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Do cover crop sowing date and fertilization affect field weed suppression?

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ABSTRACT

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The weed suppressive ability of oilseed radish (*Raphanus sativus* var. *oleiformis* Pers.) cover crop is attributed to high competitiveness for resources and biochemical effects on weeds. The oilseed radish cover crop was sown in five treatments plus an untreated control over a period of five weeks before and three weeks after winter wheat harvest. Additionally, fertilization effects on oilseed radish biomass and weed suppression were measured. The highest biomass of the cover crop was observed 12 weeks after harvest (WAH) when the oilseed radish was sown one week after harvest (1 WAH) (2015) and five weeks before harvest (5 WBH) (2016). No differences of fertilization were observed concerning oilseed radish and weed biomass in 2015, whereby increased biomass was found after fertilization in 2016. The highest weed control efficacy of up to 83% and 90% was achieved in treatments 1 WAH (2015) and 5 WBH (2016) at 12 WAH. The early sowing of oilseed radish in winter wheat resulted in low germination and biomass yield within the field, due to low precipitation in 2015. Nevertheless, there is a high potential of early sown oilseed radish for higher weed control efficacy, which was demonstrated in 2016.

Keywords: allelopathy; Brassicaceae; intercropping; cropping system; competition; weed density

Cover crop cultivation has become a common practice across conventional and organic cropping systems (Bond and Grundy 2001, Hartwig and Ammon 2002). Cover crops, to exemplify, deliver several ecological benefits as erosion control (Liebmann and Davis 2000), nutrient recycling (Hu et al. 1997), increase of soil fertility (Hartwig and Ammon 2002) and effective weed suppression within the field (Kunz et al. 2016). Cover crops weed suppressive ability is caused by competition for resources as light, water, space and nutrients (Rueda-Ayala et al. 2015). The family of Brassicaceae, including oilseed radish (*Raphanus sativus* var. *oleiformis* Pers.), is well documented for high allelopathic effects on weed germination and growth in controlled environments (Haramoto and Gallandt 2004) and within the field (Haramoto and Gallandt 2005). Brassicaceae tissues contain high content of glucosinolates which can be enzymatically hydrolyzed to active compounds as isothiocyanates, ionic thiocyanates and organic cyanates (Petersen et al. 2001, Haramoto and Gallandt 2004). An optimum sowing date of brassicaceous cover crops can be decisive for an effective weed control efficacy, due to decreasing glucosinolate concentrations in the plant tissue from germination to plant growth (Clossais-Besnard and Larher 1991). Furthermore, a delayed cover crop sowing date can provide a decreased weed suppression, due to lower cover crop nitrogen accumulation and biomass production (Vos and Van der Putten 1997, Anugroho et al. 2009). A vegetation period extension of 3 and 6 weeks increased cover crop biomass by 268% and 821% (Vos and Van der Putten

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1997). Moreover, the weed control efficacy was improved by 28% by extending the growth period by about 8 weeks (Anugroho et al. 2009). Cover crop fertilization can increase its biomass and achieve an enhanced weed control efficacy (Reiter et al. 2008). Vos and Van der Putten (1997) reported an increased *Brassica* ssp. cover crop biomass and nitrogen accumulation up to 60% and 124% after nitrogen fertilization. Additionally, nitrogen fertilization may increase biochemical weed suppression due to higher glucosinolate production (Gustine and Jung 1985). Yet, there is a lack of research concerning the performance of coated oilseed radish seeds and the effective prolongation of the vegetation period linked with a higher field weed suppression. Moreover, the optimum seeding time of cover crops is still undetermined.

The aim of this two-year field experiment was to investigate the weed suppressive ability of *Raphanus sativus* var. *oleiformis* as a cover crop at five different sowing dates. The study investigated the optimum sowing date to enhance the weed control efficacy within the field. Furthermore, the performance of coated oilseed radish seeds concerning their suitability to weed suppression was tested. Additionally, the influence of fertilization on cover crop and weed growth was measured. In order to achieve the above-mentioned goals, the following hypotheses were investigated: (i) Early sown oilseed radish cover crop suppresses weed biomass and density more effectively, compared to conventional sown oilseed radish; (ii) cover crop fertilization increases oilseed radish biomass and consequently leads to reduced weeds, and (iii) an optimum sowing date of oilseed radish can be established for an optimum weed control during yearly changing weather conditions.

MATERIAL AND METHODS

Experimental set-up and meteorological conditions. The experiments were carried out over a 2-year period (2015 and 2016) at the Ihinger Hof location (48.74°N, 8.92°E, 475 m a.s.l.) of the Hohenheim University in southern Germany. The soil type was classified as a loam on subsoil clay. Soil tests indicated 2.3% organic matter and pH-value of 7.5.

The yearly average air temperature was 10.1°C in 2015 and 9.1°C in 2016. The average air temperature during the experiments (July–November) was generally higher in 2015 (13.8°C) compared to 2016 (12.8°C) (Table 1). Annual precipitation total was 545 mm and 647 mm in 2015 and 2016, respectively. The total precipitation across the experimental period varied between 2015 (226 mm) and 2016 (247 mm). The water balance ($\Delta\Theta$) was calculated as: $\Delta\Theta = P - ET - S$ and describes the changes of the soil water content, where P is the precipitation, ET is the evapotranspiration and S is the streamflow (Stahr et al. 2016). The monthly water balance tended to be higher during the cover crop vegetation period in 2015. The low water balance and high precipitation, from July–August in 2016, is an indicator of a very heterogenic distribution of the precipitations with water losses due to high evapotranspiration and/or streamflow.

In the previous years, winter wheat cv. Pamier was cultivated with 190 kg N/ha and 300 g, 100 g and 0.8 L of the herbicides Atlantis WG (5.6 g/kg Iodosulfuron, 29.2 g/kg Mesosulfuron), Alliance (57.8 g/kg Metsulfuron, 600 g/kg Diflufenican) and Tomigan 200 (200 g/L Fluroxpyr) were applied in mixture in spring. The winter wheat was harvested (CR960, New Holland, Heilbronn, Germany) at the 3rd (2015) and 10th (2016) of August. The winter

Table 1. Meteorological data of the monthly average temperatures (°C), monthly precipitation totals (mm) and the water balance (mm) at the Ihinger Hof experimental station in 2015 and 2016

Year	Month	Temperature	Precipitation	Water balance
2015	May	13.0	67.7	20.9
	June	16.5	75.2	29.3
	July	20.8	28.9	–46.9
	August	20.0	75.0	14.2
	September	12.6	36.0	–5.1
	October	8.4	16.0	–9.2
	November	7.2	69.5	38.5
	December	6.1	18.7	–3.9
2016	May	12.2	88.0	0.3
	June	16.1	108.3	13.5
	July	18.5	64.8	–50.8
	August	18.0	29.3	–78.2
	September	16.2	50.6	–25.9
	October	7.9	53.3	26.4
	November	3.5	48.7	36.4
	December	0.6	5.0	–0.8

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wheat straw was chopped by the harvester and left on the field. Experimental treatments were: (i) five different sowing dates of oilseed radish cover crop (Table 2) and (ii) two levels of nitrogen fertilization (0 and 45 kg N/ha). The experiments were arranged in a randomized complete block design replicated four times with a plot size of 30 m^2.

For the two treatments, where oilseed radish was sown before the winter wheat harvest (3 WBH and 5 WBH), oilseed radish cv. Farmer was sown in the pre-existing winter wheat crop with 25 kg/ha of coated seeds (149 seeds/m^2) (Feldsaaten Freudenberger, Krefeld, Germany) with a pneumatic fertilizer spreader (Aero, Rauch Landmaschinen GmbH, Sinzheim, Germany). The oilseed radish coat consisted of different layers containing humic acid, lime, plant strengthening agents and protection layers. Coated oilseed radish seeds were developed to allow an optimum cover crop emergence and growth. The increased seed weight compared to conventional seeds allows an increased flight distance and more homogeneous sowing, while sowing with a pneumatic fertilizer. The included humic acids, plant strengthening agents (Biplantol®), lime for the pH regulation and the increased water storage can improve the oilseed radish germination and development. For treatments sown at harvest (H), one (1 WAH) and three (3 WAH) weeks after harvest, a flat stubble cultivation (4 cm) (Dyna Drive, Bomford, Worcestershire, UK) was performed prior to sowing. Then uncoated oilseed radish cv. Farmer was sown in 2 cm depth with 25 kg seeds/ha (198 seeds/m^2) with a pneumatic sowing machine (D82, Agrarmarkt Deppe GmbH, Bad Lauterberg, Germany). Calcium-ammonium-nitrate (27% N, 2% S) fertilizer was applied in half of the plots (Aero, Rauch Landmaschinen GmbH, Sinzheim, Germany) at cover crop sowing dates with 45 kg N/ha (N45). Two controls with no cover crop sowing (NCC) and fertilization (N0) were included.

Predominant weed species were *Alopecurus myosuroides* Huds. (11% and 16%), *Veronica persica* Poir. (14% and 18%), *Matricaria chamomilla* L. (8% and 10%), *Lamium purpureum* L. (24% and 2%), *Galium aparine* L. (10% and 5%) and volunteer wheat (31% and 46%) in the untreated controls in 2015 and 2016, respectively. Cover crop and weed biomass were measured by harvesting two 0.25 m^2 quadrats within each plot at 7 WAH and 12 WAH. Collected biomass was washed and dried in a drying chamber at 80°C for 48 h. The reductions of weed density, cover crop and weed dry biomass were calculated, relative to the untreated control.

Data analysis. In order to evaluate the effect of the experiment, a linear mixed effect model was used. The analysis was performed with the statistic program R version 3.0.2 (R Core Team 2016). Years, replications (nested within years) and all interactions between these variables were considered as random effects. Considering years as environmental or random effects permits conclusions about treatments to be made over a range of environments (Carmer et al. 1989). Prior to analysis, data were visually checked for normal distribution and homogeneity of variance. An analysis of variance (ANOVA) was performed at $P \leq 0.05$. Differences were evaluated using the Tukey's honest significant differences test at $P = 0.05$.

RESULTS AND DISCUSSION

Oilseed radish and weed dry biomass. In 2015, oilseed radish biomass ranged from 5.6 to 4083.2 kg/ha measured at 7 WAH and 12 WAH (Table 3). The highest crop biomass was achieved in treatment 1 WAH at 7 WAH (100 kg/ha) and 12 WAH (3069 kg/ha), respectively. The highest weed biomass was measured in treatment NCC (73 kg/ha) and treatments 5 WBH (81 kg/ha) and 3 WBH (163 kg/ha) at 7 WAH and 12 WAH. The highest weed control efficacy was achieved by

Table 2. Different oilseed radish treatments and sowing dates of the field experiments in two experimental years

Treatment	Sowing date	2015	2016
No cover crop (NCC)	no cover crop	–	–
5 WBH (weeks before harvest)	five weeks before winter wheat harvest	June 29th	July 6th
3 WBH	three weeks before winter wheat harvest	July 13th	July 20th
Harvest (H)	at winter wheat harvest	August 3rd	August 10th
1 WAH (weeks after harvest)	one week after winter wheat harvest	August 11th	August 17th
3 WAH	three weeks after winter wheat harvest	August 24th	August 31th

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Table 3. Dry biomass of oilseed radish and weeds without (N0) and with (N45) fertilization 7 and 12 weeks after harvest (WAH) across all treatments in 2015 and 2016

Year	Date	Treatment	Oilseed radish biomass (kg/ha)		Weed biomass (kg/ha)	
			N0	N45	N0	N45
2015	7 WAH	NCC	0^{bA}	0^{bA}	82^{abA}	62^{abA}
		5 WBH	6^{bA}	10^{bA}	85^{aA}	82^{aA}
		3 WBH	18^{bA}	20^{bA}	76^{abA}	68^{abA}
		H	56^{abA}	35^{abA}	28^{bcA}	44^{abA}
		1 WAH	100^{aA}	128^{aA}	10^{cA}	6^{bA}
		3 WAH	29^{abA}	24^{bA}	34^{abcA}	42^{abA}
	12 WAH	NCC	0^{cA}	0^{bA}	78^{abA}	70^{abcA}
		5 WBH	439^{bA}	436^{bA}	83^{abA}	74^{abA}
		3 WBH	1501^{abA}	637^{bA}	88^{aA}	94^{aA}
		H	1563^{abA}	1412^{abA}	29^{bcA}	63^{abcA}
		1 WAH	3069^{aA}	4083^{aA}	9^{cA}	21^{cA}
		3 WAH	827^{bA}	1532^{abA}	40^{abcA}	42^{bcA}
2016	7 WAH	NCC	0^{cA}	0^{cA}	328^{aA}	223^{aA}
		5 WBH	1883^{aA}	2247^{aA}	11^{bA}	24^{bA}
		3 WBH	1115^{abB}	1995^{aA}	19^{bA}	41^{bA}
		H	906^{abA}	1764^{abA}	68^{bA}	26^{bA}
		1 WAH	410^{abA}	242^{bcA}	30^{bA}	8^{bA}
		3 WAH	81^{bA}	131^{cA}	15^{bA}	32^{bA}
	12 WAH	NCC	0^{cA}	0^{bA}	721^{aA}	1142^{aA}
		5 WBH	1760^{aB}	2715^{aA}	6^{cA}	9^{bA}
		3 WBH	962^{abB}	1353^{aA}	4^{cA}	8^{bA}
		H	1583^{aA}	2579^{aA}	139^{abA}	44^{bA}
		1 WAH	630^{abA}	1215^{aA}	105^{abA}	45^{bA}
		3 WAH	383^{bB}	1216^{aA}	60^{bcA}	51^{bA}

Lowercase letters are used to compare the oilseed radish and weed biomass among the different treatments and the uppercase letters are used to compare the oilseed radish and weed biomass between the two fertilization levels (N0, N45). Means with identical letters within the table do not differ significantly based on the Tukey's *HSD* (honest significant difference) test ($P < 0.05$); NCC – no cover crop; WBH – weeks before harvest; H – harvest

treatment 1 WAH with 89% and 80% at 7 WAH and 12 WAH across both fertilization levels (N0 and N45), respectively.

Reversed oilseed radish biomass was measured among all sowing treatments in 2015 compared to 2016. In 2015, the highest biomass was measured in treatment 1 WAH compared to 5 WBH and 3 WBH in 2016. This could be contributed to insufficient precipitation, which resulted in unfavourable field conditions for cover crop germination and growth at the early beginning (Table 1). The lower precipitation (–55%) with higher mean temperature (+11%) in 2015 during the vegetation period of treatments 5 WBH and 3 WBH led to lower oilseed radish germination, which resulted in a reduced biomass production in 2015 compared to 2016. Kruidhof et al. (2008) demonstrated that an early light interception accumulation has a negative correlation with weed biomass compared during the cover crop vegetation period. Especially in 2016, the treatments 5 WBH and 3 WBH provided high weed suppression, due to the early sowing and fast oilseed radish development under favorable field conditions. Moreover, the similar oilseed radish biomass in treatments 5 WBH (2238 kg/ha) and H (2081 kg/ha) showed different weed control efficacies at 12 WAH, which can be attributed to an earlier light interception due to a faster soil coverage and weed shading. After wheat harvest, the stubble area was already covered with the cover crop. This growth advantage compared to

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Table 4. Coefficients of determination of the Pearson's correlation between cover crop (kg/ha) and weed (kg/ha) biomass

Year	Date	N0	N45
2015	7 WAH	−0.6134***	−0.3111**
	12 WAH	−0.5954***	−0.4481***
2016	7 WAH	−0.1127^{ns}	−0.1685*
	12 WAH	−0.0988^{ns}	−0.3655**

*P ≤ 0.05; **P ≤ 0.01; ***P ≤ 0.001; ns – not significant; WAH – weeks after harvest

weeds led to higher weed suppression, especially in the pre-harvest treatments (5 WBH and 3 WBH) in 2016. It was found a linear relationship between weed and cover crop biomass in 2015 (Table 4). In the following year, no significant correlation was calculated at 7 WAH and 12 WAH without fertilization, which is in line with the results of Hodgdon et al. (2016).

Further, it was observed a linear relationship between weed biomass and density in 2016 (R^2 = 0.4406, P ≤ 0.05), however this relationship was much weaker and not significant in 2015 (R^2 = 0.2522). It is assumed that the competition of the weeds with the cover crop biomass played a major role in weed biomass suppression in 2015. In 2016, weed emergence, which illustrates weed density, was highly suppressed by the cover crop and consequently reduced the weed biomass. Beside competitive effects of oilseed radish on the overall weed suppression, the family of Brassicaceae is well documented for the active and passive release of allelochemicals, as isothiocyanates, in the environment (Haramoto and Gallandt 2004). In other studies, cover crops inhibited weed biomass by more than 80%, due to competitive and biochemical effects (Lawley et al. 2011, Silva 2014, Rueda-Ayala et al. 2015, Kunz et al. 2016). A significant reduction of weed biomass of up to 97% was observed by radish cover crops in fall in different studies (Stivers-Young 1998, Hodgdon et al. 2016). Kruidhof et al. (2008) measured similar weed biomass reductions of 80% and 86% at 7 and 12 weeks after sowing. In this experiment, no weed seed production could be observed until the mulching of the cover crops. Therefore, the weeds offer several ecological benefits within the field as pest control (Frank and Barone 1999), improving soil nutrient cycle by arbuscular mycorrhizal fungi (Vatovec et al. 2005) and the reduction in soil loss and runoff (Pannkuk et al. 1997).

Weed density. The weed density varied between 9 and 202 plants/m^2 across the experimental years 2015 and 2016. In 2015, the highest weed density reduction of the monocotyledons, dicotyledons and volunteer wheat was observed in treatments H and 1 WAH with 72, 65, 69 and 83, 86, 80%, respectively, compared to NCC across both measurement dates and fertilization levels (Figure 1).

In the following year, the weed density was reduced by all treatments compared to the untreated control. The most effective weed control efficacy was achieved by treatments 3 WBH and 5 WBH with up to 91, 84, 83 and 86, 90, 85% on monocotyledons, dicotyledons and volunteer wheat compared to NCC at 12 WAH, respectively (Figure 2). Effective weed density reductions by fall-sown cover

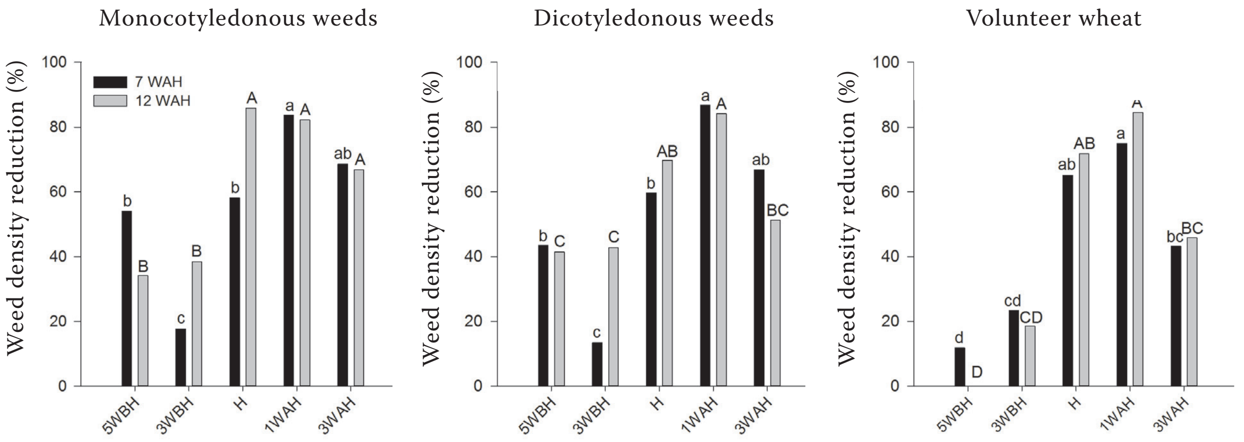

Figure 1. Weed density reduction (%) of monocotyledonous and dicotyledonous weeds and volunteer wheat (*Triticum aestivum*) at five different sowing dates of oilseed radish cover crop measured at 7 WAH (weeks after harvest) and 12 WAH in 2015. Means with identical letters within the table do not differ significantly based on the Tukey's *HSD* (honest significant difference) test (P < 0.05); WBH – weeks before harvest; H – harvest

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crops of up to 42–68% were demonstrated by several similar studies (Silva 2014, Kunz et al. 2016, Sturm et al. 2016); Brust et al. (2014) reported weed density suppression by 98% after oilseed radish cultivation.

Fertilization effects. In both years, there was no significant interaction between the factors fertilization and sowing date on cover crop and weed biomass and weed density. Cover crop fertilization did not demonstrate any changes on oilseed radish and weed biomass 7 WAH and 12 WAH in 2015 (Table 3). The low effects of the fertilization can be attributed to exceptional weather conditions in 2015 with low precipitation during the experimental period (Table 1). Water shortage and the C:N ratio increased by wheat straw decomposition can decrease nitrogen availability for cover crop plants within the field (Hu et al. 1997, Borken and Matzner 2009). Furthermore, an increased duration and intensity of drought are associated with a decreased N mineralization into the soil (Borken and Matzner 2009, Bloor and Bardgett 2012).

In the following year, the oilseed radish biomass was significantly increased by 54, 41 and 218% in treatments 5 WBH, 3 WBH and 3 WAH, respectively, at 12 WAH due to fertilization. The soil sample observation measured an N_{min} content of 20.9 kg N/ha (0–90 cm) at the beginning of the experiment. The increased biomass can be attributed to the missing soil nutrients after 7 WAH. No differences were detected for weed biomass between N0 and N45 at 7 WAH and 12 WAH. Furthermore, higher nutrient uptake efficacy and the influence of allelopathic compounds by cover crops can lead to lower effects of fertilization on weed growth (Jabran et al. 2015). However, Mazzoncini et al. (2011) observed a significantly increased cover crop and weed biomass by 17% and 75% compared to the untreated control.

The fertilization of the oilseed radish revealed insignificant changes in weed density in both years, which is in line with the results of Swanton et al. (1999). However, Yin et al. (2006) reported a decreased weed density due to the application of different nitrogen fertilizers. Similar results were found in the study of Carson and Peterson (1990) who found that the weed density is less influenced than the weed biomass within the field. Different weeds are able to compensate a constant or reduced weed density by higher biomass production per plant.

This study assumes that the weed suppressive ability of coated oilseed radish cover crops depends on sufficient precipitation for germination and growth. Further studies should be conducted to proof the influence of the soil water availability on cover crop and weed biomass accumulation. An early cover crop sowing can provide higher cover crop biomass and increased weed control efficacy as observed in 2016. The use of coated cover crops combined with a pre-harvest sowing can prolong the cover crop vegetation period in the field, reduce the workload peaks during and after winter wheat harvest and suppress weeds more effectively compared to conventionally sown cover crops. More research with further coated cover crops needs to be conducted to investigate the full potential of a prolonged cover crop vegetation period.

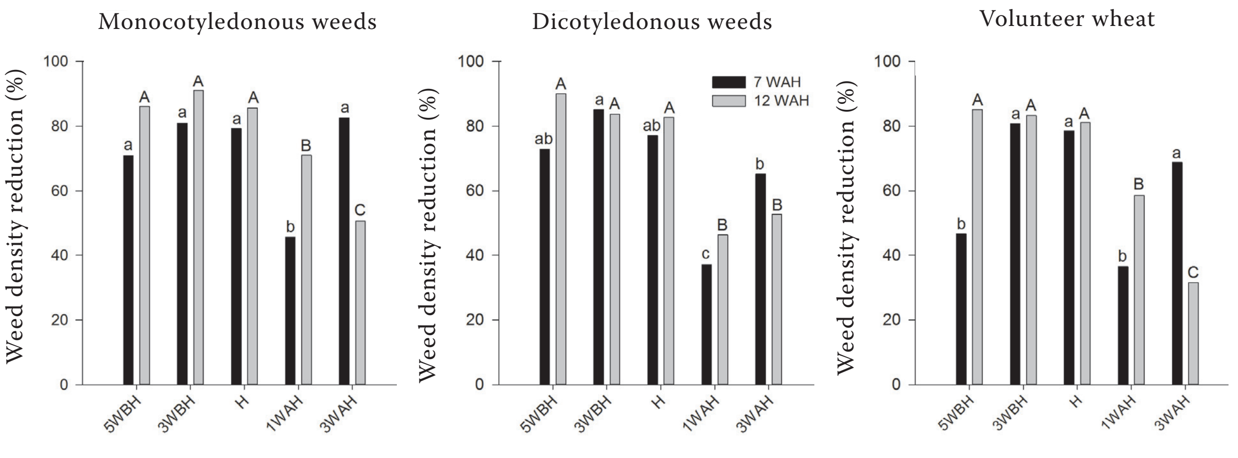

Figure 2. Weed density reduction (%) of monocotyledonous and dicotyledonous weeds and volunteer wheat (*Triticum aestivum*) at five different sowing dates of oilseed radish cover crop measured at 7 WAH (weeks after harvest) and 12 WAH in 2016. Means with identical letters within the table do not differ significantly based on the Tukey's *HSD* (honest significant difference) test ($P < 0.05$); WBH – weeks before harvest; H – harvest

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REFERENCES

Anugroho F., Kitou M., Nagumo F., Kinjo K., Tokashiki Y. (2009): Effect of the sowing date on the growth of hairy vetch (*Vicia villosa*) as a cover crop influenced the weed biomass and soil chemical properties in a subtropical region. Weed Biology and Management, 9: 129–136.

Bloor J.M.G., Bardgett R.D. (2012): Stability of above-ground and below-ground processes to extreme drought in model grassland ecosystems: Interactions with plant species diversity and soil nitrogen availability. Perspectives in Plant Ecology, Evolution and Systematics, 14: 193–204.

Bond W., Grundy A.C. (2001): Non-chemical weed management in organic farming systems. Weed Research, 41: 383–405.

Borken W., Matzner E. (2009): Reappraisal of drying and wetting effects on C and N mineralization and fluxes in soils. Global Change Biology, 15: 808–824.

Brust J., Claupein W., Gerhards R. (2014): Growth and weed suppression ability of common and new cover crops in Germany. Crop Protection, 63: 1–8.

Carmer S.G., Nyquist W.E., Walker W.M. (1989): Least significant differences for combined analyses of experiments with two- or three-factor treatment designs. Agronomy Journal, 81: 665–672.

Carson W.P., Peterson C.J. (1990): The role of litter in an old-field community: Impact of litter quantity in different seasons on plant species richness and abundance. Oecologia, 85: 8–13.

Clossais-Besnard N., Larher F. (1991): Physiological role of glucosinolates in *Brassica napus*. Concentration and distribution pattern of glucosinolates among plant organs during a complete life cycle. Journal of the Science of Food and Agriculture, 56: 25–38.

Frank T., Barone M. (1999): Short-term field study on weeds reducing slug feeding on oilseed rape/Kurzzeitstudie an Ablenkunkräutern gegenüber Schneckenfrass an Raps. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz/Journal of Plant Diseases and Protection, 106: 534–538.

Gustine D.L., Jung G.A. (1985): Influence of some management parameters on glucosinolate levels in *Brassica* forage. Agronomy Journal, 77: 593–597.

Haramoto E.R., Gallandt E.R. (2004): Brassica cover cropping for weed management: A review. Renewable Agriculture and Food Systems, 19: 187–198.

Haramoto E.R., Gallandt E.R. (2005): Brassica cover cropping: I. Effects on weed and crop establishment. Weed Science, 53: 695–701.

Hartwig N.L., Ammon H.U. (2002): Cover crops and living mulches. Weed Science, 50: 688–699.

Hodgdon E.A., Warren N.D., Smith R.G., Sideman R.G. (2016): In-season and carry-over effects of cover crops on productivity and weed suppression. Agronomy Journal, 108: 1624–1635.

Hu S., Grünwald N.J., van Bruggen A.H.C., Gamble G.R., Drinkwater L.E., Shennan C., Demment M.W. (1997): Short-term effects of cover crop incorporation on soil carbon pools and nitrogen availability. Soil Science Society of America Journal, 61: 901–911.

Jabran K., Mahajan G., Sardana V., Chauhan B.S. (2015): Allelopathy for weed control in agricultural systems. Crop Protection, 72: 57–65.

Kruidhof H.M., Bastiaans L., Kropff M.J. (2008): Ecological weed management by cover cropping: Effects on weed growth in autumn and weed establishment in spring. Weed Research, 48: 492–502.

Kunz Ch., Sturm D.J., Varnholt D., Walker F., Gerhards R. (2016): Allelopathic effects and weed suppressive ability of cover crops. Plant, Soil and Environment, 62: 60–66.

Lawley Y.E., Weil R.R., Teasdale J.R. (2011): Forage radish cover crop suppresses winter annual weeds in fall and before corn planting. Agronomy Journal, 103: 137–144.

Liebman M., Davis A.S. (2000): Integration of soil, crop and weed management in low-external-input farming systems. Weed Research, 40: 27–47.

Mazzoncini M., Sapkota T.B., Bàrberi P., Antichi D., Risaliti R. (2011): Long-term effect of tillage, nitrogen fertilization and cover crops on soil organic carbon and total nitrogen content. Soil and Tillage Research, 114: 165–174.

Pannkuk C.D., Papendick R.I., Saxton K.E. (1997): Fallow management effects on soil water storage and wheat yields in the Pacific Northwest. Agronomy Journal, 89: 386–391.

Petersen J., Belz R., Walker F., Hurle K. (2001): Weed suppression by release of isothiocyanates from turnip-rape mulch. Agronomy Journal, 93: 37–43.

R Core Team (2016): A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria.

Reiter M.S., Reeves D.W., Burmester C.H., Torbert H.A. (2008): Cotton nitrogen management in a high-residue conservation system: Cover crop fertilization. Soil Science Society of America Journal, 72: 1321–1329.

Rueda-Ayala V., Jaeck O., Gerhards R. (2015): Investigation of biochemical and competitive effects of cover crops on crops and weeds. Crop Protection, 71: 79–87.

Silva E.M. (2014): Screening five fall-sown cover crops for use in organic no-till crop production in the Upper Midwest. Agroecology and Sustainable Food Systems, 38: 748–763.

Stahr K., Kandeler E., Herrmann L., Streck T. (2016): Bodenkunde und Standortlehre (Vol. 2967). Stuttgart, Ulmer UTB.

Stivers-Young L. (1998): Growth, nitrogen accumulation, and weed suppression by fall cover crops following early harvest of vegetables. HortScience, 33: 60–63.

Sturm D.J., Kunz C., Gerhards R. (2016): Inhibitory effects of cover crop mulch on germination and growth of *Stellaria media* (L.) Vill., *Chenopodium album* L. and *Matricaria chamomilla* L. Crop Protection, 90: 125–131.

Swanton C.J., Shrestha A., Roy R.C., Ball-Coelho B.R., Knezevic S.Z. (1999): Effect of tillage systems, N, and cover crop on the composition of weed flora. Weed Science, 47: 454–461.

Vatovec C., Jordan N., Huerd S.C. (2005): Responsiveness of certain agronomic weed species to arbuscular mycorrhizal fungi. Renewable Agriculture and Food Systems, 20: 181–189.

Vos J., van der Putten P.E.L. (1997): Field observations on nitrogen catch crops. I. Potential and actual growth and nitrogen accumulation in relation to sowing date and crop species. Plant and Soil, 195: 299–309.

Yin L.C., Cai Z.C., Zhong W.H. (2006): Changes in weed community diversity of maize crops due to long-term fertilization. Crop Protection, 25: 910–914.

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