Sektion 2: Precision Farming und Anwendungstechnik

Section 2: Precision farming and application technology

Using bi-spectral imaging technology for simulated online-weed control in winter wheat and maize

Simulation einer online Unkrautkontrolle in Winterweizen und Mais unter Verwendung von Bispektralkameras

Markus Sökefeld*, Martina Keller, Martin Weis, Christoph Gutjahr & Roland Gerhards
Institute for Phytomedicine 360, Department of Weed Science, University of Hohenheim, Otto-Sander-Strasse 5, D-70599 Stuttgart, Germany
*Corresponding author, markus.soekefeld@uni-hohenheim.de

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Summary

In spring 2011, two field trials on site-specific weed control in winter wheat and maize were carried out at Ihinger Hof research station of the University of Hohenheim. For the image acquisition, bi-spectral cameras were mounted on a vehicle. These cameras are able to take images free from disturbances by soil, mulch and stones. Images and the corresponding GPS-data were stored on-the-go. Afterwards, the images were analyzed by a weed recognition software. Weed infestation was mapped in consideration of weed species and weeds grouped according to their herbicide sensitivity. In order to simulate an online herbicide application, a one-sided moving average of order five was used for the weed mapping. This kind of rearward calculation uses only the data of weed infestation which were already assessed behind or directly in the current position of the vehicle. The calculated weed distribution maps were checked by visual grid sampling. Herbicide application maps were generated by applying weed thresholds on the weed distribution maps. The herbicide application based on the maps was conducted by a multiple sprayer which allows the application of up to three herbicides independently from each other in a single pass across the field. Later on, the performance of the herbicide application was controlled again by visual grid sampling. Compared to a uniform herbicide application, the site-specific weed control saved 83 % and 58 % herbicides respectively in winter wheat and 66 % in maize. The average efficacy of the site-specific herbicide application system in winter wheat was 70 % of the conventional herbicide application.

Keywords: Bi-spectral cameras, herbicide application, image analysis, site-specific, weed control

Zusammenfassung

Im Frühjahr 2011 wurden auf der Versuchsstation Ihinger Hof der Universität Hohenheim Feldversuche zur teilschlagspezifischen online-Unkrautkontrolle in den Kulturen Winterweizen und Mais durchgeführt. Die Bildaufnahme für die Erfassung der Verunkrautung mit Hilfe von digitaler Bildverarbeitung erfolgte mit einem Kamerafahrzeug, auf welchem Bispektralkameras montiert waren. Die Verwendung dieser Kameras gewährleistet die Aufnahme von Bildern, die von Boden, Steinen und Mulch weitestgehend ungestört sind. Zusammen mit den Bildern wurden die korrespondierenden Geokoordinaten gespeichert. Nach der anschließenden Bildauswertung unter Verwendung digitaler Bildauswerteverfahren erfolgte eine Kartierung der ermittelten Verunkrautung nach Unkrautarten bzw. Unkräuter gruppiert gemäß der Herbizidempfindlichkeit. Für die Kartierung wurden einseitig gleitende Mittelwerte der fünften Ordnung berechnet. Die Bestimmung des Mittelwertes erfolgte jeweils mit den vier Messwerten die zeitlich gesehen hinter dem aktuellen Messwert lagen und dem aktuellen Messwert. Durch diese rückwärtsgewandte Mittelwertbildung wurde die online Bildverarbeitung simuliert. Zur Überprüfung der Plausibilität der berechneten Unkrautverteilungskarten wurden die aus einer visuellen Rasterbonitur stammenden Daten herangezogen.

Unter Verwendung von Schadschwellen wurden die auf der Basis der Bildanalyse erstellten Unkrautverteilungskarten für die Berechnung von Applikationskarten benutzt. Die Umsetzung der Applikationskarten erfolgte mit einer Dreikammerspritze, welche eine simultane Applikation von bis zu drei Herbiziden unabhängig voneinander erlaubt. Eine Erfolgskontrolle der durchgeführten Herbizidapplikation erfolgte im zeitlichen Abstand wiederum anhand einer visuellen Rasterbonitur. Im Vergleich zur betriebsüblichen Variante wurde durch die teilschlagspezifische Herbizidapplikation im Winterweizen eine Herbizideinsparung von 83 % bzw. 58 % und im Mais von 66 % realisiert. Die durchschnittliche Wirksamkeit der

teilschlagspezifischen Herbizidmaßnahme im Winterweizen betrug 70 % der betriebsüblichen Variante.

Stichwörter: Bildverarbeitung, Bispektralkameras, Herbizidapplikation, teilschlagspezifisch, Unkrautkontrolle

1. Introduction

Several studies have shown that weed distribution is heterogeneous in time and space within fields (MARSHALL, 1988; THORNTON et al., 1990; CHRISTENSEN and HEISEL, 1998; GERHARDS and CHRISTENSEN, 2003; NORDMEYER and ZUK, 2002). Weeds often tend to occur in patches (CARDINA et al., 1997; DIELMANN and MORTENSEN, 1999). This offers the potential for herbicide savings using site-specific weed control. Apart from this biological prerequisite, other requirements have also to be fulfilled. These requirements are: First an accurate weed detection, second a decision component (algorithm) and third an adapted application technology (GERHARDS and OEBEL, 2006). NORDBO et al. (1994) distinguished site-specific herbicide application in a mapping and a real-time concept. The mapping concept consists of two steps. In the first step, the weed distribution is determined and visualized in a map. In the second step, the herbicide application is carried out according to the derived weed map. GERHARDS and OEBEL (2006) used this approach and achieved a wide range of herbicide savings from 6 % up to 81 % depending on the crop and the applied herbicide. In the real-time concept, weed detection and herbicide application are performed simultaneously. This approach requires online weed detection, a fast decision algorithm and an interface to the sprayer and a sprayer with a short lag time (SÖKEFELD et al., 2004). In contrast to the mapping concept, where information on the complete weed infestation of the entire field is available before spraying, in a real-time concept, the information on the weed distribution is limited to the area already assessed by the sensors on the sprayer. So far, online application was mainly restricted to vegetation recognition (plant versus soil and mulch) using reflectance properties (FELTON and MCCLOY, 1992; VRINDTS and DE BAERDEMAEKER, 1997; BILLER, 1998). For an in-crop application, discrimination of weed species or at least weed groups (weed groups show similar sensitivity to certain herbicides) is desirable as it maximizes the herbicide saving potential (GERHARDS and SÖKEFELD, 2003; WILES, 2009). For weed species discrimination, imaging technology using morphological properties is most promising (HEMMING and RATH, 2001; WEIS and GERHARDS, 2007). In addition, an online approach including weed discrimination seems to be the only practicable approach as it requires no extra vehicle crossing and thus no additional working hours. Therefore adoption by farmers is more likely. Site-specific weed control can be carried out at different spatial resolutions: Sub-field, individual weed patches or even single weed plants (CHRISTENSEN et al., 2009). In our opinion, a system at the patch-level is most suited for adoption into practice. However, an online system has to compete with the standard whole field application. Thus, the aim of the study was to compare these two systems in field trials, one in winter wheat (*Triticum aestivum*) and one in maize (*Zea mays*), regarding the herbicide input and weed control.

2. Materials and methods

2.1 Field description and experimental design

The two field experiments were carried out at the Ihinger Hof research station near Stuttgart, Germany in 2011. The average temperature is 9.3 °C and the average precipitation is 715 mm (average of the last 10 years). For both fields, tillage, seed densities, fertilization levels and plant protection corresponded to the typical regional farming practice except for the herbicide application. The wheat experiment (Kirrlay Wald) was about 2.5 ha in size and the soil type was a loamy clay, whereas the maize experiment (Schafweide) was about 3.6 ha in size and the soil type was loam (Tab. 1).

The experiments were designed as randomized complete block design (RCBD; Fig. 1a). A standard herbicide application, a site-specific application and an untreated control were included. In winter wheat, the trial comprised nine blocks, in maize 16 blocks. Single plot size was 9 x 70-100 m. A grid with cells of 9 x 9 m was established in each plot. In winter wheat tramlines were excluded from the grids to avoid any effect due to lower wheat stand.

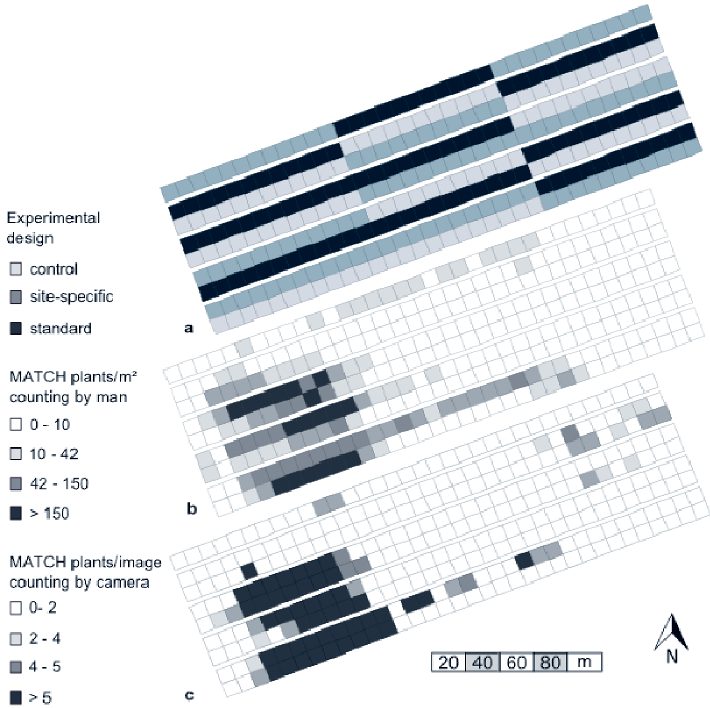

Fig. 1 Experimental design (a), distribution of *Chamomilla recutita* by man counting (b) and distribution of *Chamomilla recutita* by camera counting (c) of the winter wheat trial (Kirrlay Wald). Single grid size is 9 m x 9 m.

Abb. 1 *Versuchsplan (a), Verteilung von Chamomilla recutita ermittelt durch Zählung (b) und Verteilung von Chamomilla recutita ermittelt durch automatische Klassifikation (c) des Winterweizenversuchs (Kirrlay Wald). Rastergröße 9 m x 9 m.*

2.2 Determination of weed distribution

Weed distribution was determined at the grid size of 9 x 9 m by counting in an area of 0.4 m^2 at the grid center before and in the winter wheat trial also after the herbicide application. The center of each grid was geo-referenced.

Images were taken by bi-spectral cameras to access the weed infestation of the field. The bi-spectral cameras take two pixel congruent images in the red and infrared spectrum. The difference image does not contain any disturbances like straw or organic matter. In addition, a strong contrast between plants and background can be achieved (SÖKEFELD et al., 2007). For the weed classification a data based image analysis system was used. In this database, parameters (shape features and morphological features) of the different weed species and crops are stored. The features of the objects found in the images are compared with the features in the database and can be classified (WEIS and GERHARDS, 2007). The bi-spectral cameras were mounted on a self propelled sensor platform at a height of about 1 m above ground resulting in image sizes of 30 cm x 40 cm (KELLER et al., 2011). In winter wheat, the images were taken in the middle of the grids to allow for comparison with man weed counts. *Chamomilla recutita*, *Stellaria media*, *Veronica* spp., *Alopecurus myosuroides*, *Galium aparine* and *Triticum aestivum* were classified in the images. In the maize trial, the images were taken between the rows. Thus, no maize plants were visible in the images and therefore no crop-weed discrimination was necessary. In contrast to the winter wheat trial, weed species were not classified. Instead weed coverage was calculated after disturbances in the images smaller than 150 Pixel had been eliminated. In average 2-4 images were taken per m driving distance.

Tab. 1 Details of the field trials in winter wheat and maize.

Tab. 1 *Beschreibende Daten zur Durchführung der Feldversuche in Winterweizen und Mais.*

	Winter wheat	**Maize**
Field size	2.5 ha	3.6 ha
Soil type	Loamy clay	Loam
Time of application	March 30, 2011	June 10, 2011
Growth stage crop (BBCH)	22-24	13-15
Weed group I	MATCH, STEME, ALOMY	All weeds
Growth stage weed (BBCH)	12-14	13-15
Threshold (plants/image)	> 7	> 0
Herbicide treatment	Isoproturon 2.5 l/ha	Tritosulfuron & dicamba 200 g/ha
Weed group II	GALAP	-
Growth stage weed (BBCH)	12-14	-
Threshold (plants/image)	>2	-
Herbicide treatment	Fluroxypyr 1 l/ha	-

2.3 Herbicide treatment

According to the weed infestation, the herbicide and application rate were chosen (Tab. 1). In winter wheat 1 l/ha fluroxypyr (Tomigan) and 2.5 l/ha isoproturon (Arelon fluessig 500) were applied. In maize, 200 l/ha tritosulfuron and dicamba (Arrat) were applied plus the surfactant Dash E.C. (1 l/ha). The application was carried out at BBCH 22-24 of the crop in winter wheat and BBCH 13-14 in maize. In the standard herbicide application treatment, the herbicide was applied to the whole area. The control was left untreated. In the site-specific treatment, the herbicide was applied dependent on the weed infestation. If the weed density was above a certain threshold the herbicide was applied otherwise the sprayer was switched off. Table 1 shows the thresholds for herbicide application for the site-specific treatment in both trials. In the winter wheat trial isoproturon was applied if the sum of *Chamomilla recutita*, *Stellaria media* and *Alopecurus myosuroides* was higher than seven per image. Fluroxypyr was applied if more than two objects per image were classified as *Galium aparine*. The thresholds were chosen rather high to take into account a slight overestimation of weed infestation due to misclassification by the classification algorithm. In previous studies, the average identification rate of this image analysis system ranged between 85 % - 98 % in winter wheat (WEIS et al., 2008). A one-sided moving average of order five, taking into account the four last images and the image at the current position of the sprayer, was used, as in an online site-specific herbicide application only this previous information is available. In maize, tritosulfuron and dicamba was applied if any weed coverage was found in one of the five images which were used for calculating the moving average. Herbicide application maps generated by using the above mentioned thresholds and the calculated moving average simulated an online approach. The actual spraying was realized by a multiple sprayer which allows the application of up to three herbicides independently from each other in a single pass across the field (GERHARDS and OEBEL, 2006). This sprayer was constructed in the frame of a research project and it is not available on the market. In winter wheat, weeds were counted again four weeks after herbicide application. The weed control performance of the standard and the site-specific treatment was determined comparing the weed density after the herbicide application (second weed count by man) and the weed density before the herbicide application (first weed count by man). In maize, no second weed count was carried out due to the very low weed infestation and the rapid maize growth resulting in the canopy closure and thus a low weed competition soon after the herbicide application.

3. Results

3.1 Weed distribution in the fields

The weed infestation in the two field trials was found to be heterogeneously (Fig. 1 b/c). In the maize field, the weed density was rather low thus herbicide savings were high. Especially grass weeds were lacking, hence only one herbicide had to be sprayed and no differentiation between weed species was necessary. In the winter wheat field, the weed infestation was moderate only *Galium aparine* and *Chamomilla recutita* appeared in a very high density with maximum counts of more than 400 plants/m^2 (Tab. 2 and Fig. 1 b/c)).

Tab. 2 Weed density for single species in the two field trials (weed count by man).

Tab. 2 *Unkrautdichte einzelner Arten in den beiden Feldversuchen (ermittelt durch Zählung).*

Weed species	**Winter wheat**				**Maize**			
	Mean	Max.	Min.	SD	Mean	Max.	Min.	SD
Chamomilla recutita	27.9	468	0	78.4	-	-	-	-
Galium aparine	14.1	400	0	34.2	0.1	15	0	1
Stellaria media	7.1	170	0	19.8	-	-	-	-
Alopecurus myosuroides	3.5	108	0	10.7	-	-	-	-
Cirsium arvense	< 0.1	10	0	0.7	0.3	20	0	1.7
Chenopodium album	< 0.1	2.5	0	0.2	0.2	2.5	0	0.7
Brassica napus	< 0.1	7.5	0	0.4	0.2	2.5	0	0.6

Table 2 shows the density for single weed species in the two field trials. In the winter wheat trial, the dominant weed species (listed in decreasing order) were according to weed count by man: *Chamomilla recutita*, *Galium aparine*, *Stellaria media* and *Alopecurus myosuroides* (leaf stage 2-4). The results of the automatic classification based on bi-spectral images were similar (Fig. 1 b/c). However, *Alopecurus myosuroides* was found to be the most frequent weed. This can be ascribed to winter wheat leaf tips in the images, which were misclassified as *Alopecurus myosuroides* (Fig. 2).

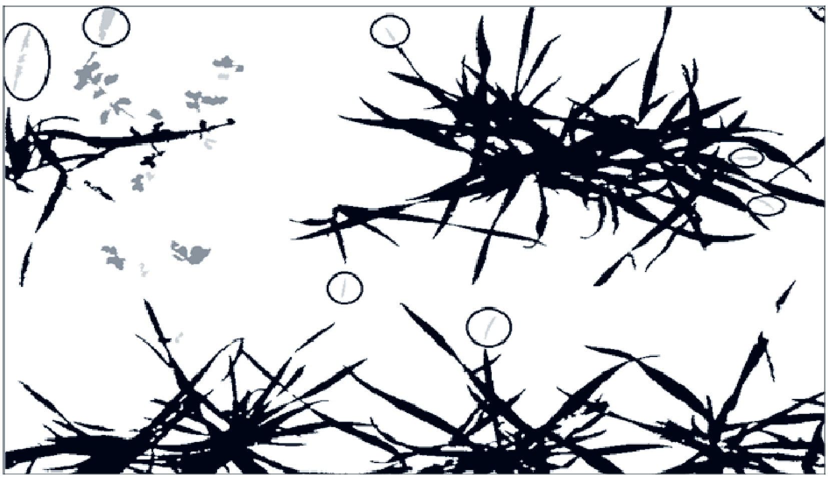

Fig. 2 Section of a classified bi-spectral image. Black: wheat, light gray (marked by circles): *Alopecurus myosuroides*, dark gray: broadleaved weeds.

Abb. 2 *Ausschnitt eines klassifizierten Bildes. Schwarz: Weizen, hellgrau (Kreismarkierung): Alopecurus myosuroides, dunkelgrau: breitblättrige Unkräuter.*

In the maize trial, *Cirsium arvense*, *Chenopodium album*, *Brassica napus* and *Galium aparine* were the dominant weed species (Tab. 2). The growth stage was between leaf stage 3 and 5.

In winter wheat, distinct patches of *Chamomilla recutita* and *Galium aparine* in the western part of the field were recognized (Fig. 1 b/c). In maize, *Cirsium arvense* and other perennials showed a high level of aggregation. In general, weed densities were rather low.

3.2 Weed control and savings

The average weed control of the site-specific treatment in winter wheat was 70 % of the conventional weed management i.e. standard treatment (Tab. 3). The level of weed control was higher in the standard treatment compared with the site-specific treatment for all weeds. In the latter, herbicides were applied according to thresholds and thus a certain number of weeds are tolerated. For *Galium aparine,* only 43 % were controlled in the site-specific treatment compared to the high level of 94 % control achieved in the standard treatment. A very poor efficacy of isoproturon was found against *Alopecurus myosuroides*.

In the winter wheat trial, approximately 83 % of the site-specific variant was not treated with isoproturon according to the applied decision rules. No application with fluroxypyr was carried out at 58 % of the site-specific treatment. In the maize trial 66 % of the site-specific variant was left unsprayed.

Tab. 3 Average weed control (%) in the winter wheat field with standard and site-specific application. 100 % = no weeds found after herbicide application.

Tab. 3 *Durchschnittliche Unkrautkontrolle (%) im Winterweizenversuch mit betriebsüblicher und teilschlagspezifischer Behandlung. 100 % = nach der Behandlung keine Unkräuter.*

Weed species	Standard application	Site-specific application
Alopecurus myosuroides	61 %	47 %
Chamomilla recutita	99 %	81 %
Galium aparine	94 %	43 %
Stellaria media	100 %	70 %

4. Discussion

Both field trials show the potential of site-specific herbicide application using digital image analysis and an application technology with the opportunity to change herbicides on-the-go. The achieved herbicide savings are comparable with the results of former studies (NORDMEYER and ZUK, 2002; GERHARDS and OEBEL, 2006). In the winter wheat trial, the low herbicide efficacy against *Alopecurus myosuroides* in the site-specific variant as well as in the standard application might be explained by very dry weather conditions 3-4 weeks after the application. Isoproturon could not be taken up in an adequate amount due to missing soil moisture.

Basically, the presented system which is consisting of the components image acquisition, weed detection by image analysis, decision algorithm (spray/not spray) and special spraying equipment is capable for site-specific herbicide application. Especially the processing speed of the image analysis system has to be improved if it should be used as an online system.

With the use of a multiple sprayer different herbicides can be applied independently and in respect to the weed infestation. This could also be achieved with a direct injection system. The advantage of this systems is that due to direct injection the type and the amount of the herbicide can be changed on-the-go. Yet, the lag time of the currently available systems is long, because they all have a central point of injection (SÖKEFELD et al., 2004). If this drawback could be overcome, direct injection systems in combination with weed species detection technology could be used for online site-specific weed control on a large scale.

The determined thresholds particular for *Galium aparine* (Tab.1) seemed to be too high which is indicated by the low level of weed control against it (Tab. 3).

The high frequency of the image acquisition of 2 to 4 images per m driving distance required the calculation of a moving average in order to avoid a frequently switching on and off of the sprayer. On the other hand the calculation of the moving average smooths the density of the detected weed species and thus it can result in a delayed activation of the sprayer, i.e. not at the beginning of a weed patch. In future field trials the weed thresholds should be lower to achieve a better weed control. Certainly, lower thresholds will result in lower herbicide savings.

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