

Another question that is not well answered yet is, if the observed yield losses in organic reduced tillage are caused by weed competition or by nutrient deficiencies.

This thesis study increases the understanding of weed management and dynamics in an organic reduced tillage system. It will thus contribute to the search for practical solutions which are needed to adopt this sustainable tillage method into practical farming (Wezel et al. 2014). From an agro-ecological perspective, the thesis will focus on the field level, studying the effects of reduced tillage on weed pressure and winter wheat growth and determining if and how much crop growth will be reduced by the concurrence of weeds. It will also assess the result of a grass-clover ley destruction by reduced tillage which can cause a considerable regrowth and a subsequent weed problem in the following crop if not successful.

Research questions:

1. Is there a difference in the development of winter wheat and weeds including voluntary grass-clover between the two tillage systems (RT versus CT)?
2. Will this weed competition affect crop physiology and wheat biomass?
3. Is the choice of fertiliser, slurry or composted manure, of influence on the development of winter wheat and weeds?

Hypotheses:

1. There is a higher occurrence of weeds and voluntary grass-clover in the reduced tillage system.
2. An increased weed competition affects crop physiology and wheat biomass.
3. There is no influence regarding fertilisation on the development of winter wheat and weeds.

2 Materials and Methods

2.1 Site conditions

The master thesis was carried out at the Research Institute of Organic Agriculture (FiBL) in Frick, Switzerland (47°30'N, 81°01'E, 350 m a.s.l.). The experimental work was done within the Frick tillage experiment; a three factorial field experiment with reduced (RT) and conventional tillage (CT) as the first factor, fertilisation with only slurry (S) and manure compost and reduced quantity of slurry (McS) as the second and biodynamic preparations (with or without) as the third factor (Berner et al. 2008). Research topics that were addressed over the years included agronomic parameters next to a soil monitoring of soil organic carbon and soil microbial biomass (Mäder and Berner 2012).

The climate in Frick has an average annual temperature and rainfall of 8.9 °C and 1000 mm respectively. The soil type at the experiment field site is a Stagnic Eutric Cambisol with a mean soil pH (2012, 0-20 cm) of 7.1 and a mineral fraction of 22 % sand, 33 % silt and 45 % clay (Krauss et al. 2010). The experimental management since 2002 increased carbon stocks (0-50 cm) in the RT plots (Table 1) with a pronounced stratification (Gadermaier et al. 2012). After grass-clover ley destruction in autumn 2013 (Table 2) and the following winter period, high mineral nitrogen contents were found in RT plots in March 2014 (Table 1).

2.2 Farm Management

The Frick tillage trial started in 2002 on an organically managed field, which was ploughed in earlier times. The crop rotation has slightly changed in the third period and consists since 2014 of a 7 years crop rotation consisting of winter wheat, maize, spelt, sunflower, barley and two years of grass-clover ley.

In the years 2012 and 2013, the field was planted with a grass-clover ley. This ley was tilled differently in RT and CT before sowing winter wheat in October 2013. The farm operations are displayed in Table 2. Due to unfavourable weather and soil conditions in autumn 2013, the grass-clover destruction couldn't be performed successfully, and in particular grass and clover roots survived in the RT plots. A strong weed infestation was expected for winter wheat 2014.

Table 1 Differentiation of soil carbon stocks and soil mineral nitrogen (mean ± standard deviation) in 0 - 50 cm soil depth of the Frick tillage experiment sampled in [a]March 2012 and [b]March 2014.

	Carbon stocks[a] t ha^{-1}	Mineral nitrogen[b] kg ha^{-1}
CT x McS	137.5 ± 10.2	20.2 ± 3.9
CT x S	136.4 ± 13.9	21.2 ± 1.7
RT x McS	144.5 ± 7.7	27.2 ± 5.4
RT x S	144.1 ± 5.6	26.7 ± 3.5
ANOVA (ns = not significant)		
Tillage	p = 0.084	p = 0.016
Fertilisation	ns	ns
Tillage x Fertilisation	ns	ns

Table 2. Farm operations in 2013 and 2014 including soil tillage, fertilisation and sampling in the different treatments.

Treatments CT	RT	McS	S	Farm operation	Date	Comment	N applied
	X			1. Cleaning (Skim plough)	23.9.2013	5-10 cm deep	
	X			2. Cleaning (Chisel plough)	2.10.2013	5-10 cm deep	
X				Ploughing	9.10.2013	15 cm deep	
X	X			Rototiller/ Sowing winter wheat „Wiwa"	20.10.2013	250 kg /ha	
X	X			Sampling Before Tillering	12.3.2014		
		X		Manure compost spreading	12.3.2014	14.4 t/ha	94 kg N_t/ha 12 kg N_{min}/ha
		X		1. Slurry spreading	19.3.2014	20 m^3/ha	24 kg N_t /ha 9 kg N_{min} /ha
			X	1. Slurry spreading	19.3.2014	50 m^3/ha	59 kg N_t /ha 23 kg N_{min} /ha
		X		2. Slurry spreading	9.4.2014	25 m^3/ha	26 kg N_t /ha 10 kg N_{min} /ha
			X	2. Slurry spreading	9.4.2014	40 m^3/ha	42 kg N_t /ha 16 kg N_{min} /ha
X	X			Sampling After Tillering	14.4.2014		
X	X			Sampling Flowering	27.5.2014		

2.3 Experimental setup

The master study was conducted within the Frick long-term trial that focuses on the influence of biodynamic preparations, fertilisation and reduced tillage on soil fertility and yields. The field trial is laid out consisting of 32 plots of 12 by 12 meter, subdivided in ploughed and reduced tillage, slurry and manure, with or without BD preparations. The combination of these three factors results in 8 treatments that were arranged in a strip-split-plot design. Each treatment has four replicates. The trial design is shown in Figure 1.

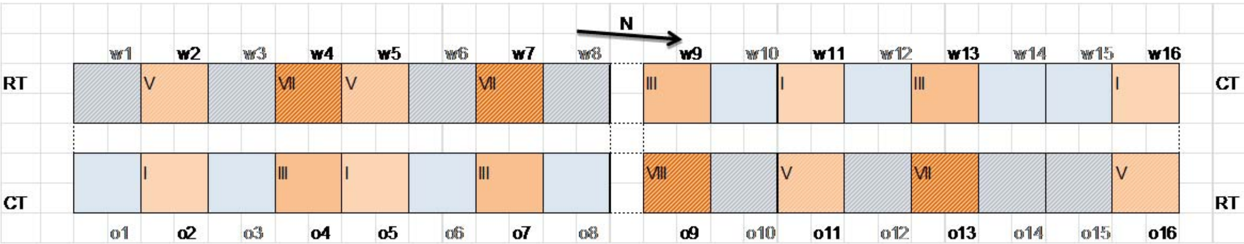


Figure 1. Design of the Frick tillage trial. Orange plots are receiving organic fertilisers, in the form of slurry (S, dark orange) or composted manure and small amounts of slurry (McS, light orange). The tillage factor is arranged in strips with ploughing (CT) and reduced tillage (RT, dashed). The grey fields receive additionally biodynamic preparations and were excluded in this study.

The master study was not focused on BD preparations. Thus the subplots included in this study are restricted to the plots without BD preparations. To assess the development of wheat and weeds over the season, four sampling dates were chosen at important growth stages of the winter wheat: **Before Tillering (BT), After Tillering (AT), Flowering (F) and Harvest (H)** based on the cereal growth stadia on the BBCH scale of Meier 2001. The BT stage is at wheat growth stage 23-29, the AT stage at wheat growth stage 30 just before the first node appears, and the F stage indicates the wheat growth stage 61, when ears are fully formed and are flowering. Within the 16 plots, seven subplots of 1 x 1 m were defined, two for each sampling date, with an exception of BT. To assess the effect of weed infestation, one of these subplots was left untreated with the **weed presence** as occurring on that place **(weed, w**). The other subplot was cleaned as a **control subplot (cleaned, c)**. The cleaning was done manually during the whole growing season, once every one to two weeks and additionally when needed. There was no clean plot at the BT stage yet due to the concurrence of the first sampling date with the start of the master study in early March. The subplots were located 2 meters from the borders from three of the four plot borders, to avoid boundary effects. The layout is shown in Figure 2. The harvest stage was not included in this thesis due to time limitations, but the data will be collected to conclude the overall weed monitoring.

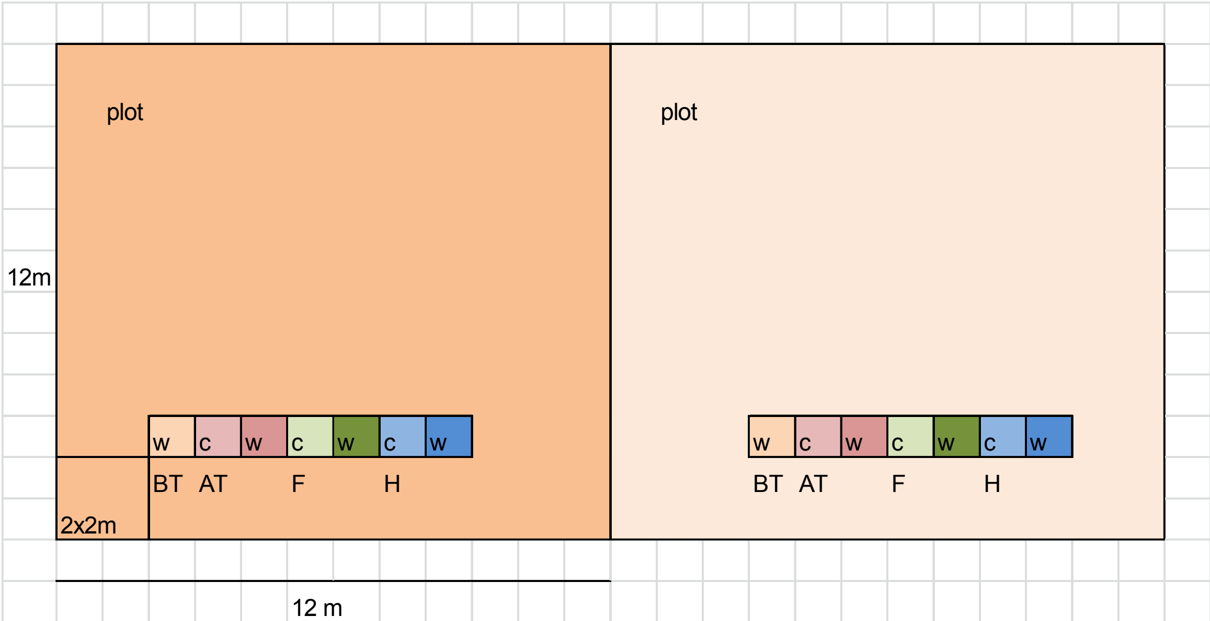


Figure 2. Design of the experimental subplots studied in the master thesis. Subplots were set out for the four sampling dates: Before Tillering (BT), After Tillering (AT), Flowering (F) and Harvest (H). For each moment, with the exception of BT, samplings were done for a subplot with weeds (w) and a control plot without weeds (c). Each subplot had the dimension of 1 m x 1 m.

2.4 Crop and weed analysis

To evaluate the competition between the wheat crop and the weeds, crop growth and development was monitored. Thus crop above ground biomass, plant height, chlorophyll content (SPAD) and plant density was collected at the four defined stages. The monitoring was done in both the clean, weed free control subplots and in subplots with weeds. The weed was assessed by determining above ground biomass and coverage at the four stages. Beside weed pressure, the different weed species were determined to assess the reoccurrence of the grass-clover pre-crop and to characterise the weed communities as influenced by the two tillage and the two fertilisation systems. To assess in which way the weed competition was affecting the wheat crop, light and nutrient competition were assessed by SPAD and light interception (Lux) analysis.

2.4.1 Winter wheat

Tiller density

To develop an idea of the seed density, the emergence and development of the wheat crop in both tillage systems, the tiller density was assessed. At all stages, the numbers of tillers were counted for both the cleaned and weed infested subplots. At BT, the emerged seedlings and small plants were pulled out and counted. At AT, the number of tillers was counted. At F and H, the number of ears was counted.

Biomass

The biomass of the winter wheat crop was determined by the dry weight of the above ground biomass. The wheat biomass was therefore harvested at all stages during its development for both the cleaned and weed infested subplots, with the exception of BT where the cleaned subplot weren't introduced yet. The wheat plants were cut by hand at soil level out of a 60 x 60 cm square within the subplots. This square was placed in such a manner that a good representation of the specific square meter could be obtained while avoiding boundary effects. The plant samples were collected in bags, processed, weighed and dried in the oven at 60˚C for 24 hours. The dry matter was calculated with equation (1).

$$dry\ matter\ (\%) = \frac{dry\ weight\ (g) - tara\ (g)}{fresh\ weight\ (g) - tara\ (g)} * 100 \qquad \text{equation (1)}$$

Plant length

At the stages AT, F and H, the length of 15 wheat plants (cm) was measured within the clean and weed subplots. This was done manually with a yard stick choosing wheat plants randomly within the subplot. The length was taken from soil level to the tip of the least emerged leaf at AT and to the end of the ear at the following stages. BT was excluded because the wheat had not yet time to elongate after winter dormancy.

Chlorophyll content (SPAD)

In order to assess the development of the wheat and the effect of the different soil tillage treatments on nutrient supply, the chlorophyll contents were measured. This was done at the first three stages. At H, the wheat plants had ripened and lost their chlorophyll. The analysis was done with a SPAD meter (SPAD 502 Plus, Konica Minolta Dietikon, Switzerland), taking three readings and their average of randomly 20 wheat top leaves throughout the subplot of the respective stage.

2.4.2 Weeds

Biomass

In order to determine the biomass (g) of the weeds at the different crop stages and treatments, the weeds were collected at the same time as the winter wheat biomass of the respective subplot and stage. The above ground parts were collected by cutting them manually at soil level, retrieving all weed biomass dead or alive. The plants were sorted into three categories of species: monocotyledons, dicotyledons and clover. Where possible, the different species were determined and weighed (fresh weight) to estimate the distribution of the species. Afterwards, all weed species of each subplot were pooled again to the above mentioned categories and dried in the oven at 60˚C for 24 hours and weighed to determine dry weight with equation (1).

Total and weed cover

The cover (%) of the winter wheat crop and the weed species was estimated at all stages within the growing season. Cover was chosen instead of plant density, because it gives additional information on weed growth and light competition. The sampling was done at the respective subplots of that stage both for the cleaned plots as well as the infested plots, except for the BT where there was no cleaned plot present. The total weed cover and the cover of the individual weeds was estimated using the method of Tüxen and Ellenberg (1937) with tables from Gehlker (1977) on a scale of 0-100 %. This percentage was estimated by a vertical visual observation of the green leaf surface covering the soil. Therefore the total cover of crop and weed species combined will never exceed a maximum of 100 %. Pictures were taken for reference and an example is shown in Figure 3. This method was chosen after (Meese and Tomich 1992; Zhou et al. 1998), whose research concluded that a visual estimation of cover is accurate and more efficient in time and costs, especially in combination with pictures.

Light inception (LUX)

In order to study the light competition between the winter wheat and weeds, the light interception was measured. This was done with a lux meter (Panlux electronic 2, Gossen, Nürnberg, Germany) at the AT, F and H within both the clean and weed infested plots. The BT was again excluded from this analysis. At this stage the winter wheat did not exceed a length of 10 cm, thus did not cover the soil yet. Measurements were performed at the same spot at the same time of the day and when possible with the same light intensity. There were three replications, in the row at (depended on the height of wheat) 0, 10, 25, 50 and 75 cm height starting at soil level (Liu et al. 2011; Sarlikioti et al. 2011). Because the light intensity was rarely constant, the LUX data were converted into percentages of the total irradiation measured at the same time above the crop.

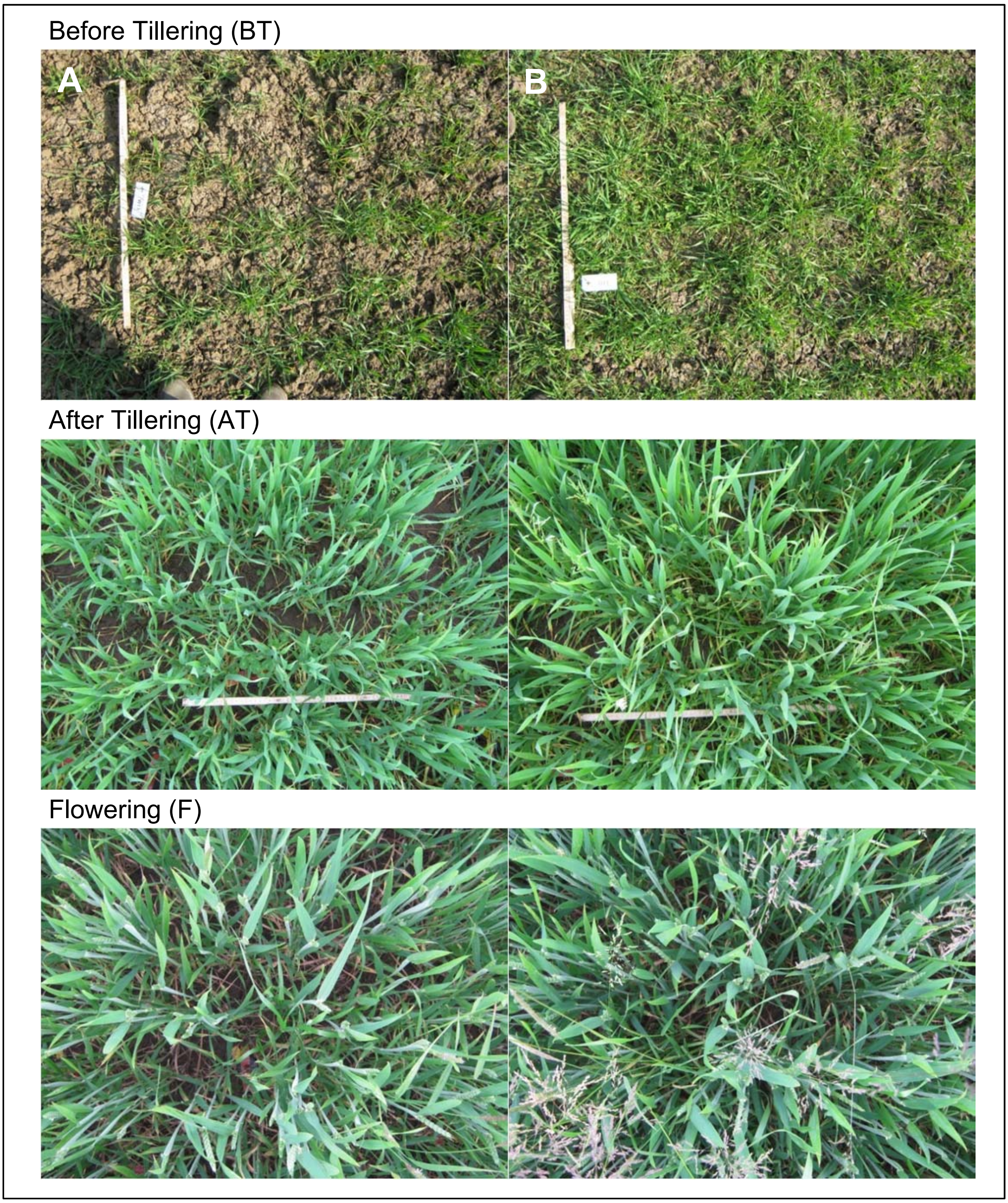


Figure 3. Visual monitoring of the differences in weed infestation and coverage in the weed infested A) CT and B) RT subplots at BT, AT and F stage.

2.4.3 Statistics

For statistical analysis, the distribution of the datasets was analysed for normal distribution and log-transformed if necessary. ANOVA's were calculated with JMP 5 (SAS Institute) including the field replication as random and the treatments tillage, fertilisation and weeding as fixed effects.

3 Results

3.1 Qualitative monitoring of plant growth

'Before Tillering' stage (BT, March 5th)

At this stage, the colour of the flag leaves showed differences. In RT, leaves were darker green than the leaves under CT. Furthermore the green colours varied throughout the field. At that time, the lower part in the 3^{rd} and 4^{th} replication was waterlogged and the wheat plants more yellow than in the rest of the field. In the CT but not in RT plots, tractor tire marks were still visible. More earthworm casts were observed in the RT plots. Due to the wet conditions at sowing the seeding machine was clogged by soil from time to time. Thus plants were missing for a few meters in some strips and in the following densely accumulated at one spot. The RT plots generally appeared more homogenous. At that time there were very few weeds, mostly *Veronica persica, V. hederifolium* and *Trifolium spec*.

'After Tillering' stage (AT, April 3rd)

Manure compost and slurry were applied the 16^{th} and 19^{th} March respectively (Table 2). Manure compost was spread evenly and slurry in stripes with drag hoses. The slurry stripes were still visible as the wheat plants varied in their colour depending if they were fertilised or not (Figure 4). It seemed that the dry weather conditions in March/April impeded the subsoil distribution of the slurry. In terms of plant colour, the McS plots were more evenly greenish. The CT plots in the first two replicates were less dense in biomass and less green than the rest of the plots though the heterogeneity was overall high even within the same treatments.

'Flowering' stage (F, May 12th)

At flowering, colour differences were equalised at field scale. However, the heterogeneity in the subplots was still high. The wheat plants in CT were visibly smaller in length than RT plants, especially in the 3^{rd} and 4^{th} replication. Regarding wheat maturation, the two oldest leaves in CT and the oldest leaf in RT started to desiccate. Besides, the grasses *Poa trivialis* and *Lolium perenne* were flowering in RT. A vegetation shift could be observed with the wheat crop and some weed species starting to mature and diminish and new weed species emerging like *Convolvulus arvensis* and *Calystegia sepium*.

Figure 4. Colour differences of winter wheat plants due to an uneven spreading of slurry.

3.2 Monitoring of winter wheat and weed cover

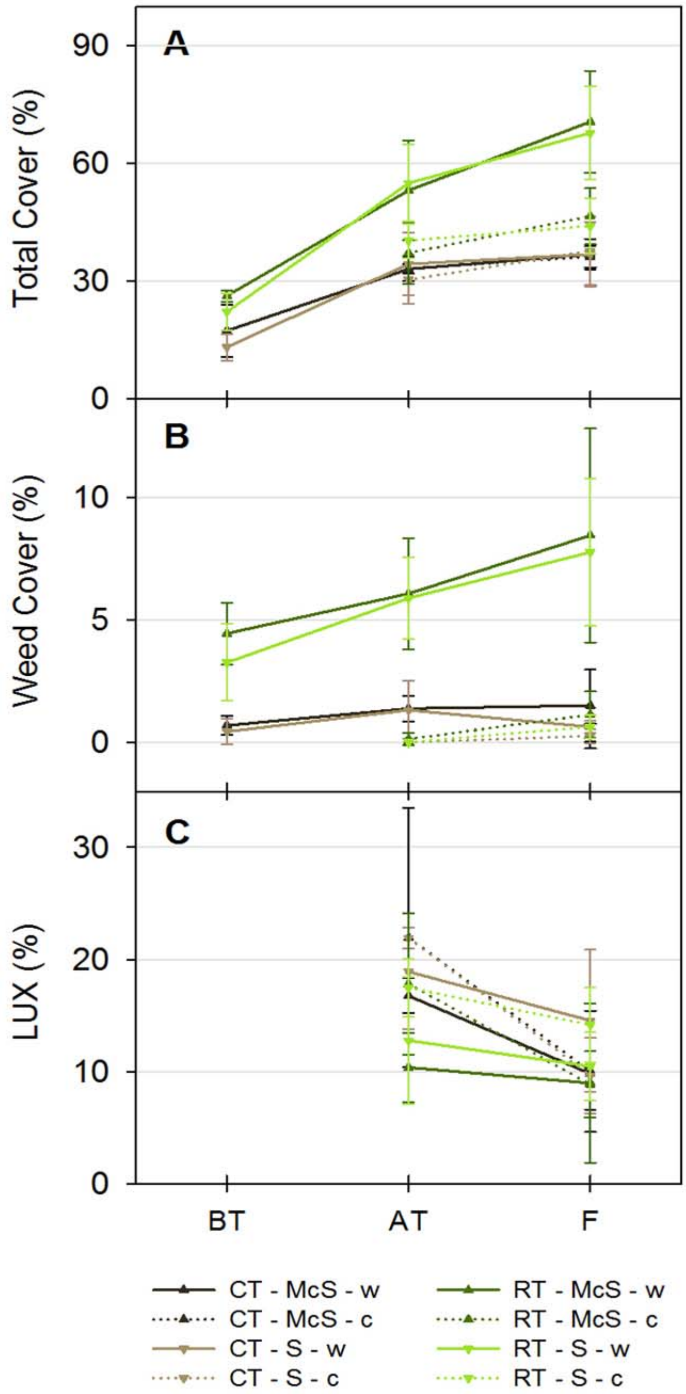
The total cover (Figure 5 A) including both winter wheat and weeds increased during the season. In RT, the total cover was ca. 50 % and significantly higher than in CT plots at all stages. Also the weeding had a significant influence with 26 - 29 % less total cover in the cleaned RT subplots at AT and F. As there were hardly any weeds in the CT subplots as shown in Figure 5 B, the weeding effect was negligible there. Thus an interactive effect of tillage and weeding could be observed increasing the difference of total cover in the weed infested RT subplots compared to the CT subplots over time. In the same manner, the weed cover (Figure 5 B) developed with the greatest effect of weeding in RT subplots (highly significant). Correspondent to this, the light interception (Figure 5 C) increased at the 0 cm level above ground over time. While significant differences in LUX values were found for tillage and weeding at the AT stage where more light reached the ground in the CT and cleaned plots, the effect disappeared at flowering. At this stage the wheat cover accounted for ca. 60 % and therefore shadowed the ground effectively. Interestingly, a significant fertilisation effect with SL subplots showing 22 % higher LUX values at F could be observed.

3.3 Winter wheat development

The winter wheat had the same plant density regardless of treatment and growth stage (data shown in Annex B). Thus the seed emergence was not affected by the different tillage conditions. However, differences were found for the wheat biomass (Figure 6 A). In the beginning of the growing season (BT), the wheat biomass was 30 % higher in RT than in CT (not significant). This difference disappeared during growth indicating that growing conditions between the tillage systems outbalanced through time. Also the plant length (Figure 6 B) was 6 - 7 % higher in RT at all stages which underlines the qualitative observations in the field. Surprisingly the plant length in the weed infested subplots were 3 % and significantly higher after tillering (AT) than in the cleaned ones. This effect should probably not be over interpreted but gives hints that weeds didn't deteriorate wheat growth. SPAD analysis measuring the chlorophyll content of wheat leaves refers to their nutrient status and illustrates especially the nitrogen supply. SPAD values were at all stages higher in RT (4 - 6 %), which was also significant in the later stages (Figure 6 C). Thus, it seemed that reduced tillage supplied more nitrogen which can be confirmed by the higher soil nitrogen availability in March 2013 shown in Table 1. There is a depression in SPAD values at the AT stage which are significantly less pronounced in the slurry plots (S). Weeding the plots didn't make any difference in chlorophyll contents.

3.4 Weed development

Depending on the treatment, the total weed biomass increased three to four fold during the growing season (Figure 7 A). At BT, the weed biomass was 10.5 times higher in RT than in CT (not significant, high variation). This difference decreased to 5.6 times at AT and 4.1 times at F, both being significant regarding tillage. There were some differences in the weed development within RT subplots. The RT treatment with McS showed a sharp increase of 256 % in the first months. However, during the period between AT and F, the weed biomass remained stable. The RT treatment with slurry application (S) in contrast, showed a less pronounced increase of weed biomass (95 %) during the first period which then further increased after AT. In the CT subplots, the fertiliser treatment revealed the same pattern but on a lower level. This fertilisation effect was not significant regarding the total weed biomass but regarding the biomass of monocotyledonous species (Figure 7 B). Here, a similar temporal pattern could be observed whereas the dicotyledoneous species (Figure 7 C) only slightly increased over time indicating that the total biomass was mostly influenced by grass species. In case of clover biomass (Figure 7 D), the emergence was generally very low compared to the other weed groups and therefore wasn't affected by tillage. The weeding effect was significant for all weed species as expected.

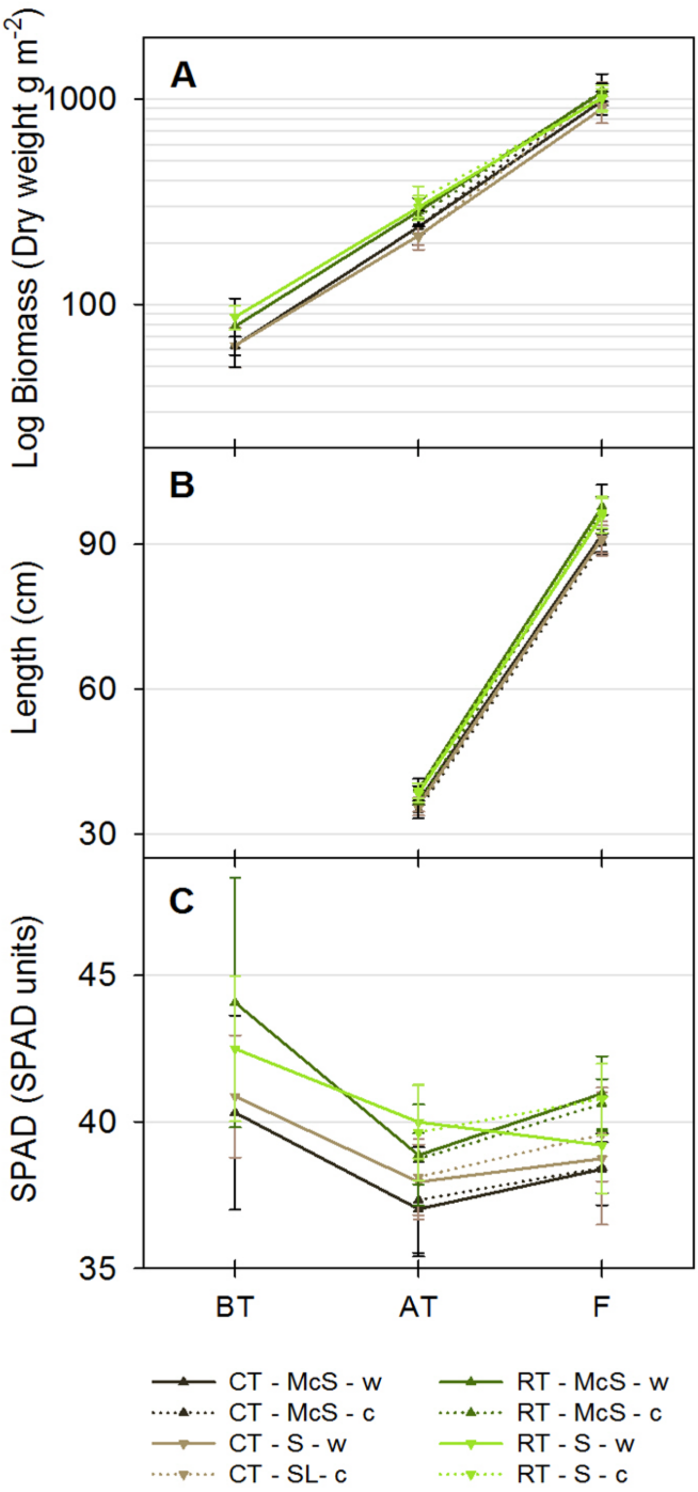


Total Cover	BT	AT	F
Tillage	**	*	*
Fertilisation	ns	ns	ns
Weeding	-	*	***
T x W	-	*	***

Weed Cover	BT	AT	F
Tillage	*	*	*
Fertilisation	ns	ns	ns
Weeding	-	***	***
T x W	-	***	***

LUX	BT	AT	F
Tillage	-	*	ns
Fertilisation	-	ns	*
Weeding	-	**	ns
T x W	ns	ns	ns

Figure 5. Means and standard deviations of A. total cover of winter wheat and weeds, B. weed cover and C. irradiation measured as LUX in the lower 0-10 cm plant layer at the 'Before Tillering' (BT), 'After Tillering' (AT) and 'Flowering' (F) stage. Treatments shown combine tillage (CT = Conventional Tillage, RT = Reduced Tillage), Fertilisation (McS = Manure compost/Slurry, S = Slurry only) and Weeding (w = weed infested, c = cleaned). Adjacent tables show the correspondent ANOVA analysis with T = Tillage, F = Fertilisation, W = Weeding and *p < 0.05, ** p < 0.01, *** p < 0.001 and ns = not significant.

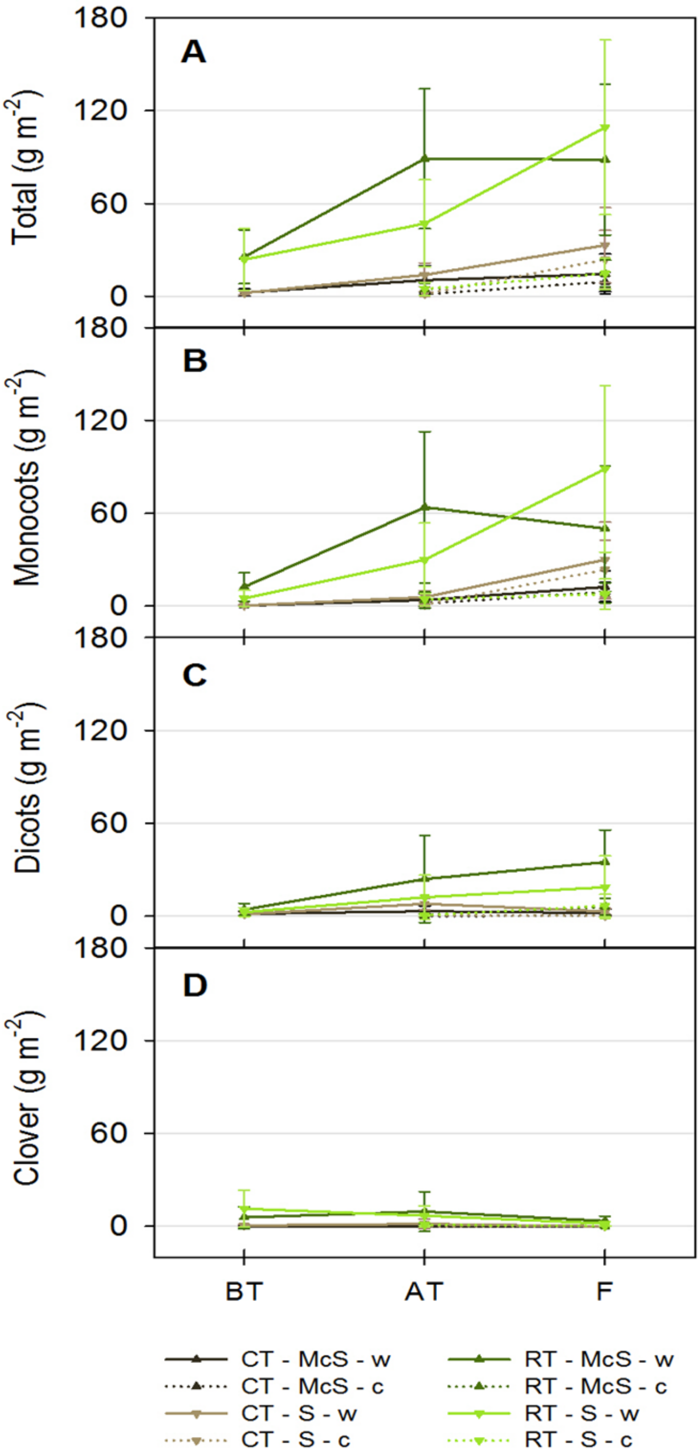


Biomass	BT	AT	F
Tillage	ns	*	ns
Fertilisation	ns	ns	ns
Weeding	-	ns	ns
T x F	ns	**	ns

Length	BT	AT	F
Tillage	-	**	*
Fertilisation	-	ns	ns
Weeding	-	*	ns
F x W	-	*	ns

SPAD	BT	AT	F
Tillage	*	ns	*
Fertilisation	ns	*	ns
Weeding	-	ns	ns
T x F	ns	ns	ns

Figure 6. Means and standard deviations of A. biomass (in logarithmic scale), B. length and C. SPAD units of winter wheat at the 'Before Tillering' (BT), 'After Tillering' (AT) and 'Flowering' (F) stage. Treatments shown combine tillage (CT = Conventional Tillage, RT = Reduced Tillage), Fertilisation (McS = Manure compost/Slurry, S = Slurry only) and Weeding (w = weed infested, c = cleaned). Adjacent tables show the correspondent ANOVA analysis with T = Tillage, F = Fertilisation, W = Weeding and *p < 0.05, ** p < 0.01, *** p < 0.001 and ns = not significant.



Total Weed	BT	AT	F
Tillage	ns	*	*
Fertilisation	ns	ns	ns
Weeding	-	*	***
T x F	ns	ns	ns
T x W	-	*	***

Monocots	BT	AT	F
Tillage	ns	ns	ns
Fertilisation	*	*	*
Weeding	-	***	**
T x F	*	*	ns
T x W	-	***	**

Dicots	BT	AT	F
Tillage	ns	ns	*
Fertilisation	ns	ns	ns
Weeding	-	*	*
T x F	ns	ns	ns
T x W	-	ns	*

Clover	BT	AT	F
Tillage	ns	ns	ns
Fertilisation	ns	ns	ns
Weeding	-	*	**
T x F	ns	ns	ns
T x W	-	*	**

Figure 7. Means and standard deviations of A. total cover (wheat and weeds), B. cover of monocotyledons, C. cover of dicotyledons and D. cover of clover at the 'Before Tillering' (BT), 'After Tillering' (AT) and 'Flowering' (F) stage. Treatments shown combine tillage (CT = Conventional Tillage, RT = Reduced Tillage), Fertilisation (McS = Manure compost/Slurry, S = Slurry only) and Weeding (w = weed infested, c = cleaned). Adjacent tables show the correspondent ANOVA analysis with T = Tillage, F = Fertilisation, W = Weeding and *p < 0.05, ** p < 0.01, *** p < 0.001 and ns = not significant.

4 Discussion

4.1 Impact of different tillage systems on wheat and weed growth

The tiller density of winter wheat was the same for all treatments during the whole season up to the F stage. In the Frick trial, seedbed preparation was done in both tillage treatments with a rototiller. However, due to the mulch cover still present in the RT plots after tillage also partly remained after rototilling. Despite this difference, the emergence of wheat was the same in both tillage treatments, indicating homogeneous seeding and germination conditions. In the paper of Gruber et al. (2012) the emergence of winter wheat plants and the number of tillers per m^2 were also the same between tillage treatments. This means that a certain mulch cover before seedbed preparation is not necessarily impeding germination.

During the development of the winter wheat, a difference in biomass between the tillage treatments was observed. The wheat plants showed a 29 - 30 % higher biomass at BT and AT in RT. At the later stages, there was no significant difference between RT and CT treatments anymore. Also the plant length was higher in RT at all stages. It seems that the wheat crop had a better start in the RT plots. If this will end up in higher yields cannot be answered with this work. Compared with other studies, the same yields (Gruber et al. 2012) or less yields in organic RT were recorded (Van den Putte et al. 2010; Peigné et al. 2014). However, those yields were heavily influenced by the environmental factors like soil type, climate and crop. When looking at the previous wheat yields in this trial (Berner et al. 2008; Sans et al. 2011; Armengot et al. 2014), it was observed that the winter wheat yield in 2002 - 2003 was 14 % lower in RT, and in 2008 - 2009 20 % higher. It could thus be concluded that the wheat yields and biomasses under RT are fluctuating depending on precrop management and environmental conditions.

Weed biomass also reacted positively on a reduction in tillage: weed biomass was higher from the AT stage towards the end of the season in the RT treatments compared to CT. In literature, results for weed biomass in RT are ranging between 5 and 327 g m^{-2} in cereal crops (Nakamoto et al. 2006; Vakali et al. 2011; Caldwell et al. 2014; Peigné et al. 2014). Comparing these studies to our study, the weed biomass found in the winter wheat 2014 was with maximum of 109.27 g m^{-2} in the RT/S plots on the higher end of the spectrum.

The total weed cover was 42 to 58 % and significantly higher in RT throughout the season. The research of Armengot (2014) in the same trial showed that the total weed cover over the years was around 17 % and that it was generally higher under reduced tillage. However during the two previous winter wheat crops, she observed no significant differences between the tillage treatments. The coverage of weed in RT reached a maximum of 11.8 % in 2003 and 15.6 % in 2009. Compared to this season with a maximum coverage of 8.4 % in RT/McS subplots, this could indicate a decrease in weed infestation. However it could also be the result of a bias as the cover was estimated by different observers. Although visual cover estimation were found to be accurate and reliable when one person is doing the observation at all times, it can differ between observers (Zhou et al. 1998).

Regarding weed biomass and/or cover in relation with organic reduced tillage, literature is quite limited, as this research field is very specific. Work on weeds has been done in organic no-till systems (Vaisman et al. 2011; Shirtliffe and Johnson 2012; Carr et al. 2013) but those use a dense mulch cover together with a roller crimper, affecting the weed composition and occurrence in a totally different way. Weeds are also studied in conventional reduced and no-tillage systems (Sutton et al. 2006; Miller and D'Auria 2011; Velykis and Satkus 2012). However, these studies use herbicides, making it difficult to compare results. Thus more weed research in organic reduced tillage is desirable to draw a more general conclusion about weed development in different pedo-climatic conditions.

The monocotyledonous weeds showed the strongest growth of all weeds with a maximum of a 20 fold biomass increase in RT/S plots between the AT and F stage. However, the monocotyledonous weed biomass did not show a significant difference between the tillage treatments. Other studies have found an increase in monocotyledonous weeds under reduced tillage (Pekrun et al. 2003; Gruber and Claupein 2009; Sans et al. 2011). The latest study of Armengot (2014) compiling weed results of the Frick trial describes a grass cover of around 2 - 3 % in the previous wheat crops. In 2014, the maximum grass cover accounted for 4.4 % in RT plots (data not shown). This indicates either an increase in monocotyledonous weeds over the years in this trial or shows that grasses survived the previous ley destruction more successfully.

Next to the total monocotyledon biomass, the proportion of the different species changed during the season in 2014 (data not shown): in CT plots, grasses were represented by *Alopecurus myosuroides*, a common arable weed in winter wheat crop rotations. However, the RT plots were dominated by *Lolium perenne*, *L. multiflorum*, *Pleum pratense* and *Dactilus glomerata*, which were part of the previous grass-clover mixture. But the main grass species in RT was still *Poa trivialis* and to a lesser extent *A. myosuroides*. These species but not the grass-clover ley species were already reported by (Sans et al. 2011; Armengot et al. 2014) strengthening the argument that the biomass increase of grasses is related to the incomplete ley destruction.

The dicotyledonous biomass increased continuously 7 - 13 fold during the season for RT and was significantly different from CT at the F stage. This growth was a function of changing species (data not shown). In the beginning of the season, the total weed community was dominated by *Veronica persica* and *V. hederifolia*. *Veronica sp.* decreased during season, while the group of dicotyledon weeds was more and more dominated by the later growing *Convolvulus arvensis*. At the F stage, the grasses reached the end of their growing cycle, while *C. arvensis* was still developing. For clover (*Trifolium spec.*), there were no differences between any of the treatments for any of the stages and its biomass was negligible. Clover biomass was even reduced during season. The voluntary regrowth of the preceding grass-clover ley was therefore problematic regarding the grass but not the clover species.

Finally, the RT treatment had a dominant effect on the wheat and weed development. Both wheat and weeds showed an enhanced growth in the RT plots. The reasons will be discussed in the next chapter. However regarding weed groups individually, this tillage effect was much less clear. To reflect on the research question and hypothesis, the wheat and weed growth was positively influenced by RT. Concerning the grass-clover mixture, only the grasses reoccurred to a relevant degree. Even if not being sufficiently destroyed during autumn tillage, the clover that was present in the beginning was outcompeted by the crop.

4.2 Effect of nutrient supply and weed competition on winter wheat growth

4.2.1 Nutrient supply

While the wheat biomass was higher only in the earlier stages of development, the plant length was at all stages higher in RT. The total plant cover was also higher in RT even when the weed cover was excluded. Higher SPAD values were furthermore detected. All those aspects could be a sign of a higher nutrient availability and an indicator for a better physiological plant development in the reduced tillage system. To explain this apparent crop response to reduced tillage, available soil data of 2014 were compared to the results mentioned above. There was a statistical difference in the mineral nitrogen contents (0 - 50 cm) between the tillage treatments, where reduced tillage revealed higher concentrations of available nitrogen than CT. Also, there was a difference between the carbon stocks ($p = 0.084$). Carbon stocks indicate organic matter that is stored in the longer term. Organic matter does not only contain nutrients but is also able to adhere and release nutrients from the soil solution (Blume et al. 2010). The higher nutrient availability in RT soils in spring 2014 may have pushed wheat growth especially in the beginning of the season. This is contradictory to the quite common experience that nitrogen mineralisation in RT soils is slower than in ploughed soil due to the missing aeration. The soil just slowly warms up and mineralisation is reduced (Ehlers and Claupein 1994; Alvarez et al. 1998; Pekrun et al. 2003; Kravchenko and Thelen 2007; Peigné et al. 2007; Alvarez and Steinbach 2009). The higher mineral nitrogen content in 2014 was probably caused by the earlier destruction of the grass-clover ley in the RT plots in autumn 2013. The grass-clover sward was incorporated shallower into the upper soil layers, meaning in the microbial active zone. Together with the higher and more stratified organic matter in the RT soil, higher amounts of organically bound nitrogen could have been mineralised during the relatively mild winter in 2013/2014.

4.2.2 Weed competition

One of the main questions of this master thesis was, if the expected higher weed infestation after the less successful ley destruction in RT will cause a weed competition and consequently lower wheat yields. As the harvest stage was excluded in this thesis, weed competition will mainly be discussed in relation to wheat biomass and cover during crop growth. Overall, weeds showed an increase of growth in RT compared to CT. This shows that a reduced ley destruction is less effective in weed and volunteer grass-clover species suppression than ploughing (Triplett and Dick 2008). The weeds also might have had an additional benefit from the higher mineral nitrogen available in the beginning of the season as mentioned above.

In this experiment, subplots were cleaned to exclude the competition between weeds and the wheat crop concerning nutrients and light and to determine the effect the weed pressure on wheat physiology. To assess the light competition, the results from the cover and light interception (LUX) can be studied. The data from the weed cover showed that the weed infested subplots had a significantly higher weed cover than the cleaned subplots at all stages. This is a good result as it confirms that the experimental setup was successful and the weeds where removed from the 'cleaned' subplots to a sufficient extend. The LUX was affected by the presence of weeds just above the soil surface (0 – 10 cm) at the AT stage. Here the amount of light reaching the soil was lower when weeds were present. Huggins (1991) also showed a lower irradiation for a no-till crop in spring, caused by a better development in the beginning of the season. In our study, this effect disappeared at the F stage. This might have been caused by the shift in the weed community from broad leaf dicotyledonous ground covering weed species to the more vertical growing monocotyledonous weeds and the broad leaf, but climbing Convolvulus species.

Although there were signs of light competition between the crop and the weeds, the biomass of the wheat was unaffected by the weeding factor. Only at the F stage, the wheat biomass in the weed infested subplots was 7 % lower, but not significantly reduced. This result could be a first indication of yield reduction by weed competition. If so, the biomass results at the harvest stage will show a further reduction.

This lack in the growth response of wheat might be explained by weed thresholds that were not exceeded. In literature, a multitude of articles can be found on weed thresholds (Gerowitt and Heitefuss 1990; Thornton et al. 1990; Zanin et al. 1993; Alvarez et al. 1998; Benjamin et al. 2010; Casagrande et al. 2010) which use the unit of plants per m^{-2}. In practice, this is an easy unit for farmers to evaluate actions like applying herbicides in early crop stages. However in this study, the weeds were assessed by biomass and cover, not by number of plants or seedlings. This difference in unit makes a comparison assessment difficult. There is literature that challenges this common method and proposes a weed assessment based on cover and relative weed area (Kropff and Spitters 1991; Lotz et al. 1996; Florez et al. 1999; Storkey et al. 2003). So far, these publications didn’t include new threshold values. What does become clear from literature (Zanin et al. 1993), (Gerowitt and Heitefuss 1990) is that certain species have different competition pressures which are not very well explained by the number of plants but better by the assessment of their biomass and cover. Only the paper of Gerowitt et al. (1990) mentions a competition threshold in percentage of ground cover for dicotyledonous weeds, which lies in a range of 5-10 %. This range was not reached for dicotyledonous weeds in this study. The article of Caldwell (2014) showed a reduction in spelt yield at a total weed biomass of 327 g m^{-2} but not at 203.7 g m^{-2}. The maximum weed biomass in this study accounted for 109.3 g m^{-2} for RT/S at Flowering. It might be concluded from the results in this study and the limited number of references that the threshold was generally not reached in this cropping season. In terms of thresholds, more work has to be done still.

Regarding the higher wheat biomass and overall wheat physiology in correlation with the nutrient content of the soil, it can be concluded that the wheat grown under RT had an advantage in nutrient supply compared to CT. Concerning wheat and weed biomass and density between cleaned and weed infested subplots, we can conclude that weed competition had no effect on wheat growth. Consequently, the second hypothesis can be denied.

4.3 Effect of fertilisation on winter wheat and weed development

In 2014, only a limited number of fertiliser effects were observed. These were found for the SPAD and LUX analyses and for the development of monocotyledonous weeds. The difference in chlorophyll content (SPAD) could be a reaction to the slurry application after the BT stage. The first slurry application took place a month prior and the second slurry application 5 days prior the AT sampling. The slurry derived nitrogen was easily available for the crop. As the amount of slurry applied was half the amount in McS compared to the S treatment, the chlorophyll content was higher in the slurry plots. The LUX values were also significantly higher in the slurry treatment in the F stage. This means that the wheat plants in the McS plots had a nitrogen deficit. However, no such differences were found in total cover, wheat biomass or plant length.

Although the total weed biomass showed no reaction to fertilisation, the monocotyledon biomass showed a statistically significant reaction throughout the whole season. These grasses did profit from the easily available nitrogen of the slurry and their growth was positively correlated to the amount of slurry applied. The other weed groups might have had a too short life cycle to react to the different nitrogen availability. Or they might have had different nutrient requirements (Blackshaw et al. 2003). Results of Berner (2008) for the same trial indicate that yields responded differently to fertilisation in the crops grown in the prior years. The winter wheat in 2003 had higher yields in the slurry treatment. If this slightly better nutrition observed in the S plots result in higher yields in 2014 will be seen later.

The hypothesis that fertilisation doesn't have an effect on wheat growth could be partly confirmed. Altogether there is no strong general effect from the fertiliser treatment on the wheat and weed development, although the monocotyledonous reacted positively to the amount of slurry applied.

5 Conclusion

The tillage treatment showed a major effect on wheat and weeds. Rather unexpected, the wheat benefited in RT from better growing conditions like the increased available nitrogen and as a result showed a higher biomass, cover, length and chlorophyll content. The RT system was also dominated by weeds, represented by a higher biomass and cover. Grass species such as *Lolium sp*. and others from a not properly removed grass-clover ley as precrop, survived the RT management and grew in the following winter wheat. However, *Trifolium sp*. from the same mixture was not competitive enough and supressed by the dense winter wheat crop. The main monocotyledonous weed in RT was *Poa trivialis* and in CT this was *A. myosuroides.* The annual dicotyledonous weeds caused no problems in this trial. However, the long-term trend of perennial dicotyledons is not clear in both tillage systems. Although there was a higher biomass and cover of weeds in RT, this increased competition did not affect the wheat development. At the F stage a tendency towards a reduction of 7 % in the weed infested subplots was observed. The measurement at harvest time will show if this tendency still will be present and will affect wheat yields.

Fertilisation had only a minor effect on the biomass of wheat, but slurry stimulated the growth of monocotyledonous weed species.

Farmers are used to have clean fields through ploughing. To promote the adoption of reduced tillage, the weed infestation shouldn't exceed a certain threshold and definitely shouldn't cause yield reductions. This weed threshold still has to be found. More studies in organic reduced tillage are therefore needed. The Frick experiment is running now in its 12th year. Thus, it is still a mid-term trial and it is important to monitor the long-term weed development in two directions: first, if the weed composition changes towards more problematic species and second, if the weed seed bank grows over the years. Both are the farmers' greatest concerns when dealing with reduced tillage.

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7 Appendix

Annex A : Means and standard deviation of the total cover, weed cover and the light above ground in % of total irradiation by wheat in the Frick experiment

			Total Cover (%)			Weed Cover (%)			Light above ground (% of total irradiation)		
Tillage	**Fetilization**	**Weeding**	**Before Tillering**	**After Tillering**	**Flowering**	**Before Tillering**	**After Tillering**	**Flowering**	**Before Tillering**	**After Tillering**	**Flowering**
Treatment											
CT	McS	w	17.37 ± 6.65	33.12 ± 3.15	36.87 ± 3.88	0.69 ± 0.37	1.37 ± 0.52	1.50 ± 1.47	-	16.75 ± 1.56	9.80 ± 3.19
CT	McS	c	-	33.19 ± 1.21	36.25 ± 2.70	-	0 ± 0	0.25 ± 0.50	-	21.95 ± 11.58	10.01 ± 5.41
CT	S	w	13.19 ± 3.36	34.38 ± 8.00	36.88 ± 8.19	0.44 ± 0.51	1.31 ± 1.18	0.63 ± 0.25	-	18.92 ± 5.16	14.54 ± 6.33
CT	S	c	-	30.31 ± 6.15	37.75 ± 8.72	-	0 ± 0	0.25 ± 0.29	-	21.92 ± 0.91	9.63 ± 3.35
RT	McS	w	26.25 ± 1.44	53.12 ± 12.64	70.63 ± 12.97	4.44 ± 1.26	6.06 ± 2.26	8.44 ± 4.30	-	10.37 ± 3.08	8.98 ± 7.09
RT	McS	c	-	37.19 ± 7.80	46.56 ± 7.17	-	0.12 ± 0.25	1.13 ± 0.95	-	17.81 ± 6.32	8.86 ± 2.95
RT	S	w	22.19 ± 4.83	55.00 ± 9.79	67.81 ± 11.92	3.25 ± 1.57	5.88 ± 1.65	7.75 ± 3.01	-	12.77 ± 5.63	10.47 ± 3.04
RT	S	c	-	40.31 ± 4.37	44.06 ± 7.10	-	0 ± 0	0.63 ± 0.48	-	17.48 ± 2.57	14.17 ± 3.34
Factor											
Tillage											
Reduced (%) (100% = conventional)			158%	142%	155%	686%	449%	678%	-	73%	96%
Fertilization											
Manure Compost (%) (100% = slurry)			123%	98%	102%	139%	107%	122%	-	94%	77%
Weeding											
Weed (%) (100% = clean)			-	126%	129%		12166%	816%	-	74%	97%
ANOVA											
Tillage			**	*	*	*	*	*	-	*	ns
Fertilisation			ns	ns	ns	ns	ns	ns	-	ns	*
Weeding			-	*	***	-	***	***	-	**	ns
Till x Weed			-	*	***	-	***	***	-	ns	ns
			no other interactions			no other interactions			no other interactions		

CT = Conventional Tillage; RT = Reduced Tillage; S = Slurry; McS = Manure Compost and of Slurry; c = cleaned subplots; w = weed infested subplots;
BT = Before Tillering stage; AT = After Tillering stage; F = Flowering stage; ns = not significant; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

Annex B : Means and standard deviation of biomass, tillers/m^2, length and SPAD of wheat in the Frick experiment.

			Biomass Wheat (g DM m^{-2})			Tiller m^{-2}			Length (cm)			SPAD (nmol cm^{-2})		
Tillage	**Fetilization**	**Weeding**	**BT**	**AT**	**F**	**BT**	**AT**	**F**	**BT**	**AT**	**F**	**BT**	**AT**	**F**
Treatment														
CT	McS	w	62.98±6.51	238.87 ± 44.11	980.18 ± 48.67	301 ± 54	512 ± 83	426 ± 61	-	36.81 ± 2.21	92.07 ± 4.04	40.31 ± 3.31	37.02 ± 1.61	38.38 ± 1.22
CT	McS	c	-	240.09 ± 19.34	1081.47 ± 245.13	-	522 ± 68	412 ± 38	-	34.93 ± 1.10	90.30 ± 1.90	-	37.33 ± 1.80	38.44 ± 0.87
CT	S	w	62.93 ± 13.72	216.58 ± 22.40	898.85 ± 134.56	316 ± 73	476 ± 70	380 ± 55	-	36.06 ± 1.43	91.22 ± 3.56	40.87 ± 2.08	37.95 ± 1.28	38.75 ± 2.26
CT	S	c	-	213.41 ± 28.67	1081.81 ± 129.55	-	504 ± 115	434 ± 61	-	35.38 ± 1.56	91.02 ± 2.90	-	38.12 ± 1.30	39.57 ± 1.60
RT	McS	w	78.11 ± 28.69	284.50 ± 45.32	1081.97 ± 107.76	340 ± 87	582 ± 71	432 ± 79	-	39.17 ± 2.27	97.77± 4.58	44.07 ± 4.26	38.86 ± 1.76	40.97 ± 1.27
RT	McS	c	-	266.97 ± 21.02	1104.84 ± 14.52	-	609 ± 60	454 ± 91	-	36.56 ± 3.34	96.56 ± 3.31	-	38.74 ± 0.88	40.61 ± 0.85
RT	S	w	86.84 ± 11.61	297.65 ± 41.22	1016.36 ± 149.90	364 ± 16	641 ± 152	468 ± 28	-	38.44 ± 1.96	95.93 ± 3.55	42.50 ± 2.48	39.99 ± 1.25	39.20 ± 1.65
RT	S	c	-	320.94 ± 55.65	1003.37 ± 121.32	-	556 ± 35	401 ± 21	-	38.93 ± 1.57	96.60 ± 3.35	-	39.64 ± 1.64	40.78 ± 1.21
Factor														
Tillage														
Reduced (%) (100% = conventional)			131%	129%	104%	114%	118%	106%	-	107%	106%	106%	105%	104%
Fertilization														
Manure Compost (%) (100% = slurry)			94%	98%	106%	94%	102%	102%	-	99%	101%	101%	97%	100%
Weeding														
Weed (%) (100% = clean)			-	100%	93%	-	101%	100%	-	103%	101%	-	100%	98%
ANOVA														
Tillage			ns	*	ns	ns	ns	ns	-	**	*	*	ns	*
Fertilisation			ns	ns	ns	ns	ns	ns	-	ns	ns	ns	*	ns
Weeding			-	ns	ns	-	ns	ns	-	*	ns	-	ns	ns
Till x Fert			ns	**	ns	ns	ns	ns	-	*	ns	ns	ns	ns
			no other interactions						no other interactions			no other interactions		

CT = Conventional Tillage; RT = Reduced Tillage; S = Slurry; McS = Manure Compost and of Slurry; c = cleaned subplots; w = weed infested subplots;
BT = Before Tillering stage; AT = After Tillering stage; F = Flowering stage; ns = not significant; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$

Annex C : Means and standard deviation of biomass of total, mono-, dicolyledeous weeds and *clover spec*. at three harvest times in the Frick experiment.

			Total Weeds (g DM m^{-2})			Monocots (g DM m^{-2})			Dicots (g DM m^{-2})			Clover spec. (g DM m^{-2})		
Tillage	**Fetilization**	**Weeding**	**Before Tillering**	**After Tillering**	**Flowering**	**Before Tillering**	**After Tillering**	**Flowering**	**Before Tillering**	**After Tillering**	**Flowering**	**Before Tillering**	**After Tillering**	**Flowering**
Treatment														
CT	McS	w	2.43 ± 2.22	10.42 ± 9.43	14.38 ± 12.86	0.39 ± 0.61	3.93 ± 4.13	12.35 ± 10.49	1.37 ± 0.52	3.12 ± 3.53	2.02 ± 2.59	0.10 ± 0.17	0.03 ± 0.06	0.01 ± 0.01
CT	McS	c	-	1.33 ± 0.76	9.34 ± 6.25	-	1.59 ± 1.19	9.05 ± 6.13	-	0.05 ± 0.04	0.28 ± 0.33	-	0.04 ± 0.09	0 ± 0
CT	S	w	2.24 ± 1.16	13.84 ± 7.66	33.04 ± 24.27	0.35 ± 0.39	5.74 ± 4.23	30.03 ± 24.08	1.06 ± 0.71	7.9 ± 3.71	3.06 ± 2.04	0.50 ± 0.61	1.5 ± 3.04	0.06 ± 0.12
CT	S	c	-	1.43 ± 1.62	23.76 ± 18.84	-	0.97 ± 1.95	23.53 ± 18.98	-	0.62 ± 1.14	0.34 ± 0.38	-	0.01 ± 0.02	0 ± 0
RT	McS	w	25.54± 17.31	88.92 ± 45.23	88.34 ± 48.66	12.41 ± 9.16	63.86 ± 48.96	50.06 ± 40.52	2.56 ± 2.38	23.97 ± 28.11	34.87 ± 20.87	5.76 ± 7.06	9.56 ± 12.91	3.40 ± 3.21
RT	McS	c	-	4.45 ± 3.99	14.74 ± 8.69	-	3.85 ± 5.13	8.53 ± 6.50	-	0.79 ± 0.69	6.15 ± 5.32	-	0.83 ± 0.82	0.05 ± 0.11
RT	S	w	23.74 ± 19.97	47.03 ± 28.23	109.27 ± 56.45	4.96 ± 5.10	29.89 ± 23.77	88.68 ± 53.76	2.43 ± 1.76	12.19 ± 14.30	18.75 ± 20.25	11.40 ± 12.04	6.88 ± 6.35	1.83 ± 1.38
RT	S	c	-	4.80 ± 4.26	14.65 ± 10.04	-	4.34 ± 3.99	7.68 ± 9.76	-	0.47 ± 0.37	6.76 ± 7.32	-	0.93 ± 1.53	0.21 ± 0.26
Factor														
Tillage														
Reduced (%) (100% = conventional)			1052%	536%	282%	2348%	833%	206%	206%	318%	1160%	2860%	1110%	8058%
Fertilization														
Manure Compost (%) (100% = slurry)			107%	156%	70%	240%	179%	53%	112%	131%	149%	49%	112%	164%
Weeding														
Weed (%) (100% = clean)			-	1335%	392%	-	961%	371%	-	2460%	434%		1002%	2011%
ANOVA														
Tillage			ns	*	*	ns	ns	ns	ns	ns	*	ns	ns	ns
Fertilisation			ns	ns	ns	*	*	*	ns	ns	ns	ns	ns	ns
Weeding			-	*	***	-	***	**	-	*	*	-	*	**
Till x Fert			ns	ns	ns	*	*	ns	ns	ns	ns	ns	ns	ns
Till x Weed			-	*	***	-	***	**	-	ns	*	-	*	**
			no other interactions			no other interactions			no other interactions			no other interactions		

CT = Conventional Tillage; RT = Reduced Tillage; S = Slurry; McS = Manure Compost and of Slurry; c = cleaned subplots; w = weed infested subplots;
BT = Before Tillering stage; AT = After Tillering stage; F = Flowering stage; ns = not significant; * = p < 0.05; ** = p < 0.01; *** = p < 0.001

8 Abstract

No-tillage and reduced tillage are soil conservation techniques directed to reduce soil erosion and to enhance soil fertility. These techniques are adopted into conventional agriculture where weeds are controlled with herbicides. To integrate reduced tillage into organic production, different strategies like adjusted mechanical weeding techniques and crop rotations have to be developed as the biggest challenge is weed control. The question arises if the new crop-weed interaction increases the competition resulting in yield losses. In the long-term organic tillage experiment in Frick with tillage and fertilisation as factors, the development of wheat and weed biomass and cover, as well as the proportion of mono- and dicotyledonous weed species were assessed. Wheat growth was additionally documented in chlorophyll content of the flag leaf (SPAD) and the length of the plants. Light competition was measured within the crop (LUX) at different levels. The monitoring was done at 4 different wheat growth stages before and after tillering, at flowering and just before harvest. The harvest data are not included in this report. To assess the weed competition on wheat growth more in depth, subplots were established in addition with one subplot being manually cleaned from weeds and the other being left weed infested. The wheat crop had a better start into the season in the reduced tillage plots. Wheat biomass was ca. 30 % higher than in the ploughed plots and a ca. 5 % higher chlorophyll content indicate a better nutrient supply. Wheat length was thus higher throughout the season. The grass-clover ley destruction in the preceding autumn together with the higher organic matter content in the reduced tilled soil must have induced a higher mineralisation of nitrogen during the relatively mild winter. Also weeds did profit and were at all times more present in the reduced tillage treatment with a maximum of 109.3 g m-2 in biomass and 8.4 % in cover. However, the competition assessment between cleaned and infested subplots showed that this increased weed infestation still didn't affect wheat growth. In addition to grass species already observed in the years before, the species of the grass-clover ley were regrown in the reduced but not in the ploughed plots. The clover was suppressed by the crop. Grass species profited of the fertilisation with slurry with a growth response correlated to the amount of slurry applied. It has to be seen whether the nutrient supply in spring and the weed presence differing between tillage treatments will affect yields in the end.

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