Potential of herbicide reduction by automatic spot spraying in sugar beet with regard to weed control and biodiversity

Potenzial der Herbizideinsparung durch automatisiertes Spot-Spraying in Zuckerrüben im Hinblick auf Unkrautbekämpfung und Biodiversität

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Abstract

Reducing pesticide use while maintaining crop productivity is one of the biggest challenges in modern agriculture. Spot spraying systems can achieve significant herbicide savings in weed control. This is true in particular for less competitive crops and with high herbicide treatment indices. In order to test the savings potential under practical conditions in the field, the effectiveness of a spot spraying system (WeedSeeker 2, FarmFacts Germany) was evaluated in a one-year pilot project. The study included two intensity levels in comparison with standard site practice and an untreated control in a sugar beet experimental field with each four replicates. Therefore, the degree of weed coverage, the weed density and the number of weed species present were recorded before and after each of the three treatments by visual assessment. After the last application, the abundance and diversity of soil arthropods was additionally recorded. Finally, the herbicide savings potential at a given weed density, the control success and differences in abundance and diversity of the recorded species between the treatments were compared. Our results show that a considerable decrease in herbicide use is possible with the given technology, however, weed densities remained above the economic threshold for the most dominant weed, *Chenopodium album* L. Additionally, there was a trend of a higher abundance of soil arthropods, including carbides, in the untreated plots in comparison to the different herbicide treatments. However, the biodiversity indicated by the Shannon index was not reduced. Overall, the spot spraying treatment did not lead to an improvement of biodiversity parameters in comparison to the broadcast standard spraying method. Therefore, a continuous improvement of the application technique is required to ensure stable yields while at the same time reducing pesticide use.

Keywords: Biodiversity, carabidae, herbicide, precision farming, soil arthropods, weeds

Zusammenfassung

Die Reduktion des Pflanzenschutzmittelverbrauchs bei gleichzeitiger Aufrechterhaltung der Produktivität im Pflanzenbau ist eine der größten Herausforderungen der modernen Landwirtschaft. Durch Spotspraying-Systeme können bei in der Unkrautkontrolle signifikante Einsparungen von Herbiziden erzielt werden. Dies gilt vor allem für Kulturen, die im Vergleich zu anderen Ackerbaukulturen eine geringe Konkurrenzfähigkeit gegenüber Unkräutern aufweisen und einen verhältnismäßig hohen Herbizidbehandlungsindex haben. Um das Einsparungspotenzial unter Praxisbedingungen im Feld zu testen, wurde die Effektivität eines Punktspritzsystems (WeedSeeker 2, FarmFacts, Deutschland) in einem einjährigen Pilotprojekt durchgeführt. Die Untersuchung umfasste zwei Intensitätsstufen im Vergleich zur standortüblichen Praxis und einer unbehandelten Kontrolle in einem Zuckerrübenbestand in vier Wiederholungen. Dazu wurden vor und nach jeder der drei Behandlungen der Unkrautdeckungsgrad, die Unkrautdichte und die Anzahl der vorkommenden Unkrautarten durch visuelle Bonitur erfasst. Nach der letzten Applikation wurden zusätzlich Abundanz und Diversität von Bodenarthropoden erhoben. Abschließend wurden das Herbizideinsparungspotenzial bei gegebener Unkrautdichte, der Bekämpfungserfolg, sowie Unterschiede in Abundanz und Diversität der erfassten Arten zwischen den Behandlungen verglichen. Unsere Ergebnisse zeigen, dass der Herbizideinsatz mit dieser Technologie erheblich reduziert werden kann. Die Unkrautdichte blieb jedoch über dem ökonomischen Schwellenwert für das dominanteste Unkraut, *Chenopodium album* L. Darüber hinaus war in den unbehandelten Parzellen im Vergleich zu den verschiedenen Herbizidbehandlungen tendenziell eine höhere Abundanz von Bodenarthropoden, einschließlich Laufkäfern, festzustellen. Die durch den Shannon-Index angezeigte Artenvielfalt wurde jedoch nicht verringert. Insgesamt führte die Spotspraying-Behandlung nicht zu einer Verbesserung der Biodiversitätsparameter im Vergleich zur Standard-Spritzmethode. Daher ist eine kontinuierliche Verbesserung der Anwendungstechnik erforderlich, um stabile Erträge zu gewährleisten und gleichzeitig den Pflanzenschutzmitteleinsatz zu verringern.

Stichwörter: Biodiversität, Bodenarthropoden, Herbizide, Laufkäfer, Präzisionslandwirtschaft, Unkraut

Introduction

Precision agriculture is an important component in facing modern agricultural challenges such as labour shortages, reduction of pesticide usage and promotion of biodiversity, while maintaining agricultural productivity. The reduction potential is particularly high for herbicides (POHL et al., 2018), as weeds are sessile and can be distinguished from cultivated plants relatively well with modern methods (SA et al., 2018). Furthermore, weeds are rarely homogeneously distributed across fields, so intelligent weed control systems can adapt weed control intensity to weed occurrence (KÄMPFER & NORDMEYER, 2021). With the rise of affordable computer vision and efficient image recognition, based on artificial intelligence, various of these systems including hoeing and spraying systems are under development and have advanced particularly over the past decade (ESPOSITO et al., 2021). Spot spraying is a powerful weed control method that potentially provides effective intra row weed control and has high herbicide saving potential. This particularly applies to crops that are sensitive to weed competition and have a high herbicide treatment index. Spot spraying instead of conventional chemical weed control in sugar beet can potentially save significant amounts of herbicide, as significant amounts of herbicide are applied during the usual three herbicide applications with an average treatment index of 2.6 (JULIUS KÜHN-INSTITUT, 2020). This is especially relevant since control thresholds are rarely applied due to the higher effectiveness of weed control at the cotyledon stage (GUMMERT et al., 2011) and as reduced chemical plant protection in sugar beet can have beneficial effects on ground beetles that can deliver important ecosystem services (KOSEWSKA et al., 2020). Herbicides, can have direct, but more importantly, indirect effects on insects via the vegetation cover and plant diversity (NORRIS & KOGAN, 2005). However, the spot spraying technology is still in the beginning and requires constant evaluation and improvement to bring the technology to widespread market maturity. For this reason, the present study investigated the savings potential of a spot spraying system with optoelectronic sensors, discriminating weeds from bare soil, at different herbicide intensities. In addition, the weed control success, as well as the abundance and diversity of the weed flora and the soil arthropods present in the field were recorded.

Material and methods

The field trial was drilled in Bovenden, Germany on April 23, 2021 (variety KWS Annarosa) on a loamy sugar beet production site (88 points). The experiment was designed as a randomized complete block design with four treatments and four replicates with plot sizes of 8.1 x 13.5 m. The blocks were framed by calibration plots and separated by conventionally-treated sugar beet plots.

The herbicide treatments were applied 27, 38, and 49 days after sowing as a combination of 1.5 L Goltix Titan (metamitron + quinmerac) ha^{-1}, 2 L Betasana SC (phenmedipham) ha^{-1} and 0.5 L Oblix (ethofumesat) ha^{-1}. The only deviation was an increase of the application rate of Betasana to 2 L ha^{-1} on the second application date. The herbicides were applied using a WeedSeeker 2 system (FarmFacts, Germany) with 12 optoelectronic sensors mounted on the sprayer boom at 45 cm intervals and connected to spraying nozzles controlled via an ISOBUS system. The weed seeker system has been calibrated according to the manufacturer's calibration procedure. To evaluate the sensitivity of the system, two different calibration setups were implemented. The first one with a very high sensitivity which enables the detection of smallest weeds, the second with less sensitivity to concentrate on larger weeds and more herbicide saving. The application was carried out at a speed of 4.5 km h^{-1} and 2.2 bar.
Vegetation monitorings were carried out two days before the first herbicide application, ten days after the first and the second application and twelve days after the third application. They included the estimation of the sugar beet coverage, the weed coverage and weeds within sampling windows of 2.7 x 6 m were counted and identified.
Soil arthropods were collected during a five-day period in three pitfall traps (8.5 cm Ø) containing 50% ethylene glycol per plot starting three days after the last herbicide application (BARBER, 1931). The number of centipedes (Chilopoda), millipedes (Diplopoda), arachnids (Arachnida) and beetles (Coleoptera) was determined. All ground beetles (Carabidae) were identified at the species level. Collembola and individuals < 2 mm were discarded due to large quantities (several thousands of individuals per trap). Finally, sugar beet yield (fresh mass) was determined after harvest in October, except for the untreated control plots, where the weeds were removed after the last weed assessment. The statistical evaluation included Shapiro-Wilk-tests for normality, which were conducted for all data sets. Statistical differences between treatments were then examined using the Wilcoxon rank-sum test. Additionally, linear regression analyses were conducted for the number of ground beetles as a function of weed density and herbicide application using the package 'ggpmisc'. Additionally, Shannon indices were calculated for carbides and weeds and analysed using linear regressions in a similar way. All analyses were conducted in R statistical software (version 4.0.0, (R CORE TEAM, 2021).

Results and discussion

This study investigated the potential herbicide reduction by automatic spot spraying in sugar beet, considering biodiversity aspects. It could be shown that in case of the high-intensity spot spraying treatment 17-67% and in case of the low-intensity spot spraying treatment 33-75% of the herbicide quantity was saved compared to the standard treatment (Fig. 1). The average herbicide savings were 39 and 61%, respectively. The weed coverage increased in all plots over the observed period (Fig. 2). After the third treatment, the weed coverage in the control showed with 66.3%, a significantly higher coverage than the treated plots. However, with weed coverage rates of 6.3 and 3.0% also the two spot spraying treatments reached levels below the typical standards of good agricultural practice. As typical for locations with a high percentage of sugar beets in the crop rotation, common lambsquarters (*Chenopodium album* L.) was the predominant weed (PETERSEN & HURLE, 1998). This is particularly true for the untreated control plots, where 94.4% of the weeds were identified as common lambsquarters (Fig. 3C). In the Weedseeker treatments, the proportion of common lambsquarters was at a similar level of 91.6 and 87.2% respectively. Considering the percentage of common lambsquarters and the weed density, this weed reached densities of 62.7 individuals m^{-2} in the control plots and 17.7 and 15.0 individuals m^{-2} in the spot spraying treatments with low and high intensity, respectively. Therefore, all of these treatments exceeded the sugar beet specific economic threshold of < 10 plants m^{-2} (NEURURER, 1976). These results correlate with the sugar beet fresh mass, as the yield was with 74.4 ± 2.2 t ha^{-1} highest in the standard treatment, followed by the spot spraying treatments with high intensity with 72.1 ± 3.07 t ha^{-1} and low intensity with 36.1 ± 8.5 t ha^{-1}.

However, these results were statistically not significant. Yet, for the practical application, the effectiveness and reliability of the tested spot spraying system needs to be improved in the in order to reduce the enrichment of the seedbank with seeds of common lambsquarters to an acceptable level for the farmer. This is of particular importance as these seeds are viable for decades, and under optimal conditions even centuries (THOMPSON et al., 1997). In addition, it is important to minimise the risk of yield reduction by weed competition, as the sugar beet coverage already indicated a yield effect (Fig. 2H). However, this effect was only found to be significant in the untreated control when compared to the standard plots and the high intensity spot spraying treatment. Significant yield reduction was not expected for the plots treated with the standard herbicide applications, where common lambsquarters accounted for only 30.7% of the weeds (0.4 individuals m^{-2}). In these plots, common knotgrass (*Polygonum aviculare* L.) with 46.7% was the most dominant weed, presumably due to the efficacy gaps of the herbicides (LAUFER & LADEWIG, 2020). This change in the abundance of common lambsquarters is also evident in the sense that, the biodiversity of weeds in the control plots with a Shannon index of 0.24 was significantly lower than the Shannon index of 0.85, calculated for the standard plots ($p = 0.029$, Fig. 4D). Thus, a weak positive correlation between Shannon index and herbicide use was found with an R^2 of 0.45. A similar, but even much weaker trend (R^2 = 0.2), was observed in the diversity of ground beetles (Fig. 4C). This can be attributed to the dominant occurrence of *Pterostichus melanarius* (Illiger), a predator of slugs and aphids (SUNDERLAND, 1975), in the untreated control plots. Unlike most beetles, this species tends to stay in the centre of the field rather than at the edge (FOURNIER & LOREAU, 1999). The next most common beetles were *Bembidion lampros* (Herbst), *Harpalus rufipes* (DeGeer), *Trichocellus placidus* (Gyll.) and *Harpalus affinis* (Schrank). These species occur frequently on arable land, also feed on aphids or weed seeds and therefore provide ecosystem services (SUNDERLAND, 1975; HONĚK & JAROŠÍK, 2000).

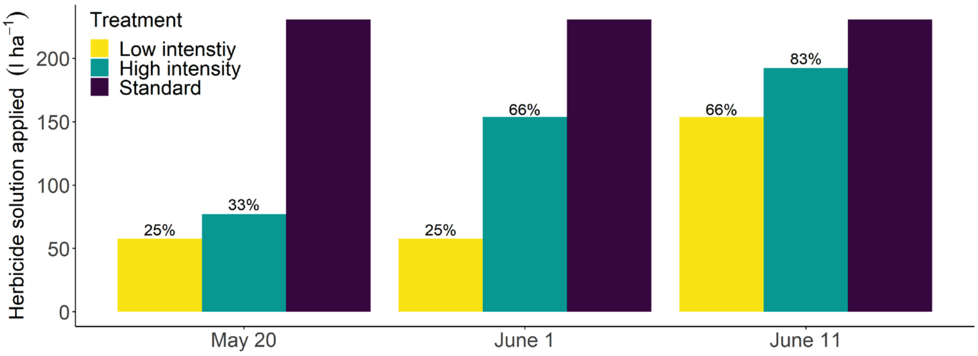

Figure 1 Amount of herbicide solution applied per treatment and application date. The reduction potential of the spot spraying treatments 'High intensity' and 'Low intensity' are indicated relative (%) to the standard treatment.

Abbildung 1 *Menge der ausgebrachten Herbizidlösung pro Behandlung und Anwendungsdatum. Das Reduktionspotenzial der Spotspraying-Behandlungen 'Hohe Intensität' und 'Niedrige Intensität' ist relativ (%) zur Standardbehandlung angegeben.*

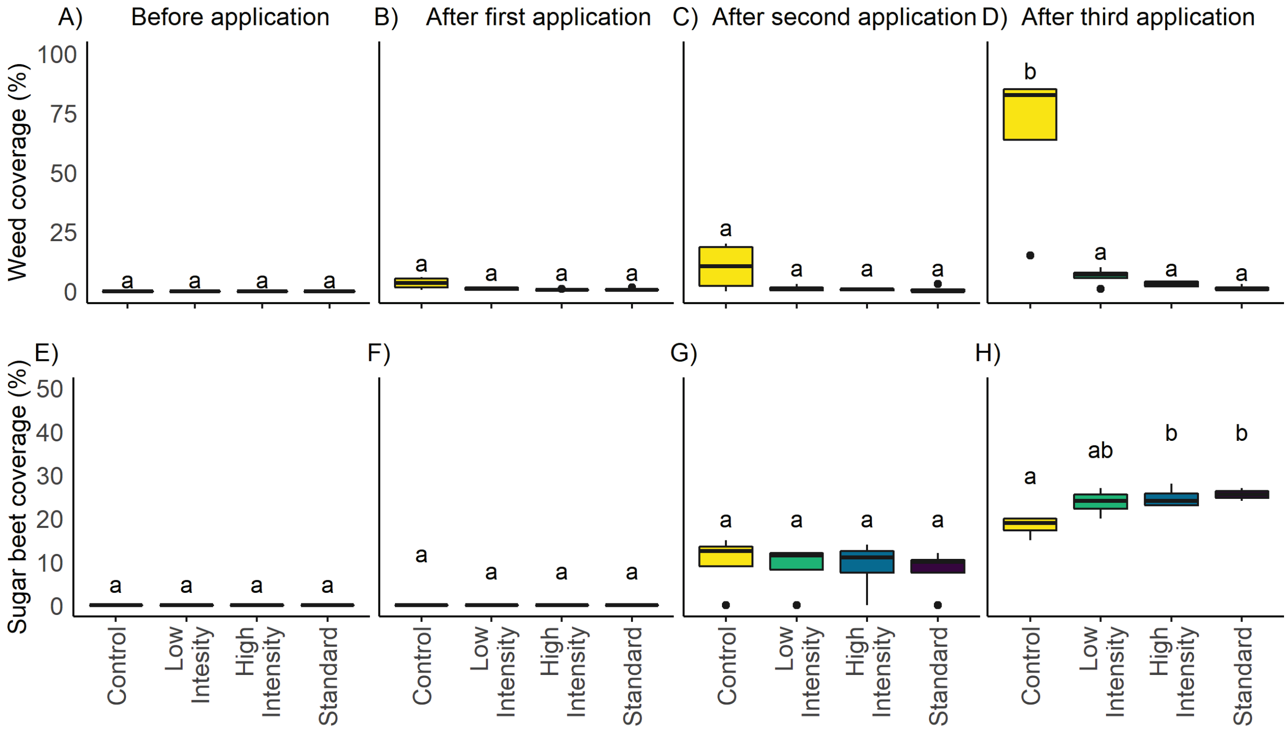

Figure 2 *Sugar beet and weed coverage rates in untreated control plots, plots with low intensity spot spraying treatments, high intensity spot spraying treatments and plots with standard site-specific treatment before application, after the first, the second and the third post-emergence application.*

Abbildung 2 *Zuckerrüben- und Unkrautdeckungsgrade in den unbehandelten Kontrollparzellen, Parzellen mit Spotsprayingbehandlungen mit niedriger Intensität, Spotsprayingbehandlungen mit hoher Intensität und Parzellen mit standorttypischer Standardbehandlung, vor Applikation, nach der ersten, zweiten und dritten Nachauflaufapplikation.*

H. rufipes however also feeds on seeds of sugar beet and other crops (BRYGADYRENKO et al., 2014). Among the most common species, *B. lampros* was more abundant in the treated plots, while the overall abundance of ground beetles as well as soil arthropods was higher in the untreated control plots. However the abundance was comparable among the different treated plots (Fig. 3A and 3B), which is in accordance with the literature (SASKA et al., 2014). Yet, with the exception of a rarely found beetle species *Trechus quadristriatus* (Schrank) and other Coleoptera spp. none of these differences were significant. The results should be interpreted with caution, as the arthropod community was only monitored once after herbicide application. Therefore, they only represent a short period of time during the year. Nevertheless, the observed effect of herbicide applications likely due to changes in vegetation cover rather than direct effects (NORRIS & KOGAN, 2005). These is also indicated by the stronger positive correlation between ground beetle abundance and weed density (R^2 = 0.64, Fig. 4A) in comparison to ground beetle abundance and herbicide use (R^2= 0.30, Fig. 4B).

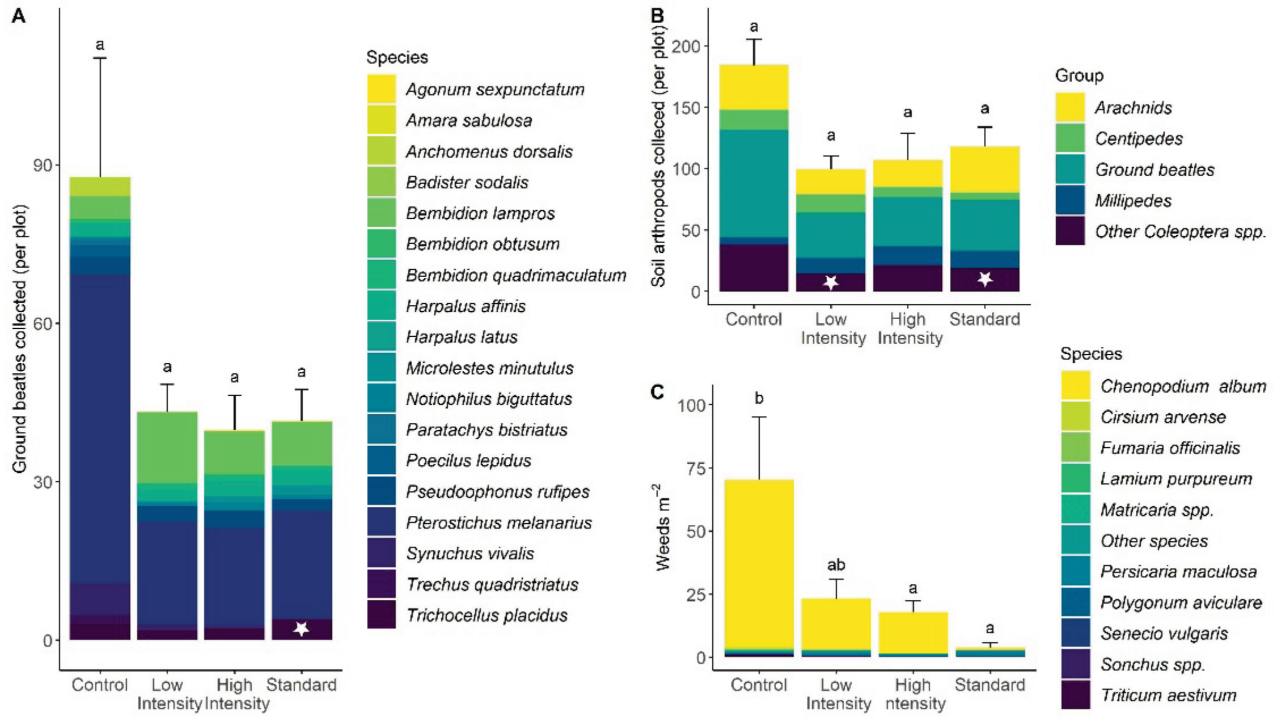

Figure 3 Ground beetles per plot on species level A), soil arthropods (> 2mm) per plot B), and weed species per m^2 C). Data shown here were collected after the last herbicide treatment. White asterisks indicate statistically significant differences between the treatments ‚Standard' and ‚High Intensity' (p<0.05) for *Trichocellus placidus* or between the number of other *Coleoptera* spp. in comparison to the control plot (p<0.05).

Abbildung 3 *Laufkäfer pro Parzelle auf Artniveau A), Bodenarthropoden (> 2 mm) pro Parzelle B) und Unkrautarten pro m^2 C). Die hier gezeigten Daten wurden nach der letzten Herbizidbehandlung erhoben. Weiße Asterisken zeigen statistisch signifikante Unterschiede zwischen den Behandlungen 'Standard' und 'Hohe Intensität' (p<0,05) für* Trichocellus placidus *oder zwischen der Anzahl anderer* Coleoptera *spp. im Vergleich zur Kontrollfläche an (p<0,05).*

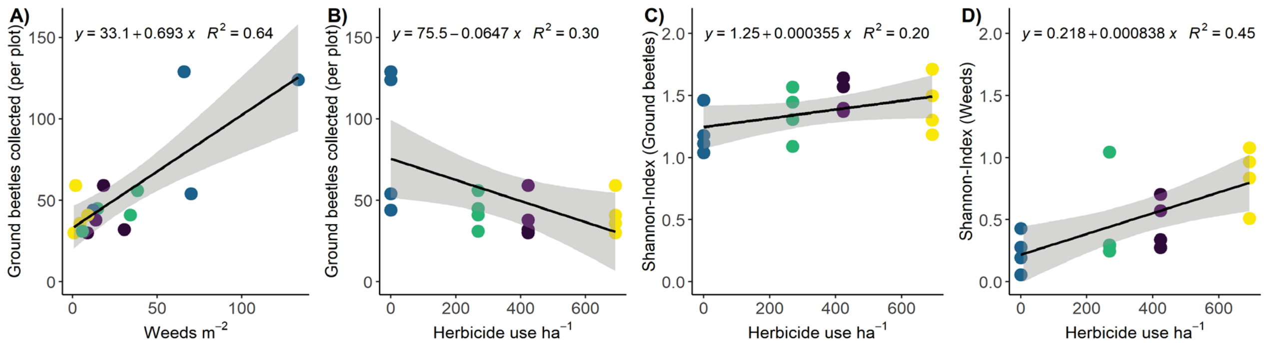

Figure 4 Number of ground beetles collected in control plots (●), low-intensity spot spraying plots (●), high intensity spot spraying plots (●) and standard plots (●) after the last herbicide treatment as a function of weed density A) and herbicide use B) or Shannon-index calculated for ground beetles C) or weeds D) as a function of herbicide use.

Abbildung 4 *Anzahl der Laufkäfer, die nach der letzten Herbizidbehandlung in Kontrollparzellen (●), Parzellen mit niedriger Spotspraying-Intensität (●), Parzellen mit hoher Spotspraying-Intensität (●) und Standardparzellen (●) gesammelt wurden in Abhängigkeit von Unkrautdichte A) und Herbizideinsatz B), sowie Shannon-Index für Laufkäfer C) und Unkräuter D) in Abhängigkeit vom Herbizideinsatz.*

In this one-year trial, it was possible to reduce the amount of herbicide used considerably. Therefore, the tested technology offers the potential to save herbicide costs, avoid herbicide entries into the environment and groundwater, although risk indices for sugar beet cultivation have been classified mainly into low or very low risk categories (NAUSE et al., 2021). However, in the present trial, the density of common lambsquarters in the plots treated with the spot spraying method exceeded the damage threshold of ten individuals per m^2 while biodiversity parameters did not improve im comparison to the standard broadcast treatment. However, the repetition of the experiment will allow more reliable conclusion. Therefore, the tested praying system needs to be further improved to balance the risks and benefits for a large proportion of potential users.

In principle, this consists of bringing the development status of spot spraying from Technology Readiness Level (TRL) 8 (proof of functionality in the field of application) to level 9, which stands for proof of successful application. This includes improving weed detection, especially at the cotyledon stage. One way of achieving these goals is the implementation of advanced sensors and smaller boom sections. However, these improvements often involve several components of the system and often have trade-offs with impact. In addition, there is the need for reliable predictions of the critical period as well as the economic and ecological thresholds of the weeds present. For a successful implementation in agricultural practice, also an adaptation of the herbicide recommendations, e.g. through extension services, should be aimed for. Based on the present trial results, a traditional broadcast application of soil active herbicides in post-emergence at the early cotyledon stage in combination with further spot spraying treatments could achieve a satisfactory herbicide effect while still reducing the amount of herbicide sprayed. Ultimately, new herbicide registrations and herbicide combinations would also be conceivable. Presumably, despite advancing technology, there will probably remain a greater risk of lower yields.

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