Mechanical control of weeds within the crop row of organically grown soybeans

Mechanische Unkrautregulierung in der Saatreihe von Soja

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Summary

Despite the increasing demand for organically grown soybeans (*Glycine max* (L.) Merr.), this crop is barely cultivated on organic farms in Switzerland. One reason is that an economically feasible organic cultivation of soybeans mainly depends on the successful control of weeds – especially within the crop row. The aim of this study was to investigate the effect of three types of weeding machines (finger hoe = FI, torsion hoe = TO, weeder harrow = WE) and of two combinations thereof (FI+WE, TO+WE) on the control of two model weed species (*Brassica x chinensis* L. and *Phacelia tanacetifolia* L.) seeded at the same time as the soybean directly in the rows of soybeans. In all plots, including the control plots, hoeing between the rows was conducted. Experiments were conducted from 2007 to 2010 in the surrounding of Zurich (Switzerland). Soil cover (%) of the two model weed species and soybeans in the crop row was evaluated. In addition, the yield of the main crop was assessed in two growing seasons.

Averaged over three years, the soil cover within the crop row was reduced after two interventions by 17 % (WE) up to 45 % (FI) for *P. tanacetifolia* when the machines were used alone. The combination of the machines increased the effect and resulted in the best control with FI+WE with a reduction of 60 %. A comparable effect with the same ranking of the machines was found for *Brassica x chinensis*. FI+WE did not only provide the highest weed control level but also showed significantly higher yields (2.91 t/ha) than the control (2.49 t/ha). The data show that the control of weeds within the row of soybeans can be successful and as a consequence also the cultivation of organically produced soybean. However, the optimal plant growth stages for the weed regulation has to coincide with ideal weather and soil conditions.

Keywords: *Brassica x chinensis* L., *Glycine max* (L.) Merr., organic farming, *Phacelia tanacetifolia* L.

Zusammenfassung

Trotz zunehmender Nachfrage nach biologisch angebauter Soja (*Glycine max* (L.) Merr.) wird diese interessante Kultur in der Schweiz selten angebaut. Grund dafür ist die langsame Jugendentwicklung und die damit im Ökolandbau verbundenen Herausforderungen für eine wirtschaftliche und gleichzeitig wirksame Regulierung der Begleitflora, insbesondere in den Reihen der Soja. Ziel dieser Versuche war es, die Wirkung von drei verschiedenen Unkrautregulierungs-geräten (Fingerhacke = FI, Torsionshacke = TO, Striegel = WE) und zwei Kombinationen davon (FI+WE, TO+WE) auf zwei direkt in die Sojareihen eingesäten Pflanzenarten (*Brassica x chinensis* L. und *Phacelia tanacetifolia* L.) zu untersuchen. Die Versuche wurden von 2007 bis 2010 in der Umgebung von Zürich (Schweiz) durchgeführt. Der Bodenbedeckungsgrad (%) der beiden Pflanzenarten sowie der Hauptkultur wurde in der Sojareihe erfasst. Zusätzlich wurde in zwei Jahren der Ertrag von Soja erfasst.

Im Mittel von drei Jahren konnte nach zwei Durchgängen der Bodenbedeckungsgrad von *P. tanacetifolia* um 17 % (WE) bis 45 % (FI) vermindert werden, wenn die Maschinen einzeln eingesetzt wurden. Die Kombination der Maschinen verstärkte den Effekt und führte im besten Verfahren zu einer Reduktion von 60 % (FI+WE). Einen vergleichbaren Effekt mit derselben Rangfolge der Verfahren wurde für *Brassica x chinensis* beobachtet. Das Verfahren Fingerhacke kombiniert mit dem Striegel (FI+WE) hatte nicht nur die beste unkrautunterdrückende Wirkung sondern führte zusätzlich zu einem signifikant höheren Kornertrag (2,91 t/ha) als das Kontrollverfahren (2,49 t/ha). Die Daten zeigen, dass die untersuchten Pflanzenarten in der Reihe wirksam reguliert werden können und folglich auch Soja unter biologischen Bedingungen erfolgreich angebaut werden kann. Voraussetzung ist aber, dass die mechanischen Eingriffe in einem optimalen Pflanzenstadium sowie bei guten Witterungs- und Bodenbedingungen erfolgen können.

Stichwörter: Biologischer Landbau, *Brassica x chinensis* L., *Glycine max* (L.) Merr., *Phacelia tanacetifolia* L., Phacelia, Rübsen

1. Introduction

Soybean (*Glycine max* (L.) Merr.) is the most important oil crop worldwide. Additionally to the high oil content, the plant provides high quality protein for human and animal nutrition. In Switzerland, there is a rising demand for organically-grown soybean. Despite of the interesting price and its positive effect on the following crop (N input via N-fixation), farmers do not cultivate soybeans because of the challenge of successful control of weeds due to the slow initial development of soybeans and the risk of weed presence during the ripening of the soybean. Nevertheless, indirect or direct methods such as planting in narrow rows, increase of seed density, intercropping and flame weeding are known to control weeds in organic soybean production. Hoeing in between the rows can be effective (IRLA, 1995) but its success depends on weather and soil conditions. The mechanical control of weeds within the crop row is difficult. The objective of this study was to investigate the effect of three types of weeding machines and two combinations thereof on the soybeans itself and on two plant species sown in the crop row.

2. Materials and methods

2.1 Plant material, experimental location and treatments

The field study was conducted from 2007 to 2010 at Agroscope Reckenholz-Tänikon Research Station (ART) in Zurich (450 m above sea level, average temperature: 9.2 °C, average annual precipitation: 1040 mm) on a brown earth soil. Soybeans (*Glycine max* (L.) Merr. cv. Gallec) were sown with a row distance of 0.36 m. As model weeds two dicotyledonous species [the fast growing and competitive *Brassica x chinensis* L. (8 kg/ha) and the less competitive *Phacelia tanacetifolia* L. (4 kg/ha)] were sown at the same time as the soybean directly into the row of soybeans. Neither chemicals nor fertilizers were applied. Three different types of machines were applied twice (Tab. 1) to control weeds within the row of the main crop: Torsion hoe (TO), finger hoe (FI) and weeder harrow[2] (WE). In addition two combinations thereof were investigated TO+WE and FI+WE. In all plots, including the control (H), hoeing in between the crop rows was applied. Before and after each investigation, the soil cover (%) of the model weeds, of other occurring plant species as well as of soybeans was scored two times per plot on a length of 1 m in the ultimate proximity of the crop row resulting in an area of 0.25 m^2 each. By the end of September, soybeans were harvested with a small plot combine. Yields have been corrected to t/ha at 11 % humidity.

Tab. 1 Dates of sowing, interventions applied to control weeds (with growth stage of the main crop) and harvest date of the soybean field trials conducted from 2007 to 2010 in the surrounding of Zurich.

Tab. 1 *Saat- und Erntetermine sowie Zeitpunkte der Unkrautregulierungsmassnahmen (inklusive Wachstumsstadium der Hauptkultur) in den Feldversuchen mit Soja der Jahre 2007 bis 2010 in der Umgebung von Zürich.*

Agricultural practice	Year			
	2007	2008	2009	2010
Sowing	April 26	May 6	May 8	April 23
Intervention 1 (BBCH[1])	May 11 (11)	May 16 (10)	May 22 (11)	June 5 (12)
Intervention 2 (BBCH)	*	May 23 (11)	June 3 (13)	June 15 (>14)
Harvest	*	Sept. 29 (89)	Sept. 30 (89)	*

[1]BBCH (Biologische Bundesanstalt für Land- und Forstwirtschaft, Bundessortenamt für Chemische Industrie), MUNGER et al. (1997). *trial not continued.

2.2 Experimental design and data analysis

The experiments were established in a strip plot design with three replicates. Within each strip the treatments were distributed randomly. Plot size was 12.75 m^2 and 6.75 m^2 in 2007 and 2008 to 2010, respectively. Prior to analyses, data were checked for normal distribution. Statistical analyses were

[2]English translation for the German weeding machine „Striegel“

conducted with the open source Programme R (R DEVELOPMENT CORE TEAM, 2007) using analysis of variance (ANOVA). Mean separation was accomplished using Tukey HSD (Honestly Significant Difference) test at a 0.05 probability level.

3. Results

Analyses of variance did not reveal any significant interaction between the factor year and management for any of the data analyzed except for the soil cover of *P. tanacetifolia* after the first intervention (P.1). This significant interaction was due to data of 2010 where the weeder harrow in combination with the torsion hoe did not increase the effect of the torsion hoe (if applied alone).

3.1 Impact of the tested machines on the soil cover of the two model weeds

After the first intervention, no impact on the two model weed species was observed (Tab. 2). After the second intervention, soil cover of *P. tanacetifolia* reached 19 % in the control treatment and was reduced with the finger hoe (FI) by 45 %. This effect was even more pronounced when FI was applied in combination with the weeder harrow (FI+WE) and decreased the cover of *P. tanacetifolia* by 60 %. Also for torsion hoe (TO), the effect was increased from 18 % to 49 % when applied in combination with the weeder harrow (TO+WE). This effect was less pronounced for *Brassica x chinensis* resulting in a significant decrease only for FI+WE after the second intervention. Soil cover did not differ before harvest for *Brassica x chinensis* whereas for *P. tanacetifolia,* the effect of TO+WE and FI+WE still was observed (data not shown). The date of the first intervention had an impact on the effect of the treatments applied: Due to unfavourable weather conditions in 2007 and 2010 the first intervention took place late. Hence, little effect of the treatment was observed allowing *Brassica x chinensis* to overgrow the soybeans. Additionally, the relatively early sowing in 2007 and 2010 may have led to a comparatively faster development of *Brassica x chinensis* compared to the thermophile soybean which led to the imbalance of the species investigated in this experiment. As a result, the experiments were stopped and not harvested (Tab. 1). However in 2008 and 2009 good weather conditions allowed an early first weed regulation and as a consequence treatment effects were more pronounced.

3.2 Impact of the tested machines on the soil cover of the soybeans and its yield

Comparable to the two model weed species also the soybeans were most affected by FI+WE. In contrast to the effect observed for the weed species, the effect in soybeans was already significant after the first intervention, reducing the soil cover by 21 % when compared to the control (Tab. 2). Nevertheless, this reduction did not affect the yield and even a significantly higher yield was obtained with FI+WE (2.91 t/ha) when compared to the control (2.49 t/ha). Yields were slightly higher in 2009 compared to 2008 reaching 2.86 t/ha and 2.59 t/ha, respectively.

A significant negative correlation ($r = -0.5$, $p < 0.001$) between total weed soil cover (including also other monocotyledonous and dicotyledonous plant species) after the second intervention and soybean yield was observed (Fig. 1).

Tab. 2 Means for soil cover (%) of *Brassica x chinensis* (B.), *Phacelia tanacetifolia* (P.) and the main crop *Glycine max* (G.) in the years 2007 to 2010 before the first (P.0, B.0, G.0), after the first (P.1, B.1, G.1) and after the second (P.2, B.2, G.2, only 2008 - 2010) intervention with a weeder harrow (WE), a finger hoe (FI), a torsion hoe (TO) or combinations thereof (FI+WE, TO+WE) in the surrounding of Zurich.

Tab. 2 *Mittelwerte der Bodenbedeckungsgrade (%) von Brassica x chinensis (B.), Phacelia tanacetifolia (P.) und der Hauptkultur Glycine max (G.) in den Jahren 2007 bis 2010 vor dem ersten (P.0, B.0, G.0), nach dem ersten (P.1, B.1, G.1) bzw. nach dem zweiten (P.2, B.2, G.2, nur 2008 – 2010) Eingriff mit einem Striegel (WE), einer Fingerhacke (FI), einer Torsionshacke (TO) oder Kombinationen davon (FI+WE, TO+WE) in der Umgebung von Zürich.*

Treatment	**Soil cover (%)**								
	P.0	**P.1**	**P.2**	**B.0**	**B.1**	**B.2**	**G.0**	**G.1**	**G.2**
Control (H)	5.7	8.1	19.3	18.0	21.3	27.5	11.0	18.7	41.0
WE	5.4	6.7	14.1	18.0	21.0	28.0	11.2	17.4	37.9
FI	4.9	6.0	10.6	17.3	21.0	26.9	11.0	16.2	36.8
FI + WE	4.7	5.5	7.7	18.4	19.5	21.7	11.6	14.7	34.2
TO	5.0	6.1	13.9	19.0	23.0	27.0	10.4	17.3	39.0
TO + WE	4.9	5.9	9.8	17.0	19.6	24.0	10.6	16.4	35.9
SD[1]	0.35	0.92	4.09	0.72	1.24	2.49	0.41	1.36	2.41
Tukey HSD[2]	2.07	2.77	2.95	8.41	8.77	5.07	3.36	3.50	5.76

[1] SD = Standard deviation; [2] Tukey HSD at a 0.05 probability level.

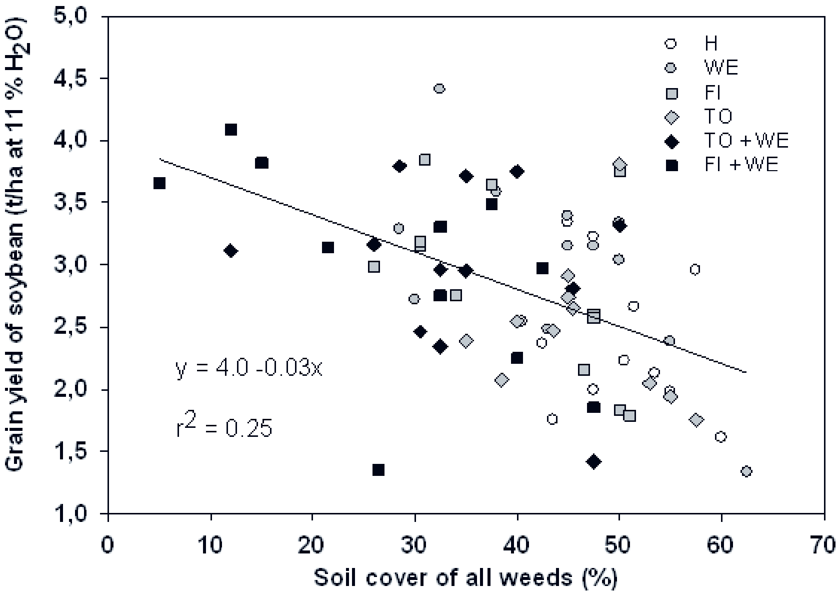

Fig. 1 Soybean yield (t/ha at 11 % humidity) and total soil cover (%) of all non-crop plant species after the second intervention with weeder harrow (WE), torsion hoe (TO), finger hoe (FI) or combinations thereof (TO + WE, FI + WE) in comparison to the control (H = hoeing in between the crop rows) in trials in the surrounding of Zurich (2008 – 2009).

Abb. 1 *Ertrag von Sojabohnen (t/ha bei 11 % Feuchtigkeit) und Bodenbedeckungsgrad (%) aller Begleitarten nach dem zweiten Eingriff mit Striegel (WE), Torsionshacke (TO), Fingerhacke (FI) oder Kombinationen davon (TO + WE, FI + WE) im Vergleich zur Kontrolle (H = Hacken zwischen den Reihen). Versuche der Jahre 2008 und 2009 in der Umgebung von Zürich.*

4. Discussion

Reduction of weed soil cover was observed when TO or FI were applied alone, which is in line with the effects reported by ZILLGER et al. (2006). The effect was increased by the combination of either of the hoes with the weeder harrow (FI + WE or TO + WE) but became only significant after two applications. Though, the effect depended on the model weed species which may be a consequence of the higher competitiveness of *Brassica x chinensis* resulting in a more pronounced effect on *P. tanacetifolia* when compared to *Brassica x chinensis*. Other monocotyledonous and dicotyledonous plant species as well as volunteers were present in the trials but the weed pressure was mainly due to the sown (model) weed species (data not shown). As observed especially in the year 2008, small soybean plants (≤ BBCH 11) suffered more from the intervention applied than plants in a later growth stage. But since this was also the case for the weeds, the determination of the optimal time is crucial in order not to harm the soybean to a greater extent than the weeds. Thus weed control within and also between the crop row is promising if it is applied as early as possible (MÜCKE and MEYERCORDT, 2011; PROOST et al., 1998). However, ideal weather and soil conditions are necessary. Although soybeans may suffer from an early intervention, experiments showed that soybean yield is generally not negatively affected even with the most aggressive treatment investigated in this study. Although a fairly wide range for the grain yield of soybean within the different treatments was detected, the average yield level of the presented experiments is in line with the findings of other studies in southern Germany and the Alsace (VETTER and NAWRATH, 2001).

4.1 Conclusions

The combination of the finger hoe with the weeder harrow (FI+WE) is an effective mean to control weeds within the crop row without reducing the yield of soybean. The torsion hoe in combination with the weeder (TO+WE) also revealed good efficacy though being less distinct compared to the finger hoe in combination with the weeder (FI+WE). It can therfore be considered to use the combination TO+WE for the first intervention after emergence of the soybean and the more aggressive combination FI+WE for the following ones. As the timing of the mechanical control of weeds remains important for the success of any mechanical means, the risk of heavy weed infestation should be prevented by the selection of fields for the cropping of soybean with a low weed pressure. Soils with a serious amount of stones could also cause problems by damaging the combine at the time of the harvest, since every mechanical treatment moves the soil and stones are brought up to the surface. In order to allow farmers to use the best combination of weeding machines, special equipment is necessary (inter-axis-mounted hoe combined with a weeder at the rear) which can be costly and should therefore be used on larger farms or be shared by several farmers to reduce fix costs. Data from on-farm trials, different soils and various weed communities are needed in order to gain a broader data set allowing recommendations for various regions in Switzerland.

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