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Weed Control Using Conventional Tillage, Reduced Tillage, No-Tillage, and Cover Crops in Organic Soybean

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Abstract: Soybean field experiments were performed to investigate the weed-suppressing effects of different tillage systems and cover crop mulches at two locations in southwest Germany during 2014 and 2015. The influence of three different tillage systems on weed control efficacy, soybean plant density, and crop yield was determined. In the no-till system (NT), two different cover crops, (rye and barley), were treated by a roller-crimper before soybean sowing. For the reduced tillage system (RT), shallow soil cultivation (7.5 cm depth) using a cultivator after cover crop harvest was performed. The third system was conventional tillage (CT), which used a plow (25 cm depth) without any previous cover crop treatment. Finally, a CT system without weed control was used as a control treatment (C). Weed densities in the field experiments ranged from 1 to 164 plants m^{-2} with *Chenopodium album* (L.), *Echinochloa crus-galli* (L.) P. Beauv., and *Sonchus arvensis* (L.) as the predominant weed species. No difference in weed suppression was found between the two cover crops. The highest cover crop soil coverage was measured in the NT treatment. The greatest weed density (164 plants m^{-2}) was measured in the untreated control. CT, RT and NT reduced weed density up to 71%, 85%, and 61%, respectively, to C, across both locations and years. Soybean plant density was reduced in NT (−36%) and CT (−18%) based on aimed sown plant density. Highest crop yields up to 2.4 t ha^{-1} were observed in RT, while NT resulted in lower yields (1.1 t ha^{-1}). Our work reveals the importance of cover crops for weed suppression in soybean cropping systems without herbicide application.

Keywords: conservation tillage; cover crop barley (*Hordeum vulgare* L.); cover crop rye (*Secale cereale* L.); organic no-till systems; roller-crimper; soybean (*Glycine max* L. Merr.)

1. Introduction

During the last few decades, various cultivation methods have been examined for improving the yield potential of different crops [1] which, at the same time, have the ability to enhance ecosystem services (e.g., increases in soil organic matter, soil water retention capacity and soil biodiversity) [2]. In this context, soil tillage plays a crucial role, as it determines both the productivity of the cropping system in terms of yield as well as its environmental impacts, such as soil erosion or carbon sequestration. Soil tillage has been performed for millennia because it reduces weed density while positively affecting water and nutrient availability [3]. At the same time, brief exposure to sunlight, due to soil inversion after tillage, can trigger the germination of deeply buried weed seeds [4].

Modern agriculture must strive to optimize time, cost, and labor efficiencies [5,6]. RT and, in particular, NT can provide a competitive advantage in agriculture [7] compared with CT and may lead to an increase in soil quality, e.g., in organic carbon content [8] and to a reduction of topsoil erosion [9]. On the other hand, by reducing tillage depth and frequency in temperate regions, winter annual weed species, perennial and annual grass weeds, as well as perennial dicots, e.g., Canadian thistle (*Cirsium arvense* L. Scop.) will become more prevalent than under CT systems [10,11].

The main soybean (*Glycine max* L. Merr.) growing areas are North and South America where, in 2006, the USA, Brazil, and Argentina accounted for 81% of total global production [12]. In those countries, soybean cultivation is typically performed using NT systems [7,12]. These systems usually include herbicide-resistant genetically modified (GM) soybean varieties in combination with a non-selective herbicide applied after the crop's establishment [13]. This practice is very efficient for maintaining soil protection.

In Europe, soybean cultivation is established in several countries (e.g., Romania, Italy) and is gaining importance in others (e.g., Germany and Austria) as soybean varieties adapted to cooler climates become more readily available. Soybean is an interesting crop for organic farmers because it provides nitrogen (N) via biological N fixation, is an ideal feed for monogastric livestock due to its amino acid composition, and has gained recent popularity within western consumer diets. Currently, in Europe, 983,000 ha (1% of total arable land) are cultivated with soybeans in 2016. Six percent of the total arable land base is under organic management [14].

As the use of GM crops is not permitted in organic farming, as well as in conventional farming in most EU member states, soybean cropping systems identical to those in North and South America cannot be established under European conditions. In conventional farming, besides using non-selective herbicides prior to seeding, application of pre- and post- emergence herbicides in combination with NT can be a viable solution for the production of non-GM soybean [7]. Pre-emergence herbicides reduce weeds prior to crop emergence, providing a clean field for crop establishment. As synthetic herbicides are prohibited in organic farming, such cropping systems are not an option for organic farmers; therefore, another system-based approach has to be developed to (a) reduce weed pressure, (b) reduce labor and tillage operations costs, and (c) maintain soil quality. In a system-based approach, cover crops can sometimes be an effective alternative to conventional tillage for preventive weed management. Rapid biomass production and the competition of cover crops for light, water and nutrients suppresses weed development during the winter and early spring. Furthermore, the release of biochemical substances can inhibit weed growth during emergence and create a biochemical environment unfavorable for weed emergence [15,16]. In the literature, NT soybean cultivation systems are often associated with the use of rye (*Secale cereale* L.) as a preceding cover crop [17–19]. Mirsky et al. [20] investigated a roller-crimper as a useful agronomic tool for crushing the cover crop's stems while depositing them on the soil surface, creating a mulch layer. The roller-crimper is a cylindrical steel roll with metal slates, which is mounted on the front of the tractor. This technique was adapted from southern Brazil and Paraguay and is well described by Ashford and Reeves [21]. The use of a roller-crimper generates a uniform mulch layer that can persist for months. The mulch layer creates a physical barrier that can reduce weed growth and germination [22]. Mirsky et al. [23] found that this system provides a high level of weed suppression.

For soybean, there is little information available regarding the use of various tillage systems in organic farming under European conditions. Therefore, field studies were conducted with two modified tillage systems combined with two different cover crops. RT and NT systems were examined with both rye and barley (*Hordeum vulgare* L.) as a cover crop. Furthermore, CT was applied with or without weed control. Our research objectives were to quantify soil surface coverage, weed emergence, and weed density responses to CT, RT, and NT systems. We also investigated whether or not differences in soybean plant density and soybean yield occurred.

2. Materials and Methods

2.1. Experimental Sites

Soybean trials were located at the research stations Kleinhohenheim (KH) (48.73° N, 9.20° E, 435 m altitude) and Ihinger Hof (IHO) (48.74° N, 8.92° E, 478 m altitude), in southwest Germany during 2014 and 2015. The research station KH has been managed according to the organic guidelines of the German organic farming associations Demeter, Naturland and Bioland since 1994, while the IHO station is a conventional farm. Only the plots for our experiment were managed according to organic standards at the IHO station. Average annual temperature and precipitation is 8.8 °C and 700 mm at KH and 7.9 and 714 mm at IHO. Soil texture is characterized as a silty loam at KH and as a loamy and silty clay at IHO. In fields at both locations where field experiments were located, three different seedbeds were prepared: conventional tillage (plow 25 cm depth, without weed control) = C, conventional tillage (plow 25 cm depth, weed control with three mechanical hoeing treatments) = CT, reduced tillage (cultivator 7.5 cm depth, weed control with three hoeing treatments) = RT, and no-tillage (without tillage and weed control) = NT (Table 1).

The rye cultivar 'Protector' (150 kg ha^{-1}) and the barley cultivar 'Anisette' (127 kg ha^{-1}) were sown in the first week of October of the previous year as cover crops in both, the RT and NT treatments. Plowing in C and CT treatments was done in November before sowing soybean the following spring. During the second week of May, the RT cover crops rye and barley (growth stage 61–65 [24]) were cut with a front mower (Pöttinger GmbH, Grieskirchen, Austria) and removed, followed by shallow (7.5 cm) soil cultivation using a cultivator (Amazone, Hasbergen, Germany). In NT, cover crops were terminated with a roller-crimper (Friedrich Wenz GmbH, Schwanau, Germany) (Figure 1). The weight of the roller-crimper was 900 kg and the driving speed of the tractor was 15 km h^{-1}. At the same time, seedbed preparation was performed in C and CT using a cultivator (Amazone, Hasbergen, Germany). Afterwards, the soybean cultivar 'Sultana' was sown with a no-till sowing machine (Kuhn Maxima 2 GT, Genthin, Germany) at a density of 650,000 seeds ha^{-1} and a plot size of 45 m^2 to all treatments. The sowing machine had a double disc opener with pressure rolls that followed behind. Residue removers were mounted to the front of the two discs, which had an estimated pressure of about 150 kg each. Mechanical weed control was performed with a hoe (Einböck CHOPSTAR, Dorf an der Pram, Austria) in the CT and RT treatments three times. No weed control was performed in the C and NT treatments during the growing season and no fertilizer was applied during the experiment at either location during either year (Table 1).

Plots were arranged in a strip-plot experimental design with the tillage treatment as the main strip and cover crops as a sub-plot. Four replications were created.

Table 1. Tillage treatments and cultivation measures for soybean growing under organic management at both trial sites (KH = Kleinhohenheim, IHO = Ihinger Hof, C = Control, CT = Conventional tillage, RT = Reduced tillage, and NT = No-till).

Site/Year	Treatment	Sowing Cover Crop	Soil Tillage	Cutting of Cover Crop	Seed Bed Preparation	Soybean Sowing	Weed Control	Harvest
KH 2014	C	- [a]	11 November 2013	-	19 May	21 May	-	15 October
	CT	-	11 November 2013	-	19 May	21 May	hoeing [b]	15 October
	RT	2 October 2013	-	19 May	19 May	21 May	hoeing	15 October
	NT	2 October 2013	-	21 May	-	21 May	-	15 October
KH 2015	C	-	15 November 2014	-	18 May	19 May	-	13 October
	CT	-	15 November 2014	-	18 May	19 May	hoeing	13 October
	RT	2 October 2014	-	18 May	18 May	19 May	hoeing	13 October
	NT	2 October 2014	-	19 May	-	19 May	-	13 October
IHO 2014	C	-	21 November 2013	-	18 May	21 May	-	20 October
	CT	-	21 November 2013	-	18 May	21 May	hoeing	20 October
	RT	2 October 2013	-	18 May	18 May	21 May	hoeing	20 October
	NT	2 October 2013	-	21 May	-	21 May	-	20 October
IHO 2015	C	-	16 November 2014	-	18 May	21 May	-	13 October
	CT	-	16 November 2014	-	18 May	21 May	hoeing	13 October
	RT	2 October 2014	-	18 May	18 May	21 May	hoeing	13 October
	NT	2 October 2014	-	21 May	-	21 May	-	13 October

[a] No treatment; [b] three hoeing repetitions.

Figure 1. No-till soybean cultivation system. (**A**): cover crop rye and a roller-crimper. (**B**): Cover crop rye creating a uniform mulch layer after rolling-crimping. (**C**): Soybean emerging through the mulch layer. (**D**): Established soybean stand in the no-till system with cover crop residues underneath.

2.2. Data Collection

The percentage composition of bare (soil), cover crop residues (mulch), weeds, and soybean plants was visually estimated at three randomly selected locations within each plot by two experienced observers. In 2014, observations were done on six separate days at KH and on five days at IHO. In 2015, observations were done on three days measurements at both locations. In all cases, observations were made over a period of 60 days after sowing (DAS). Estimated relative values for soil cover are given in Figures 2 and 3.

All weed species were counted at ten weeks after sowing. This monitoring was performed within a 0.5-m^2 frame at three randomly located positions within each plot. The total number of weeds was separated in two different groups: the weeds that emerged before (PRE weeds) and after (POST weeds) soybean sowing (Figure 4). This grouping was based on the development stage of the weeds: PRE emergence weeds were assumed to be at shoot tillering (grass) or beyond the 12 leaf development (broad leaf) stages at the first measurement date, while the POST emergence weeds were before shoot tillering (grass) or maximum in the 8-leaf development stage (broad leaf). Plant density of soybeans was determined by counting plants in two rows four weeks after sowing in each plot. Soybean density was described as a percentage of the sowing density of 65 plants m^{-2}. Soybeans were harvested in mid-October using a plot harvester (Zürn 150, Westernhausen, Germany). Yield was reported based on a 14% water content.

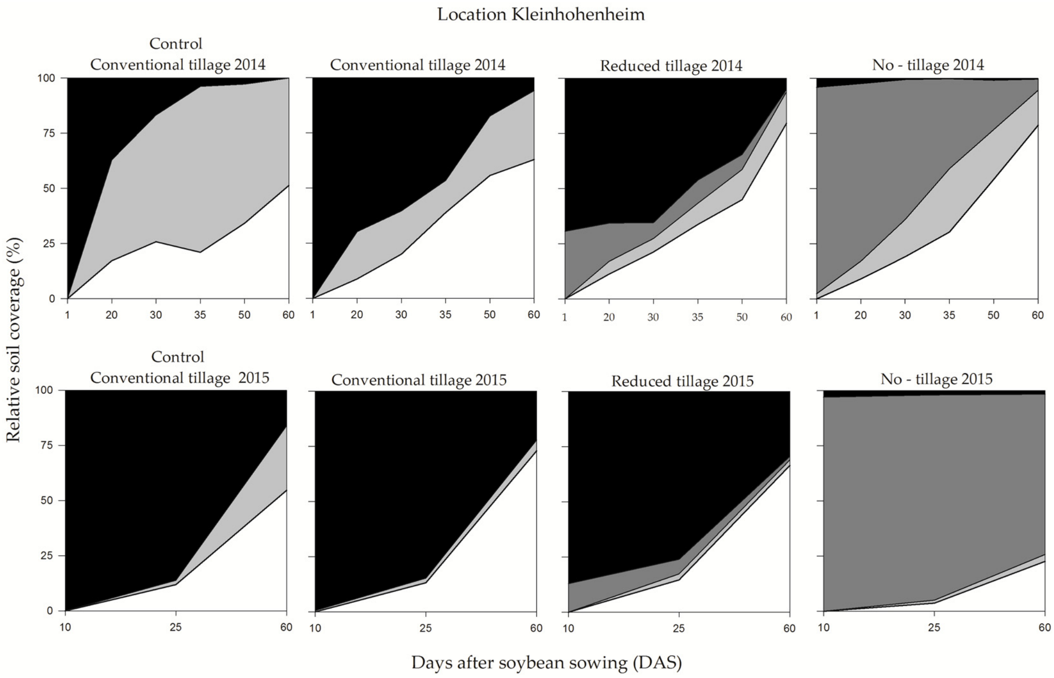

Figure 2. Mean relative soil cover of the total area of the four different treatments in percent at different days after soybean sowing at the location Kleinhohenheim in 2014 and 2015. Black = bare soil; grey = cover crop; light grey = weeds; and white = soybean.

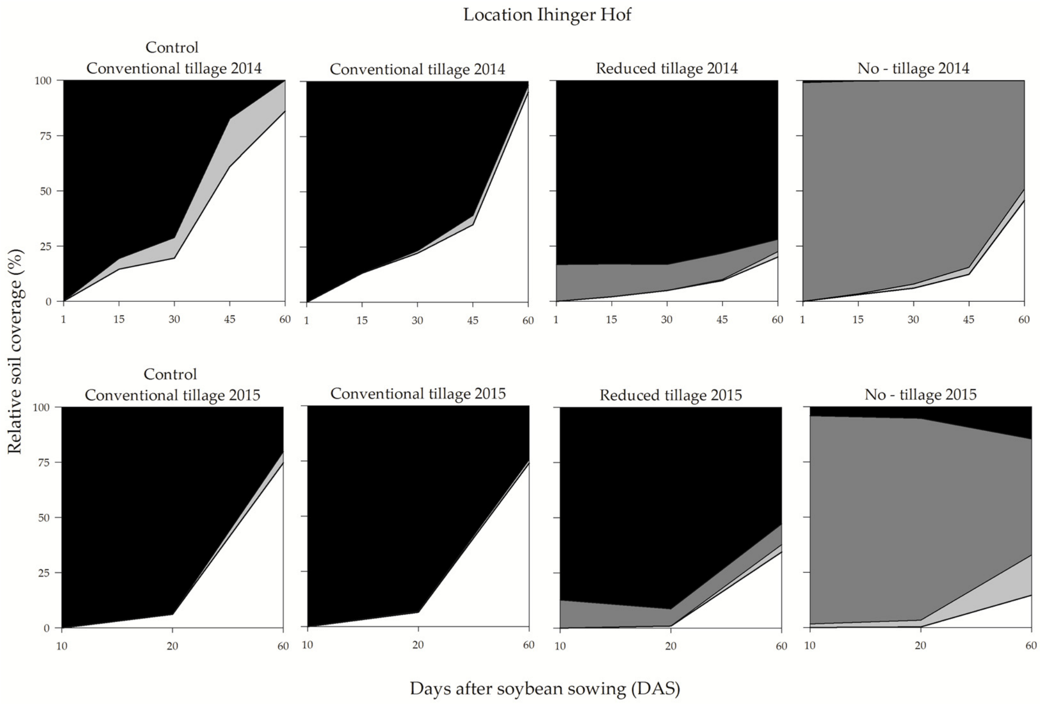

Figure 3. Relative soil coverage of the total area of the four different treatments in percent at different days after soybean sowing at the location Ihinger Hof in 2014 and 2015. Black = bare soil; grey = cover crop; light grey = weeds; and white = soybean.

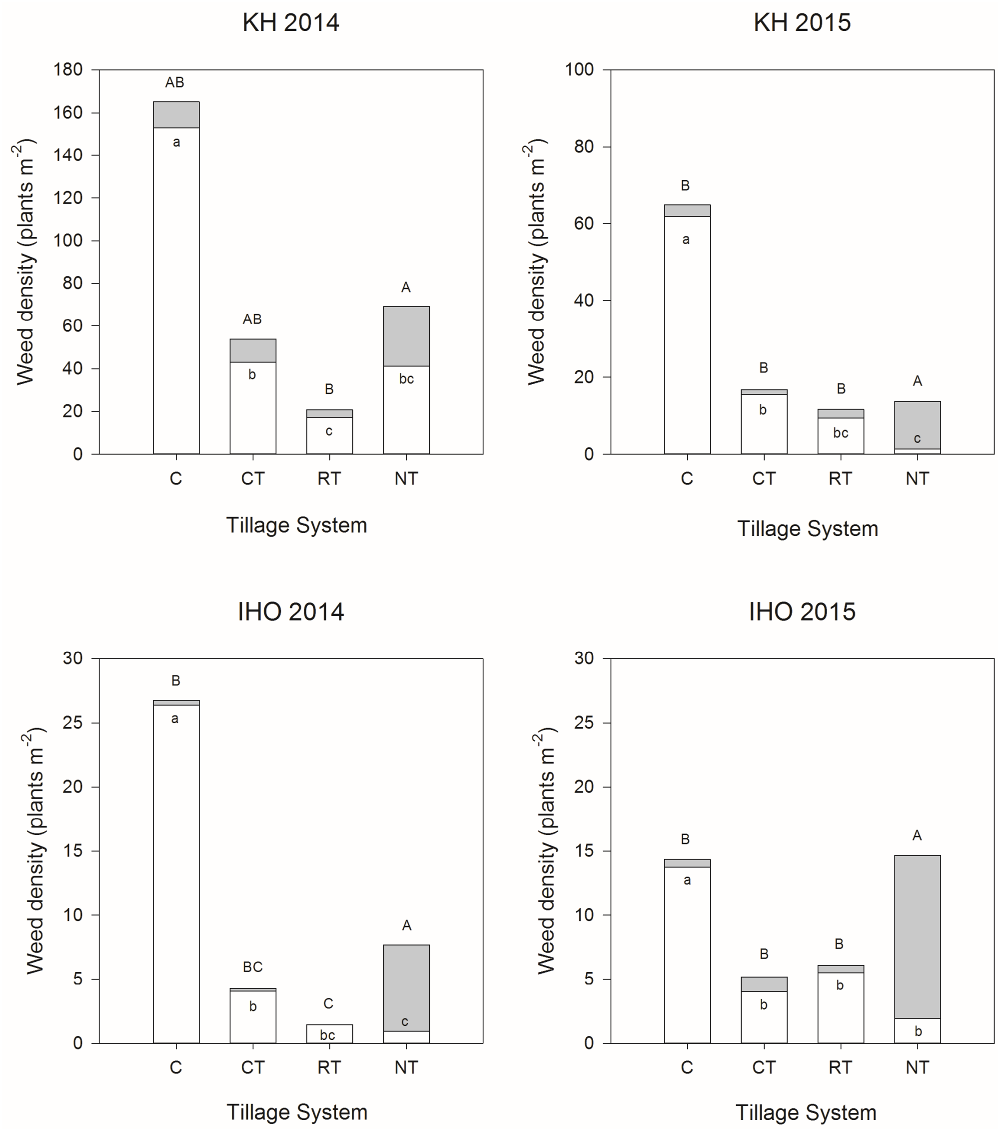

Figure 4. Weed density (plants m^{-2}) of four different treatments at Kleinhohenheim (KH) and Ihinger Hof (IHO) in 2014 and 2015. C = Control, CT = Conventional tillage, RT = Reduced tillage, and NT = No-till. The dark part of the columns represents weed emergence before (POST weeds) crop sowing (capital letters) and the white part of the graph represent weed emergence after (PRE weeds) soybean sowing (lowercase letters). Columns with the same letters do not differ according to the Tukey-HSD Test ($p \leq 0.05$).

2.3. Statistical Analysis

Analysis was performed using R Studio 0.99.491 (R Development Core Team, Vienna, Austria) [25]. A linear mixed model was used to evaluate the response of weed density (plants m^{-2}), soybean plant density (%), and crop yield (t ha^{-1}), to the examined systems. Data were visually checked for normal distribution and homogeneity and subjected to an ANOVA. Tillage systems and cover crops and all interactions between these variables were considered fixed effects [26]. Locations and replications and all interactions between these terms were considered random effects. The Tukey Honest Significant Difference Test (Tukey-HSD Test) was applied for testing the significant differences ($p \leq 0.05$).

3. Results and Discussion

3.1. Soil Cover

3.1.1. Trial Kleinhohenheim

One day after seeding (DAS), treatments C and CT resulted in similar bare soil proportions in 2014 (Figure 2). In treatments RT and NT, the pre-existing proportion of cover crop residues was estimated to be 31% and 94%, respectively. This corresponds to the definition for conservation tillage reported by Kassam et al. [27]. In the C treatment, the complete soil surface was covered either by weeds (49%) or the crop (51%). Soybean, weeds, bare soil, and mulch coverage in RT plots was 80%, 14%, 5%, and 1%, respectively. Soybean plant coverage of the soil surface was 79% in NT plots, with 16% for weeds and 5% for mulch at 60 DAS (Figure 2).

In 2015, the relative crop coverage was 55%, 73%, and 67% in C, CT, and RT treatments, respectively, at 60 DAS. Under RT, bare soil comprised 29% of the area. NT had the greatest amount of mulch coverage (72%) and a low amount of weed coverage (3%; Figure 2). Teasdale and Mohler [28] found a negative correlation between weed emergence rate and mulch coverage in NT systems due to reduced light stimuli. In their study, weed species were impacted differently by the amount of mulch, regardless of the cover crop species (e.g., *Amaranthus retroflexus* (L.) > *Chenopodium album* (L.) > *Setaria faberi* (Herrm.) > *Abutilon theophrasti* (Medik.)). Bilalis et al. [29] pointed out that with 60% mulch coverage, weed frequency, diversity, density, and dry matter were reduced. Nevertheless, Chauhan et al. [30] proposed that perennial weed species will be more challenging in RT and NT than CT systems, due to the lack of weed seed burial as occurs in tilled systems. Perennial weeds do not exhibit dormancy, nor are in need of a light impulse to germinate. Therefore, mechanical control methods like tillage can suppress them.

3.1.2. Trial Ihinger Hof

In 2014, mulch covered 17% and 99% of the soil surface at 1 DAS under RT and NT, respectively (Figure 3). By 60 DAS, soybean plants covered 86%, 95%, 20%, and 46% of the surface in C, CT, RT, and NT plots, respectively. In these treatments, weeds covered 14%, 3%, 2%, and 5% of the surface. In 2015, the greatest amount of mulch on 1 DAS was observed in the NT treatment with 94% of the soil surface covered. By 60 DAS, soybean plants covered 75%, 74%, 34%, and 15% of the surface under C, CT, RT, and NT, respectively. In 2015, the greatest amount of weed cover was under NT (18%; Figure 3) which can be explained by the low amount of cover crop biomass that year (Table 2). At IHO, cover crop biomass was reduced in 2015 compared to 2014 (Table 2), resulting in reduced mulch coverage. The amount of cover crop biomass can have an impact on the weed control efficiency due to the reduction of light and the quantity of allelopathic substances [17].

Table 2. Biomass yield of the cover crops in treatment RT and NT.

Biomass Yield			
Location	Year	Date	kg ha^{-1}
KH	2014	- [a]	-
	2015	18 May	8809
IHO	2014	16 May	7834
	2015	18 May	5883

[a] No data available.

3.2. Weed Density

Weed densities in the experiment at 64 DAS ranged from 1 to 165 plants m^{-2} (Figure 4). There were 14 different weed species identified, but the most abundant were *Chenopodium album* (L.), *Echinochloa crus-galli* (L.) P. Beauv., *Sonchus arvensis* (L.), *Matricaria inodora* (L.), and *Stellaria media* (L.) Vill.. According to Schroeder et al. [31], this weed species composition is typical for European soybean cropping conditions. The highest PRE weed densities of 28 and 12 plants m^{-2} were observed in NT at KH in 2014 and 2015, respectively. Hayden et al. [32] observed a weed reduction of 78% compared to an untreated control by using rye as a cover crop. A significantly lower PRE weed density was detected under C, CT, and RT (3, 1, and 2 plants m^{-2}, respectively) compared with NT at the same location in 2015 (Figure 4). Tillage can effectively control PRE emerged weeds [16]. In both years, at the IHO location, the NT treatment had significantly greater amounts of PRE weeds (7 and 12 plants m^{-2}), than other treatments (Figure 4). Since these PRE weeds were established prior to the soybean, they were highly competitive for water and nutrients.

Cover crops reduced POST weed density by a mean of 51 plants m^{-2} in NT treatments over both locations and years. At location KH, greatest density of POST weeds was observed in C plots with 153 plants m^{-2}. POST weed reduction (17 plants m^{-2}) was significantly less under RT compared to CT (43 plants m^{-2}) and C in 2014 (Figure 4). Conflicting results were found in a study by Buhler [11], where an increased number of perennial broadleaf weeds, summer annual grasses, biennial, and winter annual weed species were found under RT.

At IHO, the highest POST weed density was observed under C (26 and 14 plants m^{-2}) in 2014 and 2015. In the RT and CT treatments, an average weed density of 4 plants m^{-2} was found in both years (Figure 4). In these tillage systems, weed control was performed by hoeing and resulted in similar weed suppression to that found in a study by Kunz et al. [33]. In that study, three hoeing treatments were performed with a camera controlled hoe in soybean and sugar beet (*Beta vulgaris* subsp. *vulgaris*) under similar environmental conditions. Peachey et al. [34] described a reduced amount of POST weeds after the elimination of primary tillage. Froud-Williams et al. [35] and Shilling et al. [36] observed an increased emergence of annual broadleaf weeds after spring tillage. This is caused by light exposure [37] and the occurrence of different weed species in the upper soil layer [38].

In the NT treatment, greater POST weed control occurred in 2015 than in 2014 (Figure 4). Reberg-Horton et al. [39] observed that harvesting time and cultivars of rye influenced weed suppression because of different benzoxazinoid compounds. The results of Reberg-Horton et al. [39] showed that the cultivar 'Wheeler' resulted in the best weed control if the rye was harvested in March. In addition to cover crop cultivation, potential allelopathic substances could be introduced to the soil during active plant growth or by decomposition and leaching of rye biomass after treatment [40]. The cultivars and treatment dates were similar at both locations during 2014 and 2015 in our study. However, weed control efficacy of NT varied between years. Such effects are often correlated with the amount of cover crop biomass [19]. Conditions for weed emergence were more favorable due to reduced mulch soil coverage and less cover crop biomass in 2015 (Table 2). Mischler et al. [41] observed high weed control efficacy, similar to a post-emergence herbicide application, when using rye as cover crop mulch at Rock Springs and Landisville, PA, USA in 2007. Liebl et al. [9] presented similar results for a four-year study on soybeans and cover crops in Urbana, IL, USA.

A high number of PRE and POST weeds occurred in the NT system at both KH and IHO in our study, which can result in an increase of the weed seed bank. In NT systems, seeds will accumulate in the topsoil because they are not incorporated in deeper layers by tillage. The former can lead to a higher mortality risk of the seeds, due to predation and detrimental environmental conditions [16]. An increase of the weed seed bank could be expected in the NT treatments in our experiment due to the high weed infestation level. The KH and IHO locations had different weed densities, which can be explained by the cultivation history. The organically managed location KH had a higher weed density due to its history as an organic farm with no herbicide application in the previous 20 years. No herbicide applications occurred before or during the experiment at the IHO location, but there was a previous history of herbicide use.

3.3. Soybean Plant Density and Yield

In 2014, the soybean plant density ranged from 81% (C) to 99% (RT) across all treatments at KH. In 2015, fewer soybean plants were detected across all treatments compared to 2014. A higher soybean plant density occurred under RT (80%) than CT (64%), C (63%), and NT (59%; Table 3). At IHO, a higher soybean plant density occurred under C, CT, and NT compared to RT in 2014. In 2015, soybean plant density was similar under C and CT (82% and 80%), with relatively low plant densities under RT and NT (Table 3). A reduction of soybean plants was observed in RT and NT systems in research by Vyn et al. [42].

The higher soybean plant density at KH probably was due to more favorable seedbed conditions for germination and emergence. At IHO, with its clayey soils, the high moisture content during seeding resulted in clumpy soil aggregates. As a result, the seeding machine could create a furrow but was unable to cover all seed because of a lack in loose soil aggregates. Consequently, some seed in the furrow remained uncovered and failed to germinate and plant establishment was reduced at IHO. This may help explain the poor establishment in the NT treatment that was observed. In addition, cover crop mulch can be a physical barrier preventing the emergence of not only weed but also crop seedlings [22]. Nichols et al. [16] concluded that a reduced crop emergence rate can be caused by light limitations, a delayed increase of spring soil temperatures, and allelopathic effects caused by cover crop mulch in NT systems. Oplinger and Philbrook [43] recommended increasing the number of seeds ha^{-1} to compensate for the reduced crop emergence under RT and NT conditions.

A roller-crimper was used successfully to kill the cover crops in a NT system in previous research [21]. Using a roller-crimper to transform the preexisting cover crops into a mulch layer improved the weed suppression in the NT system, but did not help in crop establishment. Ashford et al. [21] described different benefits in terms of providing maximum soil coverage, thereby preventing erosion, decreasing soil water evaporation, and reducing weed density when using a roller-crimper. To optimize benefits when using this implement, higher driving speeds should be used and the roller should be filled with water to increase its weight. Derpsch et al. [44] reported that the roller-crimper has been used effectively on thousands of hectares in southern Brazil and Paraguay. Despite these promising results, in our trial, after roller-crimper application, the sowing machine was unable to drill seed effectively through the thick mulch layer produced by the cover crops.

At KH, higher soybean yields in the CT (1.92 t ha^{-1} and 1.98 t ha^{-1}) and RT treatment (2.19 t ha^{-1} and 2.35 t ha^{-1}) were observed compared to the untreated control (0.49 t ha^{-1} and 0.92 t ha^{-1}) in 2014 and 2015 (Table 3). A higher soybean yield occurred under NT in 2014 compared to 2015 (1.64 t ha^{-1} and 0.66 t ha^{-1}, respectively), which can be explained by a higher plant density in 2014 (+25%) compared to 2015. At IHO, soybean yields in treatment C (1.76 t ha^{-1}) and CT (2.05 t ha^{-1}) were higher compared to RT plots (0.41 t ha^{-1}) in 2014, and higher soybean yields occurred under C (1.61 t ha^{-1}), CT (1.92 t ha^{-1}), and RT (1.10 t ha^{-1}) compared with NT (0.26 t ha^{-1}) in 2015 (Table 3). Compared to a CT system, soybean yield losses of about 20% occurred when using rolled rye as a cover crop in a NT system in a three-year field study [45]. The yield depression under NT reported by Davis [45] was explained by a reduced soil water content after the cover crop vegetation period. Our results, as well as those of Davis [45], are contrary to Smith et al. [18], who observed no negative yield effects in soybean when using rye as cover crop in a NT soybean system. As expected, the precipitation pattern and resultant soil water availability seem to be crucial factors in determining the yield level of a cover crop based no-till organic soybean systems. In addition, plant density in NT and RT should be increased to ensure similar yields to CT [17]. Despite these difficulties, NT can improve the sustainability of organic soybean production by reducing fuel and labor costs [46], while simultaneously improving the soil quality parameters and reducing the risk of erosion [8,9].

Table 3. Soybean plant density (%) and yield (t ha^{-1}) of the four different treatments at the location Kleinhohenheim (KH) and Ihinger Hof (IHO) in 2014 and 2015. Means with the same letter are not statistically different (Tukey-HSD Test ($p \leq 0.05$)).

	Plant Density (%) [a]				**Yield (t ha^{-1})**			
	KH		IHO		KH		IHO	
Treatments	2014	2015	2014	2015	2014	2015	2014	2015
Control	81.0 b	62.5 b	78.2 a	81.9 a	0.49 c	0.92 b	1.76 ab	1.61 ab
Conventional tillage	93.5 ab	64.4 b	90.4 a	80.4 a	1.92 ab	1.98 a	2.05 a	1.92 a
Reduced tillage	98.8 a	79.7 a	57.5 b	43.9 b	2.19 a	2.35 a	0.41 c	1.10 b
No-tillage	83.9 b	59.2 b	72.9 a	41.0 b	1.64 b	0.66 b	1.65 b	0.26 c

[a] Plant density in percentage based on aimed sown plant density (100%).

4. Conclusions

The use of cover crops like rye and barley can be successful for weed suppression and maintenance of soil quality. Our study demonstrated a reduced weed density of up to 79% when using rye or barley as cover crops. The roller-crimper used in this study was able to transform cover crops into a uniform mulch layer, but soybean yield under NT was reduced compared to the CT system. Soybean yield was highest under CT (at IHO) and RT (at KH) but additional weed control treatments were applied by using a hoe two to three times during the growing season. The lower yield levels in the NT system mainly resulted from poor plant emergence connected to technical problems at seeding. In Germany, currently available NT seeding machines are not suitable for cropping systems that use thick mulch layers for weed suppression, as exists in organic NT systems. Therefore, a task for agriculture engineers is to design new seeding equipment with sufficient downward pressure from disc openers and a precise seed furrow-closing mechanism for use in high-residue, cover crop mulch seedbeds. Future NT studies are needed that include this improved equipment design to demonstrate that high soybean plant density and higher yields can be produced in organic NT systems.

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Conflicts of Interest: The authors declare no conflict of interest.

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