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Effects of Tillage Intensity, Cover Crop Species and Cover Crop Biomass on N-Fluxes, Weeds and Oat Yields in an Organic Field Experiment in Germany

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Abstract: The non-turning or only superficial turning of soil is considered to be a gentle tillage method. Nevertheless, conventional ploughs are widely used in organic farming for crop production reasons. For the further development of reduced tillage, and up to no tillage, the effects of three cover crop species and their incorporation with different tillage intensities on nitrogen (N) dynamics, weed emergence and the yield of the subsequent main crop, oats, were examined in a repeated organic one-year trial. *Sinapis alba*, *Trifolium resupinatum, Vicia sativa* and bare fallow were tested and incorporated using (1) a plough (PL), (2) reduced tillage (RT), (3) mulching + drilling (MD) and (4) direct drilling (DD). *V. sativa* was the most promising cover crop in combination with RT, MD and DD. In Trial 1, the soil mineral N content and oat yields after the introduction of *V. sativa* were on a similar level as those in the PL treatments, and weeds were not yield-limiting there. In Trial 2, the biomass production of *V. sativa* was only about half of that of Trial 1 and did not offer sufficient weed control, but *V. sativa* was still successful in the RT treatments. In both trials, the yield differences were more pronounced between the cover crop treatments after RT than after PL. RT, therefore, was more dependent on an adequate cover crop species than PL. The no-till method was not only dependent on an adequate cover crop species but also on its proper biomass production for sufficient weed control.

Keywords: reduced tillage; conventional tillage; no-till; *Sinapis alba*; *Trifolium resupinatum*; *Vicia sativa*; organic farming; weeds; C/N ratio; N-dynamic

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1. Introduction

Reduced tillage (RT) methods such as non-turning or superficial turning are considered to be environmentally friendly alternatives to conventional ploughing (PL). Compared to tillage systems that involve PL, continuously applied RT can improve soil biological and physical parameters [1–9]. In addition, in relation to climate change, the better structure in the topsoil from RT due to the presence of more organic carbon (C_{org}) in the topsoil may be suitable for providing better resilience [10].

In conventional agriculture, RT is only considered practicable with full herbicide use [11,12] because there can be a higher level of weed infestation without PL [12–14]. In addition, RT can lead to the delayed warming and reduced aeration of soil in spring and thus to delayed or reduced nitrogen (N) mineralization [12]. In organic farming it is therefore more difficult to avoid using a plough [15–17]. RT in organic farming can lead to yield losses [4,7,18].

While RT has been studied in organic farming research for some decades [7], studies on the complete avoidance of tillage ("no-till", NT) in organic farming are less widespread [19–21]. Organic NT is often combined with *Vicia villosa* and roller crimpers [22]. These systems rely on the successful establishment and termination of *V. villosa* [19]. Sometimes, organic NT systems comprise a combination of tillage and NT [23,24]. Weeds, and especially perennial weeds, are a major problem in organic NT systems [19,21,23] and variabilities in the of these systems success are reported [23].

However, due to the positive aspects of RT and NT, abandoning the plough has the potential to further increase the ecosystem services of organic farming. In order to promote RT or NT in organic farming, an adaptation of the entire system is necessary [18]. In addition to the tillage technique, crop rotation must be adapted to the specific needs of RT. It offers the possibility of responding to the challenges of RT. For this, the integration of cover crops into the crop rotation is indispensable. The cultivation of cover crops can contribute to a better N supply [22,25] as well as to weed control [18,22,26,27]. Thus, the advanced cultivation of cover crops can help to minimize or completely avoid yield losses due to RT [28]. A specific advantage of winter-killed cover crops for RT and NT systems is that they die after a cold winter and do not have to be terminated by tillage. For both leguminous and non-leguminous species, the level of N uptake depends largely on their biomass production [29]. The C/N ratio influences the mineralization, i.e., the closer the C/N ratio, the faster the plant material is mineralized [30]. Good synchronization with the N requirement of the succeeding main crop is important for the success of the main crop and for avoiding N losses through leaching [30]. For weed control, rapid soil cover and a high biomass production of cover crops are crucial [31]. Some cover crops also have allelopathic effects that help to control weeds [32].

For the further development of RT and NT in organic farming, the short-term effects of cultivating different winter-killed cover crops and incorporating them with different tillage intensities on N dynamics, weed emergence and the yield of the subsequent main crop, oats, were investigated in this study. Three different leguminous and non-leguminous cover crops with different C/N rations and different weed-suppressing abilities were chosen. *Sinapis alba* (white mustard) was chosen as a non-leguminous cover crop with a rather wide C/N ratio whose cultivation is very widespread in Germany [31]. The seed is inexpensive, it is easy to grow, it usually produces a lot of biomass, it absorbs N and thus prevents it from leaching (catch crop) and it has allelopathic properties [32]. As leguminous crops, *Vicia sativa* (common vetch) and *Trifolium resupinatum* were chosen. Both have a rather narrow C/N ratio but vary in their seed size and weed-suppressing ability. The following questions were addressed on the basis of the trial results:

- Which of the tested cover crop species leads to the highest mineralized N (N_{min}) content in spring before tillage?
- How does N_{min} develop after the cover crops under the main crop, oats, in the different tillage treatments?
- Which of the tested cover crop species have the best weed-suppressing effect in spring before tillage? How do weed density, cover and biomass develop during oat growth after tillage?
- How do the different cover crop–tillage combinations affect the yield of the main crop (oats)?

2. Material and Methods

2.1. Site Description

The repeated one-year field trial was carried out in the trial years 2011/12 and 2012/13 on two different sites, hereafter referred to as Trial 1 and Trial 2. The location was the teaching and experimental farm of the University of Kassel, the "Hessian State Domain Frankenhausen" (51.412 N, 9.440 E; 231 m above sea level). The soil type was haplic luvisol. The soil texture in the Ap horizon was a strong clayey silt in both fields. The previous crop in both trials was winter wheat, and the pre-pre-crop was carrots.

2.2. Experimental Design

The sowing of the cover crops was followed by the sowing of the main crop, oats, under different tillage treatments. The duration of the trials was from the August of one year to the August of the next. Trial 1 was set up as a two-factor strip split-plot experiment, with the factor of cover crops on the main plots and, from differentiation in terms of tillage in spring, with the factor of tillage in the strips above. In Trial 2, the cover crops were laid out on randomized sub-plots and spring tillage was conducted above them in the main plots.

With the exception of Trial 1, the trials were conducted in four replicates. Trial 1 was continued in eightfold repetition with differentiation according to tillage, since, due to the technical feasibility of tillage in fourfold repetition, no complete randomization and thus no proper statistical evaluation was possible.

The cover crop species, varieties and seed rates in both years were as follows:

- *Sinapis alba* (*cv.* Asta; seed rate 20 kg ha^{-1}),
- *Trifolium resupinatum* (*cv.* Marco Polo; 20 kg ha^{-1}),
- *Vicia sativa* (*cv.* Ereica; 105 kg ha^{-1}).
- A bare fallow served as a control.
- Oat (*Avena sativa*, *cv.* Scorpion) was sown at the following seed rates:
- Trial 1: 400 germinable grains m^{-2}.
- Trial 2: due to late sowing, 450 germinable grains m^{-2}.

The tillage treatments and an overview of the other arable measures are shown in Table 1. No mechanical weed control and no fertilization were carried out.

Table 1. Overview of the arable measures of Trial 1 and Trial 2.

Date		Measure	Depth/Row Distance
Trial 1	Trial 2		
22 August 2011	20 and 21 August 2012	Stubble tillage:Chisel	Depth 10 cm
23 August 2011	22 August 2012	Rotary harrow	
26 August 2011	22 August 2012	Sowing cover crops and rolling	Row distance 12 cm
17 October 2011	—	Flaming of bare fallow (=control) plots	
5 April 2012	18 April 2013	Plough Chisel (Trial 1)/disc harrow (Trial 2)	Depth 22–24 cm Depth 10–12 cm/7 cm
10 April 2012	18 April 2013	Rotary harrow in PL and RT Nothing in the NT plots	
10 April 2012	22 April 2013	Sowing oats	Row distance 12 cm in PL and RT/15 cm in NT

2.3. Data Collection

The cover crops were sampled in November (17 November 2011 (Trial 1)/24 November 2012 (Trial 2)) before freezing. For this purpose, half a square meter was harvested by hand and randomly distributed six times per plot in Trial 1 (i.e., 3 m^2 in total per plot). In Trial 2, one square with a 1.5 m side length (=2.25 m^2) per plot was harvested by hand. Immediately after harvesting, the green cuttings were weighed. Then, a sub-sample was obtained from each sample, which was dried at 60 °C. The samples were used for above-ground biomass yield determination and to analyze its total nitrogen (TN) and total carbon (TC) contents with a Macro C and N auto-analyzer (Elementar Analysesysteme, Hanau, Germany).

Soil samples were taken at least from a depth of 60 cm, and if possible, to 90 cm. Sampling was carried out at the beginning of the trial, in November, before and after tillage in spring and at the end of the trial. On the first two dates of Trial 1, the sample was divided into the following layers: 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm and 60–90 cm. On all other dates it was conducted in 30 cm sections. A mixed sample was obtained per plot and layer from between 3 and 8 samples depending on the size of the plot. These mixed samples were immediately packed into cooled isolation boxes at the experimental sites. All samples were frozen as soon as possible. For analysis of the N_{min} content, the samples were taken to the Hessian State Laboratory in Kassel/Harleshausen. The analysis of the samples with regard to NO_3-N in all three layers and additionally NH_4-N in the uppermost layer was carried out according to DIN ISO 14255 and DIN EN ISO 11732.

With regard to weeds, the degree of weed cover (WC) was determined at a late stage of the cover crop and a late stage of the main crop, oats, (BBCH 77 to 80) in an area of one square meter per plot. Reference images were used to estimate the percentage ground cover. For the total cover, the cover percentages of the different species were added. Since the plants grew at different levels, the total cover could exceed 100%. The weed density (WD) was determined at an early stage of the main crop, oats (BBCH 10 to 11), i.e., all weed plants in the sampling area were counted. The sampling area was one tenth of a square meter and was randomly distributed four times over the plot. The total above-ground biomass was quantified at a late stage of the oats' growing process (BBCH 77 to 80) at the same time as the WC and on the same plot. For this purpose, all weeds were cut off close to the ground. The samples were dried, and, after complete drying, the dry matter was determined.

The oats were harvested by hand. For this purpose, an area of half a square meter per plot was cut by hand twice in Trial 1 and four times per plot in Trial 2.

2.4. Data Analysis

To describe the distribution of N_{min}, C and N in the cover crop biomass, weed emergence, cover crop and oat yields, mean value and standard error were calculated. The evaluation was carried out separately by year to take account of the different weather conditions. Each data set was checked for normally distributed residuals (Kolmogorov–Smirnov test). If there was no normal distribution, the data were transformed for statistical evaluation. The type of transformation was indicated in the results. The presentation of the data in the bar charts was based on the mean values of the original data. Large plot, small plot and block were tested as fixed factors with a univariate analysis of variance for significant effects and interactions. In Trial 1, due to the experimental design, it was necessary to include horizontal "row blocks" in the analysis in addition to the vertical blocks [33]. If the analysis of variance indicated significant effects or interactions, a post hoc test (Tukey-B) was then carried out on the factor combination of cover crop x tillage or on the individual factors (alpha ≤ 0.05). In the results section, significant effects (from two factors only in the case of significant interaction) are indicated by different letters.

The statistical analyses were carried out with SPSS-21.

3. Results

3.1. Weather

Data from the Frankenhausen weather station were used. If these were not available, data from other weather stations in the vicinity were used (approx. 10 km away). The 30-year mean was based on data from 1981 to 2010 from the German Weather Service (DWD) from the Kassel weather station. The mean temperature for this location and period was 9.1 °C, and the mean annual precipitation was 725 m. For Trial 1, the mean temperature was 9.4 °C, and the precipitation total was 557 mm; for Trial 2 they were 8.2 °C and 482 mm (Table 2).

Table 2. Temperature and precipitation for Trial 1 and Trial 2 compared to 30-year average.

Temperature	30-year average	9.1 °C
	Trial 1 (September 2011 to August 2012)	9.4 °C
	Trial 2 (September 2012 to August 2013)	8.2 °C
Precipitation	30-year average	725 mm
	Trial 1 (September 2011 to August 2012)	557 mm
	Trial 2 (September 2012 to August 2013)	482 mm

The temperature course in the trial period 2011 to 2013 was similar to the course of the 30-year mean. The biggest deviation was a significantly cooler March in 2013. The precipitation was lower than the averaged totals in many months. May 2013 stood out with an above-average precipitation total.

3.2. Yield, N-Uptake and C/N Ratio of the Cover Crops

In Trial 1, the above-ground biomass yield of the cover crops averaged at 2.1 t dry matter (DM) ha^{-1} for *S. alba* and 3.0 t DM ha^{-1} for *V. sativa* in the four replicates. *T. resupinatum* emerged so poorly that it could not be sampled. In Trial 2, the above-ground biomass yield of *S. alba* was 1.7 t DM ha^{-1}, that of *T. resupinatum* was 0.6 t DM ha^{-1} and that of *V. sativa* was 1.5 t DM ha^{-1}. The yields of *S. alba* and *V. sativa* were significantly higher than the yield of *T. resupinatum* (Figure 1a,b).

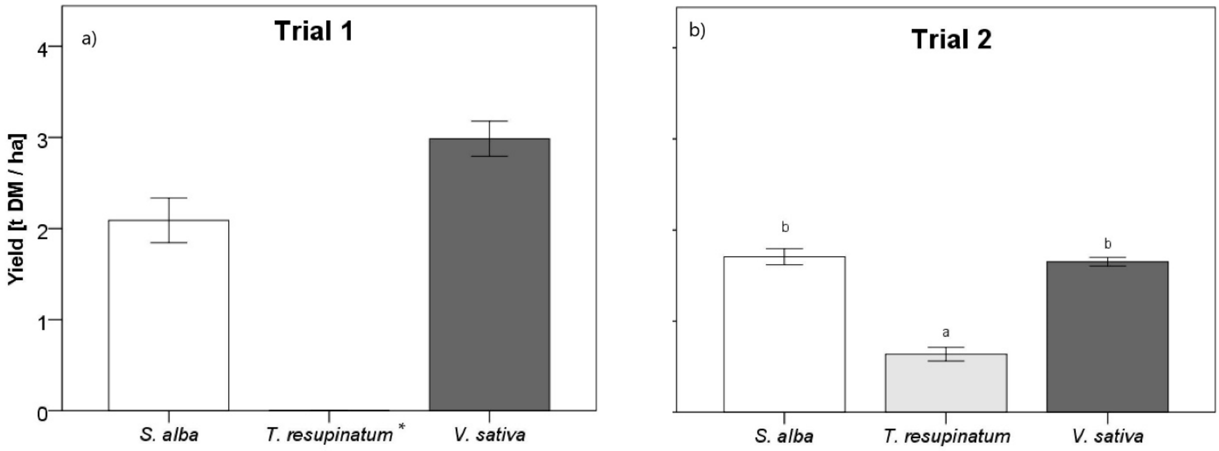

Figure 1. (**a**,**b**): Dry matter yields of the cover crops in Trial 1 and Trial 2. * *T. resupinatum* could not be sampled and therefore no ANOVA could be carried out. Different letters indicate significant differences ($p \leq 0.05$).

In Trial 1, the N uptake in the above-ground biomass of *S. alba* averaged at 34.9 kg N ha^{-1} and that of *V. sativa* averaged at 124.4 kg N ha^{-1} over the four replicates. In Trial 2, the N uptake in the above-ground biomass of *S. alba* was 43.4 kg N ha^{-1}, that of *T. resupinatum* was 22.9 kg N ha^{-1} and that of *V. sativa* was 72.7 kg N ha^{-1} (Figure 2a,b).

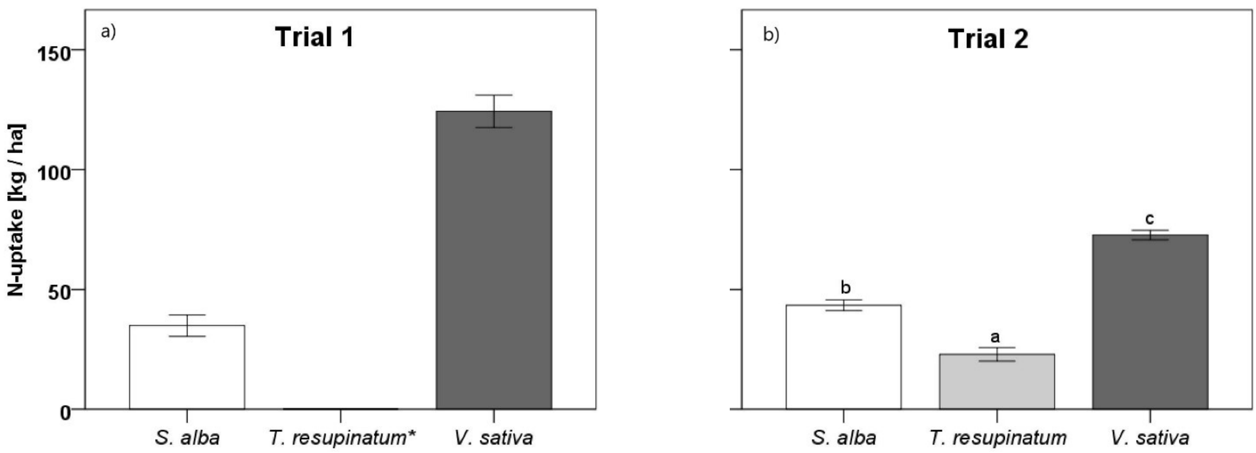

Figure 2. (**a**,**b**): Total N uptake of cover crops in the above-ground biomass in Trial 1 and Trial 2. * *T. resupinatum* could not be sampled and therefore no ANOVA could be carried out. Different letters indicate significant differences ($p \leq 0.05$).

The C/N ratio of *S. alba* was 16.7 and 25.9, that of *T. resupinatum* was 10.9 and that of *V. sativa* was 9.9 and 10 (Table 3).

Table 3. C/N ratio of cover crops in the two trials.

Species	Trial 1	Trial 2
S. alba	25.9 ± 0.72	16.7 ± 0.47 c
T. resupinatum *	n.a.	10.9 ± 0.10 b
V. sativa	10.0 ± 0.19	9.9 ± 0.12 a

* *T. resupinatum* could not be sampled. Therefore, no analysis of variance could be carried out for Trial 1. Different letters indicate significant differences ($p \leq 0.05$). n.a. = not available.

3.3. N-Dynamic

Since in Trial 1 the proportion of NH_4-N in the total N_{min} was low on all the sampling dates (generally less than 1 kg ha^{-1} layer^{-1}, with a maximum of 1.6 kg ha^{-1} layer^{-1}), separate presentation of NO_3-N and NH_4-N was omitted in the following section. At the start of Trial 1 on 29 August 2011 the N_{min} contents were at similar levels across the trial area and there were no significant differences. On 24 November 2011, there was a significant influence of the cover crop factor. The N_{min} contents in all the soil layers were significantly the highest in the bare fallow treatment compared to the other treatments. In the 20–40 cm layer, the *T. resupinatum* and *V. sativa* treatments occupied an intermediate position, i.e., the N_{min} content was significantly higher than in the *S. alba* treatment, but significantly lower than in the bare fallow treatment. On 26 March 2012 there was still a significant influence of the cover crop factor on the N_{min} content of all the investigated layers. In the *V. sativa* treatment, the N_{min} content was significantly the highest in the upper two layers. In the 60–90 cm layer, the N_{min} content was at the same level in the *V. sativa* and bare fallow treatments. The three soil layers of the *T. resupinatum* treatment had medium values, as did the 30–60 cm layer in the bare fallow treatment. The *S. alba* treatment had significantly the lowest values in all three layers (Figure 3a).

After differentiation in terms of tillage on 2 May 2012 there was a significant influence of the cover crop factor on the N_{min} content of all three soil layers and a significant influence of the tillage factor on the N_{min} content of the top two soil layers in Trial 1. The N_{min} content was significantly the highest in the 0–30 cm layer and in the 30–60 cm layer in the *V. sativa* x plough and *V. sativa* x chisel treatments. The second highest N_{min} content in these two layers was in the *T. resupinatum* x plough and *T. resupinatum* x chisel and bare fallow x plough and bare fallow x chisel treatments. The N_{min} content was the lowest in the *S. alba* treatments. The mulch and no-till treatments had a lower N_{min} content in the upper two soil layers in each cover crop than in the plough and chisel treatments, although the N_{min} content for the mulch and no-till treatments in the *V. sativa* plots was still at a high level. In the soil layer at 60–90 cm, there were no significant differences between the treatments. There was no significant interaction (Figure 3b). At the end of the trial on 29 August 2012 there were only minor differences between the remaining treatments in terms of quantity. Nevertheless, the treatments differed significantly. There was a significant influence of both factors and a significant interaction in the 0–30 cm layer. In the 30–60 cm layer, the cover crop factor had a significant influence. In the *V. sativa* x plough treatment, the N_{min} content in the 0–30 cm layer was significantly higher than in all the other treatments. In the 30–60 cm layer, the N_{min} content in the *V. sativa* x chisel treatment was significantly higher than in the *S. alba* x plough and *S. alba* x chisel treatments.

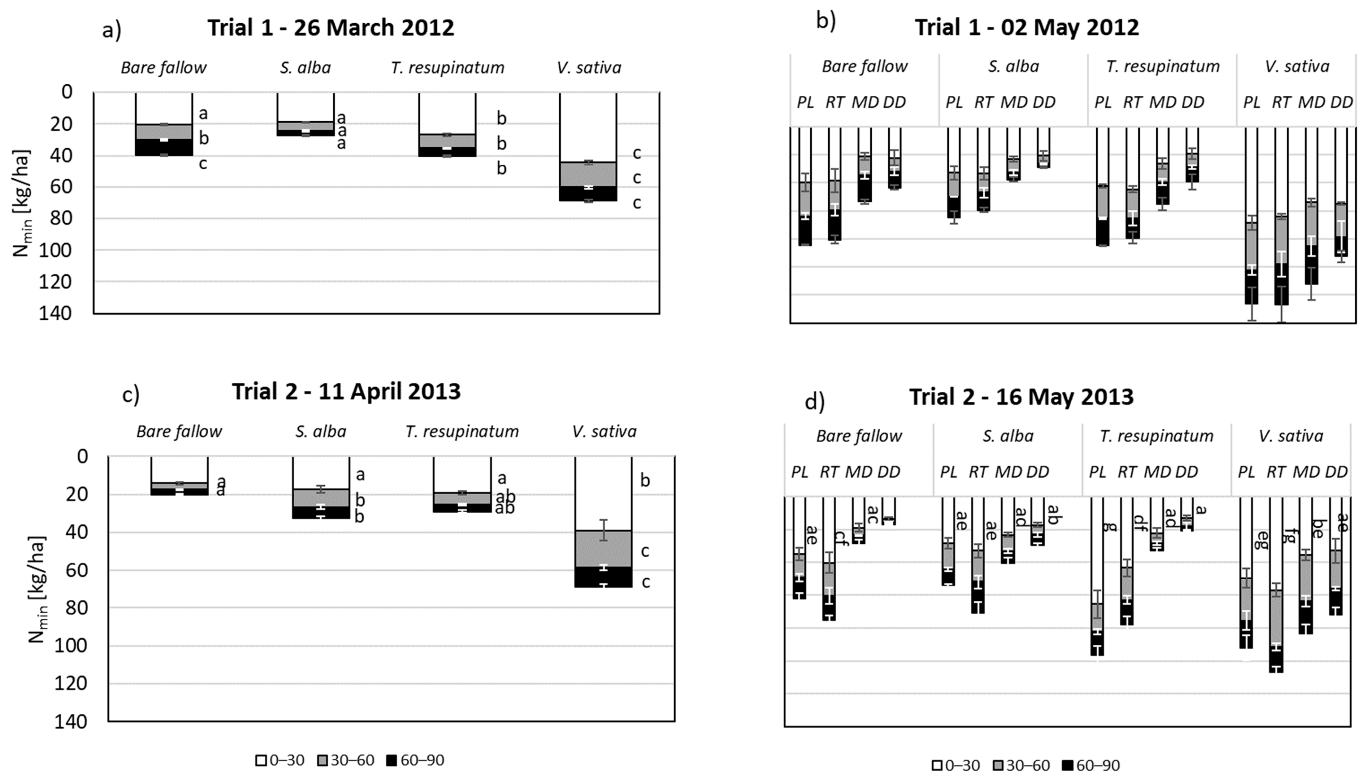

Figure 3. (**a**–**d**): N_{min} on selected dates in Trial 1 and Trial 2. PL = plough, RT = reduced tillage (chisel in Trial 1 and disc harrow in Trial 2), MD = mulching and drilling, DD = direct drilling. Different letters indicate significant differences ($p \leq 0.05$).

In Trial 2, the proportion of NH_4-N in the total N_{min} was higher on all sampling dates than in Trial 1, but the proportion was also only low, so no separate presentation also is given here. The highest NH_4-N values were achieved in the *V. sativa* treatments in general and in the *V. sativa* x plough treatments in particular (in the 0–30 cm layer up to a maximum of 6 kg NH_4-N ha^{-1}).

In addition, in this trial, the N_{min} content at the start of the trial on 24 August 2012 was at a similar level in all the treatments, and there were no significant differences. On 6 December 2012 there was a significant effect of the cover crops on the N_{min} content of each of the three soil layers. The N_{min} content in the 0–30 cm layer in the *V. sativa* treatment was significantly the highest, and in the bare fallow treatment it was significantly the lowest. The N_{min} content of the *T. resupinatum* treatment was in between that of the other treatments. In the 30–60 cm layer, the N_{min} content of the *V. sativa* treatment was significantly the highest, although the differences in quantity were only slight from a plant cultivation point of view. The situation was similar in the 60–90 cm layer; the N_{min} content was low overall, but there were significant differences. The N_{min} content ranged from the highest values being obtained in the *V. sativa* treatment to medium values being obtained in the *T. resupinatum* treatment to the lowest values being obtained in the *S. alba* and bare fallow treatments. On 11 April 2013 there was a significant influence of the cover crop factor. The differences in quantity increased. Again, the highest N_{min} content was found in the *V. sativa* treatment in all three layers. In the top layer, the N_{min} content after the bare fallow, *S. alba* and *T. resupinatum* treatments was similarly low, and in the lower two layers the N_{min} content after the fallow treatment was significantly lowest (Figure 3c).

On 16 May 2013, after differentiation by tillage, both the cover crop factor and the tillage factor had a significant influence on the N_{min} content of all three soil layers, and there was a significant interaction with respect to the N_{min} content of the topsoil layer. The N_{min} content in the 0–30 cm layer was significantly the highest in the *T. resupinatum* x plough treatment. The N_{min} content was similarly high in the *V. sativa* x plough and *V. sativa* x disc harrow treatments. In the 30–60 cm layer, the *V. sativa* x disc harrow treatment had significantly the highest N_{min} content. There were no significant differences in the 60–90 cm layer. The mulch and no-till treatments after the *V. sativa* treatment had significantly higher N_{min} contents in all three soil layers than the mulch and no-till treatments after the other cover crops and the fallow treatments (Figure 3d). On 25 June 2013, the differences in terms of quantity were again only slight. However, there was a significant interaction in the 0–30 cm layer; the N_{min} content was highest in the fallow x mulch, *S. alba* x plough, *V. sativa* x mulch and *V. sativa* x no-till treatments, and it was the lowest in the fallow x plough treatment. In the 30–60 cm layer, there were no significant differences between the treatments. In the 60–90 cm layer there was a significant influence of the cover crop factor and a significant interaction as well. The *V. sativa* x mulch seed treatment had significantly the highest N_{min} content, while the mulch and no-till treatments had significantly the lowest values in the other cover crops and the bare fallow treatments. At the end of the trial on 3 September 2013, there were no significant differences in any soil layer in the remaining treatments.

3.4. Weed Cover, Density and Biomass

The data for weed cover in the late stage of cover crops in Trial 1 were not normally distributed. For the statistical evaluation, the data were log-transformed. The weed cover was significantly the lowest in the *V. sativa* treatment and significantly the highest in the *T. resupinatum* treatment. In the *S. alba* treatment, the weed cover was at a medium level (Figure 4a). In Trial 2, the weed cover in the late stage of cover crops was again significantly the lowest in the *V. sativa* treatment. This was followed by the *S. alba* treatment and the *T. resupinatum* treatment, each with a significantly higher degree of weed cover. The weed cover was significantly highest in the bare fallow treatment. Overall, the weed cover was seven times higher than in Trial 1 (Figure 4b).

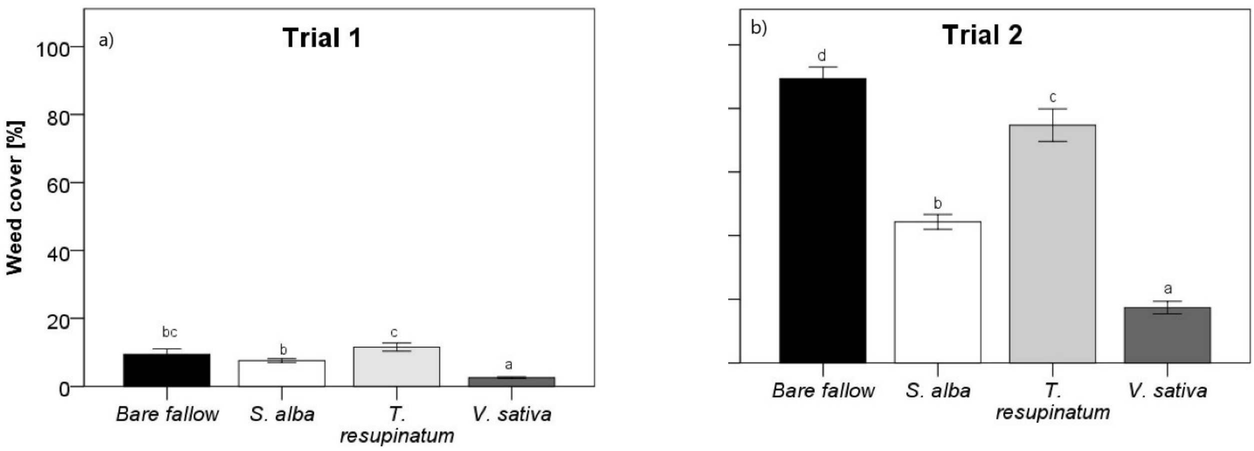

Figure 4. (**a**,**b**): Weed cover as a percentage in the late stage of cover crops in Trial 1 and Trial 2. Different letters indicate significant differences ($p \leq 0.05$).

There was a significant interaction between the cover crop and tillage factors on the weed density in Trial 1. In all the mulch and no-till treatments, the weed density was significantly lower than in the other tillage treatments (with the exception of *V. sativa* x mulch sowing). The no-till treatment did not disturb or hardly disturbed the development of the existing weeds and no or only few new weed seeds were brought to the surface. Thus, there were fewer but larger weeds in these treatments. Significantly, the most weeds were found in the *S. alba* x plough treatment (Figure 5a).

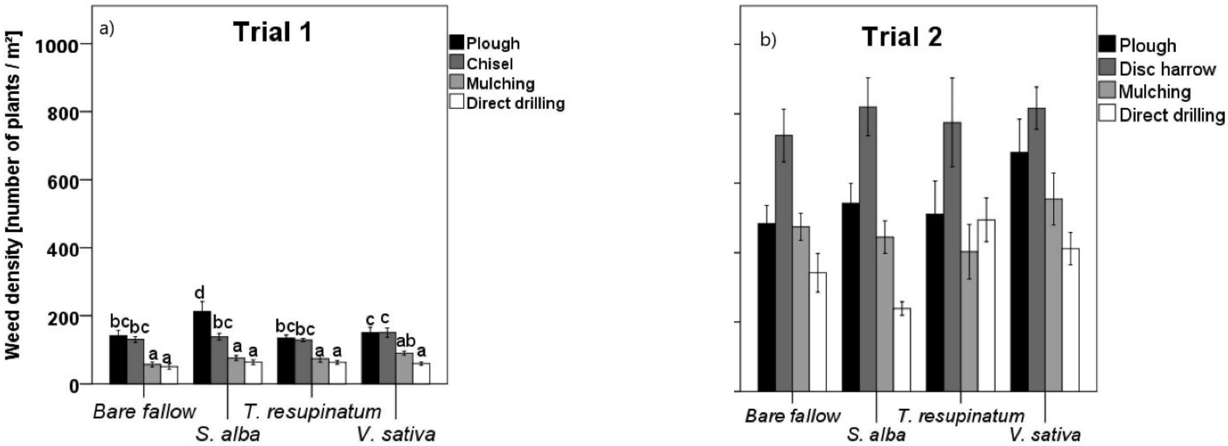

Figure 5. (**a**,**b**): Weed density in the early stage of the main crop, oats, in Trial 1 and Trial 2. Different letters indicate significant differences ($p \leq 0.05$).

In Trial 2, there was a great deal of volunteer growth of the preceding crop, winter wheat. In order to enable the continuation of the mulch and no-till plots, one half of each of these treatments was flamed. In the following section, the results of the flamed plot halves are always shown. There was no significant interaction between the cover crop and tillage factors. The tillage factor had a significant effect. The no-till treatments had significantly the lowest weed density due to the flaming. The ploughed treatments had a medium weed density. The disc harrow treatments had significantly the highest weed density (Figure 5b). Overall, the weed density in Trial 2 was nearly three times higher than in Trial 1.

The data for weed cover in the late stage of the main crop, oats, for Trial 1 were not normally distributed. Log-transformed data were used for the analysis of variance. There was a significant interaction between cover crop and tillage. The *T. resupinatum* x plough and the *V. sativa* x plough treatments had significantly the lowest weed cover. The bare fallow x chisel, *T. resupinatum* x chisel and *V. sativa* x no-till treatments had significantly the highest weed cover (Figure 6a). The mulch and no-till treatments in the bare fallow, *S. alba* and *T. resupinatum* treatments had to be abandoned due to there being too much weed pressure. The mulch and no-till treatments in the *V. sativa* plots could be maintained.

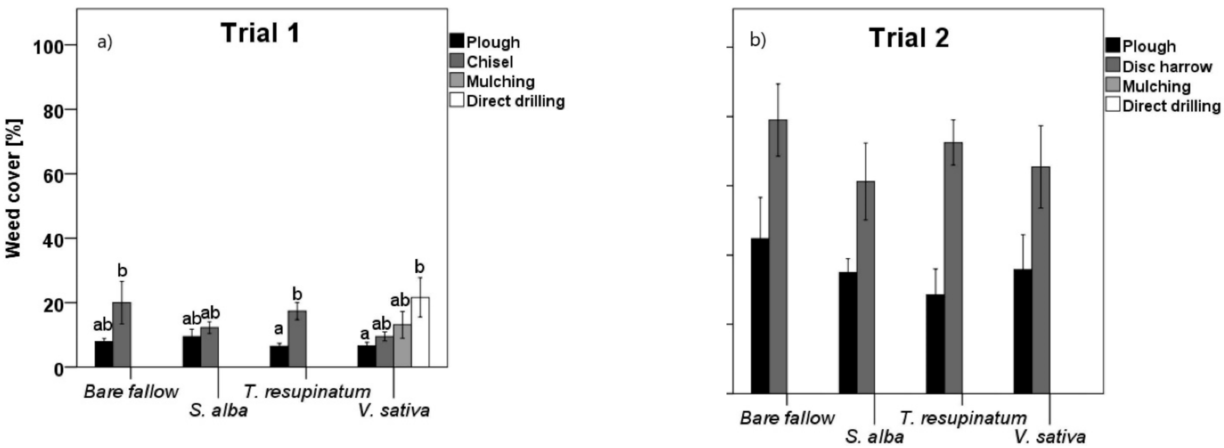

Figure 6. (**a**,**b**): Weed cover in the late stage of the main crop, oats, in Trial 1 and Trial 2. Different letters indicate significant differences ($p \leq 0.05$).

In Trial 2, there was no significant interaction between the cover crop and tillage factors. The tillage had a significant effect. The plough treatments had a significantly lower weed cover than the disc harrow treatments. The weed emergence was overall significantly higher than in Trial 1. All the mulch and no-till treatments had to be abandoned (Figure 6b).

The no-till treatments, besides that after *V. sativa* in Trial 1, were not included in the analyses due to there being too much weed pressure

The weed biomass data in Trial 1 were not normally distributed. Log-transformed data were used for the analysis of variance. There was no significant interaction between the factors cover crop and tillage. Tillage had a significant effect on weed biomass. The plough treatments had a significantly lower weed biomass than the chisel treatments in each cover crop treatment. The weed biomass in the *V. sativa* x mulch treatment was at a similar level to the chisel treatments. The *V. sativa* x no-till treatment had a significantly higher weed biomass (Figure 7a).

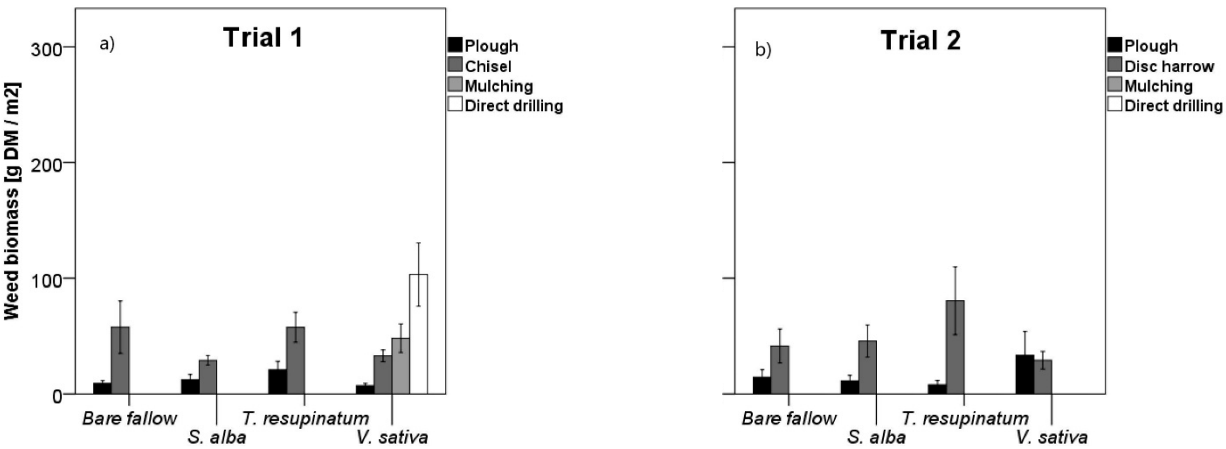

Figure 7. (**a**,**b**): Weed biomass dry matter in the late stage of the main crop, oats, in Trial 1 and Trial 2.

In Trial 2, tillage had a significant effect. In the plough treatments of the bare fallow, *S. alba* and *T. resupinatum* plots, there was a lower weed biomass than in the disc harrow treatments. For *V. sativa*, however, there was no significant difference in weed biomass between the plough and disc harrow treatments (Figure 7b).

The no-till treatments, besides that after *V. sativa* in Trial 1, were not included in the analyses due to there being too much weed pressure.

3.5. Yield of the Main Crop, Oats

There was a statistically significant interaction between the cover crop and tillage for oat yield in Trial 1. The grain yield of oats was significantly the lowest in the *S. alba* plough and chisel treatments. It was significantly the highest in the *V. sativa* chisel treatment (Figure 8a).

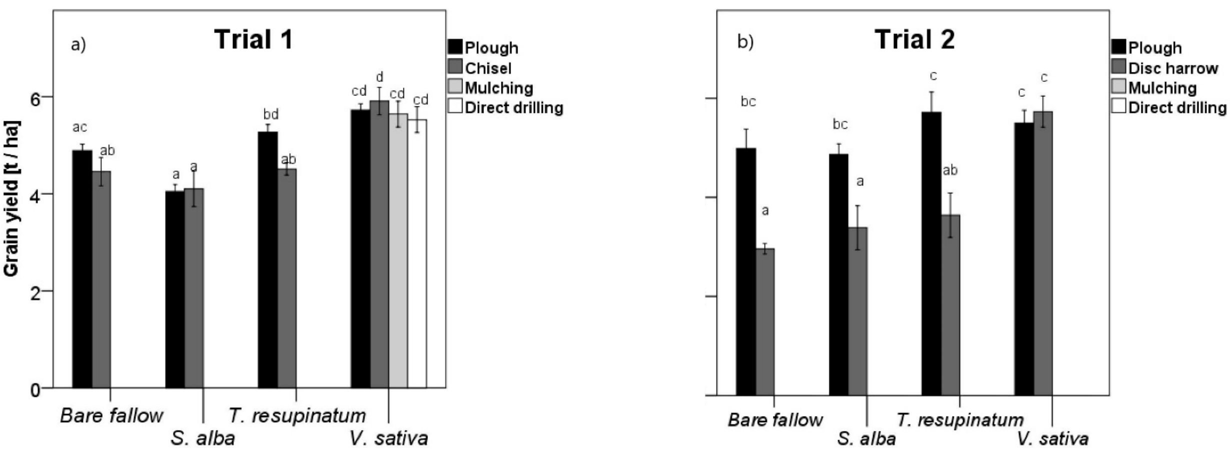

Figure 8. (**a**,**b**): Oat yield at 86% dry matter in Trial 1 and Trial 2. Different letters indicate significant differences ($p \leq 0.05$).

There was a statistically significant interaction between cover crop and tillage in Trial 2. The grain yield in Trial 2 was significantly the lowest in the disc harrow treatments after bare fallow and *S. alba*. It was significantly the highest in the plough treatments after *T. resupinatum* and *V. sativa* as well as in the disc harrow treatment after *V. sativa* (Figure 8b).

The no-till treatments, besides that after *V. sativa* in Trial 1, were not included in the analyses due to there being too much weed pressure.

4. Discussion

In Trial 1, the biomass yield of *S. alba* was approximately 0.4 t DM ha^{-1}, and that of *V. sativa* was approximately 1.5 t DM ha^{-1} higher than in Trial 2. This meant that the yields of *S. alba* varied only slightly, while the yield of *V. sativa* in Trial 2 was only about half of the first. The four-days-earlier sowing in the second year therefore had had no measurable positive effect. Both the sowing dates (26 August and 22 August) were considered late.

The temperature may have been the decisive factor for the lower yield of *V. sativa* in Trial 2. For example, September 2011, with an average temperature of 15.4 °C, and October 2011, with an average temperature of 9.7 °C, contrasted with the cooler September 2012, with a temperature of 12.8°C, and the cooler October 2012, with a temperature of 8.0 °C. Furthermore, both months of both years were drier than the long-term average; the Septembers in both years were very similar at 39 mm of rain versus 39.4 mm, but October 2012 at 30.1 mm of rain was even drier than October 2011 at 41 mm of rain.

T. resupinatum had a very poor emergence in Trial 1. In the literature, a poor emergence or total failure of *T. resupinatum* is mentioned several times [34–36]. In Trial 1, silting due to heavy rainfall shortly after sowing was probably decisive for the unfavorable emergence conditions in 2011. In Trial 2, *T. resupinatum* emerged better and yielded 0.6 t DM ha^{-1}, which corresponded to the average value given in the literature [34].

S. alba was more yield-stable than the other two cover crop species and was more tolerant to the late sowing date. This confirmed various studies [30,31,36,37]. *S. alba* had a higher C/N ratio in Trial 1 than in Trial 2. *S. alba* was in a more advanced stage of vegetation in Trial 1 than in Trial 2, and there was woodier stem material in the samples than in the samples from Trial 2. In the literature, values of 12.9 [36], 17.8–30.3 [38] and 11–28 [39] are given for the C/N ratio of *S. alba*. The high value of 25.9 was therefore not unusual and was within the ranges of these data.

In both trials, the cover crops had a clear influence on the N_{min} content. In spring, before tillage, *V. sativa* resulted in the highest N_{min} content in the 0–30 cm and 30–60 cm layers in both years. In addition, after tillage, *V. sativa* resulted in a higher N_{min} content than the other cover crops. The biomass yield of *V. sativa* was only about half as high in Trial 2 as in Trial 1. Nevertheless, the N_{min} content after the *V. sativa* treatment in Trial 2 was at a similar level as in Trial 1. The better emergence of *T. resupinatum* in Trial 2 was visible in the results for the N_{min} content of the ploughed system. In the RT system, however, the *T. resupinatum* treatment performed significantly worse than the *V. sativa* treatment, even in Trial 2. The N_{min} content was the lowest in both trials in the *S. alba* treatments. As desired, the N uptake of *S. alba* in the growing season led to a low N_{min} content in autumn. However, the N uptake was rather low, with values of 34.9 kg N ha^{-1} in Trial 1 and 43.4 kg N ha^{-1} in Trial 2. Presumably, the N uptake could have been higher with a higher N_{min} content. The initial N_{min} content of both plots was around 34 kg N ha^{-1} in the 0–60 cm layer. In spring, after tillage, the N_{min} overall content of the *S. alba* treatments did not reach the N_{min} content after the other cover crops and bare fallow treatments.

Soil cultivation with a chisel or disc harrow did not lead to a significantly lower N_{min} content in spring compared to the ploughed treatment of the respective cover crop. The mulch and no-till treatments, on the other hand, led to significantly lower N_{min} levels, especially after the bare fallow, *S. alba* and *T. resupinatum* treatments. In the mulch and no-till treatments, the N_{min} content was the highest after *V. sativa* in Trial 1. The higher yield of *V. sativa* compared to Trial 2 was probably noticeable here.

Regarding weed cover in the late stage of the cover crops, it was significantly the lowest in both trials after *V. sativa*. *S. alba* had a medium weed suppression potential. In Trial 2, weed emergence in all the treatments was significantly higher than in Trial 1.

The weed density was significantly the highest in Trial 1 in the *S. alba* x plough treatment. This higher number of weeds was put into perspective again during the growing season of the oats. The weed density was counted when the weeds were young and thus only said something about the existing weed potential and not about further development. The weed density was lowest in the mulch and no-till treatments, where there were significantly fewer but larger weeds. In these plots, the weeds were hardly or not at all disturbed in terms of their development due to the lack of tillage and were thus able to continue growing undisturbed, in some cases from the previous autumn.

The significantly higher weed emergence in Trial 2 compared to Trial 1 was also reflected in the weed density; the number was many times higher in each treatment of Trial 2 than in Trial 1. The problem here was the strong volunteer growth of the previous crop, winter wheat, which was also counted as a weed. The weed density was the highest in the disc harrow plots. It was the lowest in the mulch and no-till treatments due to flaming.

In Trial 1, the weed cover in the late stage of oats was generally low in the plough treatments compared to the other tillage treatments and did not differ with regard to the cover crop treatment. In the mulch and no-till treatments, the oats could not be harvested after the cover crops *S. alba* and *T. resupinatum* and after the bare fallow treatments due to excessive weed growth. In comparison, *V. sativa* was much better at suppressing the weeds. In Trial 2, all the mulch and no-till treatments had to be abandoned due to excessive weed pressure. The one-time flaming did not achieve a sufficient effect. The weed pressure in the disc harrow treatments was significantly higher than the weed pressure in the plough treatments, and there were no significant differences between the cover crop treatments. Overall, there was a significantly higher degree of weed cover in Trial 2 than in Trial 1, including in the plough treatments.

The superiority of the plough as an instrument for weed control was shown in terms of weed biomass. In both trials, the weed biomass was overall the lowest in the ploughed treatments.

The relative excellence of *V. sativa* in Frankenhausen in Trial 1 with regard to weed suppression confirmed the results of [40]. The results of [41] showed a similarly good success of *S. alba* and *V. sativa*, which corresponded to the results of Trial 2. In Trial 1, it was observed that *V. sativa* literally formed "felt plates" when it froze, which kept the soil well covered where there was sufficient biomass and largely prevented the weeds from appearing. The lack of success of *V. sativa* in the mulch and no-till treatments of Trial 2 was found on the one hand in the lower biomass production of *V. sativa* and on the other hand in the generally higher occurrence of weeds.

Regarding oat yields, in Trial 1, the *S. alba* treatments showed a reduced yield in both the remaining tillage systems. In the study in [42], oat yields were also reduced after *S. alba* treatment. The authors concluded that the N taken up by brassica cover crops was often not available when the subsequent crop needed it. *V. sativa* resulted in the highest oat yields in all the tillage treatments and in the only harvestable mulch and no-till treatments. These were at a similar level of yield as the plough and chisel treatments. In Trial 2, the yield differences were greater than in Trial 1. Ploughing led to consistently good oat yields; RT resulted in yield losses, except after *V. sativa*, where the highest yields were harvested just after RT.

Of the cover crops presented here, *V. sativa* seemed particularly suitable for being combined with RT in organic farming. In this respect, the positive results of [41] were confirmed, where, using *V. sativa* as a cover crop in a system with RT, yields comparable to those achieved with a ploughing system were achieved.

In Trial 1, the results showed that in organic farming, even with mulch and no-till treatments after the cultivation of a suitable cover crop, in this case *V. sativa*, in a suitable location, oat yields comparable to those obtained after tillage with a plough can be achieved. In Trial 2, however, in contrast to Trial 1, none of the cover crop treatments were able to suppress the weeds to such an extent that a mulch or no-till treatment would have led to satisfactory yields for the main crop, oats. This may have been due to the fact that the cover crops, especially *V. sativa*, produced significantly less biomass than in Trial 1. Therefore, it could not provide sufficient weed control. In addition, the flaming did not show a sufficient weed-suppressing effect, so much so that the mulch and no-till treatments finally had to be abandoned in Trial 2.

In both years, the yield differences were more pronounced between the cover crop treatments after RT than after PL. RT, therefore, was more dependent on an adequate cover crop species than the PL system. The no-till treatment was not only dependent on an adequate cover crop species but also on its proper biomass production for sufficient weed control. In this regard, the results of [43] were confirmed, who found that cover crop effects increased with decreasing management intensity.

5. Conclusions

The results showed that in organic farming with methods of RT (here chisel and disc harrow) in combination with a suitable cover crop, in this case *V. sativa*, comparable oat yields could be achieved in the short term to those after tillage with a plough. In order to further reduce the intensity of tillage in the direction of no-till, it is not only important that a suitable cover crop is cultivated but that it also produces enough biomass for good ground cover and satisfactory weed suppression. However, since the biomass production of the cover crop will be subject to fluctuation, a flexible choice of tillage method could be the most promising solution. With sufficient biomass production and soil cover of the cover crop, a reduction in tillage intensity in the direction of no-till could be considered for the subsequent crop. On the other hand, less growth of the cover crop would speak for a somewhat higher tillage intensity, e.g., the use of a chisel or a disc harrow.

Of course, one-year trials cannot be used to conclude for no-ploughing in the long term. How weed growth and soil properties develop in the case of several years of exclusively using RT cannot be answered on the basis of these trials and requires long-term ongoing trials. The experiences of practitioners are also of great value for answering such questions.

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