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Weed Suppression and Early Sugar Beet Development under Different Cover Crop Mulches

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Abstract

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Field experiments were conducted at two locations in 2014–2015 and 2015–2016 to investigate the weed suppressive ability of cover crop mulches in sugar beets. Three cover crops and two cover crop mixtures were tested in all four experiments. Weed densities ranged from 2 up to 210 plants/m^2 in *Chenopodium album* L. and *Stellaria media* (L.) Vill. as predominant species. *Sinapis alba* grew significantly faster than *Vicia sativa*, *Raphanus sativus* var. *niger*, and both cover crop mixtures. *Sinapis alba*, *Vicia sativa*, *Raphanus sativus* var. *niger* reduced weed density by 57, 22, and 15% across all locations, respectively. A mixture of seven different cover crops reduced weed emergence by 64% compared to the control plot without cover crop mulch. Early sugar beet growth was enhanced by all mulch treatments in 2015 and decelerated in 2016.

Keywords: *Beta vulgaris* L.; *Chenopodium album* L.; conservation tillage; cover crop mixture; integrated weed management; intercropping; *Stellaria media* (L.)

Cover cropping has become an important component of Integrated Weed Management (IWM) in sugar beet production. Conservation agriculture facilitates a persistent soil cover with plant mulches by different cover crop mulches (Kassam *et al.* 2009). Based on EU directives (EU No 1307/2013), farmers are asked to comply with specific regulations. Within these regulations the increase of biodiversity is financially encouraged, therefore using cover crop mixtures for weed suppression can provide an economic benefit to the farmer. Moreover, there are several benefits of producing sugar beets in cover crop mulch systems. Cover crop mulches provide the possibility of reducing wind and water erosion (De Baets *et al.* 2011), the improvement of soil fertility and crop performance (Teasdale 1996) plus the potential for carbon sequestration (Freibauer *et al.* 2004). Furthermore, cover crops are able to suppress weeds during their growth period in autumn by competition for water, light, space and nutrients (Brust *et al.* 2014; Kunz *et al.* 2016) and as mulch in spring (Campiglia *et al.* 2015). Additionally, several cover crops suppress weeds due to biochemical effects by releasing allelopathic substances into the environment (Kelton *et al.* 2012; Kunz *et al.* 2016). Biochemical as well as physical weed control approaches should be utilised to minimise the use of chemical inputs in order to comply with the principles of IWM (Doyle 1997). Only a few studies have shown the weed suppression effect as a result of the mulch of cover crops (Schilling 1995; Petersen & Röver 2004) and especially cover crop mixtures in sugar beets so far. The aim of this study was to combine the cover crop effect on weed suppression and crop emergence of sugar beet plants.

The objectives of this study were to analyse: (*i*) if cover crop mixtures (CCM) compared to the monocultivation of cover crop species (MC) result in faster cover crop emergence and higher soil coverage, while providing higher mulch biomass yields in spring and (*ii*) if there is a difference in sugar beet emergence between different cover crop mulches. We further

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investigated (*iii*) if cover crop mulches suppressed weed seedling emergence in sugar beet.

MATERIAL AND METHODS

Cover crop experiment. Three cover crop experiments were performed at Hohenheim (HOH) (48.71°N, 9.19°E, 370 a.s.l.) in 2014–2015, Bretzfeld-Weißlenburg (BW) (49.20°N, 9.42°E, 210 a.s.l.) in 2015, and Renningen (RE) (48.74°N, 8.92°E, 478 a.s.l.) in 2014–2015 and 2015–2016. All experiments were designed as a randomised complete block design with four replicates and a plot size of 30 m^2 (3 × 10 m). Different cultivation procedures, weather conditions during the experimental period and information about soil types are illustrated in Table 1. Winter cereals were grown before the cover crops were sown (Table 2). Soil coverage was recorded after sowing every seven days with a common RGB camera in an area of 12 m^2 in each treatment up to 50 days after sowing (DAS). Images were analysed with ImageJ 1.47v. For the determination of the mulch dry matter directly before sugar beet sowing, the mulch was collected in an area of 0.5 m^2 at three random positions in each plot, cleaned with water and afterwards dried at 90°C for 48 hours.

Cover crop mulch experiment. At HOH and RE locations, sugar beets were sown in the following year after cover crop cultivation. At BW location, the seeding of sugar beets was not executed due to detrimental weather conditions. At HOH location, conservation tillage was conducted in the whole field with shallow soil cultivation (rotary harrow; Rau, Brigachtal, Germany) to a depth of 5 cm. At RE location, soil cultivation was performed with a Horsch Focus TD (HORSCH Maschinen GmbH, Schwandorf, Germany) on frozen ground in a small strip (15 cm) to a depth of 17 cm during the winter season. The distance of the strips was 50 cm. Sugar beet cv. Hannibal with 107 000 seeds/ha was sown to a depth of 3 cm with a row distance of 0.5 m between March and April (Table 1). Prior to sugar beet emergence 120 kg N, 62 kg S, and 0.8 kg B/ha were applied as ammonium-sulphate-nitrate with boron (ass®bor®) across all locations.

In order to estimate the weed suppressive ability of the mulch during the sugar beet vegetation period, weed density was counted three times within each plot prior to all herbicide treatments using a 0.1 m^2 frame. Mulch soil coverage was visually estimated at three randomly located positions within each plot using a frame (0.5 m × 0.5 m) three days after sowing. Two sugar beet rows per plot were counted daily for the evaluation of sugar beet emergence over a period of two weeks on the total plot length.

Statistical analysis. All data were analysed using ANOVA with R version 3.0.2 (R Core Team 2014). Means were separated using Tukey's HSD test at a 95% level of probability, if the ANOVA *F*-test showed significant differences at 95% probability levels. To evaluate the cover crop effect on sugar beet emergence, data was fitted by a three-parameter logistic model (Ritz & Streibig 2005). To evaluate cover crop emergence, T_{50} parameters were used which represent the required time for 50% of maximum emergence.

RESULTS

Cover crop coverage of soil. At HOH, BW, and RE locations (2015), the noteworthy mean canopy cover-

Table 1. Description of cultivation and environmental conditions at the trial sites

	Hohenheim 2014/2015	Bretzfeld-Weißlenburg 2014	Renningen 2014/2015	Renningen 2015/2016
Mean precipitation (mm)	659	777	804	804
Mean temperature (°C)	10.1	10.7	9.5	9.5
Harvest of cereals (before cover crop sowing)	(2014-August 3)	(2015-July 27)	(2014-August 17)	(2015-July 28)
Soil preparation details	mouldboard plough (20 cm)	stubble cultivator (10 cm)	stubble cultivator (5 cm)	stubble cultivator (5 cm)
Soil type	loam, subsoil clay	loam	silty loam	loam, subsoil clay
pH value/organic matter (%)	5.9/2.1	7.0/3.4	6.3/5.0	7.0/2.1
Cover crop sowing (date)	(2014-August 23)	(2014-August 27)	(2014-August 20)	(2015-August 21)
Sugar beet sowing (date)	(2015-March 18)	no sugar beet sowing	(2015-April 10)	(2016-April 11)

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Table 2. Weight proportion, sowing rate and 1000-seed weight of the evaluated cover crop treatments of four experiments (Hohenheim, Bretzfeld-Weißlenburg, and Renningen)

Cover crops	Weight proportion (%)	Sowing rate (kg/ha)	1000-seed weight (g)
Untreated control	–	–	–
Sinapis alba L.	100	15–18	5.5
Raphanus sativus var. *niger* J. Kern	100	8	21
Vicia sativa L.	100	85–120	70
Mixture 1 (CCM1)	–	37	–
Vicia sativa L.	43	–	70
Avena strigosa Schreb.	22.5	–	16
Raphanus sativus var. *niger* J. Kern	25.5	–	5.5
Trifolium alexandrinum L.	6	–	3
Guizotia abyssinica (L.f.) Cass.	3	–	2.5
Mixture 2 (CCM2)	–	40–42	–
Vicia sativa L.	25	–	70
Pisum sativum L.	24	–	160
Lupinus angustifolius L.	18	–	150
Avena strigosa Schreb.	13	–	16
Trifolium alexandrinum L.	10	–	3
Phacelia tanacetifolia Benth.	6	–	2
Guizotia abyssinica (L.f.) Cass.	4	–	2.5

age of soil in *S. alba* (11%) was observed compared to *R. sativus* var. *niger* (6%), *V. sativa* (5%), CCM1 (6%), and CCM2 (5%) at two weeks after sowing (Figure 1). At RE location (2014), the highest cover crop coverage was observed for treatment CCM2 at 14, 19, 35, and 43 DAS. At HOH location, *V. sativa* resulted in the highest cover crop coverage with 78% as well as at RE location (2015) with 57% at 50 DAS. At BW location, *S. alba* showed the highest cover crop coverage of soil across all measurement days with 78% at 50 DAS.

Sugar beet emergence. At HOH location, no statistical differences in sugar beet emergence were found across all treatments (Table 3). At RE location, sugar beets showed the fastest emergence for CCM1 mulch at 11.1 DAS in 2015. A delayed emergence was found in the non-mulched treatment (12.4 DAS) compared to the other mulch treatments. In 2016 sugar beets in the treatment with *V. sativa* mulch revealed the fastest sugar beet emergence (12.8 DAS).

Mulch biomass, mulch coverage and weed suppression. The highest mulch biomass was observed at HOH location (Figure 2). Mean mulch biomass was 189 g/m^2 across all treatments and locations with the highest average mulch were observed in *S. alba* treatment (244 g/m^2).

Table 3. The required time for 50% of maximum emergence in days after sowing (T_{50}) parameters for the emergence of sugar beets in cover crop mulch at Hohenheim (2015) and Renningen in 2015 and 2016

Treatments	Hohenheim 2015		Renningen 2015		Renningen 2016	
	T_{50}	STE	T_{50}	STE	T_{50}	STE
No mulch	20.0^a	0.26	12.4^a	0.25	13.7^c	0.20
Sinapis alba L.	19.7^a	0.22	11.4^c	0.14	13.0^{ab}	0.15
Raphanus sativus var. *niger* J. Kern	19.0^a	0.24	11.5^{bc}	0.14	13.5^c	0.16
Vicia sativa L.	19.6^a	0.21	11.9^{ab}	0.17	12.8^a	0.12
CCM 1	19.6^a	0.25	11.1^c	0.15	13.5^c	0.16
CCM 2	20.0^a	0.24	11.2^c	0.14	12.9^a	0.12

CCM – cover crop mixtures; means with identical letters do not differ significantly ($P \leq 0.05$)

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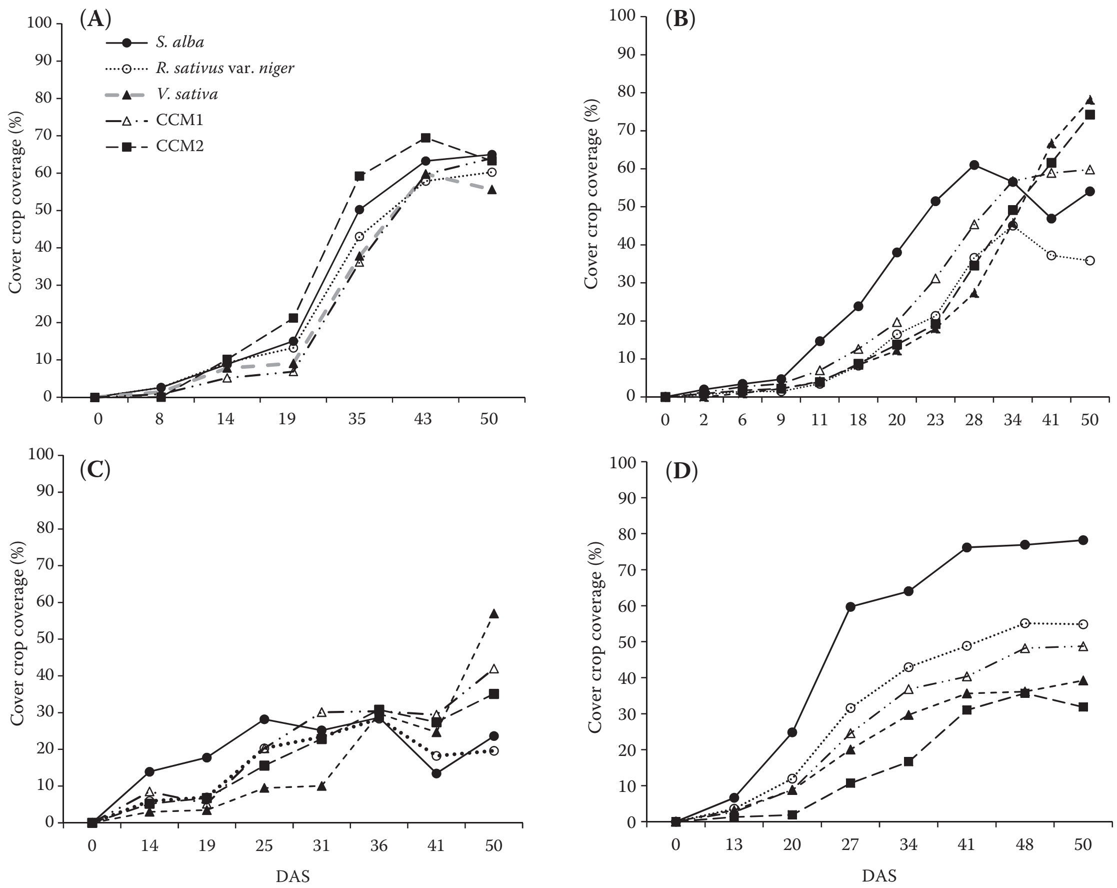

Figure 1. Soil coverage of cover crops over a period of 50 days after sowing (DAS) at Renningen in 2014 (**A**) and 2015 (**B**), at Hohenheim in 2014 (**C**), and at Bretzfeld in 2015 (**D**)

Mean mulch coverage of soil was highest in CCM2 treatment (37%) by cover crop mulches across all locations (Figure 3). The lowest mean mulch coverage of soil was recorded for the treatment with *R. sativus* var. *niger* (19%). At HOH location, a minimum level of mulch (2%) was found in this treatment.

At HOH and RE locations, seven weed species were found out (Figure 4) including *Chenopodium album* L., *Stellaria media* (L.) Vill., *Veronica persica* Poir., and volunteer wheat. Prior to herbicide application, the highest weed density (210 plants/m^2 at HOH, 194 plants/m^2 at RE 2015) was found in the non-mulched control at HOH and RE locations (2015). At HOH location, differences between cover crop treatments were insignificant before the herbicide application was performed. Significant differences of treatments *S. alba*, *R. sativus* var. *niger*, CCM1 and CCM2 from the non-mulched control were found at HOH location. Mean weed suppression compared to the non-mulched control was 54% in the MC mulch and 60% in the CCM mulch at HOH location. At RE location (2015), significant differences were observed in CCM2 mulch treatment, which reduced weed density in sugar beet up to 66% compared to the non-mulched control. In 2016 at the same location, the highest weed density was measured in *V. sativa* treatment with 16 plants/m^2. The best weed suppression was observed in *S. alba* treatment with 83% less weeds compared to the non-mulched control.

DISCUSSION

Across all locations and years, we observed a rapid cover crop development for *S. alba* which is strongly correlated with an early light interception (Kruidhof *et al.* 2008) and might result in a high weed suppression in autumn. De Baets *et al.* (2011) found the fastest cover crop development in the early growing period also for *S. alba*. Moreover, different environmental factors, e.g. seed bed preparation, seed rates, temperatures, bulk density, can influence the cover crop emergence and canopy development time (Teasdale 1996; Koch *et al.* 2009). Due to the fast

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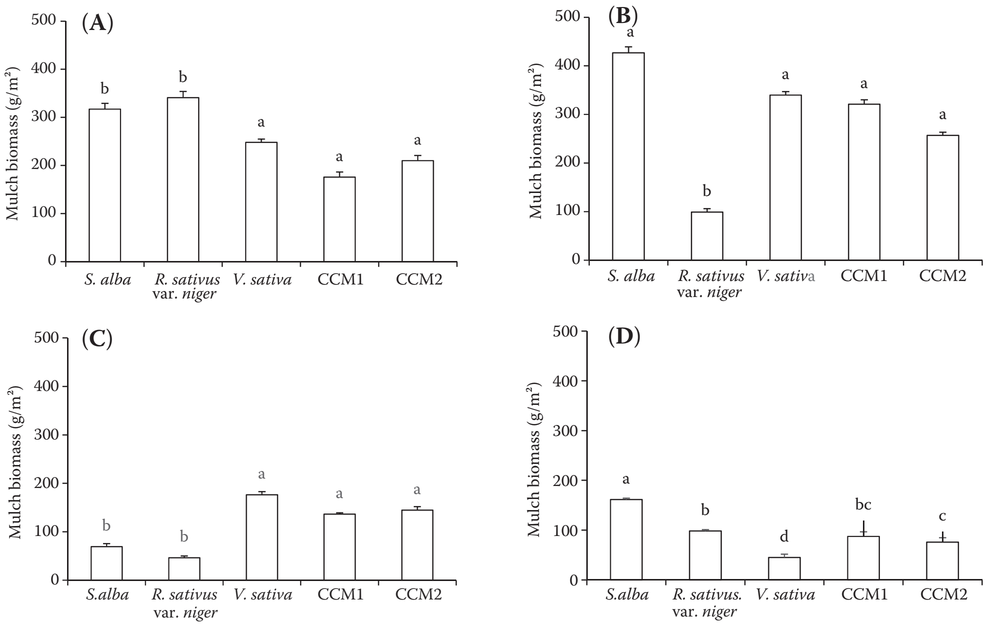

Figure 2. Average dry matter of cover crop mulch 14 days before sugar beet sowing and 7 days before seed bed preparation across all locations: (**A**) Renningen 2015, (**B**) Hohenheim 2015, (**C**) Renningen 2016, and at (**D**) Bretzfeld 2016

Means with identical letters in the graph do not significantly differ, based on Tukey's HSD test ($P \leq 0.05$)

flowering of *S. alba*, the reduced cover crop coverage of soil occurred at HOH and RE (2015) at the end of the vegetation period. In the study of Kruidhof *et al.* (2008) *R. sativus* showed the strongest competitive ability by reducing weed dry matter in autumn due to the fast canopy closure. The low soil coverage of single cover crop species can be compensated by using a mixture of different cover crop grades.

In our study, *S. alba* provided the highest mulch biomass across all locations, which is necessary for sufficiently shading mulch coverage and consequently effective weed suppression. This contrasts with RE location (2015), where the high biomass of *R. sativus* var. *niger* with a low weed control efficacy was found. The results indicate that the mulch coverage of soil can be an important factor for the successful weed control. The mulch of CCM and MC achieved a more effective weed suppression compared to the non-mulched control. We suggest that *S. alba* treatments resulted in a reduced proportion of weeds due to the high mulch biomass and soil coverage. Teasdale and Mohler (1993) reported that the mulch dry matter of 600 g/m^2 at least provides a sufficient weed control efficacy within the field. In our study, we revealed effective weed suppression with lower mulch biomass (188 g/m^2) across all locations with up to 83%. Biomass yields are expected to be lower, due to the EU directives (EU No 1307/2013) which ban the use of synthetic fertilizers in cover crops. Furthermore, Bilalis *et al.* (2003) described reduced weed density, dry matter, frequency and diversity after the appearance of high mulch coverage. The difference in the mulch coverage

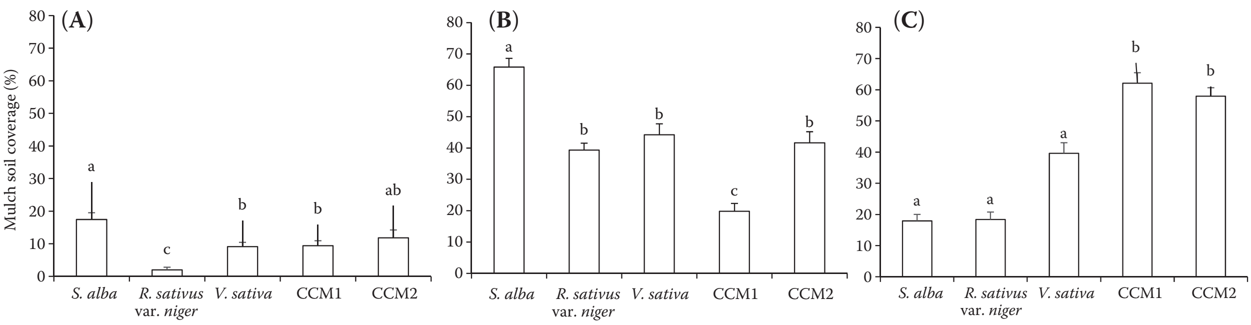

Figure 3. Coverage (%) of cover crop mulches measured three days after sugar beet sowing

Means with identical letters in the graph do not significantly differ, based on Tukey's HSD test ($P \leq 0.05$)

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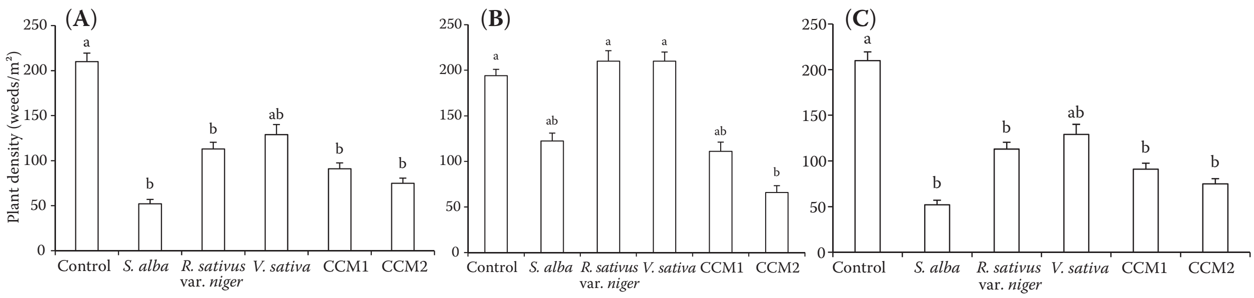

Figure 4. Weed density prior to herbicide application in sugar beet at locations (A) Hohenheim in 2015, (**B**) Renningen in 2015, and (**C**) Renningen in 2016

Means with identical letters in the Table 3 do not significantly differ, based on Tukey's HSD test ($P \leq 0.05$)

of soil in *R. sativus* var. *niger* treatment can be explained by (a) different cropping systems at locations HOH and RE. At RE location (2015), strip tillage delivers a higher amount of mulch, while *R. sativus* var. *niger* mulch was heavily reduced after soil cultivation before crop emergence. Furthermore, (b) biomass yield was three times higher in this specific treatment at RE location (2015) compared to HOH.

After sugar beet seeding in 2015, pre-existing dry soil conditions were given. Buhler *et al.* (1996) described the importance of sufficient soil moisture for crop germination. We achieved faster sugar beet emergence with the mulch layer across two locations in 2015. Therefore, the mulch retained soil water and contributed to a faster and higher emergence rate. Stoller and Wax (1973) expounded the importance of soil moisture as the primary responsible factor for crop emergence. However, some studies demonstrated delayed emergence of maize, which was attributed to lower soil temperatures due to high mulch rates on the soil surface (Willis *et al.* 1957; Unger 1978). Morris *et al.* (2009) mentioned that using a mulch system in sugar beet could result in a better crop establishment compared to a conventional ploughing system. Nevertheless, potential challenges, e.g. an increase of slug populations or complicated seed placement due to the unfavourable soil structure, can appear with high levels of mulch.

CONCLUSION

Successful cover crop management strategies in conservation sugar beet production result in competitive weed suppression effects in spring up to 83%. CCM and MC reduced the mean weed density by 56 and 31%, respectively. CCM can compensate potential deficiencies during the growing period due to the higher elasticity and ability of recovery and therefore the higher weed suppression might be an increased competitive and biochemical impact of several plant species. This can reduce the herbicide input in sugar beet cropping systems. Nevertheless, such a weed density still requires a standard herbicide application. Therefore, a combination with other chemical and mechanical approaches is needed for the weed control efficacy. Our findings suggest that cover crop mulch layers can substantially affect the amount of weeds within the field and play a major role in IWM systems.

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