Sektion 5: Unkrautmanagement ohne Herbizide

Section 5: Weed management without herbicides

Do cover crop mixtures have the same ability to suppress weeds as competitive monoculture cover crops?

Haben Zwischenfruchtmischungen dieselbe Fähigkeit zur Unkrautunterdrückung wie eine konkurrenzkräftige Reinsaat?

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Abstract

An increasing number of farmers use cover crop mixtures instead of monoculture cover crops to improve soil and crop quality. However, only little information is available about the weed suppression ability of cover crop mixtures. Therefore, two field experiments were conducted in Baden-Württemberg between 2010 and 2012, to compare growth and weed suppression of monoculture cover crops and cover crop mixtures. In the first experiment, heterogeneous results between yellow mustard and the cover crop mixture occurred. For further research, a field experiment was conducted in 2012 to compare monocultures of yellow mustard and hemp with three cover crop mixtures. The evaluated mixtures were: "MELO": for soil melioration; "BETA": includes only plant species with no close relation to main cash crops in Central Europe and "GPS": for usage as energy substrate in spring. Yellow mustard, MELO, BETA and GPS covered 90% of the soil in less than 42 days and were able to reduce photosynthetically active radiation (PAR) on soil surface by more than 96% after 52 days. Hemp covered 90% of the soil after 47 days and reduced PAR by 91% after 52 days. Eight weeks after planting, only BETA showed similar growth to yellow mustard which produced the highest dry matter. The GPS mixture had comparatively poor growth, while MELO produced similar dry matter to hemp. Yellow mustard, MELO and BETA reduced weed growth by 96% compared with a no cover crop control, while hemp and GPS reduced weeds by 85% and 79%. In spring, weed dry matter was reduced by more than 94% in plots with yellow mustard and all mixtures, while in hemp plots weeds were only reduced by 71%. The results suggest that the tested cover crop mixtures offer similar weed suppression ability until spring as the monoculture of the competitive yellow mustard.

Keywords: Cover crop, mixed cropping, Hemp, weed control, weed density, weed suppression, Yellow mustard

Zusammenfassung

Eine steigende Zahl von Landwirten verwendet Zwischenfruchtmischungen anstelle von Reinsaaten, um die Qualität ihres Standortes sowie ihrer Kulturpflanzen zu steigern. Jedoch sind nur wenige Informationen über die unkrautunterdrückende Wirkung von Zwischenfruchtmischungen verfügbar. Deshalb wurden zwischen den Jahren 2010 und 2012 zwei Feldversuche in Baden-Württemberg durchgeführt, um die unkrautunterdrückende Wirkung von Zwischenfruchtmischungen und konkurrenzkräftigen Reinsaaten zu vergleichen. Während des ersten Experiments erzielten Gelbsenf und die Zwischenfruchtmischung unterschiedliche Ergebnisse hinsichtlich Wachstum und Unkrautunterdrückung. Deshalb wurde im folgenden Jahr ein weiterer Feldversuch durchgeführt, bei dem Reinsaaten von Gelbsenf und Hanf mit drei Zwischenfruchtmischungen verglichen wurden. Die Zwischenfruchtmischungen waren: "MELO", zur Boden-Melioration, "BETA", die nur Pflanzenarten ohne nähere Verwandtschaft zu wichtigen Kulturpflanzen in Mitteleuropa enthält, sowie "GPS", die im Frühjahr zur Ganzpflanzensilage verwendet werden kann. Gelbsenf, MELO, BETA und GPS bedeckten 90 % der Bodenoberfläche in weniger als 42 Tagen und konnten die photosynthetisch aktive Strahlung (PAR) an der Bodenoberfläche nach 52 Tagen um mehr als 96 % verringern. Hanf bedeckte 90 % der Bodenoberfläche nach 47 Tagen und reduzierte die PAR an der Bodenoberfläche um 91 % nach 52 Tagen. Acht Wochen nach Aussaat zeigte nur BETA ein ähnliches Wachstum wie Gelbsenf, der die höchste Trockenmasse aller Varianten aufwies. Die GPS-Mischung zeigte zu diesem Zeitpunkt nur eine geringe Trockenmassebildung, während MELO ähnliche Werte wie Hanf aufwies. Gelbsenf, MELO und BETA konnten die Unkraut-Trockenmasse nach acht Wochen um mehr als 97 % gegenüber einer Kontrollvariante ohne Zwischenfrüchte verringern, während Hanf sowie die GPS-Mischung nur eine Verringerung von 85 % bzw. 79 % erreichten. Im Frühjahr wurde in den Parzellen mit Gelbsenf und allen Zwischenfruchtmischungen eine Reduzierung der Unkraut-Trockenmasse von mehr als 94 % festgestellt, während in den Hanf-Parzellen nur eine Verringerung von 71 % erreicht wurde. Die Ergebnisse zeigen, dass die verwendeten Zwischenfruchtmischungen bis zum Frühjahr eine ähnliche Unkrautunterdrückung wie eine Reinsaat des konkurrenzkräftigen Gelbsenfs aufweisen.

Stichwörter: Gelbsenf, Hanf, Mischfrucht, Monokultur, Unkrautdichte, Unkrautkontrolle, Zwischenfrucht, Zwischenfruchtmischung

Introduction

The cultivation of cover crops is an integral part of every agricultural system and required for best management practice, particularly if tillage intensity is reduced. Cover crops are able to improve water, air and nutrient conditions of the soil due to creation of macropores, increase of soil organic matter and the capture, recycling and redistribution of nutrients (LOGSDON *et al.*, 2001; DING *et al.*, 2006; HOOKER *et al.*, 2008; KASPAR *et al.*, 2012). Cover crops are also able to provide a habitat for beneficial insects, increase the microbial activity and reduce the leaching of herbicides into groundwater, which are all important requirements for a sustainable and environmentally friendly crop production (TILLMAN *et al.*, 2004; POTTER and BOSCH, 2007). A further important reason for cover crop cultivation, especially in reduced and no-tillage systems, is the suppression of weeds and volunteers. For effective and sustainable weed suppression, cover crops should fast reduce the photosynthetically active radiation (PAR) on the soil surface to prevent growth of weeds. Main requirements for fast PAR reduction are a quickly and intensive shading of the soil surface and a high above ground dry matter (DM) production (UCHINO *et al.*, 2011).

Today, mainly monocultures of yellow mustard (*Sinapis alba*), oilseed radish (*Raphanus sativus*) and phacelia (*Phacelia tanacetifolia*) are grown in Central Europe. Yellow mustard is the predominant cover crop because it offers lots of beneficial characteristics for simple and successful cultivation. Yellow mustard is easy to establish, covers the soil quickly and produces a high amount of above-ground biomass, which stores nitrogen and ensures a long shading of the soil surface (STIVERS-YOUNG, 1998; BODNER *et al.*, 2010). Due to these characteristics, yellow mustard is able to prevent soil erosion, to reduce leaching of nitrate into ground water and to control the growth of weeds and volunteers (BRENNAN and SMITH, 2005; BECKIE *et al.*, 2008). Although several cover crop species have a fast growth and high weed suppression ability, many field experiments indicate that cover crop mixtures are sometimes better suited for weed suppression (AKEMO *et al.*, 2000). Due to faster canopy closure, higher leaf area index and total DM production, polycultural plant stands have often higher competition ability against weeds than a single cover crop species (AKEMO *et al.*, 2000; SPEHN *et al.*, 2000; HAUGGAARD-NIELSENET *et al.*, 2001; UCHINO *et al.*, 2011). Not only for weed suppression, mixtures of plant species provide lots of benefits compared to a monoculture. Due to higher biodiversity, plant mixtures are characterized by improved DM production, increased water and nutrient-use efficiency and higher resilience to environmental influences (MORRIS and GARRITY, 1993; MALEZIEUX *et al.*, 2009; TILLMAN *et al.*, 2004). Especially the higher resilience to environmental influences and an adequate DM production under various site conditions are important factors for reliable and effective weed suppression by cover crops.

The objective of this study was the comparison of monocultural cover crops with cover crop mixtures regarding their growth and weed suppression ability in autumn and spring to determine if cover crop mixtures have the same ability for weed control than a competitive monocultural cover crop species.

Material and Methods

Field experiments in 2010 and 2011

The first field experiment was conducted in Baden-Württemberg at the experimental station Ihinger Hof (IHO) (48°74'N, 8°92'O, 478 m altitude) in 2010 and 2011, and at the experimental Station Meiereihof (MHO) (48°71'N, 9°21'O, 435 m altitude) in 2011. Soil type at IHO is a Haplic Luvisol with clay loam as soil texture in topsoil. Soil mineral nitrogen content (N_{min}) in topsoil (0-60 cm) at cover crop sowing was 18.1 kg N ha^{-1} in 2010 and 17.5 kg N ha^{-1} in 2011. The soil at MHO is classified as Haplic Luvisol with sandy clay loam as soil texture and an N_{min} content of 36.4 kg ha^{-1} in topsoil. No additional fertilizer was applied to test how cover crops perform in low-input cropping systems. The climatic conditions at IHO are characterized by an annual precipitation of 794 mm and an average temperature of 9.2 °C, while MHO has an annual precipitation of 700 mm and an average temperature of 8.8 °C. Treatments used in the experiment were yellow mustard with a seed density of 12.7 kg ha^{-1}, a cover crop mixture with a seed density of 50.0 kg ha^{-1} and a no cover crop control. The used cover crop mixture consisted of beerseem clover (*Trifolium alexandrinum*), common vetch *(Vicia sativa*), tartary buckwheat (*Fagopyrum tataricum*) and niger seed (*Guizotia abyssinica*) with a sowing ratio of 31%, 17%, 14% and 38%, respectively.

Field experiment 2012

The field experiment in 2012 was conducted at the experimental station Kleinhohenheim (KHH) (48°74'N, 9°21'O, 435 m altitude) in the south of Stuttgart. Soil type at KHH is a Haplic Luvisol with clay loam as soil texture in topsoil. N_{min} content in the 0-30 cm soil layer at cover crop sowing was 35 kg ha^{-1}. Equally to the previous experiment, no additional fertilizer was applied. Climatic conditions at the experimental station are characterized by an annual precipitation of 700 mm and an average annual temperature of 8.8 °C.

The tested treatments included two monoculture cover crop treatments, three cover crop mixtures and a no cover crop control. The monoculture treatments contain yellow mustard and hemp with a seeding rate of 20 kg ha^{-1} and 50 kg ha^{-1}, respectively. The "MELO" mixture was created for soil melioration and consists of forage radish (*R. sativus* L. variety *longipinnatus*), blue lupin (*Lupinus angustifolius*), berseem clover, fava bean (*V. faba*), flax (*Linum usitatissimum*), lopsided oat (*Avena strigosa*) and sorghum (*Sorghum bicolor*) with a sowing ratio of 15%, 15%, 15%, 15%, 20%, 15% and 5%, respectively. The "BETA" mixture included species which are not closely related to important cash crops in Central Europe, and consisted of niger seed, flax (*Linum usitatissimum*), phacelia, grain amaranth (*Amaranthus cruentus*), tartary buckwheat, common corncockle (*Agrostemma githago*) and lopsided oat with a sowing ratio of 20%, 15%, 20%, 10%, 10%, 10% and 15%, respectively. The "GPS" mixture was composed for usage as energy substrate in biogas plants and consists of rye (*Secale cereale*), triticale (*Triticosecale*), winter pea (*Pisum sativum*) and hairy vetch (*V. villosa*) with a sowing ratio of 35%, 10%, 25% and 30%, respectively. Seeding rate of MELO, BETA and GPS were 291 kg ha^{-1}, 34 kg ha^{-1} and 159 kg ha^{-1}, respectively.

Experimental design, data collection and statistical analysis

Experimental design in all trials was a randomized complete block with four replicates and a plot size of 2 m by 20 m. Cover crops were sown following to the main crop winter wheat in all experiments. Immediately after harvest, wheat straw was removed from the field and 5 cm deep tillage was conducted with a disc harrow in 2010 and 2011, while a rotary tiller was used in 2012. Cover crops were sown on August 21st, August 3rd, August 9th and August 8th at IHO 2010, IHO 2011, MHO 2011 and KHH 2012, respectively.

Soil coverage was determined by capturing RGB-pictures with a digital camera from an area of 12 m^2 in each plot eight weeks after planting (WAP). Pictures were analyzed with the computer program "ImageJ" Version 1.47a. After converting pictures into HSB-format, the procedure "Color Threshold" was used to separate green color of plants from bare soil. The estimation of separated areas was carried out using the procedure "Analyze Particles". In the field experiment 2012, reduction of the photosynthetically active radiation (PAR) by the cover crop stand was determined using the Apogee quantum sensors "MQ-100" 52 days after planting. To estimate PAR reduction by cover crops, PAR on the soil surface was compared with the PAR value directly over the canopy. For determination of cover crop and weed DM, plant samples were taken from an area of 0.5 m^{-2} eight WAP. After harvest, plant tissue was dried for three days at 80 °C. At the beginning of the vegetation period in spring, density of weeds was measured using a 0.1 m^2 frame at four randomly selected positions in the plots.

Results were analyzed using the statistical language R version 2.15 (R CORE TEAM, 2012). To compare soil coverage of cover crops in 2012, the "drc-package" version 2.3-0 was used as described by RITZ and STREIBIG (2005). Weekly values of soil coverage were compared with maximum soil coverage, transformed in percent values and afterwards fitted by a three-parameter logistic curve. T_{90}-values, which express the time (in days after planting) of 90% soil coverage, were calculated and compared using "ED" and "SI" procedures, respectively. Comparison of soil coverage in 2010 and 2011, DM of cover crops and weeds, and the weed density were conducted by analysis of variance. Data were checked for normality using the Shapiro-Wilk test and by the Levene-test for homogeneity of variance, and afterwards log-transformed if needed to achieve requirements for the statistical analysis. Afterwards multiple comparison tests were performed with the Tukey-Test at a significance level of $\alpha \leq 0.05$.

Results

Weather conditions

Weather conditions between August and November in 2010 were cold and rainy and inhibited adequate cover crop growth, especially of thermophilic species. In the following growing season during autumn 2011, weather was characterized by many warm and sunny days and adequate precipitation for cover crop growth. In autumn 2012, good growing conditions occurred in August and October, while September was characterized by weather colder than the long-term average.

Tab. 1 Monthly average temperature and precipitation during the experimental seasons at Ihinger Hof, Meiereihof and Kleinhohenheim.

Tab. 1 *Monatsmittelwerte von Temperatur und Niederschlag während der Versuchszeiträume an den Standorten Ihinger Hof, Meiereihof und Kleinhohenheim.*

Location	Air temperature (°C)				Precipitation (mm)			
	Aug.	Sept.	Oct.	Nov.	Aug.	Sept.	Oct.	Nov.
Ihinger Hof 2010	16.4	12.1	7.8	4.6	80.5	43.5	42.0	76.5
Ihinger Hof 2011	18.4	15.4	9.2	5.0	54.4	60.8	58.5	0.6
Meiereihof 2011	18.8	16.4	10.0	5.0	56.1	28.4	29.3	0.6
Kleinhohenheim 2012	20.1	14.5	9.3	5.7	42.6	43.6	51.0	128.4

Field Experiment 2010 and 2011

In 2010, yellow mustard had a 23.3% higher soil coverage than the cover crop mixture eight WAP (Fig. 1). In the following growing season, the cover crop mixture had a 15.5% higher soil coverage than yellow mustard at IHO eight WAP, while at MHO both treatments covered the soil in a similar amount. In the first growing season, DM of yellow mustard was more than four times higher than those of the cover crop mixture. In 2011, DM of both cover crop treatments was similar at IHO, however, at MHO, yellow mustard produced 488 g m^{-2} DM while the cover crop mixture was only able to produce 280 g m^{-2}.

Weed pressure was different during the experiment. While in the first growing season only 21 g m^{-2} DM was produced in the control plots at IHO, in 2011, there were 72 g m^{-2} at IHO and 236 g m^{-2} at MHO. In 2010, yellow mustard reduced weed DM by 92% eight WAP, while the cover crop mixture reduced weed DM by 61%. In 2011, yellow mustard and the cover crop mixture showed similar weed reduction by 94% and 87% at IHO. However, at MHO in 2011, the cover crop mixture reached only a weed suppression of 74%, while yellow mustard was able to reduce weed DM by 92%. At all location in both growing seasons, almost no weeds (less than three plants m^{-2}) occurred in plots of yellow mustard in spring. The cover crop mixture offered different results and could reduce weed density in spring by 38%, 86% and 88% at IHO in 2010, IHO in 2011 and MHO in 2011, respectively.

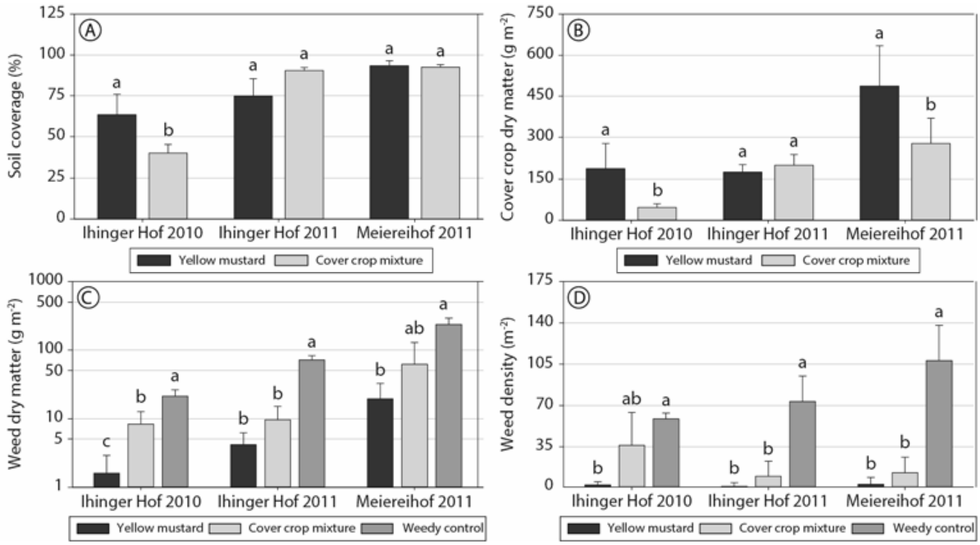

Fig. 1 Soil coverage (A), cover crop dry matter (B), weed dry matter in autumn (scaled logarithmically) (C) and weed density in spring (D) at Ihinger Hof and Meiereihof in 2010 and 2011. Bars represent mean values ± standard deviation. Within each location and year, significant differences (α≤0.05) are indicated by bars topped with different letters.

***Abb. 1** Bodenbedeckung (A), Trockenmasse der Zwischenfrüchte (B), Trockenmasse der Unkräuter im Herbst (logarithmisch skaliert) (C)sowie Unkrautdichte zu Vegetationsbeginn (D) an den Standorten Ihinger Hof und Meiereihof in den Jahren 2010 und 2011. Mittelwerte innerhalb eines Standortes und Jahres mit demselben Buchstaben weisen bei einem Signifikanzniveau von α≤0.05 keine Unterschiede auf. Die Fehlerbalken stellen jeweils die Standardabweichung der Messwerte dar.*

Field Experiment 2012

In 2012, yellow mustard had the lowest T_{90}-value and required 33 days for 90% soil coverage. MELO, BETA and GPS showed T_{90}-values of 37 days, 39 days and 42 days, respectively, which were similar to yellow mustard (Fig. 2). Hemp needed 47 days for 90% soil coverage, which was the longest period of all cover crops. The PAR on the soil surface was reduced through yellow mustard, MELO, and BETA by more than 98% after a growing period of 52 days. The GPS mixture offered a higher PAR value than the other cover crop mixtures and reduced the PAR on the soil surface by 96%. The highest PAR value was measured in plots of hemp, where a PAR reduction of 91% occurred. In general, all cover crop treatments showed a good growth and produced a high amount of DM during the experiment. The highest DM was measured in plots of yellow mustard with 538 g m^{-2}, however, no difference to BETA could be detected. Hemp, the other monocultural cover crop, produced a DM of 372 g m^{-2}, which was similar to MELO and BETA. The smallest DM amount was measured in plots with the GPS mixture that reached only a value of 234 g m^{-2}.

Growth of weeds was most effectively controlled by yellow mustard that could reduce weed DM by 98%. MELO and BETA had similar weed suppression and were able to reduce weed DM by more than 96%. Hemp and the GPS mixture offered a lower weed reduction compared with the other treatments and could reduce weed DM only by 85% and 79%. Over winter, all cover crop species died due to frost, except the species in the GPS mixture. In spring, weed DM was reduced by 98% in yellow mustard, which was the strongest weed suppression. Similar values to yellow mustard occurred in plots of MELO, BETA and GPS, where a weed reduction of 94%, 96% and 96% was measured, respectively. Lowest weed suppression among all treatments was observed in plots of hemp, with a weed DM reduction by 71%.

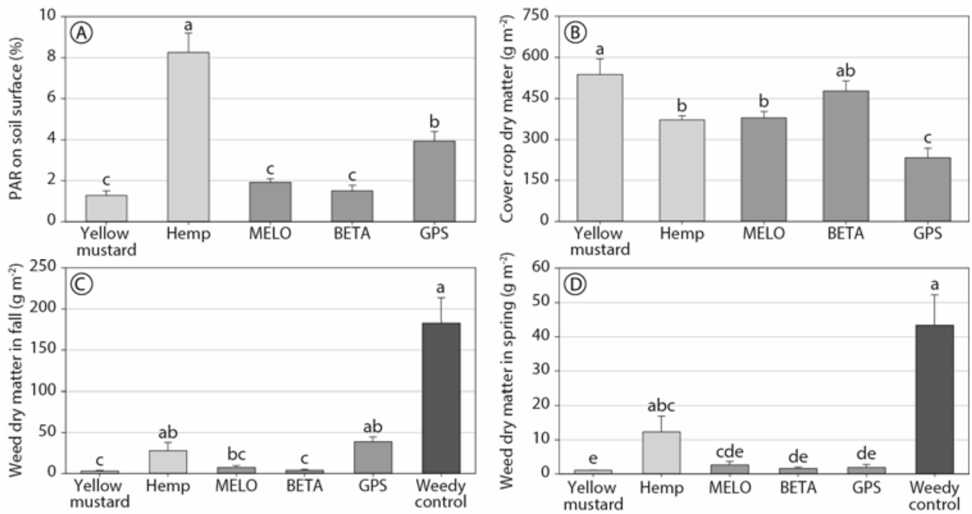

Fig. 2 Photosynthetically active radiation (PAR) (A), cover crop dry matter (B), weed dry matter in autumn (C) and weed dry matter in spring (D) at Kleinhohenheim in 2012. Bars represent mean values ± standard deviation. Significant differences (α≤0.05) are indicated by bars topped with different letters.

Abb. 2 *Photosynthetisch aktive Strahlung (PAR) (A), Trockenmasse der Zwischenfrüchte (B), Trockenmasse der Unkräuter im Herbst (C) sowie Trockenmasse der Unkräuter zu Vegetationsbeginn (D) am Standort Kleinhohenheim im Jahr 2012. Mittelwerte mit demselben Buchstaben weisen bei einem Signifikanzniveau von α≤0.05 keine Unterschiede auf. Die Fehlerbalken stellen jeweils die Standardabweichung der Messwerte dar.*

Discussion

Field experiment 2010 and 2011

Reason for the poor soil coverage and DM amount of the cover crop mixture compared to yellow mustard was probably the cold and rainy weather in 2010. The unfavorable weather conditions prevented good growth of tartary buckwheat and niger seed, which together had a 52% proportion of the entire plant density in the used mixture. For good growth, especially niger seed needs temperatures between 15 °C and 23 °C, which rarely occurred during autumn (GETINET and SHARMA, 1996). In comparison to niger seed and tartary buckwheat in the mixture, yellow mustard as a *Brassicacea* performed adequately even under cool weather conditions in autumn, which complies to earlier studies (BRENNAN and SMITH, 2005; KRUIDHOF *et al.*, 2008). While in 2010 the weather conditions limited growth of the cover crop mixture at IHO, growth conditions for cover crops were much better at both locations in the following year. While yellow mustard could take advantage of the good weather at MHO, similar soil coverage and growth as in the previous growing season were observed at IHO. This observation was mainly caused by to the low N_{min} content that prevent higher dry matter production of yellow mustard at IHO. Although N_{min} content had only the half amount at IHO compared to MHO, soil coverage and dry matter production of the cover crop mixture was similar at both locations. This may have been caused the amount of 31% beerseem clover and 17% common vetch in the mixture. In contrast to niger seed and tartary buckwheat in the mixture, beerseem clover and common vetch showed no visual symptoms of nitrogen deficiencies, especially in later growth stages. A very likely reason for this could be the fact that beerseem clover and common vetch belong to the *Fabaceae* family that does not require high amounts of nitrogen from the soil due to their ability to fix atmospheric nitrogen by symbiosis with rhizobia. Therefore, inclusion of legumes into a cover crop mixture ensures good growth even under nitrogen-limited conditions (HEICHEL and HENJUM, 1991).

The reduced weed control of the mixtures in fall 2010 and at MHO in 2011 was mainly caused by a slow and poor soil coverage and DM production. Due to slow growth within the first few WAP in combination with a high weed pressure, the cover crop mixture was not able to stop weed growth. Reason for the high weed density in plots of the cover crop mixture in spring 2011 was the reduced growth and early death of niger seed and tartary buckwheat due to frost in autumn 2010. Caused by a reduced cover crop density, sunlight could again reach the soil surface, which enhance the growth of previously shaded weeds and promote further germination of weed seeds (BALLARÉ and CASAL, 2000). Although the cover crop mixture could only reduce weed DM to a low amount at MHO in autumn 2011, weed density was very small in spring. The main reasons for this were continued competition and shading by the cover crop mixture as well as the high frost tolerance of common vetch that leads to an active suppression of weeds until start of heavy frosts in winter.

Field Experiment 2012

Due to good growing conditions and adequate nitrogen availability, the soil coverage was mainly influenced by the specific leaf morphology and the plant density of the cover crop stand (UCHINO *et al.*; 2011). The lack of shading in the GPS plots was caused by the reduced shoot length of the plant species and additionally the steeper leave angle of rye and triticale (DIDON, 2002). The inadequate PAR reduction of hemp was mainly a result of reduced plant and leaf area density that was caused by an early switch into the generative growth stage due to the short day length in autumn (COSENTINO *et al.*, 2012). The high DM production of yellow mustard in the field experiment 2012, which was already observed during the first field experiment, is consistent with earlier results of DAUGOVISH *et al.* (2002) and BECKIE *et al.* (2008). Additionally, previous results indicate that yellow mustard is well adapted to autumn growing conditions and one of the fastest growing cover crop species if adequate amount of nitrogen is available (STIVERS-YOUNG, 1998). Only the BETA mixture offered similar growth to yellow mustard, probably because it included niger seed and tartary buckwheat that are both characterized by fast growth and high DM production (GETINET and SHARMA, 1996; CAMPBELL, 1997; HERRERA *et al.*, 2010). Hemp offered reduced DM allocation compared to yellow mustard due to its fast shift into generative growth stage that prevented continued production of leaves and a higher DM accumulation, as described by COSENTINO *et al.* (2012). The MELO mixture offered equal DM production as monocultural hemp, however, focus of this mixture is not the above but the below ground growth and DM production. Therefore the selection of the included plant species was based on a strong root growth and not on their shoot growth potential. Reason for the delayed DM production of the GPS mixture in autumn was the selection of the included plant species (rye, triticale, winter pea and hairy vetch) that all have their main growth period in spring.

The reduced weed control in plots of hemp and the GPS mixture are mainly a result of their low ability to reduce PAR under the cover crop canopy (BILALIS *et al.*, 2010). Especially the high PAR value in plots of hemp promoted the growth of weeds. The higher weed control of MELO and BETA compared with hemp indicates that fast soil coverage and intensive shading is more important for weed suppression than only a high DM production. These observations confirm earlier results that emphasize a fast canopy closure and longtime intensive shading as the main factors for sustainable weed control by cover crops in autumn (UCHINO *et al.*, 2011). For fast, complete and longtime shading, an adapted and well-balanced cover crop mixture should be better suited than a monocultural cover crop due to different shoot height, leave morphologies and development rates of the included plant species. Because all included species are frost tolerant, the GPS mixture was able to reduce weed growth not only in autumn but also during the winter months and in early spring. Contrastingly to the GPS mixture, weeds in plots with hemp were able to regrow due to lack of competition and shading. Early death of frost sensitive cover crop species in autumn is a major problem for a continuous suppression of weeds until spring. If cover crops are killed during frosty nights in autumn, sunlight can reach the soil surface and promote the regrowth of already suppressed weeds or even the emergence of new weed seedlings (BALLARÉ and CASAL, 2000). Especially, monocultural cover crop stands with frost-sensitive cover crop species such as niger seed or tartary buckwheat can freeze early in autumn and then no further weed control is possible. However, the BETA mixture which includes niger seed and tartary buckwheat showed that a mixture of frost sensitive and frost tolerant plant species is able to control weed growth even after the death of frost sensitive plant species, if the proportion of frost tolerant species is not too low.

Conclusions

Cover crop mixtures have the ability to control weed growth like competitive monocultural cover crops. As a precondition for successful and sustainable weed suppression, however, cover crop mixtures should include fast growing plant species that early cover the soil surface, plant species with a long vegetative growth stage and frost tolerant plant species in an appropriate ratio.

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