

Sektion 4: Resistenzmanagement

Session 4: Resistance management

Management of herbicide resistant weeds in a crop rotation with an Acetolactat-synthase-inhibitor tolerant sugarbeet variety

Kontrolle von herbizidresistenten Unkräutern in einer Fruchtfolge mit einer Acetolactat-Synthase-Hemmer toleranten Zuckerrübensorte

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Abstract

ALS-resistant weeds are of major importance in many European agriculture systems. Resistant biotypes showed up in more weed species, more regions and in more crops. Therefore, every method or tool to control weeds, that potentially increases the selection pressure on herbicides and weeds must be handled with care. On the other hand new tools like herbicide tolerant varieties offer new possibilities for weed control. Particularly in sugarbeet, chemical weed control is still a compromise between efficacy and crop selectivity today. ALS-tolerant varieties offer the opportunity to improve crop safety and efficacy. To investigate the influence of these sugar beet varieties on the dynamic of ALS-resistant weed populations in a three-year crop rotation, a six-year field trial was conducted on two experimental sites. Four different weed control strategies were tested, which exhibit different levels of selection pressure to ALS inhibitors.

The field trial showed that continuous use of ALS herbicides quickly increased the density of resistant weed populations leading to a large yield reduction. However, this process was much slower, when the frequency of ALS inhibitor use was reduced. Yet, it was not stopped completely. Even the use of alternative modes action was only partly able to slow down the resistance evolution. While weeds resistant to ALS herbicides only could be well controlled, multiple resistant weeds were able to build up a new resistance mechanism (ACCase inhibitor resistance). Here this was the case for *Alopecurus myosuroides*. As a consequence, use of alternative MoAs failed to control *A. myosuroides*. Due to these complex interactions sustainable use of herbicide tolerant varieties is not easy in the long run. Advantages might be long lasting when site-specific resistant weed status is adequately addressed.

Keywords: *Alopecurus myosuroides*, ALS-resistant weeds, ALS-tolerant crops, herbicide rotation, *Tripleurospermum perforatum*

Zusammenfassung

In vielen europäischen Ackerbausystemen ist das Vorkommen von ALS-Hemmer resistenten Unkräutern von großer Bedeutung. In mehr und mehr Unkrautarten, Regionen und Ackerbaukulturen treten diese resistenten Biotypen auf. Daher muss jede Maßnahme, die den Selektionsdruck entsprechend verstärkt, sehr kritisch gesehen werden. Auf der anderen Seite bieten herbizidtolerante Sorten neue Möglichkeiten der Unkrautkontrolle. Gerade in Zuckerrüben ist die Herbizidanwendung immer noch ein Kompromiss zwischen Wirksamkeit und Kulturverträglichkeit. ALS-Hemmer tolerante Sorten bieten hier die Möglichkeit die Wirksamkeit aber auch die Selektivität der Herbizidmaßnahmen in Zuckerrüben zu verbessern. Um den Einfluss dieser Sorten auf die Dynamik der ALS-resistenten Unkrautpopulationen in einer dreijährigen Fruchtfolge zu untersuchen, wurden an zwei Standorten Feldversuche über sechs Jahren durchgeführt.

Dabei wurden vier verschiedenen Herbizidstrategien mit unterschiedlichem Selektionsdruck auf ALS-Hemmer resistente Unkräuter geprüft.

Die Ergebnisse zeigten, dass ein kontinuierlicher Einsatz von ALS-Hemmern zu einem schnellen Anstieg der Resistenzhäufigkeit bei den Unkräutern mit entsprechend deutlichen Ertragsverlusten führt. Mit nachlassender Einsatzhäufigkeit der ALS-Hemmer in der Fruchtfolge deutlich zeigte sich auch ein verlangsamter Anstieg der Resistenzhäufigkeit. Prinzipiell war der Prozess der Resistenzentwicklung aber nicht zu stoppen. Auch der gezielte Einsatz alternativer Herbizidwirkungsweisen war dazu nur teilweise geeignet. Zwar konnten die ALS-resistenten Unkräuter durch die alternativen Wirkungsweisen in der Dichte reduziert werden, anderseits wurden aber weitere Resistenzmechanismen bei den Unkräutern – hier beim Ackerfuchsschwanz – selektiert. Diese komplexen Interaktionen machen einen nachhaltigen Herbicideinsatz in den toleranten Kulturen nicht einfach. Die Vorteile der herbizidtoleranten Sorten können aber längerfristig genutzt werden, wenn die Maßnahmen auf die jeweilige Unkrautart und die vorliegende Resistenzsituation abgestimmt werden.

Stichwörter: Acker-Fuchsschwanz, ALS-resistente Unkräuter, ALS-tolerante Kulturen, Geruchlose Kamille, Herbizidrotation

Introduction

Weed control in sugarbeets with herbicides is still a compromise between efficacy and selectivity. Three to four repeated herbicide applications in mixtures with reduced dosages is the common strategy to control the weed flora in conventional sugarbeet growing. However, herbicide-tolerant sugar beet varieties offer the opportunity to achieve better and easier weed control in combination with a high crop safety.

Glyphosate-tolerant sugarbeet varieties are grown in the USA to a large extend of the total growing area (KHAN, 2015). In Europe, these transgenic varieties are not cultivated due to restrictions by law.

Acetolactate synthase (ALS)-inhibitor-tolerant varieties can be selected without gene transfer. In sugarbeet, natural selection of a mutation conferring resistance to ALS inhibitors was done in cell cultures exposed to foramsulfuron and thiencarbazone. A herbicide containing the ALS inhibitors foramsulfuron and thiencarbazone and the ALS-resistant sugar beets were brought to the European market since 2018 as a system named 'CONVISO' (WEGENER et al., 2016).

On the other hand, herbicide resistance to ALS inhibitors in weeds is quite common and present in many weeds in European cropping systems (HEAP, 2021). In the past, triflusulfuron-methyl was the only ALS inhibitor used in sugar beet cultivation but it was never used as the sole herbicide to control weeds. Due to applied herbicide mixtures, selection pressure towards ALS-resistant weeds was low. However, in other crops grown in rotation with sugarbeets the use of ALS inhibitors is quite common. This leads to the present study on the hypothesis that integration of ALS-tolerant sugarbeet varieties will increase the risk to select ALS inhibitor-resistant weeds and the question if it is possible to control ALS-resistant weeds in a crop rotation including ALS-tolerant sugarbeet varieties. To answer this question, a six-year field experiment was set up with a sugarbeet-wheat-wheat rotation under different herbicide regimes.

Material and Methods

Field experiments with a crop rotation consisting of sugarbeet-winter wheat-winter wheat were conducted on two sites in Germany (Bingen and Sickte/Braunschweig) from 2014 to 2020. An ALS-tolerant hybride was chosen as sugarbeet variety in all treatments. The field trial was a two-factorial complete randomized block design with four replications. Plots had a size of 90 m² in Bingen and 180 m² in Sickte and were separated from each other to reduced weed seed and pollen transfer between the plots (distances of 9 to 12 m between different plots). Four different weed strategies were applied (Tab. 1). In addition to these herbicide regimes, glyphosate was used prior sowing of sugarbeet in spring. After finishing the first crop

rotation, herbicide treatments were adapted to current weed situation (Tab. 1 and 2). Each crop was grown and each herbicide treatment was applied on each site in every year. Before seed bed preparation and planting of winter wheat or sugarbeet in the first experimental year, seeds of *Alopecurus myosuroides* (ALOMY) and *Tripleurospermum perforatum* (MATIN) were sown on both sites. Susceptible and resistant biotypes of each species were established (ALOMY: herbicide susceptible ('Appels Wilde Samen', Darmstadt); resistant: ALS inhibitor target-site resistance, Trp574Leu enhanced metabolic resistance to Pinoxaden; MATIN: herbicide susceptible (Bingen); ALS-inhibitor target-site resistance, Pro197Gln, Freiburg/Elbe). ALOMY was not present on both experimental sites before the start of trial. In contrast, ALS-susceptible MATIN populations were growing naturally on both sites. Weed density was assessed and ALOMY heads were counted in four subplots of 0.25 m² in each plot. Leaf samples of ALOMY and MATIN plants surviving the herbicide treatments were taken (maximum 15 plants per plot) in each year. Leaf samples were analysed for presence of ALS target-site resistance (LÖBMANN et al., 2019). Sugarbeet yield including the concentration of relevant ingredients as well as wheat yield was measured on subplots (15 m²) of each plot and year.

Table 1 Herbicide strategies in sugarbeet and winter wheat in first and second crop rotation**Tabelle 1** Herbizidstrategien in Zuckerrüben und Winterweizen in der ersten und zweiten Fruchtfolge-Rotation

	1. rotation			2. rotation		
regime	SB	WW 1	WW 2	SB	WW 1	WW 2
I	ALS	ALS	ALS	other+aMoA	ALS+other	ALS+other
II	ALS	other	other	ALS	other	other
III	ALS+aMoA	ALS+aMoA	other	ALS+aMoA	ALS+other	ALS+other
IV	other	other	other	other+aMoA	other	other

SB-sugarbeet, WW 1-winter wheat after sugarbeet, WW 2 – stubble winter wheat; ALS-ALS inhibitor, aMoA-alternative mode of action (here: clethodim for ALOMY and clopyralid for MATIN control), other-herbicide not belonging to ALS inhibitors and not clethodim or clopyralid

Table 2 Herbicides and dosages used in the field trial**Tabelle 2** Eingesetzte Herbizide und Aufwandmengen im Versuchszeitraum

Rotation	crop	ALS	aMoA	other
first	SB	2 x 0.5 l/ha Conviso one +1.0 l/ha Mero or 1 x 1.0 l/ha Conviso one	0.5 l/ha Select +1.0 l/ha RADIAMIX 83.5 g/ha Lontrel 720 SG	3 x 2.0 l/ha Goltix Titan 3 x 1.25 l/ha Betanal Maxxpro
				0.3 l/ha Cadou SC +0.75 l/ha Bacara forte 1.2 l/ha Axial50 3.0 l/ha Duanti
second	WW	500 g/ha Atlantis WG +1.0 l/ha Biopower +60 g/ha Pointer SX		0.3 l/ha Cadou SC +0.75 l/ha Bacara forte 1.2 l/ha Axial50 3.0 l/ha Duanti
				3 x 2.0 l/ha Goltix Titan 3 x 1.5 l/ha Betanal Maxxpro
				0.3 l/ha Cadou SC +0.75 l/ha Bacara forte 1.2 l/ha Traxos 1.5 l/ha Ariane C

Results and Discussion

Although the same weed populations and seed densities were established on both experimental sites, weed flora developed differently. In Bingen, ALOMY was the dominant weed species while MATIN dominated in Sickte. Due to continuous use of ALS inhibitor herbicides in strategy I in the first three years of the field trial, ALS inhibitor-resistant weed density increased rapidly (Tab. 3 and Fig. 1). The number of ALOMY heads increased from 1.1 in 2015 to 1,109 heads/m² in 2017 in sugarbeet (Tab. 3). In the stubble wheat ALOMY density reached more than 1,300 heads/m² within three years in Bingen. In Sickte, MATIN reached a density of ~70 plants/m² in the third year in sugarbeet due to the continuous use of ALS inhibitors (Fig. 1). However, this increase was slower when ALS frequency in the rotation was lower (regime II and III) or density of resistant weeds was kept to a moderate level when no ALS herbicides were applied. This may indicate that the isolation between the plots was not sufficient and resistance was transferred between the plots via pollen or via seed dispersal. In addition, these results shows that continuous use of alternative mode of action is able to reduce the density of ALS-resistant weeds, but not the resistance frequency within a population of a field (Fig. 2).

Table 3 Development of *Alopecurus myosuroides* head density (heads/m²) in different crops of a sugar beet – wheat – wheat – crop rotation depending on the weed control regime from 2015 to 2020 in Bingen

Tabelle 3 Entwicklung der Acker-Fuchsschwanzährendichte in einer Zuckerrüben-Weizen-Weizen Fruchtfolge in Abhängigkeit der Herbizidstrategien in den Jahren 2015 bis 2020 am Standort Bingen

strategy	crop	year		2015		2016		2017		2018		2019		2020	
		Ø	sd	Ø	sd	Ø	sd	Ø	sd	Ø	sd	Ø	sd	Ø	sd
I	sugar beet	1.1	0.4	80.3	58.6	1109.6	220.5	4.0	8.1	46.8	17.6	16.7	18.5		
	wheat	38.8	65.7	135.9	106.3	598.0	362.5	130.7	80.0	8.8	10.0	114.8	69.8		
	stubble wheat	18.5	28.4	142.0	78.0	1305.7	474.9	117.3	67.5	196.2	175.4	31.0	26.9		
II	sugar beet	1.3	1.1	47.1	46.7	613.7	359.9	39.3	37.6	20.5	24.8	174.0	130.5		
	wheat	68.5	82.3	16.0	18.9	13.3	13.1	71.4	54.4	7.0	13.4	33.7	19.5		
	stubble wheat	50.8	66.4	50.3	40.9	57.0	91.2	20.2	28.7	237.2	156.2	19.7	26.1		
III	sugar beet	0.9	0.5	41.4	39.4	108.1	75.9	48.5	38.8	171.7	87.4	56.2	49.6		
	wheat	52.9	86.3	63.2	61.7	464.7	199.1	95.4	75.4	21.3	19.8	177.0	72.5		
	stubble wheat	60.3	88.0	50.2	41.5	156.9	105.9	172.3	93.0	186.8	123.3	76.8	57.9		
IV	sugar beet	0.6	0.2	20.4	21.8	35.9	32.2	3.8	7.7	18.7	14.2	46.2	34.6		
	wheat	64.5	91.7	5.0	9.8	16.1	15.6	59.6	45.8	4.7	11.3	30.3	26.3		
	stubble wheat	69.1	86.9	63.3	41.8	17.4	19.5	18.2	25.2	167.5	104.2	26.0	24.2		
		Ø	mean	sd - standard deviation											

After changing the herbicide regime in the second rotation (2018-2020; Tab. 1) particularly in regime I, the high density of ALS-resistant weeds in these plots could be controlled (Tab. 3, Fig. 1).

Surprisingly, ALOMY densities increased from 2019 to 2020 in regimes III and IV (data not shown). Clethodim was used as an alternative mode of action to control ALS-resistant ALOMY in sugarbeet. In previous years this was a successful tool, but at the end of the six-year trial period more ALOMY plants survived this treatment. Additional investigation showed that these ALOMY plants also exhibited an Ile1781Leu substitution in the ACCase protein in addition to the Trp574Leu substitution in the ALS protein. This position is well described to confer target-site resistance to ACCase-inhibitor herbicides (data not shown). In contrast, consequent use of alternative modes of action in sugarbeet as well as in winter wheat led to sustainable control of MATIN. Yet, the evolution of multiple resistance as in ALOMY is also possible in MATIN. Here, synthetic auxin herbicides are of risk of resistance evolution.

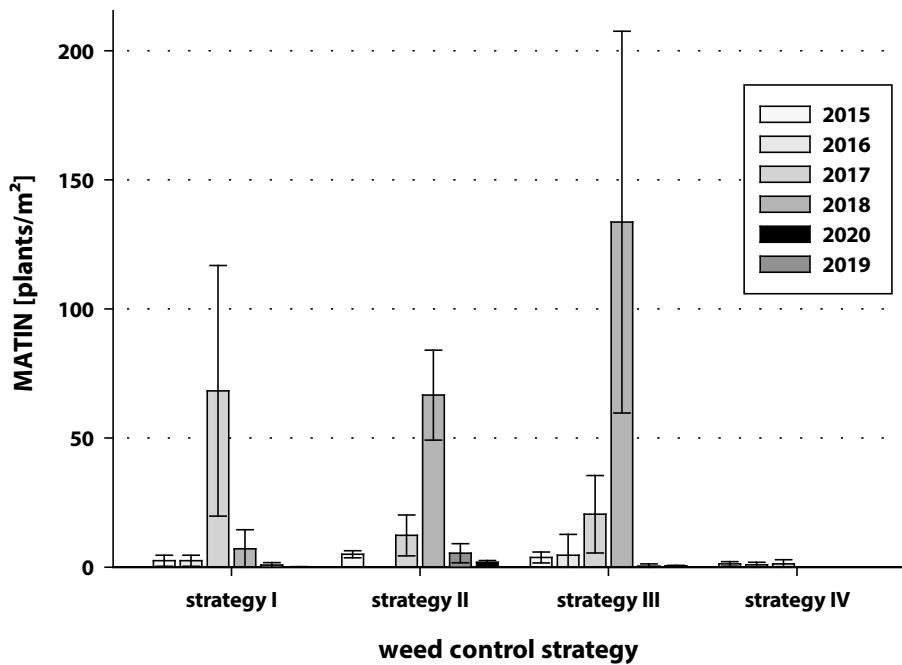


Figure 1 Development of MATIN density in an ALS inhibitor tolerant sugar beet variety depending on weed control strategy from 2015 to 2020 in Sickte.

Abbildung 1 Entwicklung der Dichte der Geruchlosen Kamille in einer ALS-toleranten Zuckerrübensorte in Abhängigkeit von der Herbizidstrategie in den Jahren 2015 bis 2020 am Standort Sickte.

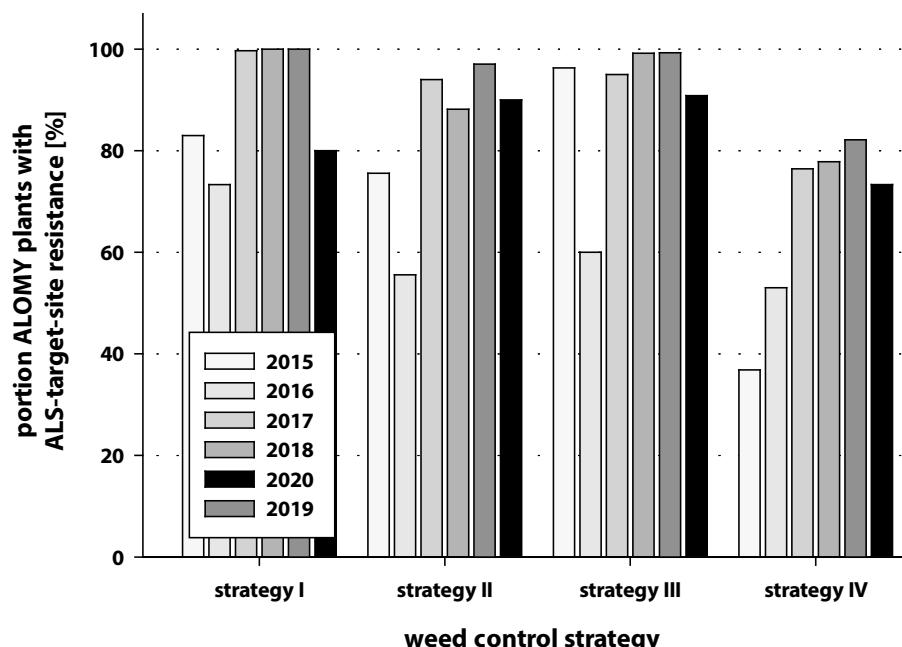


Figure 2 Proportion of ALS-inhibitor target-site resistant *Alopecurus myosuroides* plants in mean of three crops in crop rotation depending on the herbicide regime from 2015 to 2020 in Bingen.

Abbildung 2 Anteil der ALS-Hemmer zielortresistenter Acker-Fuchsschwanzpflanzen im Mittel der Fruchtfolgeglieder in Abhängigkeit der Herbizidstrategie in einer ALS-toleranten Sorte in den Jahren 2015 bis 2020 am Standort Bingen.

The yield, an indicator of sustainable production systems, decreased rapidly in response to 'regime I' herbicide treatment within the first three-year period (Fig. 3 to 5). However, even with a high weed density of resistant weeds it is possible to stabilize the yield on an acceptable level, if an alternative herbicide regime provides a good efficacy.

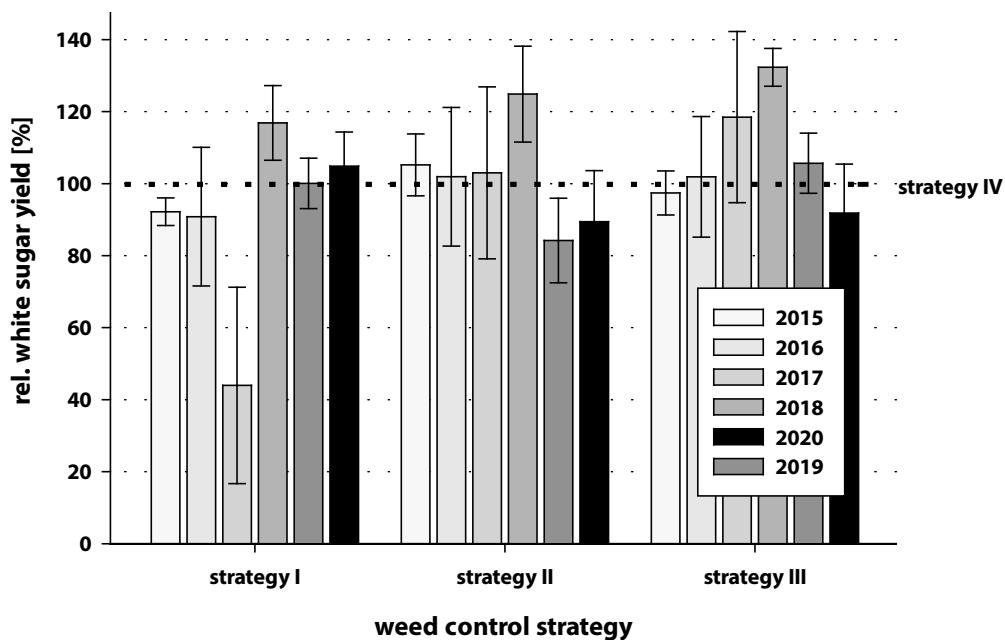


Figure 3 Development of relative white sugar yield depending on weed control strategy in ALS-tolerant variety between 2015 and 2020 (mean of sites Bingen and Sickte); 100% = yield of strategy IV in each individual year.

Abbildung 3 Entwicklung des bereinigten Zuckerertrages in Abhängigkeit der Herbizidstrategie in einer ALS-toleranten Sorten in den Jahren 2015 bis 2020 (Mittelwert der Standorte Bingen und Sickte); 100 % = Ertrag der Strategie IV je Versuchsjahr.

Apart from this, yield data showed that in mid terms using only one or two alternative modes of actions is not sufficient to ensure a high yielding system in a three year crop rotation. Consequently, sustainable weed control systems should integrate more than just an adapted herbicide rotation. Wider crop rotation, diverse soil tillage systems and other agronomic tools need to be used in an integrated weed control system to set up a sustainable growing system for herbicide-tolerant sugar beets.

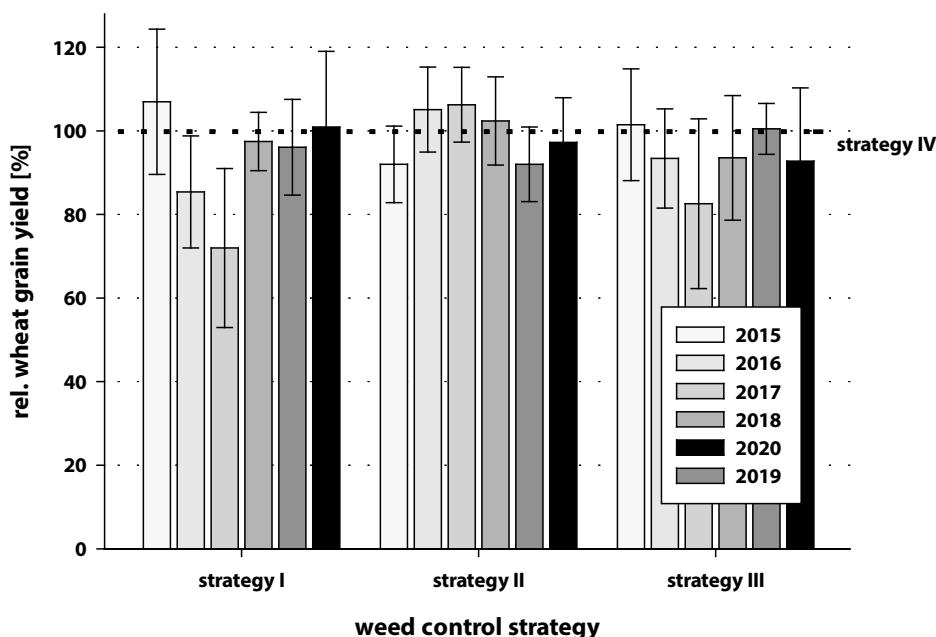


Figure 4 Development of relative wheat grain yield (wheat after sugar beet) depending on weed control strategy in ALS-tolerant variety between 2015 and 2020 (mean of sites Bingen and Sickte); 100% = yield of strategy IV in each individual year.

Abbildung 4 Entwicklung des relativen Rübenweizertrages in Abhängigkeit der Herbizidstrategie in einer ALS-toleranten Sorten in den Jahren 2015 bis 2020 (Mittelwert der Standorte Bingen und Sickte); 100 % = Ertrag der Strategie IV je Versuchsjahr.

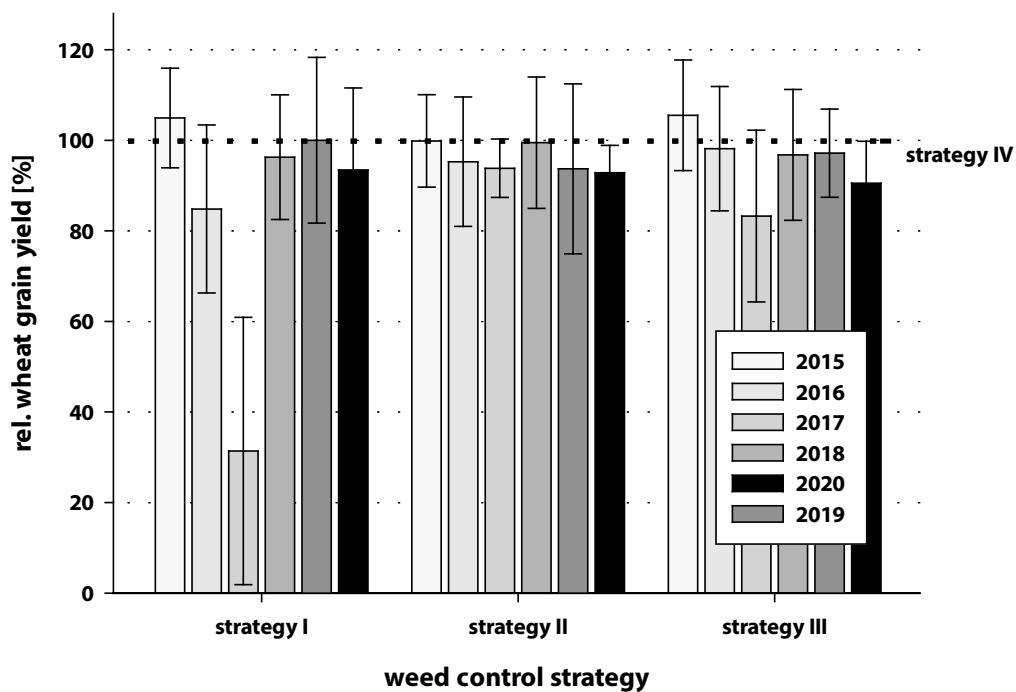


Figure 5 Development of relative stubble wheat grain yield (wheat after wheat) depending on weed control strategy in ALS-tolerant variety between 2015 and 2020 (mean of sites Bingen and Sickte); 100% = yield of strategy IV in each individual year.

Abbildung 5 Entwicklung des relativen Stoppelweizertrages in Abhängigkeit der Herbizidstrategie in einer ALS-toleranten Sorten in den Jahren 2015 bis 2020 (Mittelwert der Standorte Bingen und Sickte); 100 % = Ertrag der Strategie IV je Versuchsjahr.

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Literature

- HEAP, I., 2021 The International Survey of Herbicide Resistant Weeds. (available at www.weedscience.org)
- GÖTZE, P., C. KENTER, M.J. WENDT, E. LADEWIG, 2018: Übersicht zu Wirksamkeitsversuchen von Conviso One in Zuckerrüben. Julius-Kühn-Archiv **458**, 498-500.
- KHAN, M.F.R., 2015: Update on adoption of glyphosate-tolerant sugar beet in the United States. Outlooks on Pest Management **26** (2), 61-65.
- LÖBmann, A., O. CHRISTEN, J. PETERSEN, 2019: Development of herbicide resistance in weeds in a crop rotation with acetolactate synthase-tolerant sugar beets under varying selection pressure. Weed Research **59**, 479-489.
- WEGENER, M., N. BALGHEIM, M. KLINE, C. STIBBE, B. HOLTSCHULTE, 2016: Conviso Smart – an innovative approach of weed control in sugar beet. Zuckerindustrie **141** (8), 517-524.