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Evaluation of two chemical weed control systems in sugar beet in Germany and the Russian Federation

K. Bezhin, H.-J. Santel, R. Gerhards

Department of Weed Science, University of Hohenheim, Stuttgart, Germany

ABSTRACT

Roundup Ready® sugar beets are widely grown in the USA since their market introduction in 2005. The system has proven to be cost-efficient and reliable. However, the negative social image among consumers and politicians has prohibited the adoption of this technology in Europe. Seven field experiments were conducted over three years in Germany and the Russian Federation to compare weed control efficacy and sugar beet yields of post-emergent glyphosate applications with conventional selective herbicides. Although weed infestations at the Russian sites were higher than in Germany, weed control efficacies were similar at both locations ranging between 78% and 100%. Glyphosate applications resulted in significantly higher weed control efficacies than the conventional herbicides in four out of 7 experiments. In five experiments, a single glyphosate application gave equal weed control efficacy as two and three glyphosate applications. White sugar yield was always higher in the weed control treatments than in the untreated plots. There was no yield difference between treatments based on glyphosate and conventional herbicide applications in 6 out of 7 experiments. The results demonstrate a slight benefit of the glyphosate-based weed control program compared to the conventional herbicide system in terms of weed control efficacy.

Keywords: weed management; competition; *Beta vulgaris*; pesticide; yield loss

Weed management is playing an important role in sugar beet production. Up to 100% of the crop yield may be lost because of weed competition if weed control is poor or not performed at all (Schweizer and Dexter 1987). Special attention on weed control has to be paid during the critical period at early stage of sugar beet development, a period of the first 60 days after emergence when sugar beet does not tolerate competitive interactions with weeds without losing yield (Kobusch 2003, Petersen 2008, Jalali and Salehi 2013).

In the European Union and the Russian Federation, combinations of selective pre-emergent and post-emergent herbicide applications represent the dominant measure of weed control in sugar beet (Petersen 2008, Gummert et al. 2012). Herbicide mixtures, however, might cause negative side-effects including crop damage from chemical stress (Roeb et al. 2015). Repeated use of herbicides with the same mode of action has also promoted the evolution of herbicide resistant weed populations in sugar beet, such as resistant populations of *Chenopodium album* L. to metamitron (Aper et al. 2013). Therefore, Gummert et al. (2012) suggest integrated methods composed of preventive, mechanical and chemical weed control.

Many herbicides used for the selective weed control in sugar beet were introduced in the 1960s and early 1970s. The newest active substance for use in sugar beets, triflusulfuron, came to the market in 1994 (Cobb and Reade 2010). No significant innovation in chemical weed control for this crop has been provided since that time.

Nowadays, the selective herbicides are applied at a relatively low dosage and applications are conducted up to four times to ensure the best efficacy and selectivity. The first treatment needs to be sprayed at early growth stages of dicotyledonous weed species, either right after seed germination or at the cotyledon stage. Effective weed control becomes more challenging when plants reach more advanced development stages. In such cases, the

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dosage of the herbicide usually has to be increased to achieve suitable biological efficacy of the weeds. However, the increase of the herbicide application rate may cause stress to the crop and potentially express symptoms of phytotoxicity. The application is typically conducted as a tank mixture of several herbicidal substances adjusted to the weed species present (Petersen 2008).

Weed shift caused by conventional weed control with selective herbicides has favoured several difficult-to-control-weeds, such as *Fallopia convolvulus* L., *Mercurialis annua* L., *Solanum nigrum* L. and *Aethusa cynapium* L. (Vasel et al. 2012). These weeds became less susceptible to herbicides or escaped weed control by late emergence.

Roundup Ready® system based on glyphosate-tolerant sugar beet cultivars and use of glyphosate containing herbicide is an alternative technology for weed management in sugar beet (Nichterlein et al. 2013). In the USA, this technology was very rapidly adopted by farmers and in 2009, 85% of the sugar beets produced in the USA were Roundup Ready® cultivars (Nichterlein et al. 2013). This technology combines high weed control efficacy with high selectivity and is supposed not to require herbicide application at early growth stages of the weeds. Usually, two to three glyphosate application is performed starting at 4-leaf stage of sugar beets (Dewar et al. 2003, Brookes and Barfoot 2013, Muoni et al. 2013, May et al. 2014). This claim is contradicting the view of weed freeness necessary for yield protection reported by other authors (Kobusch 2003, Petersen 2008, Jalali and Salehi 2013).

The objective of this study was to compare conventional and glyphosate-based weed control strategies in sugar beet in two typical production areas in Germany and the Russian Federation. Weed control efficacies and yield effects were assessed. The main hypotheses are:

Weed density and weed species composition differ between the two sites due to different climate, soil conditions and crop management practice.

Weed control efficacy is equal in conventional and glyphosate-based weed control programs. A single application of glyphosate provides less weed control than two or three applications.

All weed control treatments significantly increase sugar beet yields above untreated, however no differences between herbicides strategies can be observed.

MATERIAL AND METHODS

Experimental sites. Three field experiments were conducted at the experimental station of the University of Hohenheim Ihinger Hof (IHO), Germany, Baden Württemberg (48°74'03''N, 8°91'56''E) in 2012, 2013 and 2014. The soil at IHO is classified as silty clay loam (L4LöV 62/65) with high fertility and good water retention capacity.

Four experiments were carried out in the Russian Federation, one in 2012 on a private farm at Michurinsky (MICH), district of Tambov Region (53°01'75''N, 40°68'32''E), two in 2013 and one in 2014 on an experimental station located at Doktorovo (DOK) in the Lipetsk region (52°78'47''N, 39°02'72''E). The soil at the Russian locations is a typical Voronic Chernozem with high content of organic matter of 5.5% and high biological activity. All selected sites are representative for commercial sugar beet cultivation in the respective areas.

Environmental conditions. The climate at IHO is temperate cool with average annual temperatures of 9.2°C in 2012, 8.7°C in 2013 and 10.4°C in 2014. The total annual precipitation was conducive for sugar beet growth with 727 mm in 2012, 923 mm in 2013 and 763 mm in 2014 except for two short periods of drought in spring in 2012 and 2014. Long-term annual average temperature is 9.2°C and long-term total annual precipitation is 790 mm.

The sites in the Russian Federation at MICH and DOK are characterized by a temperate continental climate with average annual temperatures of 7.0°C in 2012 and 2013 and 6.6°C in 2014 and total annual precipitation of 482 mm in 2012, 462 mm in 2013 and 340 mm in 2014. All three summer periods were hot and dry.

Experimental design. The trials were arranged as complete randomized block designs with four repetitions. The plots were 3 m wide (six rows) and 8 m long, resulting an area of 24 m^2. Sugar beets were sown at a density of app. 110 000 seeds/ha after strip tillage in April (IHO) and early May (MICH, DOK). The previous crop was winter wheat at all locations.

The experimental design includes six treatments (Table 1). Treatment 1 was an untreated control. In treatment 2, all weeds were removed manually shortly after their emergence. Hand weeding was included into the experimental scheme as a treatment to detect possible phytotoxic effects of

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Table 1. Description of the experimental treatments in the herbicide trials

No.	Treatment	Treatment's description
1	UTC	untreated control
2	weed-free control	repeated hand weeding, no chemical treatment
3	conventional	pre-emergence application of 1.0 L/ha Goltix Gold (only IHO), followed by two to four post-emergent applications of 1.0 L/ha Goltix Gold + 1.5 L/ha Betanal Expert as tank mixture
4	GT 3 × 2 L	three applications of 2.0 L/ha Roundup UltraMax
5	GT 2 × 3 L	two applications of 3.0 L/ha Roundup UltraMax
6	GT 1 × 3 L	one application of 3.0 L/ha Roundup UltraMax

herbicides on the sugar beets. In treatment 3, a set of conventional herbicides was applied according to local commercial standards as an herbicide sequence or tank mixture of different herbicides. The products were selected on demand, depending on the weed species present in the field. In all German experiments, a pre-emergence application of 1.0 L/ha Goltix Gold®, SC (700 g a.i/L metamitron) was sprayed. Due to high soil organic matter content in the Russian Federation, only post-emergent herbicides were applied. Two to four post-emergent applications of 1.0 L/ha Goltix Gold® plus 1.5 L/ha Betanal Expert®, EC (75 g a.i./L phenmedipham, 25 g a.i./L desmedipham, 151 g a.i./L ethofumesate) as tank mixture were made. Treatment 4 consisted of three applications of 2 L/ha Roundup UltraMax, SL (450 g a.e./L glyphosate) at 4-, 6- and 8-true leaf stage of sugar beet, in treatment 5, two applications of 3 L/ha Roundup Ultramax at 4- and 6-true leaf stage of sugar beet was sprayed and treatment 6 was a single application of 3 L/ha Roundup UltraMax at 6-true leaf stage of sugar beet.

The herbicide treatments were realized as a broadcast spray of formulated commercial herbicides in 200 L/ha of water using a bicycle-wheel plot-sprayer (Schachtner, Ludwigsburg, Germany) equipped with Flat-fan air-injector nozzles (IDKT 12002 by Lechler, Reutlingen, Germany), powered with pressurized air. The application was conducted at an air pressure of 1.7 bar and a driving speed of 3.6 km/h. Fertilization, fungicide and insecticide application were conducted according to the local commercial practice.

Simulation of glyphosate tolerant sugar beet. Legal limitations in Germany and Russian Federation did not allow the use of transgenic glyphosate tolerant sugar beet seeds in the experiments. Therefore, conventional seeds were sown. Glyphosate tolerance had to be simulated by physical exclusion of the non-selective herbicide from contact with the cultivar. Each individual sugar beet plant was covered up with plastic cups during application and plastic foil windbreakers were used to avoid herbicide drift to adjacent plots. No crop injury was observed using this protective method.

Assessments. Weed density by species was assessed shortly before each herbicide treatment and two weeks after the last treatment using a frame of 0.25 m^2 placed at four randomly distributed spots in each plot. Weed control efficacy (WCE) of the herbicide treatments for total density and for each species individually was calculated by means of the following Eq. 1 (Chinnusamy et al. 2013):

$$WCE = \frac{WD_c - WD_t}{WD_c} \times 100 \qquad (1)$$

Where: WCE – weed control efficacy (%); WD_c – weed density (number/m^2) before treatment; WD_t – weed density (number/m^2) after treatment.

In autumn, a subplot of 2.5 m^2 in the centre of each plot was harvested by hand and the beet roots were separated from the leaves. The beets were washed and then fresh beet weight was determined. Sugar content was analysed according to the standard refraction procedure. Visual assessments of crop tolerance to herbicide treatment were made according to EPPO-guidelines PP1/52 (3) and PP1/135 (4) (EPPO 2007). Emerged sugar beets were counted six times per plot at 2-true leaf stage using a scale of 1 m length placed along the crop row.

Statistical analysis. Weed control efficacy, sugar beet yield and white sugar yield were analysed with ANOVA. In order to highlight significant

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differences between treatments, Tukey's *HSD* test was conducted on the significance level of $P \leq 0.05$. The package 'agricolae' in the statistical program R, version 2.15.0 was used for the analysis of variance and the multiple means comparison (R Core Team, 2012).

RESULTS AND DISCUSSION

Weed infestations. Weed densities were significantly higher at the Russian sites with a total density of 82–237 weeds/m^2 in MICH and DOK than at the German location with a total density of 28–61 weeds/m^2 (Table 2). According to Dobrynin and Lipovtsev (2007), weed competition is the major problem in Russian sugar beet production. Large farm sizes and limited machinery resources often lead to the problem, that weeds cannot be controlled at early growth stages. Thus, yield losses can be recorded and weed control efficacy dramatically decreases when conventional herbicides are sprayed at later growth stages. A second reason for higher weed infestation rates in Russian sugar beet production is the high soil organic matter content, which strongly reduces availability of soil active herbicides in the soil water.

Composition of the weed infestations was also different in both regions. *Amaranthus retroflexus* L., *Echinochloa crus-galli* (L.) Pal. Beauv. and *Lamium purpureum* L. only occurred at the sites in the Russian Federation and *Stellaria media* (L.) Vill. and *Matricaria inodora* L. were only found at IHO (Table 1). Dominance of *A. retroflexus* and *E. crus-galli* many be explained by a competitive advantage of C-4 plants over C-3 when growing in areas with continental hot and dry summers (Ziska and Runion 2007).

Weed control efficacy. Total weed control efficacy in all experiments ranged from 78–100%. Although weed infestations at the Russian sites were higher than in Germany, weed control levels were equal in both locations. Glyphosate applications resulted in significantly higher weed control than the conventional herbicides in four out of 7 experiments at MICH 2012, DOK 2013, IHO 2013 and DOK 2014. In five experiments, a single glyphosate application reduced weed density as much as two and three glyphosate applications indicating the potential to reduce treatment frequency in sugar beet using glyphosate (Figure 1). However, on a long term, single applications of glyphosate in sugar beets did not result in adequate weed control efficacy (Wilson et al. 2002) in glyphosate-tolerant sugar beet. Single applications

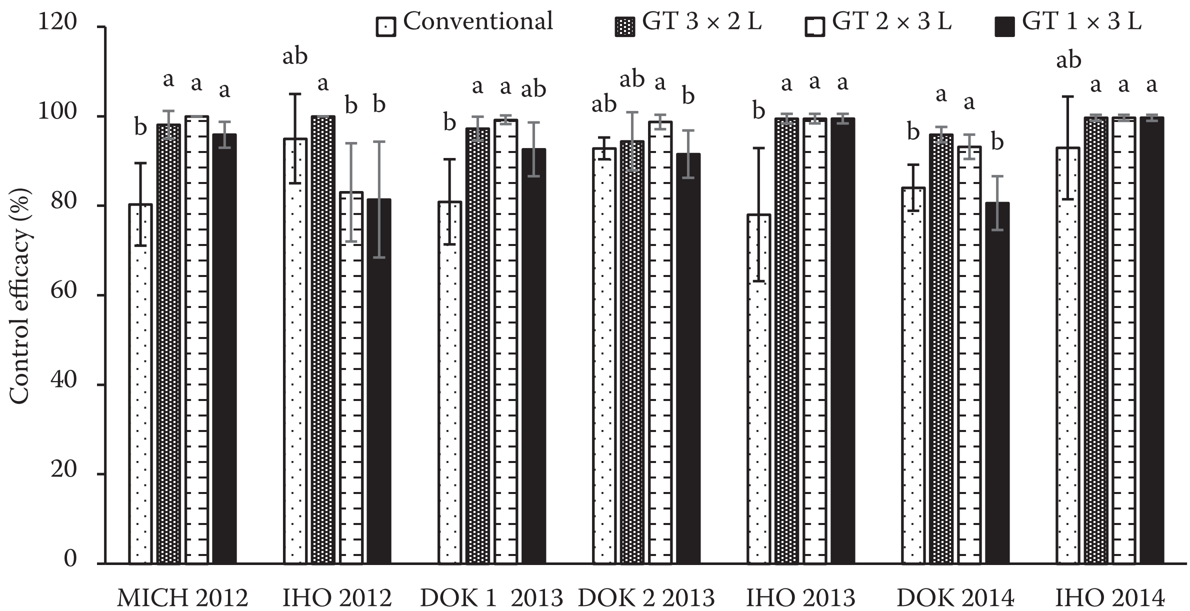

Figure 1. Total herbicide efficacy in sugar beet at 7 locations in Germany (Ihinger Hof – IHO) and the Russian Federation (Doktorovo – DOK and Michurinsky – MICH) in 2012, 2013 and 2014; GT stands for glyphosate tolerance; numbers after GT indicate the number and rate of treatments; means with different letters indicate significant differences between treatments (Tukey's test, $P \leq 0.05$)

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of glyphosate might also select for weed species that emerge after herbicide application (Vasel et al. 2012).

The results show that mainly total weed control efficacy at the Russian sites was increased in the glyphosate treatments. This corresponds to Nichterlein et al. (2013), who observed that the efficacy in the Roundup Ready® system is less sensitive to timing, soil conditions and weed species composition than in conventional weed control systems. However, if the first treatment with glyphosate is made later than four to six true leaf stage of weeds, sugar beet yield can be reduced (Dewar et al. 2000, Märländer 2005, Wilson and Sbatella 2011, Steinmann et al. 2012).

Weed control effect varied among weed species present. Control of the perennial *Convolvulus arvensis* L. never exceeded 41% in the conventional and 80% in the glyphosate treatment. Behind this may be the low sensitivity of *C. arvensis* for these herbicides and the late emergence of this species after weed control operations had been completed (Baylis 2000). Conventional herbicides also performed low against *A. retroflexus* (65%) and *V. arvensis* (75%) at DOK 2013. This could be attributed to absorption of herbicides caused by the high organic matter content of the soil (Petersen 2008). *M. inodora* at IHO in 2013 and 2014 was only suppressed by 74% with conventional herbicides which was probably caused by low root uptake of herbicides from dry soil.

Sugar beet yield and white sugar yield. On average, yields were roughly 40% lower at the Russian sites than at IHO in all treatments, likely caused by local environmental conditions, especially low precipitation there.

Sugar beet yield and white sugar yield were significantly higher compared to the control in all treatments (Figures 2 and 3). Results clearly show the need of effective weed control in sugar beet, mainly against highly competitive weed species, such as *Chenopodium album*, *A. retroflexus* and *Polygonum convolvulus*, which are capable to rapidly overgrow the sugar beet (Vasel et al. 2012). Even early weed competition shortly after crop emergence can cause significant yield losses, as we could demonstrate in the experiment IHO 2013. The treatment with a single rate of glyphosate was

Table 2. Average densities of the dominant weed species in all experiments

Weed species	2012		2013			2014	
	MICH	IHO	DOK 1	DOK 2	IHO	DOK 1	IHO
Amaranthus retroflexus	–	–	32	142	–	–	–
Chenopodium album	21.7	11.9	48	29	–	9.2	5.5
Cirsium arvense	6	–	–	–	–	–	–
Convolvulus arvensis	14.5	2.0	–	–	–	–	–
Echinochloa crus-gali	15	–	6	–	–	–	–
Galium aparine	–	–	–	–	0.2	–	–
Galeopsis tetrahit	–	–	6	–	–	12.5	–
Lamium purpureum	–	–	33	23	–	0.4	–
Matricaria inodora	–	–	–	–	13.2	–	26.7
Poa annua	–	–	–	–	–	–	4.7
Polygonum aviculare	–	–	9	–	–	–	–
Polygonum convolvulus	–	11.7	37	33	0.5	62	16
Polygonum lapathifolium	–	–	10	–	–	2	–
Sonchus arvensis	–	1.3	–	–	0.5	–	5
Stellaria media	–	1.3	–	–	10.2	–	–
Thlaspi arvense	–	–	–	–	–	–	3.5
Veronica persica	–	–	–	–	6	–	–
Vicia sativa	25	–	–	–	–	–	–
Viola arvensis	–	–	37	10	–	16	–
Total density	82.2	28.2	218	237	30.6	102.1	61.4

IHO – Ihinger Hof; DOK – Doktorovo; MICH – Michurinsky

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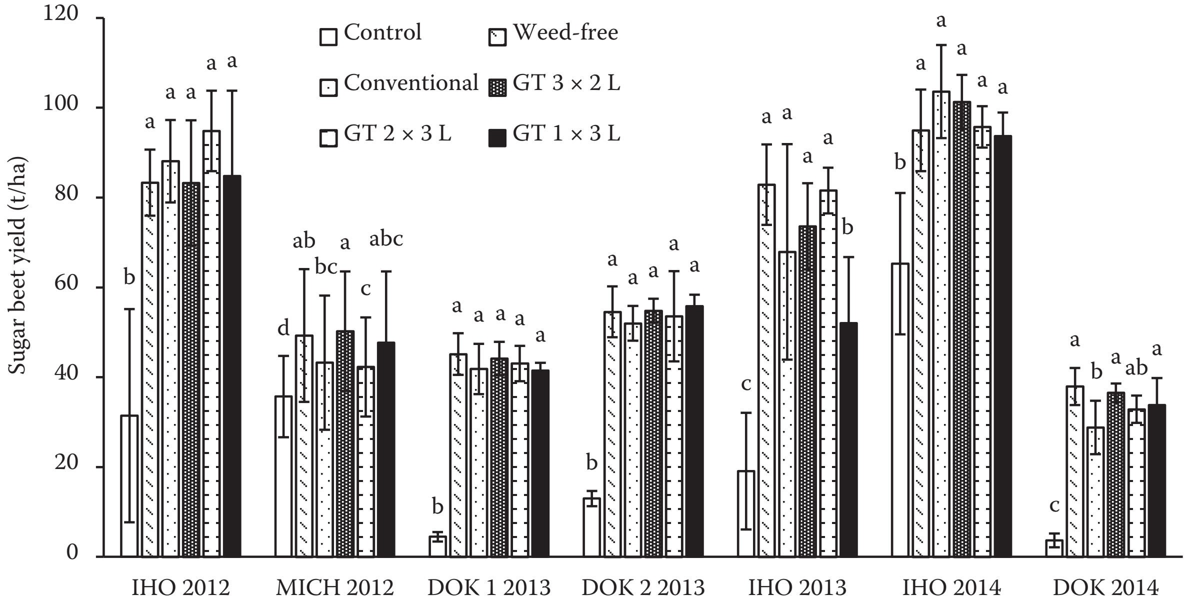

Figure 2. Sugar beet yield at 7 locations in Germany (Ihinger Hof – IHO) and the Russian Federation (Doktorovo – DOK and Michurinsky – MICH) in 2012, 2013 and 2014; GT stands for glyphosate tolerance; numbers after GT indicate the number and rate of treatments; means with different letters indicate significant differences between treatments (Tukey's test, $P \leq 0.05$)

applied late, when weeds had already developed 4–6 true leaves. Although efficacy was almost 100%, sugar beet yield was significantly reduced.

White sugar yield was equal in all treatments in 6 out of 7 experiments. Herbicides did not cause any visual damage to the sugar beets and sugar beet densities were equal in all treatments and experiments with approximately 100 000 plants/ha. Hand-weeded plots and herbicide treatments reached equal yields.

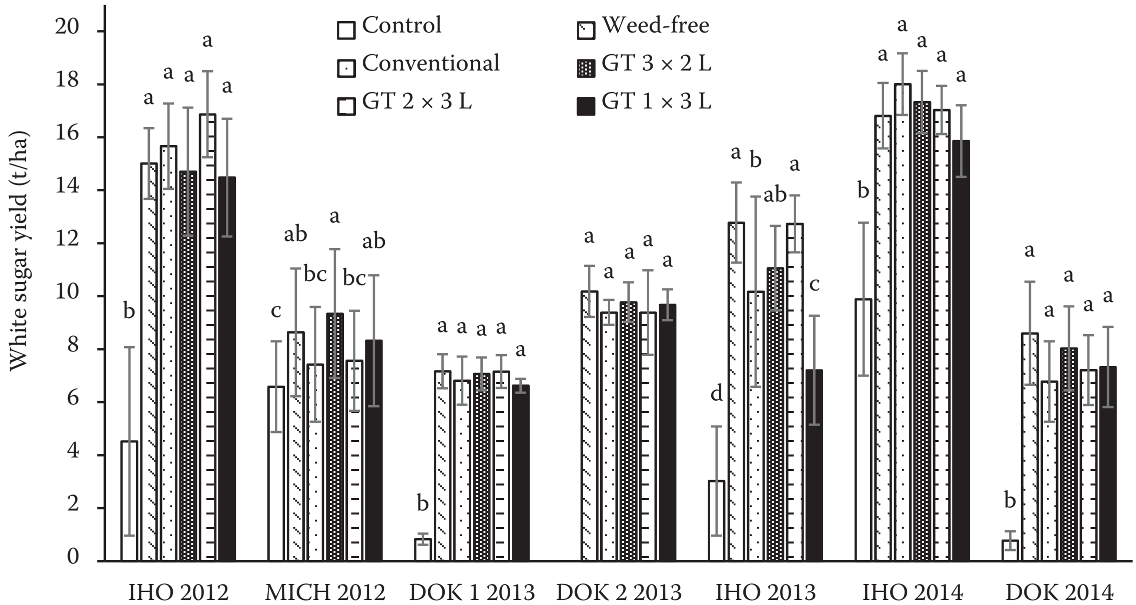

Figure 3. White sugar yield at 7 locations in Germany (Ihinger Hof – IHO) and the Russian Federation (Doktorovo – DOK and Michurinsky – MICH) in 2012, 2013 and 2014; GT stands for glyphosate tolerance; numbers after GT indicate the number and rate of treatments; means with different letters indicate significant differences between treatments (Tukey's test, $P \leq 0.05$)

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The results demonstrate a slight benefit of the glyphosate-based weed control program compared to the conventional herbicide system in terms of weed control efficacy.

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Corresponding author:

Prof. Dr. Roland Gerhards, University of Hohenheim, Department of Weed Science, 70 593 Stuttgart, Germany
e–mails: gerhards@uni–hohenheim.de, roland.gerhards@uni-hohenheim.de