Lopsided oat (*Avena strigosa*) as a new summer annual cover crop for weed suppression in Central Europe

Rauhafer (Avena strigosa) als neue Zwischenfrucht zur Unkrautunterdrückung in Mitteleuropa

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DOI: 10.5073/jka.2012.434.032

Summary

Lopsided oat (*Avena strigosa*) has been cultivated for many years, especially in Brazil, as a summer annual cover crop. Experiments were conducted in Stuttgart-Hohenheim in 2010 to estimate the capability of lopsided oat, yellow mustard (*Sinapis alba*), phacelia (*Phacelia tanacetifolia*) and a cover crop mixture to suppress weeds and volunteer wheat. A pot experiment was conducted to analyze the emergence and growth of the different cover crop species. Twelve weeks after planting, lopsided oat produced 20.7 dt/ha of shoot- and 5.5 dt/ha of root dry matter. A field experiment was established in the summer after harvest of winter wheat. The soil was cultivated with a disc harrow and the cover crops were sown one day later. At four week intervals, the plant density and dry matter of cover crops, weeds and volunteer wheat were determined. Twelve weeks after planting, lopsided oat produced 17.8 dt/ha shoot- and 6.2 dt/ha root dry matter. In the lopsided oat plots, shoot dry matter of weeds and volunteer wheat were reduced by 98 % compared with control plots without cover crops. This was the highest weed reduction of all cover crops studied. The root dry matter of weeds and volunteer wheat was reduced by 55 % to 97 % in all cover crops, compared to the control plots. Lopsided oat reduced the plant density of weeds and volunteer wheat. While there were 54.5 plants/m^2 in the control plots, only 5.5 plants/m^2 were counted in the lopsided oat plots. The results showed that lopsided oat has a high potential for suppression of weeds and volunteer wheat in autumn. It also enlarges the number of cultivated cover crops in Central Europe.

Keywords: Competition, field experiment, pot experiment, root, shoot, volunteer wheat

Zusammenfassung

Rauhafer (*Avena strigosa*) wird seit vielen Jahren vor allem in Brasilien als Zwischenfrucht angebaut. In Stuttgart-Hohenheim wurden 2010 Versuche durchgeführt, um die Eignung von Rauhafer, Gelbsenf (*Sinapis alba*), Phacelia (*Phacelia tanacetifolia*) und einer Zwischenfruchtmischung zur Unterdrückung von Unkräutern und Ausfallgetreide festzustellen. Ein Topfversuch wurde durchgeführt, um Auflaufen sowie Wachstum der Zwischenfrüchte zu bestimmen. Zwölf Wochen nach Aussaat bildete Rauhafer 20,7 dt/ha Spross- und 5,5 dt/ha Wurzel-Trockenmasse. Ein Feldversuch wurde nach erfolgter Winterweizenernte durchgeführt. Im Anschluss an eine ca. 5 cm tiefe Bodenbearbeitung mit einer Kurzscheibenegge wurden am folgenden Tag die Zwischenfrüchte gesät. Im Abstand von vier Wochen wurden Anzahl und Trockenmasse der Zwischenfrüchte, der Unkräuter sowie des Ausfallgetreides bestimmt. Zwölf Wochen nach Aussaat bildete Rauhafer 17,8 dt/ha Spross- und 6,2 dt/ha Wurzel-Trockenmasse. Die Spross-Trockenmasse der Unkräuter und des Ausfallgetreides konnte durch Rauhafer signifikant um 98 %, verglichen mit einer Kontrolle ohne Zwischenfrucht, reduziert werden. Dies war der höchste Wert aller Zwischenfrüchte. Die Wurzel-Trockenmasse von Unkräutern und Ausfallgetreide wurde von den Zwischenfrüchten durchschnittlich um 55 % bis 97 % reduziert. Rauhafer reduzierte die Anzahl an Unkräutern und Ausfallgetreide. Während 54,5 Pflanzen/m^2 in den Kontrollparzellen wuchsen, waren es 5,5 Pflanzen/m^2 bei Rauhafer. Im Rahmen des Feldversuches konnte gezeigt werden, dass Rauhafer sehr gut Unkräuter sowie Ausfallgetreide zu unterdrücken vermag. Er stellt eine Bereicherung des bisherigen Spektrums an Zwischenfrüchten in Mitteleuropa dar.

Stichwörter: Ausfallgetreide, Feldversuch, Konkurrenz, Spross, Topfversuch, Wurzel

1. Introduction

Cover crops influence the agricultural ecosystem in many positive ways; soil protection from wind and water erosion (PARLAK and PARLAK, 2010; DE BAETS et al., 2011), reduction of nutrients leaching (especially nitrate) to groundwater (LOGSDON et al., 2002) and an increase of soil organic matter (LIU et al., 2005), among others. Another important reason for the cultivation of cover crops is its weed suppressive capability.

Cover crops are able to completely suppress weeds through direct competition for water, nutrients and light (AKEMO et al., 2000; LAWLEY et al., 2011). Cover crops require a fast growing capability to generate an early shading effect in order to successfully suppress weeds (BRENNAN and SMITH, 2005; KRUIDHOF et al., 2008; UCHINO et al., 2011). Contemporary research on competition between weeds and cover crops focuses on above ground dry matter of cover crops as a reference point for competitiveness only (LINARES et al., 2008). Additionally, cover crops must have a well developed root system to ensure a strong below-ground competitiveness for water and nutrients, thus enhancing the above-ground competitive capability for light (FOFANA and RAUBER, 2000). All these characteristics are needed to effectively and sustainably suppress weeds using cover crops.

During the last decade, only a few plant species have been cultivated as cover crops in Germany. Especially yellow mustard (*Sinapis alba*) has been grown because of its capability to reduce the nematode population in crop rotations with sugar beet (*Beta vulgaris*) (SMITH et al., 2004), reduction of nitrate leaching (WYLAND et al., 1996) and good weed suppression (BECKIE et al., 2008). The second important cover crop in Germany is phacelia (*Phacelia tanacetifolia*), because it is not related to any crop in Germany and therefore no host for important plant diseases. Phacelia is mainly used in crop rotations with canola (*Brassica napus*) and is also able to prevent nitrate leaching and weed growth (STIVERS-YOUNG, 1998). An increasing number of farmers use cover crop mixtures for weed suppression. Cover crop mixtures achieve a higher weed control compared to a monoculture cover crop due to enhanced dry matter production and extended shading (AKEMO, 2000; LINARES et al., 2008). Lopsided oat (*Avena strigosa*) is an important cover crop in southern Brazil due to its fast growth and strong capability to suppress weeds (PRINCE et al., 2006; FONTANELI et al., 2009). However, limited information is available on the potential of lopsided oat as a cover crop in Germany. The objective of this study was to compare lopsided oat with current summer cover crops regarding their dry matter production and weed suppression capability.

2. Materials and methods

A pot and a field experiment were conducted with the same sowing density for four cover crop treatments. Three cover crops were sown as monoculture: lopsided oat (*Avena strigosa Schreb. cv. Pratex*) at a seed density of 100.0 kg/ha, yellow mustard (*Sinapis alba L. cv. Accent*) with a density of 12.7 kg/ha and phacelia (*Phacelia tanacetifolia Benth cv. Angelia*) at a density of 10.3 kg/ha. A cover crop mixture consisting of beerseem clover (*Trifolium alexandrinum*), common vetch (*Vicia sativa*), tartary buckwheat (*Fagopyrum tataricum*) and niger seed (*Guizotia abyssinica*) was sown as an additional treatment at a seed density of 50.0 kg/ha.

2.1 Pot experiment

The pot experiment was conducted from August until November 2010 at the Institute of Phytomedicine in Stuttgart-Hohenheim. The pots used had a size of 20 by 20 cm and a height of 25 cm. The substrate used was a clay loamy soil from the topsoil of a winter barley field at the research station 'Ihinger Hof', with an N_{min} content of 10.7 kg N/ha. The soil was crushed before filling the pots. No additional fertilizer was added. Every pot was irrigated with two dripper stakes from a 4-way multi-outlet dripper irrigation system. A randomized complete block design with four replications was used. The cover crops were sown on August 12th at a depth of 2 cm. Seedling emergence was counted five and ten days after planting (DAP). Dry matter of shoot and roots were measured four, eight and twelve weeks after planting (WAP). At harvest, the roots were cleaned from soil with water and subsequently separated from the shoot. Next, the plant material was dried for three days at 80 °C.

2.2 Field experiment

The field experiment was conducted from August until November 2010 at the research station 'Ihinger Hof', which is located 30 km southwest of Stuttgart. Soil type at the experimental site was Haplic Luvisol with clay loam as soil texture at the topsoil. The N_{min} content of the topsoil was 17.6 kg N/ha. No additional fertilizer was added to see how the cover crops manage low nitrogen content. A randomized complete block design with four replications was used. Each plot was 2.0 by 20 m. After harvesting the preceding winter wheat the straw was removed. The following day, a 5 cm deep tillage was conducted with a disc harrow. Cover crops were seeded on August 21st using a plot seeder with double disk openers, at a row spacing of 11 cm and a sowing depth of 2 cm. Seedling emergence was counted five, seven and ten DAP. Plant samples were taken four, eight and twelve WAP from an area of 0.5 m^2. At each sampling date, shoot and root dry matter and the plant density of cover crops, weeds and volunteer wheat were measured. After harvesting, the roots were cleaned and separated from the shoots; the plants were dried for three days at 80 °C. The data was analyzed with the software 'SPSS Version 15.0' (SPSS Inc.). All data was tested using the Shapiro-Wilk test for normality and the Levene-test for homogeneity of variance. Following the analysis of variance (Univariate procedure), multiple comparison tests were performed using the Tukey-test at a significance level of $\alpha = 0.05$.

3. Results

Climatic conditions during the growing season 2010 were very similar at both locations (Tab. 1). In August, the climate slightly differed from the longtime average. September and October were characterized by cool weather that inhibited the cover crop growth. At 'Ihinger Hof', the average air temperature in September and October was 0.9 °C below the longtime average.

Tab. 1 Monthly and longtime monthly (ltm.) average temperature and precipitation during the growing season 2010.

Tab. 1 *Monatliche sowie langjährige Monatsmittelwerte (ltm.) von Temperatur und Niederschlag während der Versuchsdauer.*

	Air temp. (°C)				**Precipitation (mm)**			
	Aug.	**Sept.**	**Oct.**	**Nov.**	**Aug.**	**Sept.**	**Oct.**	**Nov.**
Hohenheim 2010	17.5	12.9	8.3	5.5	82.1	50.6	24.8	62.3
Hohenheim ltm.-average	17.1	14.0	9.3	3.9	79.3	56.5	43.4	54.9
Ihinger Hof 2010	16.4	12.1	7.8	4.6	80.5	43.5	42.0	76.5
Ihinger Hof ltm.-average	16.8	13.0	8.7	3.6	81.0	54.0	54.0	51.0

3.1 Pot experiment

Five DAP, lopsided oat showed no different seedling emergence than phacelia or the cover crop mixture (Tab. 2). Five DAP, only yellow mustard had a significantly higher seedling emergence than lopsided oat. Ten DAP, there were no differences in seedling emergence among the cover crops.

Tab. 2 Seedling emergence of cover crops during the pot experiment.

Tab. 2 *Feldaufgang der Zwischenfrüchte während des Topfversuches.*

	Lopsided oat		**Yellow mustard**		**Phacelia**		**Cover crop mixture**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
5 DAP	72.9 b[z]	11.1	93.8 a	14.4	75.3 b	19.3	65.2 b	15.7
10 DAP	97.5 a	4.7	98.5 a	5.2	98.5 a	4.8	98.9 a	3.1

[z] Means within the same row followed by an identical letter do not differ statistically based on the Tukey test ($\alpha = 0.05$).

At the first harvesting date four WAP, shoot dry matter was the same for all cover crops (Fig. 1). At eight WAP, the cover crop mixture produced the significantly highest shoot dry matter with 25.6 dt/ha. With a shoot dry matter of 10.8 dt/ha, lopsided oat did not differ from yellow mustard and phacelia. At twelve WAP, the cover crop mixture accumulated the highest shoot dry matter, namely 41.0 dt/ha. Lopsided oat built 20.7 dt/ha shoot dry matter in the same time period, which did not differ from yellow mustard and phacelia. The root dry matter among cover crops was similar at four and eight WAP. Twelve WAP, lopsided oat accumulated 5.5 dt/ha of root dry matter, being significantly higher than that accumulated by yellow mustard and phacelia.

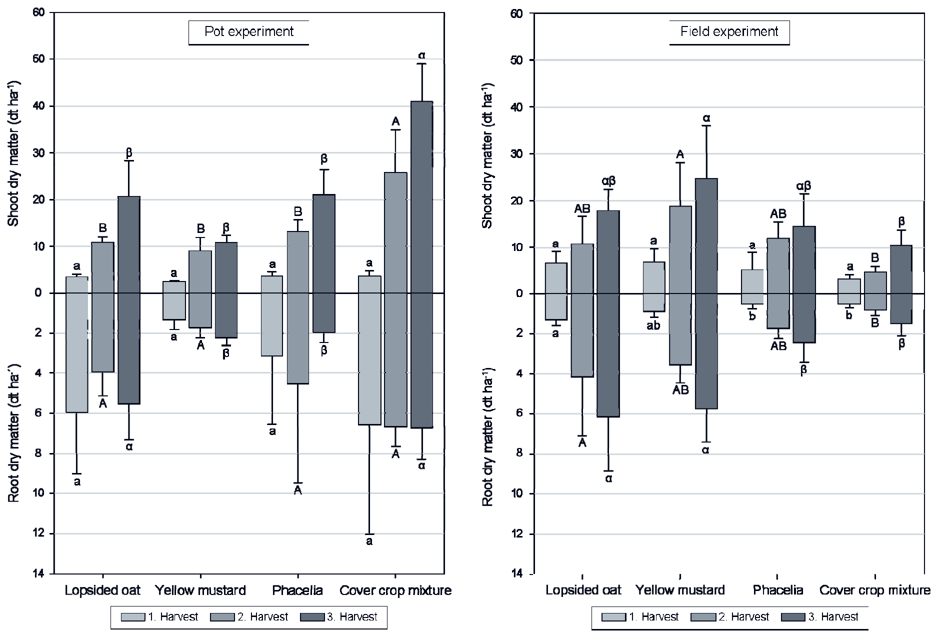

Fig. 1 Shoot and root dry matter of cover crops at three harvest dates in the pot (left) and in the field experiment (right). Columns are mean values. Vertical bars represent the standard errors. Means with the same letter were not significantly different at α = 0.05.

Abb. 1 *Spross- sowie Wurzeltrockenmasse der Zwischenfrüchte im Feldversuch, in Abhängigkeit des Erntetermines beim Topf- (links) und Feldversuch (rechts). Mittelwerte, welche mit demselben Buchstaben versehen sind, weisen bei einem Signifikanzniveau von α = 0,05 keine signifikante Differenz auf. Die Fehlerbalken stellen jeweils die Standardabweichung der Messwerte dar.*

3.2 Field experiment

At five DAP, lopsided oat showed the lowest seedling emergence (Tab. 3). However, two days later, no differences could be found among cover crops. Again three days later, the highest seedling emergence of all cover crops was observed for lopsided oat (90.1 %), although this was not significantly higher than for other cover crops.

Tab. 3 Seedling emergence of cover crops in the field experiment.

Tab. 3 Feldaufgang der Zwischenfrüchte während des Feldversuches.

	Lopsided oat		**Yellow mustard**		**Phacelia**		**Cover crop mixture**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
5 DAP	0.7 c[z]	1.4	27.1 a	5.5	12.2 bc	8.6	16.9 ab	4.4
7 DAP	78.0 a	13.0	71.7 a	27.1	73.4 a	11.4	82.2 a	11.3
10 DAP	90.1 a	13.9	79.9 a	27.1	85.9 a	20.8	84.5 a	6.6

[z] Means within the same row followed by an identical letter do not differ statistically based on the Tukey test (α = 0.05).

At every harvest date, yellow mustard had the highest shoot dry matter (Fig. 1). From the second harvest (eight WAP) onward, only the amounts of shoot dry matter of yellow mustard and the cover crop mixture were significantly different. At the third harvest date (twelve WAP), yellow mustard accumulated 24.6 dt/ha of shoot dry matter, which was 14.3 dt/ha more than the cover crop mixture. Lopsided oat built 17.8 dt/ha shoot dry matter in the same time period. At all three sampling dates, lopsided oat showed the highest root dry matter. Eight WAP, lopsided oat accumulated 4.2 dt/ha root dry matter, which was significantly higher than for the cover crop mixture. Until twelve WAP, lopsided oat build 6.2 dt/ha of root dry matter. This was a significantly higher value compared with phacelia and the cover crop mixture, but not with yellow mustard.

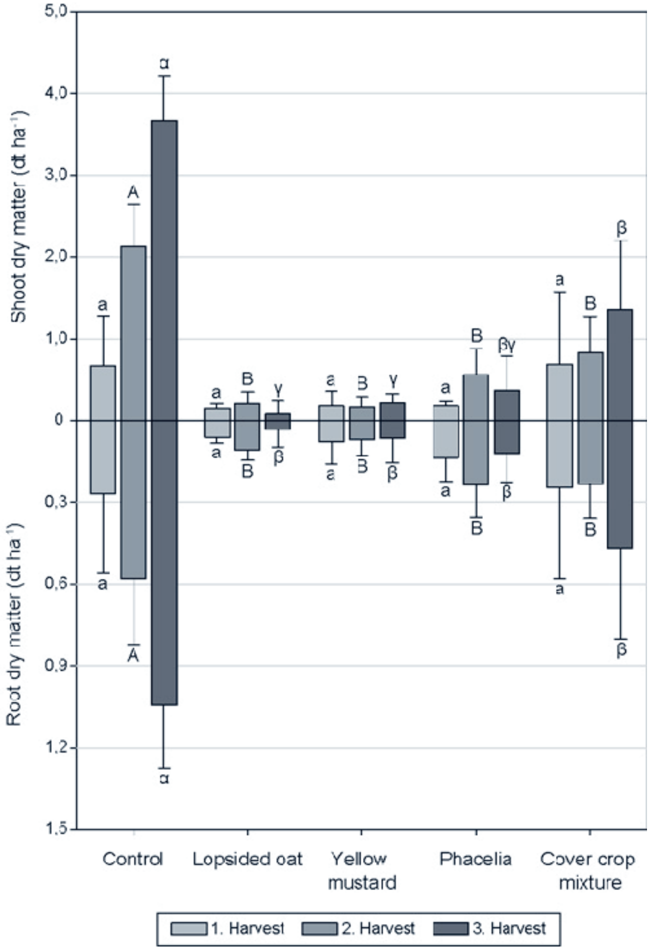

Fig. 2 Shoot and root dry matter of weeds and volunteer wheat at the three harvest dates. Columns are mean values. Vertical bars represent the standard errors. Means with the same letter were not significantly different at α ≤ 0.05.

Abb. 2 *Spross- sowie Wurzeltrockenmasse von Unkräutern sowie Ausfallgetreide in Abhängigkeit des Erntetermins. Mittelwerte, welche mit demselben Buchstaben versehen sind, weisen bei einem Signifikanzniveau von α ≤ 0,05 keine signifikante Differenz auf. Die Fehlerbalken stellen jeweils die Standardabweichung der Messwerte dar.*

The weed community was dominated by volunteer wheat (*Triticum aestivum*), common chickweed (*Stellaria media*), red deadnettle (*Lamium purpureum*) and persian speedwell (*Veronica persica*). Four WAP, the shoot and root dry matter of weeds and volunteer wheat did not differ between the control and cover crops (Fig. 2), but eight WAP they were significantly lower in cover crop plots than in the control. However, no difference was found among the cover crops. Twelve WAP, weeds and volunteer wheat built 3.67 dt/ha of shoot dry matter in the control plots, while they built 0.08 dt/ha in the lopsided oat plots, which corresponds to a 98 % reduction. Twelve WAP, thanks to lopsided oat, the root dry matter of weeds and volunteer wheat was reduced by 97 %, from 1.04 to 0.03 dt/ha. This was superior to the cover crop mixture, which reduced the root dry matter by 55 %.

The plant density of weeds and volunteer wheat four and eight WAP was not significantly different between control pots and the cover crops (Tab. 4). Lopsided oat, yellow mustard and phacelia could effectively reduce the number of weeds and volunteer wheat twelve WAP. While 54.5 plants/m^2 were counted in the control plots, there were only 5.5 plants/m^2 in the lopsided oat plots, which represents a weed reduction of 90 %.

Tab. 4 Effect of cover crop treatments and harvest date on weed- and volunteer wheat density.

Tab. 4 *Einfluss der Zwischenfrüchte sowie des Erntezeitpunktes auf die Anzahl an Unkräuter und Ausfallgetreide.*

Treatment	**4 WAP**		**8 WAP**		**12 WAP**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Control	72.5 a[z]	62.4	66.5 a	26.8	54.5 a	13.0
Lopsided oat	18.5 a	5.3	17.0 a	6.6	5.5 c	11.0
Yellow mustard	21.0 a	22.2	15.5 a	13.3	10.0 bc	16.3
Phacelia	25.0 a	7.4	39.0 a	23.5	11.0 bc	12.8
Cover crop mixture	68.5 a	82.8	78.5 a	78.7	44.0 ab	28.6

[z] Means within the same row followed by an identical letter do not differ statistically based on the Tukey test ($\alpha \leq 0.05$).

4. Discussion

Results from the pot and the field experiment show that lopsided oat has a slower seedling emergence compared to yellow mustard and phacelia. One of the reasons for this observation is the higher seed weight of lopsided oat. The time required for germination increases with seed size, because larger seeds need more water to germinate (HÅKANSSON et al., 2011). Differences among cover crop species could be clearly identified in the field experiment. Due to the rough soil structure, the seeds could not easily absorb the required water for germination. However, ten DAP there was no difference between lopsided oat and the other cover crops. This may be explained by the higher growth rate of larger seeds due to their higher energy content, once they obtain the required water amount for germinating (HÅKANSSON et al., 2011).

Lopsided oat never had a significantly lower shoot dry matter than yellow mustard or phacelia. The only occurrence of higher shoot dry matter of the cover crop mixture was observed in the pot experiment. Twelve WAP, lopsided oat produced 20.7 dt/ha of shoot dry matter in the pot experiment and 17.8 dt/ha in the field experiment. Higher values are reported by BAUER and REEVES (1999) with 29.8 dt/ha in South Carolina and by PRINCE et al. (2006) with 27.7 dt/ha in Alabama. Yellow mustard showed the highest shoot dry matter at each of the three sampling dates. This observation is consistent with results by BRENNAN and SMITH (2005), who reported a higher shoot dry matter for yellow mustard than for legumes or oat. However, our results show lower values than experiments conducted by other authors. Within a three month period, yellow mustard has the capability to produce a four times higher shoot dry matter than observed in our experiment (BRENNAN and SMITH, 2005; ALCÁNTARA et al., 2011). A reason for the low dry matter production in our experiments was the cool autumn weather in 2010.

Root dry matter of lopsided oat was similar in the pot and field experiments. At every harvest date in the field experiment, lopsided oat had the highest amount of root dry matter. Similar results were reported by FRANCHINI et al. (2004), who compared lopsided oat with nine other cereal- and legume cover crops. Lopsided oat was able to reduce the shoot dry matter of weeds and volunteer wheat by up to 98 %. The measured values of weed reduction are not uncommon. Our results agree with other studies showing a weed dry matter reduction of more than 90 % (CREAMER and BALDWIN, 2000; PRINCE et al., 2006). Lopsided oat reduced root dry matter of weeds and volunteer wheat by 97 %. Perhaps, the good weed suppressing capability is an effect of the well developed root system that makes a successful competition for nutrients and water possible. The importance of a well developed root system to suppress weeds has been shown by FOFANA and RAUBER (2000), who observed a negative correlation between root growth of rice and weed dry matter.

Because of its low dry matter production, the cover crop mixture reduced weeds significantly less than lopsided oat or yellow mustard. This is consistent with field experiments from LINARES et al. (2008), who showed that increased dry matter production raised the capability of cover crops to suppress weeds. The low dry matter production in our results of the cover crop mixture might be due to the low temperature during the field experiment. Common vetch, beersem clover and especially niger seed, which were three of the four plant species in the cover crop mixture, have a reduced growth under cool autumn weather. Niger seeds need temperatures between 15 °C and 23 °C for good growth (GETINET and SHARMA, 1996), but these were never reached during the field experiment.

Lopsided oat, yellow mustard and phacelia were able to reduce plant density of weeds and volunteer wheat by up to 90 %. These results correspond to those of KOBAYASHI et al. (2004) who also found a weed density reduction of more than 90 %. This may be an effect of the change in composition of the light that reaches the weed seeds (KRUK et al., 2006). Due to a selective absorption by photosynthetic plant tissue, the ratio of red to infrared light is reduced during its passage through the cover crops. If this light reached germinable weed seeds near the soil surface, they would not germinate (BALLARÉ and CASAL, 2000; BATILLA et al., 2000).

Although our results are only from a one-year period, it can be assumed that lopsided oat could be successfully grown as a cover crop in Central Europe. This species has the same capability for suppression of weeds and volunteer wheat like yellow mustard or phacelia. Furthermore, lopsided oat has a well developed root system that enhances its competitiveness.

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