Comparison of different mechanical weed control strategies in sugar beets

Vergleich verschiedener mechanischer Unkrautstrategien in Zuckerrüben

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Abstract

In sugar beet (*Beta vulgaris.*) weed control is commonly performed by herbicide application applied broadcast at splitting during the cultivation period. Mechanical weeding can be an alternative to chemical weed control. The aim of this experiment was the estimation of weed control efficacy with the use of automatic steering technologies by camera guidance, the use of different intra row weed control implements in conservation tillage systems and the influence of these techniques to the number of uprooted sugar beets. A field experiment with a randomized complete plot design was conducted in 2015 at Ihinger Hof, Germany. Weed density ranged from 0 to 12 plants m^{-2} with *Chenopodium album*, *Polygonum convolvulus, Polygonum aviculare* as the most abundant weed species. Hoeing with the use of automatic steering technologies reduced the weed density by 82%. The use of finger weeders, rotary-harrow and torsion finger weeder reduced the weed density by 29% compared to common hoeing strategies. Differences in the number of uprooted sugar beets were not found across all treatments. We revealed the possibility of a more intense use of mechanical weeding technologies in combination with precision farming technologies in sugar beet.

Keywords: Camera steering, inter row weeding, intra row weeding, mechanical weed control, sugar beets

Zusammenfassung

In Zuckerrüben (*Beta vulgaris*) wird die Unkrautkontrolle meistens durch eine mehrfache Herbizidapplikation auf der gesamten Ackerfläche durchgeführt. Mechanische Unkrautkontrollmaßnahmen können eine Alternative zu den üblichen chemischen Unkrautbekämpfungsstrategien darstellen. Das Ziel dieser Arbeit war es, den Einsatz von automatischen kameragesteuerten Lenkmechanismen und den Einsatz unterschiedlicher „intra row" Hackwerkzeuge in konservierender Bodenbearbeitung auf ihre Verringerung der Unkrautdichte zu untersuchen, sowie den Einfluss der angewendeten Verfahren auf die Anzahl von entwurzelten Zuckerrüben-Pflanzen zu ermitteln. Hierfür wurde ein Feldversuch im Jahr 2015 am Standort Ihinger Hof mit einer randomisierten vollständigen Blockanlage angelegt. Die Verunkrautung variierte von 0 bis 12 Pflanzen m^{-2}, mit den am häufigsten vorkommenden Arten *Chenopodium album, Polygonum convolvulus* und *Polygonum aviculare.* Der Einsatz von kameragesteuerten Lenkmechanismen reduzierte die Verunkrautung in Zuckerrüben um 82 %. Fingerhacke, Rollstriegel und Torsions-Striegel, reduzierten den Unkrautbesatz im Vergleich zum herkömmlichen Hackeinsatz um 29 %. Signifikante Unterschiede in der Bestandesdichte konnten nicht festgestellt werden. In der vorliegenden Studie wurde die Möglichkeit von mechanischen Unkrautbekämpfungsstrategien in Kombination mit konservierender Bodenbearbeitung erfolgreich untersucht.

Stichwörter: Inter-row Bekämpfung, intra-row Bekämpfung, Kamerasteuerung, mechanische Unkrautkontrolle, Zuckerrübe

Introduction

Weed control is one of the most important factors in sugar beet production. High yields cannot be realized without the use of herbicides and herbicide mixtures (MERKES et al., 2003). Unfortunately, weed composition has also diversified. Therefore chemical weed control has currently evolved as a prerequisite component of weed management in sugar beet production. The first important active ingredient was Chloridazon, mentioned in scientific literature in 1962 (FRANCIS, 2006). At the beginning of the 1980s the most important sugar beet herbicides were developed.

Integrated plant protection was established over the last decades. Nowadays the amount of herbicides should be reduced and optimized (GUMMERT et al., 2012). A part of integrated plant protection is the implementation of cover crops and cover crop mulches in sugar beet cropping systems. Cover crops can reduce wind and water erosion and can prevent the leaching of nutrients. Furthermore, cover crops can suppress different weeds and volunteer crops up to 90% (BRUST et al. 2014). GUMMERT et al. (2012) pointed out that the erosion risk was greater after hoeing, due to incorporation of organic matter into the soil.

In order to reduce chemical weed control, mechanical weeding approaches are a promising alternative. Mechanical weed control can be conducted between the rows (inter-row hoeing) and within the crop rows (intra-row hoeing). Negative aspects of hoeing are the low driving speed and the working width of the hoe. A further problem of weed hoeing is the restricted weed control efficacy in the intra-row area (BOWMAN, 1997).

The importance of hoeing close to the crop row and the use of different intra-row hoeing tools need very accurate steering for not damaging the crop (VAN DER WEIDE et al., 2008). Therefore accurate guidance systems are needed. During the last decades, mechanical weed control has been improved by the use of new automatic row guidance systems for intra row hoeing. Identifying weeds and crops is possible by the use of cameras (GERHARDS and CHRISTENSEN, 2003). Different guidance systems (visual sensors and RTK-GNSS) identify the position of sugar beet rows and a hydraulic side-shift system steers the hoe close to the crop area.

The objectives of this study were to analyze:

- The efficacy of mechanical weed control compared to the application of common herbicides.
- The efficiency of a camera steered hoe compared to a manually steered hoe.
- The combination of mechanical weeding by hoeing, with cover cropping and conservation tillage practices.
- The reduction of cover crop mulch by using different mechanical weed control treatments.
- The differences in weed control efficacy by using different intra row tools.
- The influence of the applied techniques on the number of uprooted sugar beets

Materials and Methods

A mechanical weed control experiment was conducted in sugar beets at the research station Ihinger Hof at the University of Hohenheim, Germany [48.74° N, 8.92° E, 478 m altitude]. The soil type is a deep loam with subsoil clay. The average annual rainfall and temperature are 700 mm and 7.2 °C. The experimental design was a randomized complete block with four replicates. The plot size was 36 m^{-2} including 6 sugar beet rows.

Sugar beet cv. 'Hannibal' was sown at 10^{th} of April in 2015. After the harvest of the preceding crop spring barley white mustard (*Sinapis alba*) was established as a cover crop, which remained until the sugar beets were sown. Conservation tillage was performed on the whole field with one flat cultivation. 107.000 sugar beet seeds ha^{-1} were sown at a depth of 3 cm with a row distance of 0.5 m. Prior to the emergence of the sugar beets 120 kg N ha $^{-1}$, 62 kg S ha $^{-1}$ and 0.8 kg B ha $^{-1}$ were applied as ammonium-sulphate-nitrate with boron (ass®bor®).

The experiment included 9 different weed control treatments (Tab. 1) with an untreated control (treatment 1). Treatment 2 was the conventional herbicide application across the entire field. It was performed with Agrotop Albuz® CVI-TWIN nozzles with a pressure of 2.4 bars. The herbicide application was executed at 3 application times (Tab. 2). A mixture of 3.75 l ha^{-1} Goltix® Titan® (525 g a.i. L^{-1} metamitron and 40 g a.i. L^{-1} quinmerac) and 3.75 l ha^{-1} Betanal ® maxxpro® (75 g a.i. L^{-1} ethofumesate, 60 g a.i. L^{-1} phenmedipham ,47 g a.i. L^{-1} desmedipham, 27 g a.i. L^{-1} lenacil) was sprayed.

In treatment 3-8 the first application was performed with intra-row band spraying on a 20 cm strip (60% reduced sprayed area compared to treatment 2). In all treatments a hoe (Einböck, CHOPSTAR, Dorf an der Pram, Austria) with goose feet and parallelogram was used. During the following two applications in treatment 3 the hoe was guided manually. In treatment 4-8 the hoe was managed by a visual camera system (Claas, Harsewinkel, Germany). The placement of the hoe, within the row was steered based on the cameras feedback, with a hydraulic side shift. In treatment 5, 6, 7, 8 the hoe was equipped with finger weeders, torsion weeders, rotary harrow and a heap element for intra row hoeing. A heap element, attached on the goose feet, buries the weeds by throwing soil into the intra-row region. In treatment 9 the possibility of the steering system was proofed at night. Therefore the same set up was used as in treatment 4 but under dark conditions with an additional light source.

Weed density was counted after the final weed control treatment using a frame (50 * 100 cm) at three randomly selected positions within each plot. Soil coverage (%) with mulch was estimated visually at three random selected positions within each plot with a frame (50 * 100 cm) as well after sowing and the final weed control treatment.

The data were analyzed using the statistics software language R version 3.0.2 (R CORE TEAM, 2014). All data were subjected to analysis of variance (ANOVA). Homogeneity of variances was proved and data were transformed if necessary. Weed density data were transformed using the square root or log to normalize the data distribution. Statistical significance was evaluated at p-value ≤ 0.05 with appropriate pooled standard errors of the difference (s.e.d.) or treatment means. Afterwards, multiple comparison tests were performed using the Tukey-*HSD* test at a significance level of p ≤ 0.05.

Tab. 3 Description of experimental treatments in sugar beet in 2015.

***Tab. 1** Beschreibung der Versuchsvarianten in Zuckerrüben im Jahr 2015.*

Treatment	Description
1	untreated control
2	herbicide treatment
3	manual steering
4	camera hoe
5	camera hoe with finger weeders
6	camera hoe with torsion weeder
7	camera hoe with rotary harrow
8	camera hoe + heap element
9	camera hoe (night)

Tab. 4 Timings for weed control methods (DAS = Days after sowing) in sugar beets at Ihinger Hof in 2015.

***Tab. 2** Zeitpunkte der Unkrautbekämpfungsverfahren (DAS=Tage nach der Aussaat) in Zuckerrüben am Standort Ihinger Hof im Jahr 2015.*

Treatment	Time of Application (DAS)		
1	-	-	-
2	14	25	32
3, 4, 5, 6, 7, 8, 9	14	31	36

Results

A total of 14 weed species were detected in the complete experiment. The most abundant weed species identified were *Chenopodium album*, *Stellaria media*, *Polygonum convolvulus*, *Polygonum aviculare* and *Matricaria chamomilla*. The highest weed density with 12 plants m^{-2} was found in the untreated control (treatment 1) (Fig. 1). Significant interactions between treatment and time (date of evaluation) were found for the most weed species. The overall herbicide application (treatment 2) reduced weeds by 90%. Also in treatment 2 the lowest weed density was observed. Treatment 2 (herbicide application), treatment 5 (finger weeder), treatment 8 (heap element) and treatment 9 (camera hoe at night) were significantly different compared to treatment 1 (untreated control) in weed control efficacy. Treatment 3 (manual steering) reduced weed density by 42%. Intra row weed density was not significantly different among the treatments (data not shown).

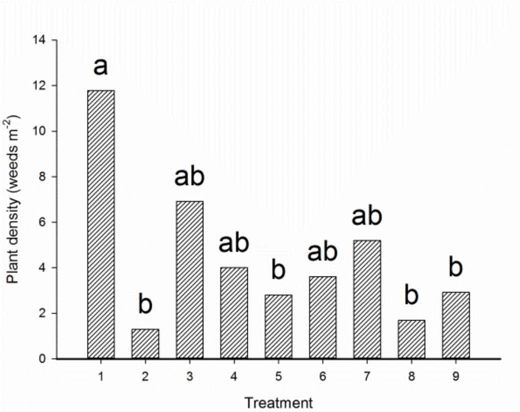

Fig. 1 Weed density in sugar beet (mean) counted after the final treatment at the Ihinger Hof. Different letters indicate significant differences at $p \leq 0.05$.

Abb. 1 *Unkrautdichte nach Abschluss der Bekämpfungsmaßnahmen am Ihinger Hof. Mittelwerte wurden mit Buchstaben gekennzeichnet. Unterschiedliche Buchstaben bezeichnen signifikante Unterschiede bei p ≤ 0,05.*

A significantly higher decrease in soil coverage was observed in treatments 3-9, where mechanical weed control was performed (Fig. 2).

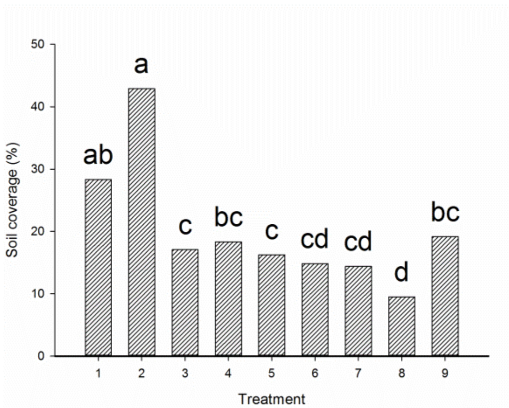

Fig. 2 Soil coverage by cover crop residues (mean) three days after completed weed control at Ihinger Hof 2015. Different letters indicate significant differences at $p \leq 0.05$.

Abb. 2 *Bodenbedeckung mit Mulch nach Beendigung der Unkrautbekämpfungsmaßnahmen am Standort Ihinger Hof im Jahr 2015. Unterschiedliche Buchstaben bezeichnen signifikante Unterschiede bei p ≤ 0,05.*

Different intra row tools (treatment 5, 6, 7, 8) reduced soil coverage significantly, compared to treatment 1 (untreated control) and treatment 2 (herbicide application). Soil coverage has shown a significant difference of 78% between treatment 2 (herbicide application) and treatment 8 (heap element).

Over all treatments no statistical differences in the number of sugar beet plants were found (Fig. 3). The mean over all treatments was 87800 plants ha^{-1}. The lowest plant density was observed in treatment 7 with 78% field emergence.

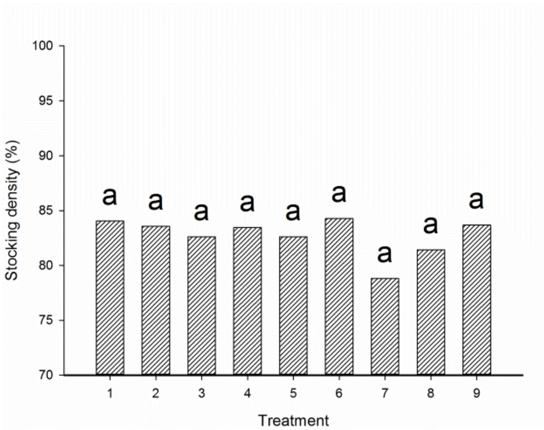

Fig. 1 Percentage stocking density of the sugar beet plants (mean) counted close to the closing of the crop rows as well as after the last treatment. Different letters indicate significant differences at $p \leq 0.05$.

Abb. 3 *Prozentuale Bestandesdichte der Zuckerrübenpflanzen, kurz vor Reihenschluss und unmittelbar nach Abschluss aller Unkrautkontrollmaßnahmen. Unterschiedliche Buchstaben bezeichnen signifikante Unterschiede bei* $p \leq 0{,}05$.

Discussion

We observed a noteworthy herbicide reduction of up to 80% when mechanical weed control and band-spraying was combined with "intra and inter row" hoeing treatments. Similar results were achieved using band spraying and mechanical weeding (KUNZ et al., 2015). To the first weed control an additional herbicide band application was necessary, because the sugar beets were still small for mechanical intra row weeding and an adequate weed control was not possible.

Visual guidance systems, as applied in this study, led to lower weed density compared to manual steering. Due to the support of the automatic steering system a relief of the operator is achieved and hence a premature fatigue is avoided. An additional advantage of the tested system is the capability to drive at higher speed and thus to reduce labor costs. Even more, it is possible to steer the hoe closer to the crop row so the efficacy of the weed control is increase. The number of uprooted sugar beets is negligible and was not significant over all treatments. Due to a high standard error in treatment 7 more studies at different locations and years are needed to be sure about this effect.

Nevertheless, mechanical weed control is time consuming and less area efficient compared to chemical weed control strategies. Favorable weather conditions are highly important for an effective mechanical weed control strategy. Even more, favorable dry soil conditions are needed and there are a lot of stony and lumpy soils in Europe (KURSTJENS and KROPFF, 2001). In the presented study proper soil and weather conditions existed during the experimental duration. If the weather conditions were not fit for mechanical weeding then a chemical application would have been obligatory.

The tested "intra row" implements resulted in similar weed control as the chemical herbicide application. This encourages the idea to substitute some of the herbicide applications by precision mechanical weeding. Finger weeders and torsion weeders need a more accurate driving part compared to the heap element and the rotary harrow. The heap element resulted in high weed control efficacy, but the driving speed was lower compared to all other hoeing treatments. Moreover, it is also covering the sugar beet plants with soil. Therefore, harvesting of sugar beets can be hindered by this treatment, and has an increased probability of fungus infestation.

Rhizoctonia solani, a soil borne fungus infestation, can be benefited when sugar beets are buried by soil (OGOSHI, 1987).

In this study mechanical weed control aided by precision steering in combination with conservation tillage and cover crops proved to be a good potential for Integrated Pest Management. Cover crop mulches can suppress different weed species in sugar beets (KRUIDHOF et al., 2009). At the early development stages the use of protective blades are a prerequisite for mechanical weed control in sugar beet cover crop mulch systems to protect the sugar beet rows from burying and eradicating. Moreover, cover crops were mixed into the soil by mechanical weed control. This could lead to an increased risk of soil erosion. Similar results were observed in previous studies (KUNZ et al., 2015). GUMMERT et al. (2012) pointed out that adverse side effects like soil erosion have to be taken into account when using mechanical weed control. Further studies are needed for the evaluation of the reduced soil coverage in regard to different mechanical weed control measures and the expected soil erosion.

In conclusion, our findings revealed that mechanical weed control is a useful agronomic tool for weed suppression in sugar beet. Weed species, especially close to the crop, will remain a key challenge for mechanical weed control. Additional research and development are needed to exploit the potential of precision steering systems.

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