Chemical and mechanical weed control in soybean (*Glycine max*)

Chemische und mechanische Unkrautkontrolle in Sojabohne (Glycine max)

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Abstract

In this study we investigated the possibility of chemical and mechanical weed control strategies in soybean. Soybean field experiments were carried out in 2013 and 2014 in Southern Germany. Five treatments including common herbicide mixtures and four mechanical weed control treatments, implementing a harrow and a hoe, were tested at different locations. In the herbicide experiments two treatments were applied by PRE emergence herbicides (metribuzin, clomazone, dimethenamid and metribuzin, flufenacet, clomazone) and another two treatments were sprayed with a combination of PRE + POST emergence herbicides (metribuzin, flufenacet, thifensulfuron and pendimethalin, thifensulfuron, bentazone, cycloxydim). Furthermore, a POST herbicide treatment was implemented (thifensulfuron, bentazone, thifensulfuron and fluazifop-P-butyl). In the mechanical weed control experiments, treatments were: three times hoeing, PRE emergence harrowing plus three times hoeing, hoeing and harrowing in rotation or three times harrowing. In both experiments an untreated control was included. A 90% weed control efficacy and 23% yield increase was observed in the POST herbicide treatment. PRE + POST treatments resulted in 92% to 99% weed control efficiency and 15% yield increase compared to the untreated control. In the mechanical weed control experiments the combination of PRE emergence harrowing and POST emergence hoeing resulted in 82% weed control efficiency and 34% higher yield compared to the untreated control. Less weed control efficiency (72%) was observed in the harrow treatment, leading to 20% higher yield compared to the control. The suitability of both strategies for implementation in "Integrated Weed Management" has been investigated.

Keywords: Harrowing, herbicide, hoeing, soybean, weed control efficacy

Zusammenfassung

In den Jahren 2013 und 2014 wurden Feldversuche mit chemischen und mechanischen Strategien zur Unkrautkontrolle in Sojabohnen angelegt. Die chemischen Experimente setzten sich aus fünf Herbizidvarianten und einer Kontrolle zusammen. In zwei der Varianten wurden Vorauflaufherbiziden mit den Wirkstoffen Metribuzin, Clomazone und Dimethenamid (Variante 1) und einer Kombination aus Metribuzin, Flufenacet und Clomazone (Variante 2) eingesetzt. Zwei weitere Varianten beinhalteten Herbizide aus dem Vor- und Nachauflauf mit den Wirkstoffen Metribuzin, Flufenacet und Thifensulfuron (Variante 3) sowie Pendimethalin, Thifensulfuron, Bentazon und Cycloxydim (Variante 4). Die fünfte Variante beinhaltete eine reine Nachauflaufstrategie mit den Wirkstoffen Thifensulfuron, Bentazon, Thifensulfuron und Fluazifop-P-butyl. In den mechanischen Experimenten wurde in Variante 1 drei Hacküberfahrten durchgeführt. In den weiteren Varianten wurde entweder im Vorauflauf gestriegelt und anschließenden ebenfalls dreimalig gehackt (Variante 2), die Hacke und der Striegel im Nachauflauf abwechselnd eingesetzt (Variante 3) oder ausschließlich der Striegel zur Unkrautkontrolle verwendet (Variante 4). Zudem wurde eine Kontrollvariante in der die Unkräuter von Hand reguliert (Variante 5) wurden und eine Variante ohne jegliche Unkrautkontrolle durchgeführt (Variante 6). Eine Effizienz in Bezug auf die Unkrautkontrolle von 90 % konnte in den Nachauflaufherbiziden beobachtet werden. Die Varianten mit Vorauflaufherbiziden und den Kombinationen aus Vor- und Nachauflaufherbiziden zeigten Werte von 92 % bis 99 % verglichen mit der unbehandelten Kontrolle. Der Ertragszuwachs in der Nachauflaufvariante betrug 23 % während in den Varianten mit Kombination aus Vor- und Nachauflauf ein Ertragszuwachs von 15 % verglichen zu unbehandelten Kontrolle erfasst wurde. In den Versuchen mit mechanischer Unkrautkontrolle zeigte die Variante aus Vorauflaufstriegeln mit anschließend dreimaligem Hacken im Nachauflauf einen Bekämpfungserfolg von 82 % und eine Ertragssteigerung von 34 % verglichen mit der Kontrollvariante. Bei dem Einsatz des Stiegels (Variante 4) konnte eine Unkrautkontrolle von 72 % bei einer Ertragssteigerung von 20 % beobachtet werden.

Stichwörter: Hacken, Herbizide, Sojabohne, Striegeln, Unkrautkontrolle

Introduction

During the last decades, the demand of soybean products increased in central Europe. Currently, soybean requirements are covered by imports from North- and South-America. Plant improvements resulted in the adaption of soybean cultivation to the cool growing season of the Central European climatic conditions. In the early development stages, soybean plants are highly competed for resources and nutrients by weeds (VAN ACKER et al., 1993). Therefore weed control is mandatory in the early growth stages. In Europe the most common weed species found in soybean are *Echinochloa crus-galli* (L.) P. beauv., *Chenopodium album* (L.) and *Amaranthus retroflexus* (L.) (SCHROEDER et al., 1993). Weed control is commonly performed either by chemical products or mechanically. UNSLEBER (2015) pointed out different gaps in the effectiveness of herbicides concerning different weed species. In this study different combinations of herbicides, registered in soybean, were proofed to evaluate weed control efficiency at different locations. KUNZ et al. (2015) presents the potential of mechanical weed control by hoeing and harrowing for sugar beet and soybean. In conventional hoeing intra row weed control is often inadequate. The aim of this study was to investigate chemical and mechanical weed control strategies and their ability in weed control efficiency at different locations.

Materials and Methods

Field experiments were carried out in 2013 and 2014 in Southern Germany. Chemical weed control was performed at three locations: "Main-Tauber-Kreis", "Ortenaukreis" and "Tübingen". The experiments included five different herbicide treatments and one untreated control. Treatments differed in active ingredients (a.i.), herbicide rate and application time (Tab. 1). PRE and POST herbicides were spread in BBCH 03-05 and BBCH 12-17, respectively.

Tab. 1 Deployed herbicides, mode of actions and application rate of the treatments. ToA = Time of application.

Tab. 1 *Eingesetztes Produkt, der Wirkstoff und die Aufwandmenge der Varianten. ToA = Time of application (Applikationszeitpunkt).*

Chemical experiments				
Treat-ment	**ToA**	**Trade name**	**Active ingredients (a.i.)**	**Rate of a.i. [g ha^{-1}] / [ml ha^{-1}]**
1	PRE	Spectrum + Sencor + Centium	dimethenamid + metribuzin + clomazone	576 + 210 + 90
2	PRE	Artist + Centium	metribuzin + flufenacet + clomazone	350 + 480 + 72
3	PRE	Artist	metribuzin + flufenacet	350 + 480
	POST	Harmony	thifensulfuron	3.75
4	PRE	Stomp Aqua	pendimethalin	682.5
	POST	Harmony + Basagran + Focus Ultra	thifensulfuron + bentazone + cycloxydim	3.75 + 960 + 150
5	POST	Harmony + Basagran	thifensulfuron + bentazone	3.75 + 960
	POST	Harmony + Fusilade Max	thifensulfuron + fluazifop-P-butyl	3.75 + 125
6		Control		

The mechanical weed control experiments were conducted at the locations Freiburg (2013) and Stuttgart (2013 and 2014). The experiments include four different mechanical treatments, one treatment where all the weeds were removed manually and an untreated control (Tab. 2). A goose foot hoe was used in treatment 1 – 3. In treatment 2, a harrow was utilized additionally before soybean emergence. Hoe and harrow were used in rotation (treatment 3) and pre- and post-emergence harrowing was performed in treatment 4.

Tab. 2 Description of the treatments and time of application (growth stage of the crop). "PRE" = pre emergence, "POST" = post emergence. "*" = not performed in Stuttgart (2013).

Tab. 2 *Beschreibung der Versuchsvarianten und Anwendungszeitpunkt (Wachstumsstadium). „PRE" = pre emergence (Vorauflauf), „POST" = post emergence (Nachauflauf). „*" = nicht durchgeführt in Stuttgart (2013).*

Mechanical experiments						
		Time of application (BBCH of Soybean)				
Treatment	**Description**	**PRE (03-05)**		**POST (10-12)**	**POST (14-16)**	**POST (18-22)**
1	Hoe		**Soybean emergence**	x	x	x(*)
2	Harrow + Hoe	x		x	x	x(*)
3	Harrow + Hoe in rotation			x	x	x(*)
4	Harrow	x		x	x	x(*)
5	Weed free			x		x
6	Untreated Control					

Experiments were carried out as a randomized complete block design with four blocks. Each block contained one replication of all treatments. Plot size was 2 × 10 m in the chemical experiments and 3 × 15 m in the mechanical experiments. In the herbicide experiments, weed density was visually estimated first in BBCH 12 - 16 and second in BBCH 22 - 26 of the soybean plants. For the mechanical experiment, weeds were counted with a $0.5m^{-2}$ frame at 3 random positions within each plot. Statistical analysis was conducted with R (R DEVELOPMENT CORE TEAM, 2014) using RStudio (Version: RStudio 0.98.501). Prior to analyses the data were checked for normal distribution and homogeny of variance. The means of every treatment were compared with Tukey's HSD (honest significant difference) test.

Results

Weed control

The results of the chemical weed control experiments are illustrated in Figure 1a. The results of the mechanical weed control are shown in Figure 1b. Weed control efficiency ranged from 72% (harrowing) up to 99% (Artist, Centium). All treatments resulted in significantly higher weed control efficiency compared to the untreated control. Concerning the herbicide experiments, efficacy was significantly increased in treatment 2 and 3 (98.5%) compared to treatment 5 (90.1%). Treatment 1 (92%) and treatment 4 (94%) showed no statistically difference compared to treatment 2, 3 and 5.

In the mechanically treated plots, all treatments had significantly higher weed control efficacy compared to the untreated control. Yet, all treatments showed significantly less weed control efficiency, than the hand controlled treatment (100%). Values ranged from 72% (harrow) up to 82% (harrow and hoe). Treatment 1 (hoe) and treatment 3 (harrow and hoe in rotation) resulted in 78% and 79% weed control efficacy, respectively. There was no significant difference between all mechanical treatments. The chemical treatments resulted in 17% higher weed control efficiency compared to the mechanical ones if we exclude the hand weeded treatments from the calculations (Fig. 1).

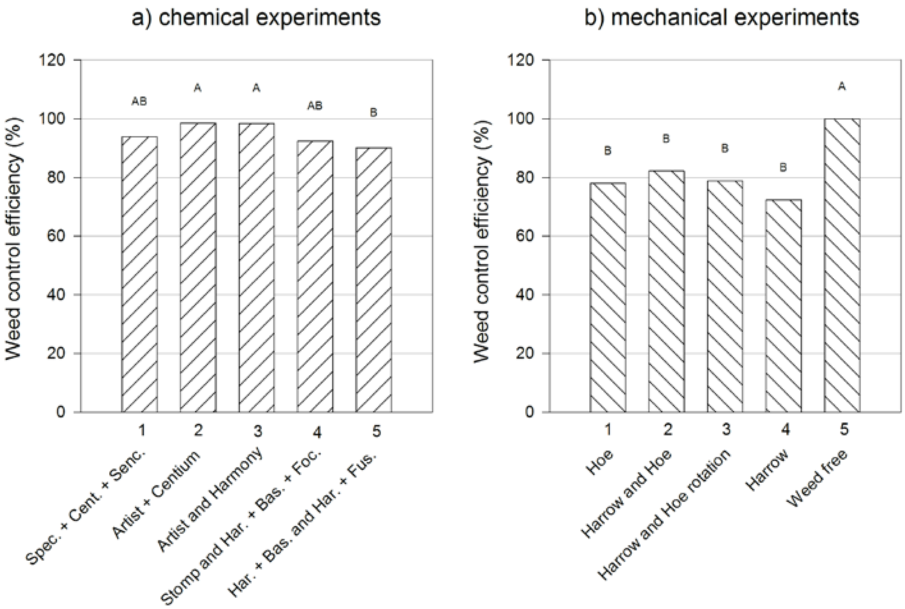

Fig. 1 Weed control efficiency compared to the untreated control in percentage of the different treatments. a) Chemical and b) mechanical experiments. Different letters indicate significant differences between treatments ($p < 0.05$). Spec. = Spectrum, Cent. = Centium, Senc. = Sencor, Har. = Harmony, Bas. = Basagran, Foc. = Focus Ultra and Fus. = Fusilade Max.

Abb. 1 *Effektivität der Unkrautregulierung der unterschiedlichen Varianten verglichen mit der unbehandelten Kontrolle in Prozent. Links sind die chemischen (a) und rechts die mechanischen (b) Versuche abgebildet. Unterschiedliche Buchstaben kennzeichnen signifikante Unterschiede zwischen den Varianten (p < 0,05). Spec. = Spectrum, Cent. = Centium, Senc. = Sencor, Har. = Harmony, Bas. = Basagran, Foc. = Focus Ultra und Fus. = Fusilade Max.*

Soybean yield

Results concerning the yield increase compared to the untreated control for the herbicide experiments can be found in Figure 2a and for the mechanical experiments in Figure 2b. All treatments, from both experiments resulted in higher yields (13% till 37%) compared to the untreated control. The mean over all treatments in the herbicide experiment was 17% yield increase compared to the untreated control. No statistically differences were observed between the different chemical combinations. In the mechanical experiment even though the yield increase was lower for all treatments compared to the weed free treatment only the harrow (treatment 4) was found statistically different. Between the 4 different mechanical treatments there was no difference. Treatments 1 to 3 (hoe, harrow and hoe, harrow and hoe in rotation) resulted in increased yield by 31%, 34% and 27%, respectively. Treatments 1 and 2 of the mechanical weed control experiment observed higher yields compared to all herbicide combinations. In the herbicide experiment only the chemical treatment 5 showed higher yields than harrowing and the rotation between hoeing and harrowing.

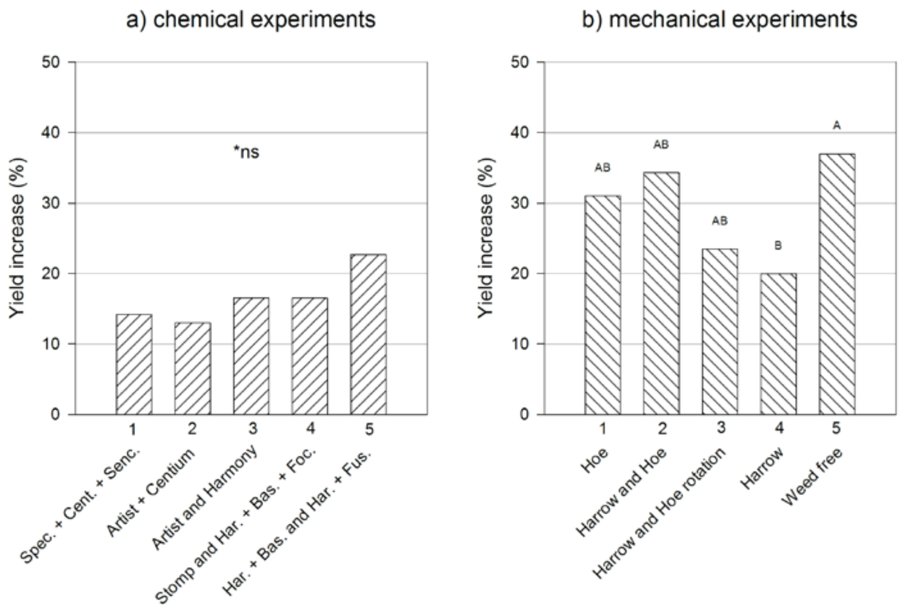

Fig. 2 Increase of yield compared to the untreated control in percentage of the different treatments. a) Chemical and b) mechanical experiments. Different letters indicate significant differences between treatments ($p < 0.05$). Spec. = Spectrum, Cent. = Centium, Senc. = Sencor, Har. = Harmony, Bas. = Basagran, Foc. = Focus Ultra and Fus. = Fusilade Max.

***Abb. 2** Ertragszuwachs der unterschiedlichen Varianten verglichen mit der unbehandelten Kontrolle in Prozent. Links sind die chemischen (a) und rechts die mechanischen (b) Versuche abgebildet. Unterschiedliche Buchstaben kennzeichnen signifikante Unterschiede zwischen den Varianten (p < 0,05). Spec. = Spectrum, Cent. = Centium, Senc. = Sencor, Har. = Harmony, Bas. = Basagran, Foc. = Focus Ultra und Fus. = Fusilade Max.*

Discussion

Weed control

PRE herbicides and the combination of PRE and POST herbicides lead to high weed control efficiency (treatment 1 - 4). This is in accordance with GEHRING (2014) in similar soybean herbicide experiments. Herbicide treatment 4 with the a.i. pendimethalin obtained a gap in the efficiency regard to *Matricaria chamomilla* and *Avena fatua* compared to treatment 1 - 3 with the a.i. metribuzin. The higher metribuzin content in treatment 2 and 3 (Artist, 350 g a.i. ha^{-1}) compared to treatment 1 (Sencor, 210 g a.i. ha^{-1}) can explain the difference in higher weed control efficiency (GREEN et al., 1988; SALZMAN and RENNER, 1992).

In the given study insufficient weed control was found for harrowing. It strongly depends on soil moisture content (KURSTJENS and KROPFF, 2001) and occurring weed species (PULLEN and COWELL, 1997). Therefore weed control by harrowing differed in location and year and resulted in less efficiency. Weeds were highly controlled in the inter row area by hoeing. Yet the efficiency was less compared to the hand weeded control. The increased weed control efficiency of the chemical experiment (+17%) compared to the mechanical treatments can be explained by the lower efficiency of the mechanical treatments at the intra row area and different environmental conditions. For hoeing, additional tools for the regulation of weeds close to the crop row area are needed. Precision farming methods with higher accuracy help steering the hoe close to the crop area by the use of Real Time Kinematic (GNSS-RTK) and camera steered systems. Furthermore, different "intra row" implements (finger weeder, torsion weeder, heap element and rotary harrow) can be used (KUNZ et al., 2015).

Soybean yield

PRE herbicide treatments resulted in lower yields compared to the POST herbicides and mechanical treatments. However, higher weed control efficiency was observed in these treatments. DONALD (1998) described crop damage caused by PRE herbicides as a reason for yield losses in soybean similar to treatment 1 - 4 compared with treatment 5. The minor yield increase of the herbicide treatments can be explained by the low weed density in the untreated control of the chemical experiments. Therefore the yield increases in the mechanical treatments were higher. BUHLER (1992) described fewer yield in mechanical treatments compared to herbicide treatments under high weed pressure. For further results, mechanical and chemical strategies should be included in one experiment and repeated at different locations and environmental conditions.

We conclude that chemical weed control results in high weed control efficiency, but also entails the risk of crop damage. More research in crop tolerance and extended spectrum of registered herbicides is needed. Mechanical weed control treatments revealed less weed control efficiency especially in the intra row area. Furthermore, mechanical weed control in combination with precise implements can help for reducing herbicides and safe proper yields.

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