Sektion 7: Alternativen im Unkrautmanagement
Session 7: Alternatives in weed management

Controlling arable weeds with natural substances as bio-based herbicides

Bekämpfung von Ackerunkräutern mit bio-basierten Herbiziden aus Naturstoffen

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Abstract

Today farmers manage arable weeds with chemical tools or mechanical tillage practices. While the heavy reliance on synthetic herbicides in conventional arable farming is under discussion, the environmentally driven trend towards reduced tillage as a climate-smart agricultural practice becomes more prominent. These trends demand for alternative control methods of weeds.

This greenhouse study investigates the control of 21 arable weeds with four natural substances. The experimental setup compared an untreated control with four natural substances (acetic, citric and pelargonic acid and magnesium chloride), and glyphosate was used as the common active ingredient for stubble and pre-sowing herbicide applications. The level of necrotisation (0-100%) was used to assess the efficacy of herbicide treatment.

The efficacy differs substantially among the bio-based herbicides. For all natural substances, pelargonic acid has the highest mean efficacy for controlling the weeds tested in this experiment. For most weeds, however, the efficacy of natural substances is much lower compared to glyphosate.

Nevertheless, the results indicate that natural substances as bio-based herbicides have the potential to offer an increased target specificity and rapid degradation in the soil. We found a high efficacy of pelargonic acid for controlling *Brassica napus*.

Keywords: Biocontrol, glyphosate, greenhouse experiment, herbicide efficacy

Zusammenfassung

Verbreitete Unkrautbekämpfungspraktiken sind intensive, wendende Bodenbearbeitung und der Einsatz chemisch-synthetischer Herbizide. Während die starke Abhängigkeit von synthetischen Herbiziden im konventionellen Ackerbau diskutiert wird, verstärkt sich gleichzeitig der Trend zur reduzierten Bodenbearbeitung als klimaschonende landwirtschaftliche Praxis. Diese Entwicklungen erfordern alternative Unkrautbekämpfungsmethoden.

Die vorliegende Gewächshausstudie untersucht die Bekämpfung von 21 Ackerunkräutern und -ungräsern mit Bioherbiziden (Essig-, Zitronen- und Pelargonsäure sowie Magnesiumchlorid). Es werden vier natürliche Säuren und der Wirkstoff Glyphosat sowie eine Variante ohne Unkrautkontrolle verglichen. Zur Bewertung der Bekämpfung der Unkräuter und Ungräser dient der Grad der Nekrotisierung (0-100 %).

Die Effizienz der natürlichen Säuren unterscheidet sich deutlich in der Bekämpfung von Unkräutern und Ungräsern, die höchste Wirkung wurde für Pelargonsäure ermittelt. Überwiegend gilt jedoch, dass die Wirksamkeit der natürlichen Säuren im Vergleich zu Glyphosat deutlich geringer ist.

Dennoch deuten die Ergebnisse darauf hin, dass natürliche Säuren potentiell geeignet sind, spezifische Unkräuter bereits kurze Zeit nach der Applikation ausreichend zu bekämpfen. Es wurde eine hohe Wirksamkeit von Pelargonsäure zur Kontrolle von Ausfallraps nachgewiesen.

Stichwörter: Biologische Bekämpfung, Gewächshausversuch, Glyphosat, Herbizideffizienz

Introduction

In arable farming, weeds require control. While the level of control needed is under discussion (LECHENET et al., 2017), complete renunciation of control of weed is certainly not rational. Currently, the common weed control management practices in arable farming rely to a high extent on the use of synthetic herbicides (SONAE et al., 2012; ANDERT et al.; 2018). While the intensive use of synthetic herbicides in the last decades greatly increased crop productivity, the accompanying environmental and ecological impacts are striking (STOATE et al., 2009; NIEMANN et al., 2015). Hence, chemical weed control with herbicides is under pressure (JABRAN, 2018; BECKIE, 2019). At the same time the management practice of intensive inversion tillage (ploughing), which has been common for centuries in arable farming, is under criticism, too. The environmentally driven trend towards reduced tillage started more than 20 years ago (PIMENTEL et al., 1995), and is now becoming more popular (LEYS et al., 2007; KNAPEN et al., 2008). As non-inversion tillage represents a climate-smart agricultural practice (TULLBERG et al., 2007), this trend is likely to continue.

Either used alone or in association with other plant protection methods, bio-based control products represent new technologies. Biocontrol agents can be categorized into four groups: macro-organisms (e.g. predators, parasitoid insects, and nematodes), micro-organisms (e.g. bacteria, fungi, and viruses), chemical mediators (e.g. pheromones) and natural substances (originated from plant or animal). Among these four categories, the last three belong to plant protection products, which fall under the 1107/2009/CEE European regulation (VILLAVERDE et al., 2014). Micro-organisms, macro-organisms, and natural substances are the most investigated biocontrol agents for weed control (ZIMDAHL, 2011; HINZ et al., 2014). Bioherbicide products are adapted from natural substances already existing in the environment, so they are expected to be more environment-friendly (CORDEAU, 2016). The half-life of bioherbicides is usually shorter than chemicals (DUKE et al., 2000).

Worldwide, thirteen bioherbicides derived from micro-organisms or natural molecules are currently available on the market (CORDEAU, 2016). In 2015, the fatty acid, pelargonic acid, was formulated and authorized as a plant protection product (under the trade name Beloukha®) to be placed on the European agriculture market. Pelargonic acid can be used in grapevine to kill suckers and control weeds, and in potatoes for plants desiccation. Fatty acids have a wide range of bioherbicide activities that can disturb cell membranes and result in the loss of cellular functioning (SAVAGE and ZORNER, 1995; LEDERER et al., 2004). While some bio-based herbicides have shown promising result, few have achieved long-term commercial success (CORDEAU, 2016) – this author thinks this is due to the inconsistent performance under field conditions.

The present study contributes to improve the state of the art for alternative weed control technologies in arable farming. Glyphosate as the most frequently used active ingredient for stubble and pre-sowing weed and volunteer management is currently discussed controversially among the scientific and public communities (BENBROOK, 2016). Henceforth the German government and other EU countries expressed their motivation to stop the use of glyphosate from the end of 2023 (FEDERAL GOVERNMENT OF GERMANY, 2019). Because shifts back to intensive tillage needs to be avoided, the stubble cultivation should be more focused as a tool of Integrated Weed Management (IWM), and innovations for pre-crop management of volunteer crops and weeds are urgently required (ANDERT et al., 2018).

This study investigates the control of 21 arable weeds with four natural substances to assess the efficacy of bio-based herbicides for stubble and pre-sowing weed management.

Material and Methods

Experimental setup

A pot experiment under controlled greenhouse conditions was conducted at the Crop Health group, University of Rostock. The experiment was repeated twice in spring and summer 2019. The weeds were germinated in one big pot per species and later separated in single pots (9x9 cm) (one weed per pot). The soil used in the pots was a mix of quartz, compost and field soil (each 1/3). Treatments were eight times repeated per herbicide and weed species.

The experimental setup included an untreated control and four natural substances and glyphosate as the common active ingredient for stubble and pre-sowing weed management (Tab. 1). The dose rates of acetic- and citric acid are determined according to previous studies (ELMORE et al., 1985; ABOUZIENA et al., 2009; RAHAYUNINGSIH and SUPRIADI, 2016). Magnesium chloride, pelargonic acid (Beloukha®) and glyphosate (Roundup Ultra®) are applicated according to manufacturers´ recommendation.

Tab. 1 Treatment active ingredients, active ingredient content (g/L or g/kg) and dose rate (L/ha).

Tab. 1 *Eingesetzte Wirkstoffe, Wirkstoffgehalt (g/l, g/kg) sowie zugelassene Aufwandmenge (l/ha, kg/ha).*

Treatment	Active ingredients	Active ingredient content (g/L) or concentration (%)	Dose rate (L/ha)
UC	Untreated control		
MgCl2	Magnesium chloride	100%	300
CA	Citric acid	10%	31.35
AA	Acetic acid	30%	97.5
PA	Pelargonic acid	680 g/L	16.0
GLY	Glyphosate	360 g/L	3.0

Weed species

The study included 21 arable weed species (Tab. 2).

Tab. 2 Investigated monocotyledonous and dicotyledonous weeds species (EPPO-code given in brackets, EPPO 2019).

Tab. 2 *Untersuchte monokotyle- und dikotyle Arten (EPPO-Kodierung in Klammern, EPPO 2019).*

Weeds species	
Monocotyledon	**Dicotyledon**
Echinochloa crus-galli (ECHCG)	*Brassica napus* (BRSNN),
Poa annua (POAAN)	*Stellaria media* (STEME)
Alopecurus myosuroides (ALOMY)	*Galium aparine* (GALAP)
Apera spica-venti (APESV)	*Veronica persica* (VERPE)
	Anchusa arvensis (LYCAR)
	Chenopodium album (CHEAL)
	Viola arvensis (VIOAR)
	Solanum nigrum (SOLNI)
	Myosotis arvensis (MYOAR)
	Thlaspi arvense (THLAR)
	Capsella bursa-pastoris (CAPBP)
	Descurainia sophia (DESSO)
	Tripleurospermum inodorum (MARTIN)
	Sonchus arvensis (SONAR)
	Ranunculus repens (RANRE)
	Rumex crispus (RUMCR)
	Cirsium arvense (CIRAR)

Application

Weed species were applied with the substances at the seedling stage (2- beginning of 4 leaf stage) in a stationary application system. All substances were applied with 267 liter water per hectare using a pressure of 2.1 bar and a speed of 4 kilometres per hour. Flat jet nozzles were used (size 03).

Assessment

The level of necrotisation (0-100%) was assessed at 1, 7, 14 and 21 days after application. A value of 0% necrotisation corresponds to a vital weed, 100% plant necrotisation is equivalent to a completely dead weed. We interpreted the level of necrotisation as the efficacy of the treatment.

Results

Efficacy of natural substances

Overall, the level of necrotisation differed substantially between the active ingredients (Fig. 1). For all natural substances, pelargonic acid had the highest mean efficacy against the weeds tested in this experiment (Fig. 1a-1d). The efficacy of magnesium chloride, citric acid and acetic acid was much lower than the efficacy of pelargonic acid, except for acetic acid 14d after application (Fig. 1c). For each assessment, the efficacy of magnesium chloride and citric acid was quite similar, around 10%.

The level of necrotisation of the weeds treated with glyphosate increased according to the number of days after application. In contrast, the level of necrotisation decreased for the pelargonic acid treatment seven days after application. Accordingly, the efficacy 7 and 14 days after application was lower than the first and third day after application.

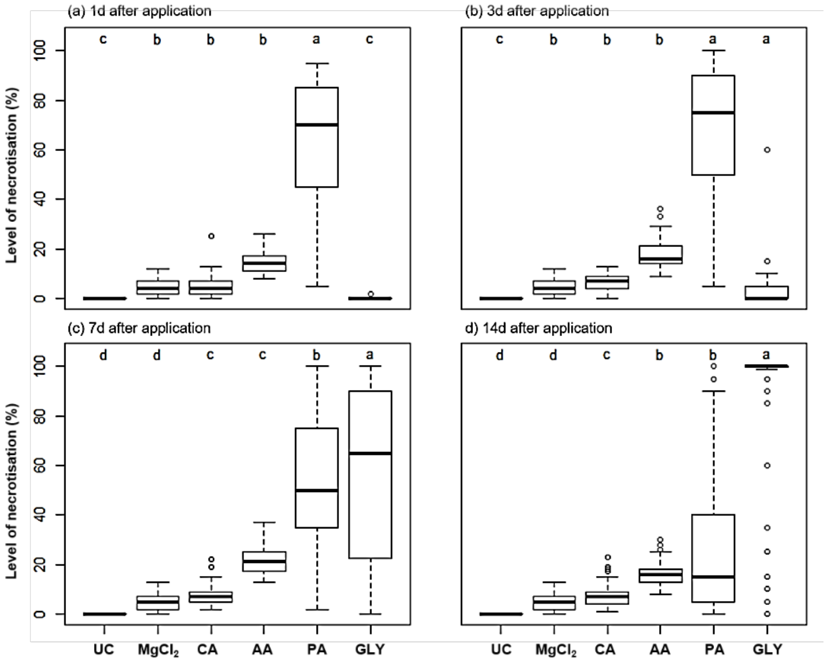

Fig. 1 Efficacy (mean of all species) of the different herbicide treatments on all investigated weeds (a) 1 day after application, (b) 3 days after application, (c) 7 days after application and (d) 14 days after application. Herbicide treatments: UC (Untreated control), MgCl2 (Magnesium chloride), CA (Citric acid), AA (Acetic acid), PA (Pelargonic acid) and GLY (Glyphosate). Different letters represent significant differences (p <0.05) between the different herbicide treatments.

Abb. 1 *Wirkungen der Herbizide (a) 1 Tag nach Applikation, (b) 3 Tage nach Applikation, (c) 7 Tage nach Applikation und (d) 14 Tage nach Applikation. Versuchsglieder: UC (Unbehandelte Kontrolle), MgCl2 (Magnesiumchlorid), CA (Zitronensäure), AA (Essigsäure), PA (Pelargonsäure) und GLY (Glyphosat). Unterschiedliche Buchstaben signalisieren signifikante Unterschiede (p <0,05) zwischen den Versuchsgliedern.*

Differences between weed species

In addition to the mean efficacy for all weed species, we analysed the efficacy separately for the tested weed species. Table 3, Figure 2 and Figure 3 illustrate the level of necrotisation for the herbicide treatments that showed the highest efficacy: Acetic acid (AA), pelargonic acid (PA) and glyphosate (GLY).

Overall, the efficacy of the three-herbicide treatments (Tab. 3, Fig. 2 and 3) differed among the weed species. For acetic acid, the level of necrotisation assessed 14 days after treatment varied between 10-28% (Tab. 3). The highest efficacy of acetic citric acid was observed against *Echinochloa crus-galli* (ECHCG), *Ranunculus repens* (RANRE), *Brassica napus* (BRSNN), *Stellaria media* (STEME) and *Sonchus arvense* (SONAR).

Tab. 3 Mean efficacy of acetic acid (AA) against all investigated weeds 14 days after application. Different letters represent significant differences (p <0.05) between the weeds.

Tab. 3 *Mittlere Wirkungen des Versuchsgliedes Essigsäure 14 Tage nach der Applikation. Unterschiedliche Buchstaben signalisieren signifikante Unterschiede (p <0,05) zwischen den Arten.*

Species	**Efficacy of acetic acid (%)**	**Species**	**Efficacy of acetic acid (%)**
SONAR	27.5^{a}	APESV	15.5^{de}
STEME	24.8^{a}	VERPE	14.8^{def}
BRSNN	24.8^{a}	RUMCR	14.5^{defg}
ECGCG	20.3^{ab}	THLAR	14.3^{defg}
RANRE	20.8^{ab}	CAPBP	13.8^{efgh}
GALAP	19.5^{abc}	POAAN	12.3^{fgh}
VIOAR	18.3^{bcd}	DESSO	11.5^{gh}
CHEAL	16.8^{bcde}	MYOAR	11.3^{gh}
ALOMY	15.8^{cde}	CIRAR	11.0^{gh}
SOLNI	16.0^{de}	MATIN	10.3^{h}
LYCAR	15.8^{de}		

The efficacy of pelargonic acid (Fig. 2) assessed 14 days after treatment differed between the weed species from over 90% efficacy against *Brassica napus* (BRSNN) to 3% efficacy against *Matricaria inodora* (MATIN). There were some weeds with an efficacy of pelargonic acid between 50-75%, namely *Stellaria media* (STEME), *Galium aparine* (GALAP) and the perennial weeds *Sonchus arvense* (SONAR) and *Ranunculus repens* (RANRE). The efficacy of pelargonic acid varies between 25-50% against *Veronica persica* (VERPE), *Anchusa arvensis* (LYCAR), *Chenopodium album* (CHEAL), *Echinochloa crus-galli* (ECHCG) and *Rumex crispus* (RUMCR). For all other investigated weed species, however, the efficacy of pelargonic acid was <20%.

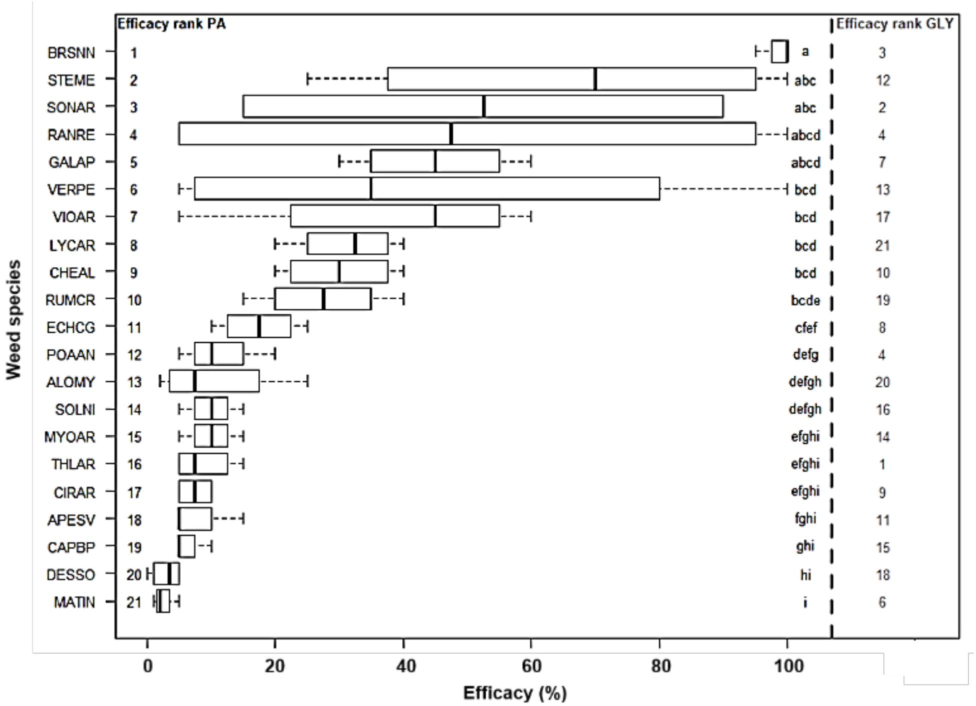

Fig. 2 Efficacy (%) and rank (1-21) of pelargonic acid (PA) against all investigated weeds 14 days after application compared to efficacy rank of glyphosate (GLY). Different letters represent significant differences (p <0.05) between the weeds (Kruskal-Wallis Test).

Abb. 2 *Wirkungen des Versuchsgliedes Pelargonsäure (PA) 14 Tage nach der Applikation. Hinter den Boxen der jeweilige Rank der Effizienz des Versuchsgliedes Glyphosat (GLY). Unterschiedliche Buchstaben signalisieren signifikante Unterschiede (p <0,05) zwischen den Arten (Kruskal-Wallis Test).*

The efficacy of glyphosate (Fig. 3) was much higher compared to acetic acid (Tab. 3) and pelargonic acid (Fig. 2). The level of necrotisation were >95%, except for *Anchusa arvensis* (LYCAR), *Alopecurus* myosuroides (ALOMY), *Rumex crispus* (RUMCR), *Descurainia sophia* (DESSO), *Viola arvense* (VIOAR) and *Solanum nigrum* (SOLNI).

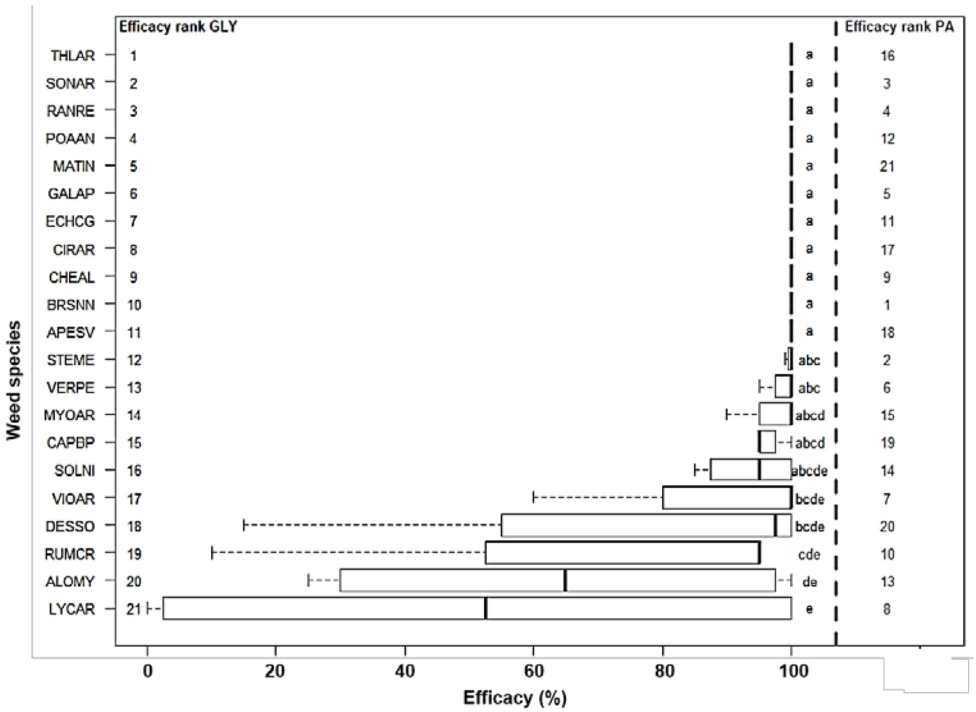

Fig. 3 Efficacy (%) and rank (1-21) of glyphosate (GLY) against all investigated weeds 14 days after application compared to efficacy rank of pelargonic acid (PA). Different letters represent significant differences (p <0.05) between the weeds (Kruskal-Wallis Test).

Abb. 3 *Wirkungen des Versuchsgliedes Glyphosate (GLY) 14 Tage nach der Applikation. Hinter den Boxen der jeweilige Rank der Effizienz des Versuchsgliedes Pelargonsäure (PA). Unterschiedliche Buchstaben signalisieren signifikante Unterschiede (p <0,05) zwischen den Arten (Kruskal-Wallis Test).*

Discussion

This study analysed the efficacy of natural substances for controlling arable weeds. Compared to glyphosate, the efficacy of natural substances in our experiment was much lower for most weed species investigated. The limitations and large differences among the studied weed species are probably mainly due to the contact effect of the natural substances (acetic, citric and pelargonic acid and magnesium chloride). Contact herbicides kill the parts of the weeds that they can physically reached by the active ingredients. In contrast, systemic herbicides, in this case glyphosate, are absorbed by the plant foliage and translocated to other parts of the weeds. For pelargonic acid, most weeds even developed new shoots and began to recover 7 days after application. The natural substances are not translocated systemically in the plants and hence, cannot provide long-term control for most species.

Natural substances as bio-based herbicides nevertheless offer (i) an increased target specificity and (ii) rapid degradation (CORDEAU et al., 2016).

(i) Our results indicate a high efficacy for controlling *Brassica napus* (BRSNN) using pelargonic acid under greenhouse conditions. Pelargonic acid has actually been launched on the European market and has been registered for use in arable farming (potatoes) and perennial crops (hops, wine). Further use registrations, e.g. for controlling volunteer oilseed rape on the stubble would allow farmers to replace the use of glyphosate under this use conditions to some extent. Beside glyphosate, selective herbicides (except of Starane XL®/ Pyrat XL® for weed management of

Calystegia sepium) are not registered as plant protection products for use on stubbles (FEDERAL OFFICE OF CONSUMER PROTECTION AND FOOD SAFETY, 2019).

(ii) Our results further indicate a reasonable high efficacy of pelargonic acid to control weeds three days after application. For volatile weather conditions or work bottlenecks, a short-term, but rapid destruction of weeds with pelargonic acid could be useful in arable farming.

Though bio-based herbicides are currently not registered for weed management in arable crops, they may serve as an additional tool in integrated weed management (CORDEAU et al., 2016). The ban of glyphosate requires further research on bio-based herbicides. Detailed knowledge on plant control mechanisms is necessary (RADHAKRISHNAN et al., 2018). Moreover, details on technical application (water temperature, additives and the effect of weather conditions during/after application) require more investigations to ensure their suitability for on-farm use.

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