Journal für Kulturpflanzen, 68 (11). S. 338–343, 2016, ISSN 1867-0911, DOI: 10.1399/JfK.2016.11.03 Verlag Eugen Ulmer KG, Stuttgart

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Efficacy of different strategies using an ALS-inhibitor herbicide for weed control in sugar beet (*Beta vulgaris* L.)

Wirksamkeit eines ALS-Inhibitor Herbizids in verschiedenen Strategien zur Unkrautkontrolle in Zuckerrüben (*Beta vulgaris* L.)

Abstract

In 2013 and 2014, field trials were conducted at six environments in Germany to evaluate the efficacy of a new ALS-inhibiting herbicide containing foramsulfuron and thiencarbazone-methyl (F/T) for weed control in sugar beet cultivation. Five herbicide strategies with different application frequencies of F/T (50 g foramsulfuron ha^{-1} + 30 g thiencarbazone-methyl ha^{-1}) and a classic herbicide strategy with three applications of phenmedipham (75 g ai ha^{-1}), desmedipham (59 g ai ha^{-1}), ethofumesate (94 g ai ha^{-1}), lenacil (34 g ai ha^{-1}) and metamitron (700 g ai ha^{-1}) were compared. The efficacy of the classic herbicide strategy was between 84 and 99% due to surviving *Chenopodium album* L., *Matricaria recutita* L., *Mercurialis annua* L. and *Solanum tuberosum* L. Average efficacy of F/T was 95% in the single application treatment. Strategies with two applications combining classic herbicides and F/T achieved an efficacy beyond 97%. This points to an increased flexibility of weed control in sugar beet.

Key words: Foramsulfuron, thiencarbazone-methyl, application frequency, standardised treatment index

Zusammenfassung

In den Jahren 2013 und 2014 wurden in sechs Umwelten in Deutschland Feldversuche durchgeführt, um die Wirksamkeit eines neuen ALS-Inhibitor Herbizids (F/T) zur Unkrautkontrolle im Zuckerrübenanbau zu bewerten. Fünf Herbizidstrategien mit verschiedenen Anwendungen von F/T (50 g Foramsulfuron ha^{-1} + 30 g Thiencarbazone-methyl ha^{-1}) und eine klassische Herbizidstrategie mit drei Applikationen von Phenmedipham (75 g Wirkstoff ha^{-1}), Desmedipham (59 g Wirkstoff ha^{-1}), Ethofumesat (94 g Wirkstoff ha^{-1}), Lenacil (34 g Wirkstoff ha^{-1}) und Metamitron (700 g Wirkstoff ha^{-1}) wurden miteinander verglichen. Die Wirksamkeit der klassischen Herbizidstrategie lag zwischen 84 und 99% durch nicht vollständig kontrollierte *Chenopodium album* L., *Matricaria recutita* L., *Mercurialis annua* L. und *Solanum tuberosum* L. Die durchschnittliche Wirksamkeit von F/T lag bei 95% in der einmaligen Applikation. Strategien mit zwei Applikationen in Kombination von klassischen Herbiziden und F/T erreichten eine Wirksamkeit über 97%. Dies führt zu einer höheren Flexibilität der Unkrautkontrolle in Zuckerrüben.

Stichwörter: Foramsulfuron, Thiencarbazone-methyl, Behandlungshäufigkeit, Behandlungsindex

Introduction

In sugar beet cultivation, high yield strongly depends on an effective weed control (May and Wilson, 2006). In Germany, the classic weed control strategy comprises on average 3.5 applications of three to five active ingredi-

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Accepted
17 October 2016

ents (ai) at the cotyledon stage of the weeds (VASEL et al., 2012). The summation of all applied ai in relation to their authorised dosages and the treated area results in the standardised treatment index (STI) which is an indicator for the use intensity of plant protection products (SATTLER et al., 2007). In Germany, the mean STI for herbicide use in sugar beet was 2.64 in 2010–2014 (PAPA, 2016). As increasing occurrence of weeds that are difficult to control, e.g. *Chenopodium album* L., *Matricaria* spp. and *Polygonum* spp., was observed in Germany during the last 15 years (BUHRE et al., 2011; VASEL et al., 2012), a future increase of STI can be assumed.

Currently, a new herbicide (Conviso®) containing foramsulfuron and thiencarbazone-methyl is under approval for sugar beet cultivation. In the following, it is referred to as 'F/T'. Both ai belong to the HRAC-group "B" and inhibit the acetolactate-synthase (ALS). Due to the susceptibility of sugar beet to this mode of action, a non-sensitive genotype is currently being developed (WEGENER et al., 2015). WEGENER et al. (2015) determined the efficacy of F/T as part of the approval procedure. They compared F/T in two application strategies as requested for registration with classic herbicides, but without presenting cumulated efficacy results. Thus, the present study was conducted to compare the cumulated efficacy of five weed control strategies with F/T for possible use in commercial practice and a classic herbicide strategy.

Material and methods

Experimental setup

Three sugar beet field trials were conducted in Northern Germany each in 2013 and 2014 (six environments, Table 1). The trial sites were selected for different soils and weed compositions. Soil texture was silt loam at Göttingen, clay loam at Angerstein, loam at Niedernjesa and loamy sand at Schwüblingsen. Schwüblingsen was especially selected to test efficacy towards *Mercurialis annua* L. and volunteer potatoes (*Solanum tuberosum* L.) which are difficult to control in sugar beet (MAY and WILSON, 2006).

Seedbed was prepared site-specifically. Seeds of a sugar beet genotype non-sensitive to ALS-inhibitor herbicides were provided by KWS Saat SE (Einbeck, Germany). The experimental setup was a four times replicated randomised block design. The size of the six row plots was 21.8 m² with 0.45 m distance between the rows and 0.18 m within the rows. Sugar beets were not harvested and tilled into the soil in the end of October.

Herbicide applications

Herbicides were applied with pneumatic plot sprayers type *Schachtner PSG,* nozzle type Air Induced (low pressure) flat fan – 110–02 (Göttingen, Angerstein, Niedernjesa); type *Agrartest*, nozzle type Agrotop Airmix 110–02 (Schwüblingsen). Used water volume was 200–300 L ha^{-1}, pressure was 250 kPa and velocity was 4.5 km/h.

The requested authorised application rate of F/T (foramsulfuron + thiencarbazone-methyl, 50 g ai L^{-1} + 30 g ai L^{-1}) is 1.00 L ha^{-1} for a single and 0.5 L ha^{-1} for a two time application (WEGENER et al., 2015). Treatments 2, 3 and 5 represent possible weed control strategies with F/T (Table 2). Treatment 4 represents the classic weed control strategy including the four most frequently applied ai in Germany: 75 g ai ha^{-1} phenmedipham (PMP), 59 g ai ha^{-1} desmedipham (DMP), 94 g ai ha^{-1} ethofumesate (ETO), 700 g ai ha^{-1} metamitron (MET) (VASEL et al., 2012) and 34 g ai ha^{-1} lenacil (LEN). Active ingredients against monocotyledonous weeds were not included. Treatments 6 and 7 are alternative application strategies for weed control with F/T. Note: registration is requested

Table 1. Site specific weed composition in field trials with sugar beet assessed in untreated plots (BBCH 39 of sugar beet in herbicide treated plots). Six environments, Germany 2013 and 2014

Environment	Canopy ground cover	Site specific weed composition (percentage of all weeds)
Göttingen 2013	100%	*Chenopodium album* L. (60%), *Matricaria recutita* L. (20%), *Solanum nigrum* L. (10%), *Urtica urens* L. (5%)
Göttingen 2014	100%	*C. album* (70%), *M. recutita* (20%), *Hordeum vulgare* L. (5%)
Angerstein 2013	10%	*C. album* (40%), *M. recutita* (20%), *Sonchus arvensis* L. (10%), *Alopecurus myosuroides* Huds. (30%)
Niedernjesa 2014	40%	*C. album* (70%), *M. recutita* (10%), *A. myosuroides* (10%), *Galium aparine* L. (5%)
Schwüblingsen 2013	90%	*C. album* (40%), *M. recutita* (20%), *Mercurialis annua* L. (20%), *Solanum tuberosum* L. (10%), *Polygonum convolvulus* L. (10%)
Schwüblingsen 2014	100%	*C. album* (30%), *M. recutita* (10%), *M. annua* (20%), *S. tuberosum* (15%), *Senecio vulgaris* L. (20%)

Table 2. Application timing, number of applications and standardised treatment index (STI) of different herbicide strategies tested in field trials with sugar beet to evaluate efficacy of an ALS-inhibitor herbicide (F/T)[1] and classic herbicides[2], six environments in Germany in 2013 and 2014

Treatment	Strategy	Application Code	Number of Applications	STI
1	Untreated		0	0.00
2	1x classic + 1x 1.0 L ha^{-1} F/T	A B*	2	1.47
3	1x 1.0 L ha^{-1} F/T + 1x classic	B A*	2	1.47
4	3x classic	A A* A*	3	1.43
5	2x 0.5 L ha^{-1} F/T	B B*	2	1.00
6	1x 1.0 L ha^{-1} F/T + classic (tankmix)	C	1	1.47
7	1x 1.0 L ha^{-1} F/T	C	1	1.00

A BBCH 10 of most developed weeds
B BBCH 12 of CHEAL
C BBCH 14 of CHEAL
* or weed regrowth after prior treatment

[1] F/T: 50 g foramsulfuron L^{-1} + 30 g thiencarbazone-methyl L^{-1}
[2] Classic: 1.25 L ha^{-1} Betanal® maxxPro (94 g ai ha^{-1} ethofumesate, 75 g ai ha^{-1} phenmedipham, 59 g ai ha^{-1} desmedipham, 34 g ai ha^{-1} lenacil) + 1.00 L ha^{-1} Goltix® Gold (700 g ai ha^{-1} metamitron)

for treatments 5 and 7. STI was calculated according to Sattler et al. (2007).

Assessments of herbicide efficacy

Efficacy was assessed at canopy closure (BBCH 39) of the sugar beet. It was rated from 0–100% for the whole plot area and is indicated as percentage of controlled weeds relative to the untreated check (EPPO, 2007). Assessments were made for overall efficacy and for efficacy against *C. album* at all sites. *M. annua* and *S. tuberosum* occurred only at Schwüblingsen (Table 1) where efficacy towards both was assessed.

Statistical evaluation

Statistical analysis was carried out with the statistic program SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). After testing for normal distribution and variance homogeneity, the data were transformed into angular values. ANOVA was carried out with the procedure PROC GLM. Original data are shown in the figures.

Results

At all environments, *C. album* and *Matricaria recutita* L. occurred and accounted for 40–90% of all weeds (Table 1). Site specific weed species also emerged. Weed density was highest at Göttingen 2013, Göttingen 2014 and Schwüblingsen 2014 and lowest at Angerstein 2013 and Niedernjesa 2014.

Herbicide efficacy

Efficacy was significantly influenced by treatment, environment and their interaction (Table 3). Due to the interaction of treatment × environment, a comparison of means for the main factor treatment was not made. Efficacy was highest in treatments 2, 3, 5 and 6 (97% and higher), second highest in treatment 7 (95%) and lowest in treatment 4 (91%) (Fig. 1). Lowest efficacy of F/T was observed in treatments 5 and 7 at Schwüblingsen 2013 (88 and 89%) and in treatment 7 at Göttingen 2013 (93%). Highest variation among environments occurred in treatment 4 (classic herbicides) with efficacy being 98% at Göttingen 2013 and Niedernjesa 2014 and 84–92% at the other environments.

Efficacy against *C. album* was highest in treatments 2, 3, 5 and 6, in treatment 5 with exception of Schwüblingsen 2013 (Fig. 2). *M. annua* and *S. tuberosum* occurred at Schwüblingsen 2013 and 2014 (Table 1). Efficacy of treatments 2, 3, 5, 6 and 7 against both was 96% and higher in both years (Fig. 3). Mean efficacy of treatment 4 (3 applications of classic herbicides) was 90 and 72% against *M. annua* and 89 and 96% against *S. tuberosum* in 2013 and 2014, respectively.

Table 3. Analysis of variance for factors influencing efficacy of herbicide strategies in field trials with sugar beet, six environments in Germany 2013 and 2014. *: significant at $p \leq 0.0001$; DF: degrees of freedom**

	DF	F-Value	Pr > F
Treatment	5	34.17	***
Environment	5	32.27	***
Treatment × environment	25	7.56	***

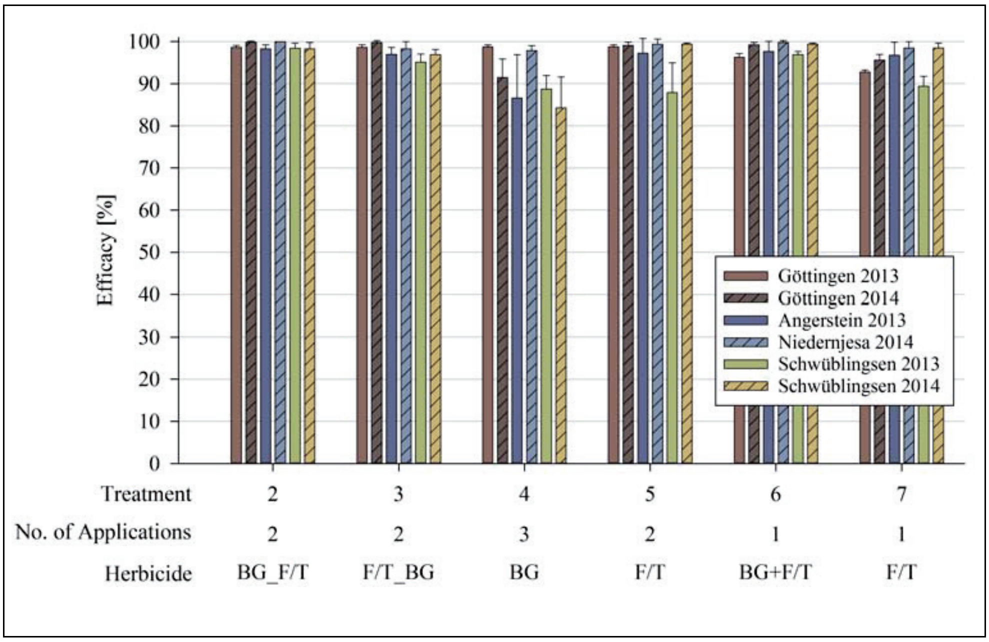

Fig. 1. Cumulated efficacy of herbicide treatments with foramsulfuron + thiencarbazone- methyl (F/T) and classic herbicides (BG) in various combinations assessed in field trials with sugar beet (BBCH 39). Six environments, Germany 2013 and 2014, n = 4. 1x F/T: 50 g foramsulfuron ha^{-1} + 30 g thiencarbazone-methyl ha^{-1}; 1x classic herbicides: 94 g ai ha^{-1} ethofumesate, 75 g ai ha^{-1} phenmedipham, 59 g ai ha^{-1} desmedipham, 34 g ai ha^{-1} lenacil + 700 g ai ha^{-1} metamitron. For details see Table 2.

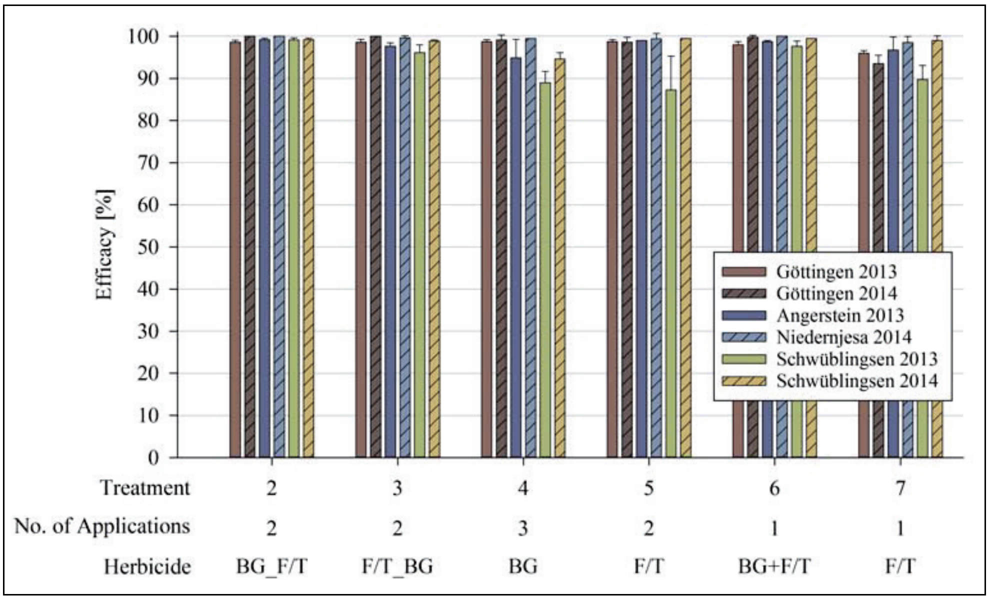

Fig. 2. Efficacy of herbicide treatments with foramsulfuron + thiencarbazone-methyl (F/T) and classic herbicides (BG) in various combinations against *Chenopodium album* L. assessed in field trials with sugar beet (BBCH 39). Six environments, Germany 2013 and 2014, n = 4. 1x F/T: 50 g foramsulfuron ha^{-1} + 30 g thiencarbazone-methyl ha^{-1}; 1x classic herbicides: 94 g ai ha^{-1} ethofumesate, 75 g ai ha^{-1} phenmedipham, 59 g ai ha^{-1} desmedipham, 34 g ai ha^{-1} lenacil + 700 g ai ha^{-1} metamitron. For details see Table 2.

Standardised treatment indexes were 1.00 when only F/T was applied, 1.43 in the classic strategy and 1.47 when F/T and classic herbicides were combined (Table 2).

Discussion

Weed control strategies with F/T had higher efficacy than classic herbicides as also described by Wegener et al. (2015). Efficacy was relatively low in treatments 5 (2x F/T) and 7 (1x F/T) at Schwüblingsen 2013 which resulted from a too late application as BBCH of *C. album* was beyond 12–14 in treatment 5 and beyond 14–16 in treatment 7 (data not shown). A similar effect was observed for treatment 7 at Göttingen 2013 and 2014, where single plants of *C. album* were beyond BBCH 16 and could not be controlled. This is in accordance with results by Wendt et al. (2016), who determined BBCH 14 and 16 of *C. album* as the latest development stage for weed control with 0.50 or 1.00 L ha^{-1} F/T, respectively. This has to be considered in herbicide strategies with F/T. The connection between cumulated efficacy and efficacy against

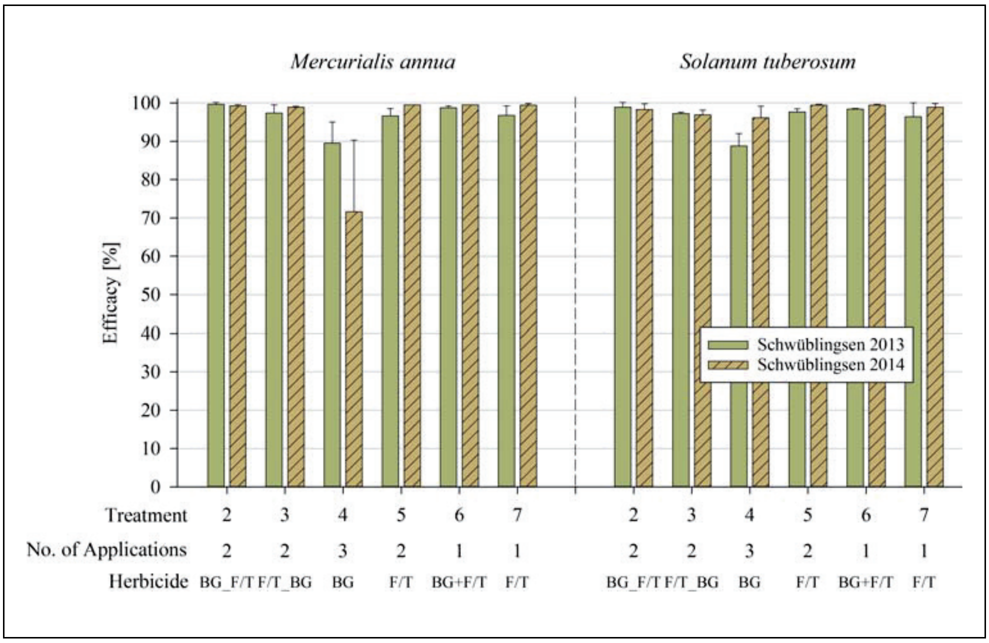

Fig. 3. Efficacy of herbicide treatments with foramsulfuron + thiencarbazone-methyl (F/T) and classic herbicides (BG) in various combinations against *Mercurialis annua* L. (left) and *Solanum tuberosum* L. (right) assessed in field trials with sugar beet (BBCH 39), Schwüblingsen 2013 and 2014, n = 4. 1x F/T: 50 g foramsulfuron ha^{-1} + 30 g thiencarbazone-methyl ha^{-1}; 1x classic herbicides: 94 g ai ha^{-1} ethofumesate, 75 g ai ha^{-1} phenmedipham, 59 g ai ha^{-1} desmedipham, 34 g ai ha^{-1} lenacil + 700 g ai ha^{-1} metamitron. For details see Table 2.

C. album points to the high importance of application timing and makes *C. album* to the key species for F/T strategies.

Limitations of the classic herbicide strategy (treatment 4) became obvious at four environments. Its efficacy was insufficient against the severe infestation with *C. album* and *M. recutita* at Göttingen 2014. Another aspect was that no ai against monocotyledonous weeds (e.g. propaquizafop or fluazifop-P) were included which caused the high occurrence rate of *Alopecurus myosuroides* Huds. at Angerstein 2013. These finds are supported by studies with similar classic herbicide strategies. In experiments by Abdollahi and Ghadiri (2004), control of *Amaranthus retroflexus* L. and *C. album* was 96 and 97% compared to 90–94% of *Echinochloa crus-galli* L. when 230 g ai ha^{-1} each of PMP, DMP and ETO were applied. In studies by Deveikyte and Seibutis (2008, 2015), the maximum control of *C. album* was 91%. It was achieved with 91 g ai ha^{-1} PMP, 71 g ai ha^{-1} DMP, 112 g ai ha^{-1} ETO and 525 g ai ha^{-1} MET.

The low efficacy against *M. annua* in treatment 4 is in accordance with results of the coordinated herbicide trials in Germany in 2014 and 2015 where three applications of only two herbicides also had a low efficacy against this fast growing weed species (IfZ, 2014, 2015). Furthermore, the control of *S. tuberosum* is difficult (May and Wilson (2006). To date, chemical treatments have low efficacy and an improvement of mechanical methods was suggested (Nieuwenhuizen et al., 2007).

It is thus concluded that either an additional ai or a fourth application is necessary for a constantly high weed control with a classic herbicide strategy. In this case, efficacy of classic herbicides towards *C. album* and *Polygonum convolvulus* L. can be beyond 97% (IfZ, 2014, 2015). Compared to the classic treatments, efficacy of strategies with F/T was higher at Schwüblingsen 2013 and 2014 showing an improved weed control on sandy soils. In general, strategies including FT should also be site-specifically adapted for different weed populations and densities.

Conclusions and Outlook

The high efficacy of F/T points to an option for a more flexible and easier weed control in sugar beet cultivation (Wegener et al., 2015; Wendt et al., 2016). This could be of importance as the populations of the dominant weeds in Germany (*C. album*, *M. annua* and *M. recutita*) have increased (Buhre et al., 2011; Vasel et al., 2012). Furthermore, the treatments with F/T indicated advantages for the control of volunteer potato and provide an option to control weed beet as well (Wegener et al., 2015). Additionally, this is accompanied by a reduction of the plant protection intensity as the STI of F/T treatments was lower (1.00–1.47) than the current mean in Germany (2.64; PAPA, 2016). Further studies are necessary to gain more data on efficacy against different weed populations and densities. However, potential risks of a weed control system with F/T, e.g. gene flow and development of weed resistance (Kudsk and Streibig, 2003), must be preventively excluded necessitating full control of volunteers of non-sensitive sugar beet. First, an effective resistance management is required due to the increasing number of weed species resistant against ALS-inhibitors (Heap, 2013). Thus, herbicide strategies with F/T only should not be applied.

Acknowledgements

The authors thank Kerstin Steil, Udo Curdt, Dr. Cord Buhre and ARGE Nord (Arbeitsgemeinschaft zur Förderung des Zuckerrübenanbaus in Norddeutschland e.V.) for technical assistance. Thanks are expressed to Dr. Sebastian Liebe and Daniel Laufer for critical review of the manuscript. Financial support was provided by Bayer CropScience AG.

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