Precision harrowing using a bispectral camera and a flexible tine harrow

Präzises Striegeln mit justierbarerem Kamerazinkenstriegel

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Abstract

In the given study an adjustable harrowing system is presented and tested. The automatic harrow can increase or decrease the harrowing intensity during operation. A gentle (20%), medium (40%) and aggressive (60%) harrow intensity was chosen. Prior to the application, measurements were performed in each plot concerning the weed density and composition. With this information, a Decision Support System based on fuzzy logic was used in order to trigger an appropriate tine angle movement. Thus, areas with high crop and weed densities were applied with more aggressive harrowing treatments and areas with lower weed densities with a gentler treatment.

A spring barley field was adopted to evaluate the suitability and effectiveness of the system at the University of Hohenheim, Germany. A harrow application was conducted at the maximum permitted harrow intensity (60%), as the farmer would have applied it on the field and an automatic adaptation, based on the results of the decision support system. A further herbicide treatment and an untreated control were also included. Weed counting was performed prior to and after the application, along with biomass cuts and yield in order to estimate the treatment efficacy. The automatic system performed well, providing similar results as the non-automatic harrowing, but with lower intensity levels. Dicotyledonous weeds were, in both mechanical applications, reduced as well as by the herbicide application, without any significant differences.

Keywords: Bi-spectral camera, harrow, mechanical weed control, precision farming

Zusammenfassung

In dieser Studie wird ein justierbarer Kamerastriegel vorgestellt und getestet. Während des Striegelns kann die Intensität automatisch an die ortsspezifische Verunkrautung angepasst werden. Hierbei wurden die drei Striegeleinstellungen leicht (20 %), mittel (40 %) und stark (60 %) getestet. Vor der Überfahrt mit dem Kamerastriegel wurden in jedem Plot die Unkrautdichte und -zusammensetzung erhoben. Diese Informationen dienten einem Decision Support System, basierend auf Fuzzylogic, zur Anpassung des Einstellwinkels der Striegelzinken. Somit konnten Bereiche mit großer Unkraut- und Getreidedichte aggressiver gestriegelt werden als Bereiche mit geringer Biomasse.

Die Handhabung und Effektivität des Systems zur Unkrautregulierung wurde in Sommergerste auf einem Feld an der Universität Hohenheim getestet. Hierzu wurde in einer Variante die maximale Striegelintensität (60 %), wie sie bei nicht automatisch justierbaren Maschinen angewandt wird getestet. Diese wurde verglichen mit der automatischen Striegeleinstellung, welche durch das Decision Support System vorgenommen wurde. Zusätzlich wurden eine unbehandelte Kontroll- und eine Herbizidvariante angelegt. Die Bonituren zur Erfassung der Verunkrautung und Biomasse erfolgten vor und nach der Behandlung, um die Wirksamkeit der verschiedenen Verfahren zu ermitteln. Das automatische System erwies sich als praxistauglich und lieferte vergleichbare Ergebnisse wie der fest voreingestellte Striegel, obwohl mit geringerer Intensität gestriegelt wurde. Zweikeimblättrige Unkräuter wurden mit dem automatischen Kamerastriegel ebenso gut behandelt, wie in der Herbizidvariante.

Stichwörter: Bi-Spektralkamera, mechanische Unkrautregulierung, Präzisionslandwirtschaft, Zinkenstriegel

Introduction

Chemical control has been the most common weed management method for the last decades (GERHARDS and CHRISTENSEN, 2003). Yet, this development has caused unintended, drawbacks such as weed resistance to herbicides and residues in the environment (STORRIE and WALTER, 1999; KROPFF and WALTER, 2000). In 2017 485 unique cases of herbicide resistant weeds have been reported globally, covering over 252 different species and 163 different herbicides (HEAP, 2017). Non-chemical weeding technologies, such as mechanical weed control, provide an option for controlling weeds without harming the environment, not only in organic but also in conventional

farming (Rueda-Ayala et al., 2013). On the other hand, mechanical weed control cannot be weed-specific and even more, it usually provides a lower weed control efficacy with higher costs than chemical control. Therefore, there is an imperative need for mechanical weed control to evolve towards a site-specific weeding approach, in order to be able to compete with the current conventional herbicide applications. For example, using a flexible-tine harrow can be quite effective in controlling small broad-leaved weeds, but less effective concerning deep-rooted weeds and grasses (Rasmussen et al., 2008).

One way that weed harrowing can improve is by increasing its selectivity. That means that weed harrowing has to obtain a high degree of weed control without damaging the crop in a considerable manner (Rasmussen et al., 2008). The crop soil cover can be correlated with the soil conditions during the application but the cultivation intensity is also an indicator for crop damage (Cirujeda et al., 2003). The fact that weed populations in arable fields present a high spatial variability can be taken into account and utilized as an advantage for mechanical weed control (Gerhards and Christensen, 2003). Therefore, harrow intensity should be adapted accordingly: increased at high-density weed patches and decreased at locations with low weed infestation, or no weeds. More aggressive intensity levels can be obtained by changing the tine angle in relation to the field surface, increasing driving speeds or including more than one consecutive passes on the same day of cultivation (Rasmussen et al., 2008).

In the last 15 years, various attempts were made to achieve an automatic control of the harrowing intensity by using a tractor equipped with an adjustable spring-tine harrow (Søgaard 1998; Engelke 2001). This system has been providing some encouraging results concerning weed harrowing (Søgaard 1998; Rueda-Ayala et al., 2013; Rueda- Ayala et al., 2015). Discriminating between weed and crop plants is paramount for autonomous weed control. In order to perform selective weed control applications, it is important to differentiate between different weed species, especially between dicotyledonous and monocotyledonous. Different methods for weed identification have been proposed (e.g. offline maps, an ultrasonic sensor). Offline maps need manual sampling prior to the application, while a calibration on the current field status and crop/weed information is imperative for the ultrasonic sensor. A typical approach is the recognition of plant species based on their shape. Binary images deriving from a combination of near-infrared and red light have been used for plant identification and weed recognition (Gerhards and Christensen, 2003; Sökefeld, 2005; Oebel, 2006; Weis and Gerhards, 2007)

In the current paper, we evaluated the use of a bispectral camera for sensor-based weed harrowing. In the proposed system the harrowing intensity is regulated based on the calculated weed density from the bispectral camera and a decision support system (DSS). This study aimed to test a harrowing system, which can gather information on weed variability by the bispectral camera, use this information to decide the treatment intensity needed and adjust the required treatment intensity. The specific objectives were i) to evaluate the feasibility of such a system, ii) to investigate the performance, and outcome of the system and finally to iii) to test the weed control effectiveness of the harrowing system in a field experiment.

Materials and Methods

Experimental setup

A spring barley (*Hordeum vulgare* L.) field was treated at the research station Ihinger Hof of the University of Hohenheim, Germany. Spring barley was sown in the end of April 2016, with a seeding rate of 350 seeds/ m² and a row distance of 15 cm. The experimental setup was a randomised complete block design. Three different weed management treatments were implemented, along with an untreated control (C). The utilized treatments were: a) sensor guided harrowing (S), b) plain harrowing with an intensity of 60% of the full harrowing potential (N) and c) a herbicide application (H). Using 60% of the full harrowing potential was chosen by an expert as the optimum harrowing intensity for the specific field conditions. This was also the highest

intensity used on the sensor guided treatment. For the herbicide treatment plots were sprayed with a herbicide mixture against both mono- and dicotyledonous weeds at an application rate of 200 L/ha (active ingredients: 60 g/ha *pinoxaden*, 15 g/ha *cloquintocet-mexyl*, 4.15 g/ha *metsulfuron-methyl*, 4.15 g/ha *tribenuron-methyl*, 5.25 g/ha *florasulam*, 75 g/ha *fluroxypyr*, 1.875 g/ha *florasulam* and 60 g/ha *clopyralid*). Each plot had a size of 6 x 25 m with an intermediate distance of 10 m between different blocks. Weed counting was performed prior to and after the application, along with biomass cuts and yield measurements in order to estimate the treatment efficacy.

System Description

A bispectral camera was used for the weed identification of the current field. The sensor is based on the principle that plant material absorbs light in the visible red spectrum (610-670nm) and reflects light in the near-infrared spectrum (770-1150nm), while soil, mulch, and stones reflect similarly in both regions. When taking images, a prism embedded in the camera divides incoming light into visual and near infrared, leading each spectral range into two different monochrome sensors. These images are automatically overlapped and a difference image is calculated, which was used for further analysis. From a collection of such images, a training set of geometric shape features and Fourier descriptors of the outer contour of plants was created. This consisted of barley and weed species commonly occurring in barley. Based on this training set a classifier was developed for automatic weed/crop classification. Three different harrowing intensities were selected, based on the in-field weed density (Tab. 1)

Concerning the harrow, a 6-m-wide flexible-tine harrow (Hatzenbichler Austrian Agrotechnik) was used. This implement was divided into four autonomous subunits, 1.5 m, each with six rows of tines with 8 tines each. For each subunit, all the tines were connected together and moved simultaneously by an actuator, which changed the tine angle for cultivating operations. The actuator was an electric cylinder which could expand (0% -100%) or compress (100% - 0%) in a total time of 7.5 s. The tine angle could change from 34 degrees (0% harrowing power) to 82 degrees (100% harrowing power).

Tab. 1 Classification of weed density in three harrow intensities for the performance of mechanical weed control with a flexible tine harrow. The 3 different intensities represent 20%, 40% and 60% of the maximum harrowing intensity, respectively.

Tab. 1 Klassifizierung der Unkrautdichte in drei Striegelintensitäten für die mechanische Unkrautkontrolle mit einem justierbaren Zinkenstriegel. Die 3 verschiedenen Einstellungen entsprechen jeweils 20 %, 40 % und 60 % der maximalen Striegelintensität.

Class	Grass density (plants m^{-1})	Broad leafed density (plants m^{-2})	Harrowing intensity
1	0	0-25	light
2	1	26-50	strong
3	≥2	>50	strongest

Results

Concerning the weed composition, *Polygonum convolvulus* L. was the most dominant weed species, followed by *Galium aparine* L. and *Stellaria media* Vill. Additionally, *Cirsium arvense* L., *Veronica* ssp. and *Alopecurus myosuroides* Huds. were also observed.

Based on the weed count after the second and final harrowing all three weed treatments showed a significant reduction in the weed density compared to the control (164 weeds/m^2)(Fig. 1). Sensor-based harrowing and nonsensor based harrowing showed similar weed densities with the herbicide treatments (45, 42, 17 weeds/m^2 respectively). Even though the herbicide-treated plots showed the lowest weed density, there was no statistical difference between the three treatments. Yet further experimentation is needed to establish this outcome.

Concerning the final yield, all treatments performed similarly (Fig. 2). The herbicide treated plots showed the highest yield compared to the mechanical treatments and the control. Both mechanical treatments led to a higher yield than the control. In all cases, there was no significant difference between all treatments based on a Tukey Honest Significant difference test at 5% confidence interval.
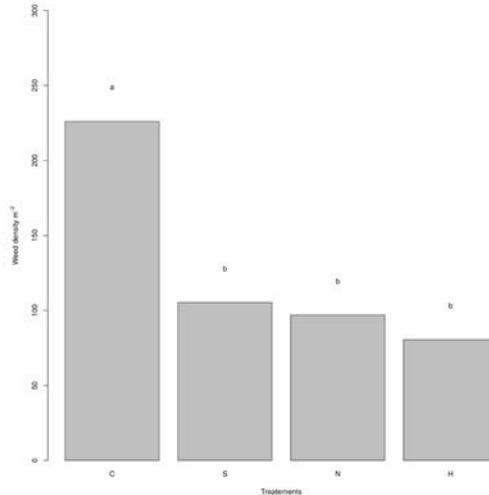
Fig. 1 Weed densities in spring barley one week after the final (second) harrowing treatment. Different letters indicate significant differences at p ≤ 0.05 performed by a Tukey HSD test. C= control, H= herbicide plot, S= sensor guided plot, N= non-sensor/ plain intensity plot (60%).
Abb. 1 *Unkrautdichte in Sommergerste eine Woche nach der zweiten Striegelüberfahrt. Verschiedene Buchstaben kennzeichnen signifikante Unterschiede. Ermittelt mit einem Tukey HSD test (p ≤ 0,05). C= Kontrollparzelle, H= Herbizidparzelle, S= Sensor gesteuerter Striegel, N= ohne Sensor, gleichbleibende Striegelintensität (60 %).*
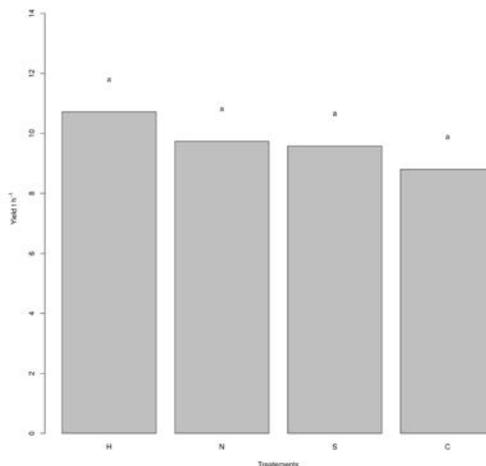
Fig. 2 Mean yield of the spring barley. There were no significant differences at p ≤ 0.05 performed by a Tukey HSD test. C= control, H= herbicide plot, S= sensor guided plot, N= non-sensor/ plain intensity plot (60%).

Abb. 2 *Mittlerer Kornertrag der Sommergerste. Keine signifikanten Unterschiede. Ermittelt mit einem Tukey HSD test (p ≤ 0,05). C= Kontrollparzelle, H= Herbizidparzelle, S= Sensor gesteuerter Striegel, N= ohne Sensor, gleichbleibende Striegelintensität.*

Discussion

Chemical weed control performed higher weed suppression and gathered a slightly higher yield than the mechanical counterpart. Nevertheless, the results showed no significant differences between both control types regarding weed densities, the determined biomass of crop or weeds and the yield. Hence mechanical control was as successful as the chemical one although the weed population remained slightly higher in the mechanical plots. Similar results were already recorded by Rasmussen and Svenningson (1995) and by Rueda-Ayala et al. (2011). The relatively low weed infestation and the absence of high densities of monocotyledonous weeds, like *A. myosuroides*, possibly hid the potential of different treatments or their expected disadvantages. Though weather conditions were rather unfavorable for harrowing, good results in weed reduction and yield were achieved. The good soil conditions in combination with sufficient nutrient provision and low weed infestations resulted in a vigor crop and high yield of the field. Another positive effect of mechanical weed control was produced at the second harrowing date. Because of heavy rainfall, the soil was very muddy and had formed a crust. The mechanical treatment loosened the soil surface. That way, aeriation, evaporation, and mineralization can be improved and can have a positive effect on crop growth (Dierhauer and Holger, 1994). Though weed seeds can get a light stimulus and might germinate, the crop had already been big enough to be competitive and could suppress new germinating weeds. The system performed well, providing similar results with the non-automatic harrowing, but with lower intensity levels. Though, further experimentation and more information are needed for the potential implementation of the sensor based harrowing.

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