Risk evaluation of mechanical, chemical and combined mechanical-chemical weed control in sugar beet

Standortspezifische Risikobewertung von Verfahren mechanischer und chemischer Unkrautbekämpfung in Zuckerrüben

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Abstract

Sugar beet field trials were conducted at two sites in Southern Lower Saxony to compare mechanical (hoeing), chemical (herbicide spraying) and combined mechanical-chemical weed control operations in their weed control efficacy, and in their effect on mulch coverage and soil erosion by water. Three treatments were tested in four replications at both sites. To measure runoff and soil erosion, rainfall simulations were carried out for mechanical and chemical treatments after completion of the last weed control operation. The cumulative soil loss was twice higher in mechanical than in chemical treatment in Sieboldshausen (p-value=0.03) but was eight times lower in mechanical than in chemical treatment in Obernjesa (p-value=0.004). The cumulative runoff was not significantly different between treatments in Sieboldshausen but was again significantly lower for hoeing than for spraying in Obernjesa. Also the effect on weed control efficacy by second weed control operation (2-4-leaf-stage) was site-specific, with no effect in Sieboldshausen and significantly reduced efficacy of mechanical weed control in Obernjesa. Mulch coverage loss due to the second weed control operation was significantly higher for mechanical than for chemical treatment at both sites.

Keywords: Band spraying, hoeing, mechanical weed control, mulch, soil erosion

Zusammenfassung

Feldversuche mit Zuckerrüben wurden an zwei Standorten in Niedersachsen durchgeführt, um die Effizienz und die Risiken mechanischer (Hacke), chemischer (Herbizidspritzung) und kombinierter mechanisch-chemischer Unkrautbekämpfung zu vergleichen. Die Unkrautbekämpfungstechniken wurden in vier Wiederholungen an zwei Standorten getestet. Hier werden Ergebnisse zur Wirksamkeit gegenüber Verunkrautung und zur Auswirkung auf Mulchbedeckung und Bodenerosion durch Wasser berichtet. Nach der Durchführung aller Nachauflaufbehandlungen wurden in den Parzellen mit rein mechanischen und rein chemischer Unkrautbekämpfung Regensimulationen durchgeführt, um den Oberflächenabfluss und den Bodenabtrag zu messen. Der kumulative Bodenabtrag war zwei Mal größer bei der mechanischen als bei der chemischen Unkrautregulierung in Sieboldshausen (p-Wert=0,03), aber 8 Mal höher bei der chemischen als bei der mechanischen Unkrautregulierung in Obernjesa (p-Wert=0,004). Der kumulative Wasserabfluss war nicht signifikant verschieden zwischen den beiden Unkrautbekämpfungstechniken in Sieboldshausen, aber wiederum signifikant höher für die chemisch als für mechanisch behandelten Flächen in Obernjesa. Der Wirkungsgrad der chemischen Unkrautregulierung war nur bei der zweiten Nachauflaufbehandlung am Standort 1 signifikant höher als der der mechanischen Unkrautregulierung. Bei der zweiten Nachauflaufbehandlung wurde die Mulchbedeckung an beiden Standorten durch das Hacken signifikant stärker reduziert als in der Herbizidvariante.

Stichwörter: Bandspritzung, Bodenerosion, Hacken, mechanische Unkrautbekämpfung, Mulch

Introduction

Weed control techniques assuring both, efficient weed removal and sustainable ecosystem functioning is crucial for future sugar beet production. Due to societal concern on toxicity hazards associated with herbicide application, interest in hoeing is growing during recent years. However, potential negative environmental impacts of hoeing like soil aggregate degradation, enhancement of soil erosion or reduction of earthworm abundance have not been studied yet. Loess soil preferable for sugar beet production is known to be highly susceptible to soil erosion (Jones et al., 2003; Panagos et al., 2015). Recent studies indicate, that mulch tillage with plant residue coverage > 20% is an effective tool to counteract soil erosion in sugar beet fields (Dieckmann et al., 2004; Scholz et al., 2008). Hoeing may, however, reduce the mulch coverage, destruct soil aggregates and promote soil particle detachability. The objectives of this study were (1) to evaluate the weed control efficacy and mulch coverage reduction by hoeing in comparison to the combined mechanical-chemical and chemical approaches, (2) to measure runoff and soil erosion for mechanical and chemical weed control in sugar beet.

Materials and Methods

Experimental setup

Field trials were carried out in 2019 on two sites in Low Saxony, about 10 km south of Göttingen, Lower Saxony. Both sites are located on slopes with a slope gradient of 3-6% in Sieboldshausen and 3-9% in Obernjesa. Both sites had silty soil derived from loess. At each site, noninversion mulch tillage was applied, so that the residues of a preceding mustard (*Sinapis alba*) cover crop were left in the field. In spring, seed bed preparation was carried out with a cultivator and tine harrow immediately before sowing of sugar beet in April. Three treatments consisted of i) hoeing with wing shares between rows plus in-row hoeing by hand (mechanical), ii) hoeing with wing shares between rows plus in-row herbicide band spraying (combined) and iii) overall herbicide application (chemical) were tested in four replicates as a randomized complete block design on both sites. Overall each site had 12 study plots of 24 m x 15 m in size. The sugar beet rows were laid out parallel to the slope gradient. Three weed control operations were conducted in Obernjesa and two in Sieboldshausen. In case of chemical and combined treatments the following herbicides were applied at both sites: 1 l/ha Betanal Expert and 1.5 l/ha Goltix Titan with a first application; 1.25 l/ha Betanal maxxPro and 1.5 l/ha Goltix Titan with a second application and finally, 1.5 l/ha Metafol SC and 1.0 l/ha Betanal maxxPro with a third application. The weed infestation and mulch coverage was determined before and after each weed control operation at 6 scoring subplots of 0.25 m^2 in size within each plot. After the last weed control operation at each site the rainfall simulation trials were carried out for chemical and mechanical treatment (Tab. 1). Before rainfall simulation the slope gradient, sugar beet coverage and mulch coverage were determined. During rainfall simulation, runoff from the area concerned was collected with a one-minute interval during the rain event. The weight of water and sediment was determined later in the laboratory. The setup of the rainfall simulation is summarized in Table 1.

Data Evaluation and Statistical Analysis

The weed number at six scoring subplots within each study plot was summed up, to get a weed infestation per 1.5 m^2 for each plot. The weed control efficacy was then quantified for each plot as a percentage of successfully removed weeds from the total number of weeds growing within a 1.5 m^2 scoring area prior to a weed control operation. The effect of treatment on weed control efficacy was then tested by analysis of variance for each site and each weed control operation using R software. If the assumptions of residual normality was not fulfilled the nonparametric Kruskal-Wallis test was applied. In case of a significant treatment effect the multiple comparisons of means between treatments were conducted by Tukey test (α=0.05). The effect of treatment on cumulative runoff and soil loss in Sieboldshausen was tested by t-test for independent samples. In Obernjesa analysis of variance was applied to test the effects of (i) treatment, (ii) rainfall simulation event (O1, O2, O3 – Tab. 1), (iii) the interaction between treatment and rainfall simulation event, (iv) mulch coverage and (v) block on cumulative runoff and erosion. The differences between specific groups were then tested by Tukey test. Unlike other data mulch loss data were repeatedly taken at 6 scoring subplots within a plot. Therefore, mixed linear model considering a random effect of a plot was used to analyze the treatment effect on mulch loss.

Tab. 1 Setup of rainfall simulation experiments.

***Tab. 1** Regensimulationen: Versuchsaufbau.*

Rainfall simulation experiment	**S1**	**O1**	**O2**	**O3**
Site	Sieboldshausen	Obernjesa	Obernjesa	Obernjesa
Date	29.05.2019	05.06.2019	06.06.2019	12.06.2019
Number of the preceding weed control operations	2	3	3	3
Area, m2	2.05	2.05	2.05	2.05
Duration, min	20	20	20	20
Rain intensity, mm/min	1.5	1	1	1
Mean number of days elapsed since last hoeing	1.5	1.5	2.5	7.5
Presence of tractor rut within the rainfall simulation area	no	no	yes	no
Treatments	mechanical, chemical	mechanical, chemical	mechanical, chemical	mechanical, chemical
Number of replicate plots per treatment	3	4	4	4

Results and Discussion

Weed control efficacy

Weed community in Obernjesa was dominated by wild buckwheat (*Polygonum convolvulus* L.) and in Sieboldshausen by fat hen (*Chenopodium album*). The initial weed infestation was 14±9 and 8±5 plants per 1.5 m^2 in Obernjesa and Sieboldshausen, respectively. Weed control efficacy was significantly influenced by treatment only during second weed control operation in Obernjesa with 53% and 100% of weeds successfully removed in mechanical and chemical treatments respectively (Tab. 2). The observed differences between mechanical and chemical weed control with respect to weed control efficacy were not only site-specific but even varied among the weed control operations within a single site. One reason for this ambiguity in data can be differing soil moisture at a time point of hoeing and during the next days after hoeing as well as difference in some weather parameters like maximum day temperature and air humidity during the next days after hoeing.

Mulch coverage reduction

The initial mulch coverage was about 15% at both study sites. The reduction of mulch did not differ between treatments after first weed control operation but was significantly larger for mechanical than for chemical control for both sites after second weed control operation (Fig. 1). The mean mulch loss through hoeing as modeled by mixed modeling was 3.6% for Sieboldshausen, and only 0.6% for Obernjesa. Interestingly, in case of Sieboldshausen the mulch loss through the combined treatment was as high as in the mechanical treatment (Fig. 1).

Tab. 2 Measured weed control efficacy, %. At each site and weed control operation the effect of treatment was tested by analysis of variance followed by pairwise comparisons among means by Tukey-Test (α=0.05) if treatment was significant. The values followed by different letters are significantly different.

Tab. 2 *Wirkungsgrad der Unkrautbekämpfung, %. Der Effekt der Unkrautbekämpfungstechnik wurde für jeden Standort und jede Nachauflaufbehandlung geprüft: ANOVA mit anschließendem Tukey-Test (α=0,05). Unterschiedliche Buchstaben kennzeichnen signifikante Unterschiede.*

	Obernjesa			**Sieboldshausen**		
	Treatment	**mean**	**sd**	**Treatment**	**mean**	**sd**
First weed control	mechanical	83.9 a	11.7	mechanical	91.0 a	11.9
	combined	91.5 a	8.5	combined	92.8 a	5.3
	chemical	99.0 a	1.9	chemical	97.4 a	5.3
Second weed control	mechanical	53.3 a	9.2	mechanical	100.0 a	0.0
	combined	91.5 b	7.5	combined	75.0 a	28.9
	chemical	100.0 b	0.0	chemical	100.0 a	0.0

Overall, in Obernjesa the initial mulch coverage was not changed by two weed control operations and did not differ between treatments, whereas in Sieboldshausen after two weed control operations the mulch coverage was reduced by 4% in mechanical and combined treatment (data not shown). Since the site in Obernjesa had a higher slope gradient than those in Sieboldshausen, the lateral transport of mulch with runoff and perhaps a preferential deposition of mulch from upslope on a rougher soil surface after hoeing could be responsible for masking the effect of hoeing on mulch coverage in Obernjesa.

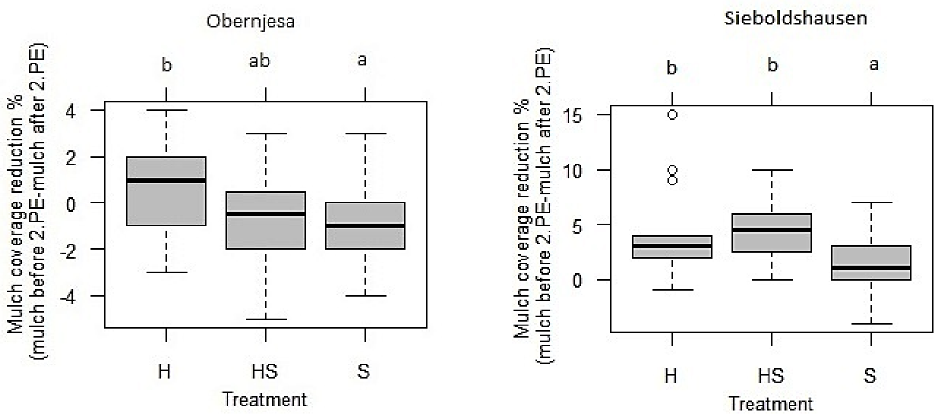

Fig. 1 The pairwise comparison of means by Tukey contrast after linear mixed modeling of mulch loss with fixed effect for treatment and random effect of a plot. Different letters denote significant differences (p-value<0.05).

Abb. 1 *Verminderung der Mulchbedeckung durch die zweite Nachauflaufbehandlung für verschiedene Unkrautbekämpfungstechniken. Paarweise Vergleiche der Gruppenmittelwerte mittels Tukey-Test nach Prüfung des Behandlungseffektes durch ein lineares gemischtes Modell. Unterschiedliche Buchstaben kennzeichnen signifikante Unterschiede.*

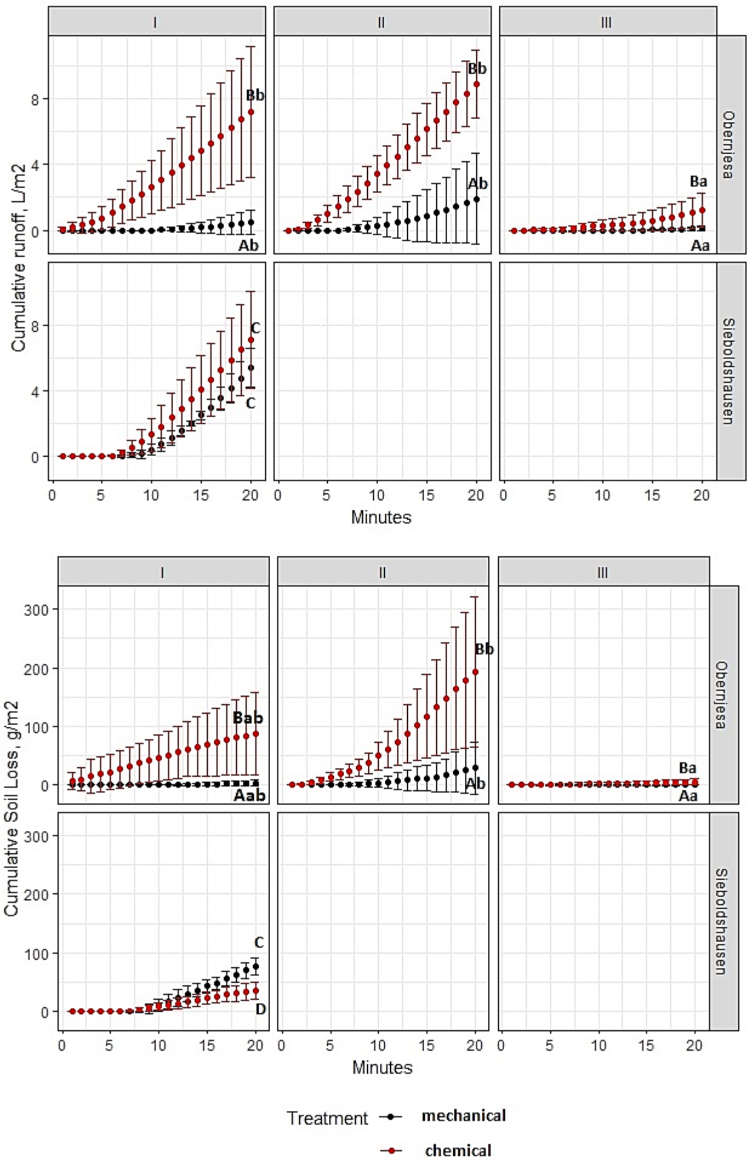

Fig. 2 Cumulative runoff and soil loss (mean±SD) measured by rainfall simulation events after weed control operations in Obernjesa and Sieboldshausen in 2019. Different capital letters denote significant differences between treatments, different small letter – among rainfall events O1, O2, O3.

Abb. 2 *Kumulativer Abfluss und Bodenabtrag (Mittelwert±SA) durch simulierten Starkregen nach den Nachauflaubehandlungen in Obernjesa und Sieboldshausen 2019. Verschiedene Großbuchstaben kennzeichnen signifikante Unterschiede zwischen mechanischer und chemischer Unkrautregulierung. Verschiedene Kleinbuchstaben bezeichnen signifikante Unterschiede zwischen den Regensimulationen O1, O2, O3.*

Runoff and Soil Loss

In Sieboldshausen, the cumulative runoff did not differ between mechanical and chemical weed control treatments. But the cumulative soil loss was significantly higher for mechanical than for chemical weed control with on average, 77 gm^{-2} and 36 gm^{-2} after 30 mm precipitation amount, respectively (Fig. 2). Also mean soil loss rate with on average 6.6 $gmin^{-1}m^{-2}$ was significantly higher in mechanical than 2.7 g $min^{-1}m^{-2}$ in chemical treatment. In Obernjesa, on the contrary, there was a significantly higher cumulative runoff and sediment loss under chemical compared to mechanical weed control (Fig. 2, Tab. 3). The onset of runoff from the rainfall simulation area occurred much later under mechanical than under chemical weed control. The presence of a tractor rut (O2) did not have a significant effect on cumulative runoff, but a one week delay in a rain event caused a severe drop in cumulative runoff in case of chemical weed control (Tab. 3).

Tab. 3 ANOVA summary for cumulative runoff and soil loss in Obernjesa.

Tab. 3 *ANOVA Zusammenfassung zum kumulativen Abfluss und Bodenabtrag in Obernjesa.*

Predictors	**Cum. Runoff, Lm^{-2}**		**Cum soil loss, gm^{-2}**	
	F-value	**Pr > F**	**F-value**	**Pr > F**
Experiment (O1,O2,O3)	9.82	0.0015**	7.59	0.004**
Treatment	30.78	<0.0001***	13.63	0.0015**
Mulch	8.17	0.011*	11.57	0.003**
Experiment:Treatment	1.32	0.29	1.42	0.27

Our working hypothesis of the enhanced soil erosion in sugar beet under mechanical in comparison to chemical weed control was confirmed only for Sieboldshausen. The higher soil roughness after hoeing was most probably responsible for a higher soil particle detachment at this site and caused therefore an observed increase in mean soil loss rate for mechanical treatment. In Obernjesa, hoeing, on the contrary, promoted infiltration in soil, shifting the onset of runoff and causing therefore a reduction in cumulative water and sediment loss. A severe reduction in cumulative runoff in Obernjesa caused by a one-week delay in rainfall application was most probably due to a significant increase in sugar beet coverage within this week (from 37% to 61% on average). The higher water interception reduced the amount of water reaching the soil surface.

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