Evaluation of transgenic herbicide-resistant oilseed rape and maize with reference to integrated pest management strategies

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ABSTRACT

In the present study, weed control in glufosinate-resistant maize and rape was comparable to that in conventional crops but was associated with fewer biological risks. New weeds emerged after glufosinate treatment. These plants increased the in-field biodiversity during vegetation but deposited their seeds in the soil, which can lead to later weed control problems. In maize, dead floral mulch and new weeds that emerged after treatment provided only a small degree of protection against soil erosion. Out-crossing of transgenic rape into neighbouring non-transgenic rape was far below the proposed thresholds of 0.5 % and 0.9 %. We believe that conservation tillage systems with herbicide-resistant crops have a greater potential in promoting integrated pest management than same systems that do not use transgenic herbicide-resistant varieties.

INTRODUCTION

Of all the options available for indirect and direct plant protection in integrated pest management (IPM), the application of pesticides should be used as the last choice and should be minimised to reduce the risk of harm to non-target organisms (Burth & Freier, 1996). Farmers growing transgenic herbicide-resistant (HR) crops commit themselves at a very early stage to use a specific herbicide. Alternative weed control measures then play a subordinate role. Without herbicides, many crops cannot be grown economically in accordance with the principles of IPM. This is especially relevant to countries like Germany, where an increasing proportion of farming land is managed by conservation tillage. Hence, the negative and positive economic and ecological effects of HR crops must be carefully considered when attempting to implement IPM strategies in agricultural practice.
Since 1996, the Biologische Bundesanstalt (BBA) in Kleinmachnow has been conducting a long-term field trial in conventional and HR maize and rape to elucidate the following key issues:

1. Effects of frequent glufosinate use on field flora after several crop rotations;
2. Consequences of volunteer HR rape in maize resistant to the same herbicide;
3. Ecological effects of new weeds that emerge in maize fields after glufosinate treatment;
4. Ecotoxicological differences in herbicide treatment strategies in conventional and herbicide-resistant maize and oilseed rape;
5. Potential impact of out-crossing of different rape varieties on the coexistence of farms cultivating transgenic and non-transgenic oilseed rape.

MATERIALS AND METHODS

The BBA trial of transgenic HR rape and maize was performed in fields in Dahnsdorf, Brandenburg, a site characterised by silty sandy soil with 1.42 % organic matter, an annual mean temperature of 8.4 °C, an average annual precipitation of 536 mm, and a pronounced pre-summer dryness period. The study, which was initiated in 1996, was designed as a randomised block field trial with four replicates and four courses of crop rotation, from winter rape to winter rye to maize to winter wheat (figure 1). Each crop rotation field (18 m x 20 m = 360 m²) was divided into three plots of equal size, where the following variants of oilseed rape and maize were grown:

- Variant 1: Conventional rape treated as needed with metazachlor, quinmerac, carbetamide, dimefuron or fluazifop-P, and conventional maize treated as needed with metolachlor, pyridate or terbuthylazin.
- Variant 2: Glufosinate-resistant rape (event GS 40/90) and maize (event T 25) with intensive glufosinate treatment, i.e. high-dose or two applications.
- Variant 3: Glufosinate-resistant rape (event GS 40/90) and maize (event T 25) with extensive glufosinate treatment, i.e. low-dose or one application.

All three variants were subjected to uniform tillage, fertilisation and other plant protection measures. The kind of weed species and their abundance (weed-coverage) were determined before and after herbicide treatment. The yield of oilseed rape, maize, rye and wheat, and the feed values of maize were also determined. An ecotoxicological analysis based on the SYNOPS model (Gutsche & Roßberg, 1997), which considers the biological risk potentials of herbicides for fish, daphnia, earthworm and alga, was also performed in all three variants of maize and rape.

In order to reduce the transmission of transgenic rape pollen to fields with conventional rape, ruderal rape or wild relatives, the 16 test fields were surrounded by an unbroken strip of isogenic rape (7.5 m in width) positioned 15 to 35 m away (figure 1). To calculate the proportion of out-crossing, the rape seedlings yielded in the catch crop strip were treated with glufosinate under greenhouse conditions, and the survivors were genetically tested by PCR.

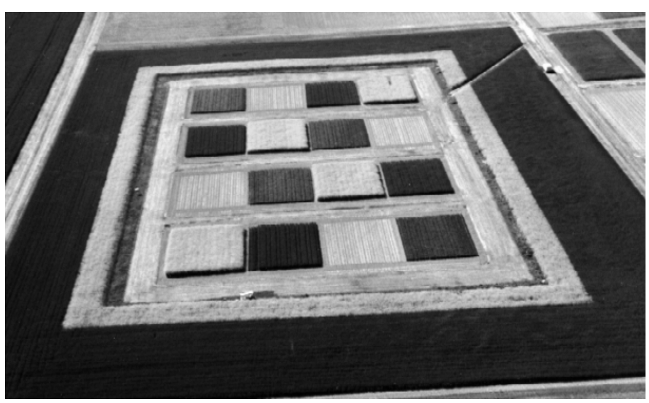

Figure 1. Aerial view showing the 4 fields of transgenic herbicide-resistant winter rape and maize surrounded by a strip of isogenic rape positioned a variable distance away; here, one crop rotation with rye and wheat has been completed. (Photo: Baier, 05/2001)

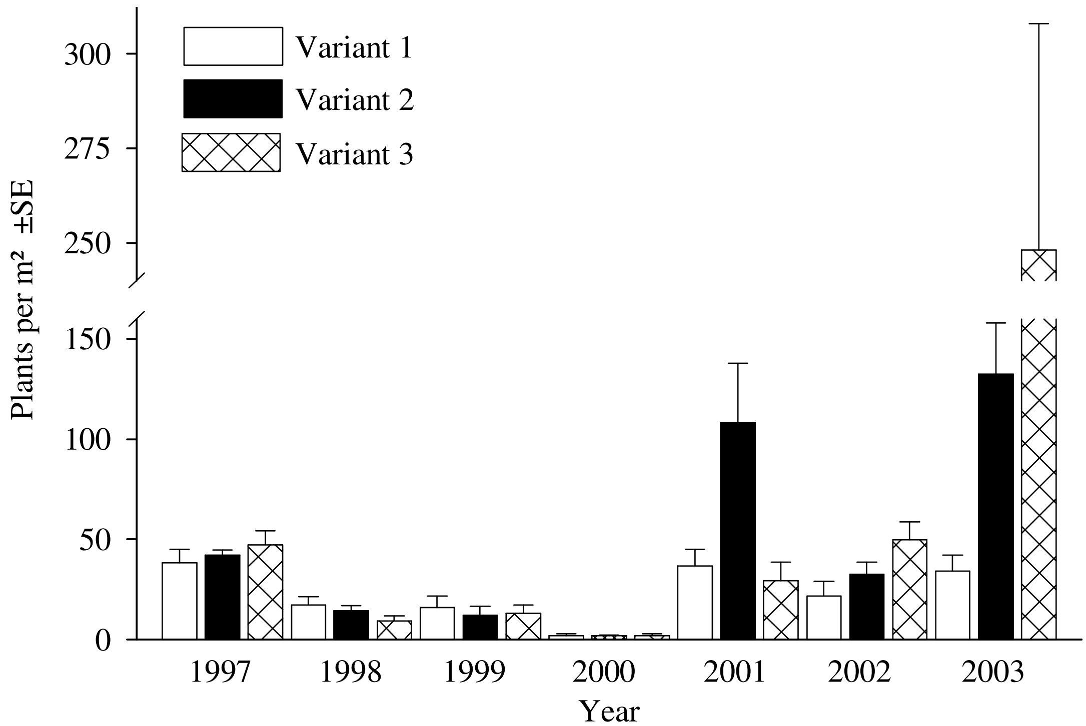

Figure 2. Annual abundance of *Chenopodium album* in maize before herbicide treatment (first crop rotation 1997 – 2000).

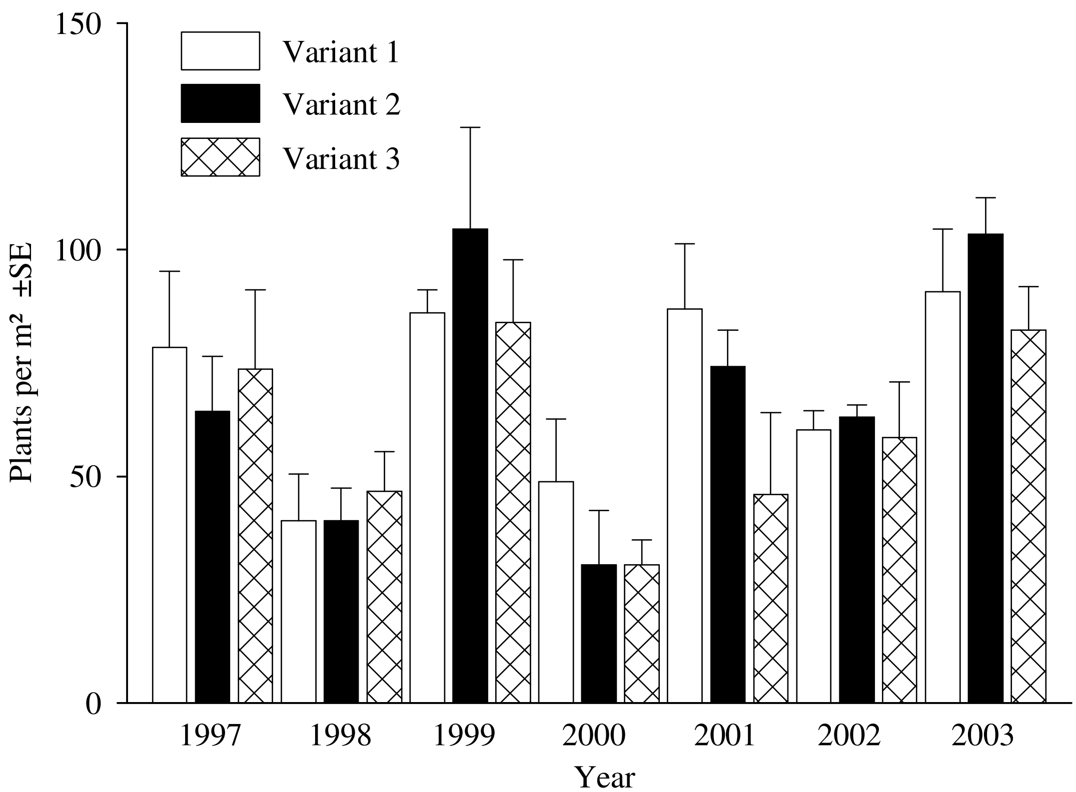

Figure 3. Annual abundance of *Viola arvensis* in maize before herbicide treatment (first crop rotation 1997 – 2000).

RESULTS

Chenopodium album and *Viola arvensis* were the most commonly observed weed species in the maize fields. *C. album* had similar abundance in all variants during the first crop rotation (1997 – 2000), but a marked annual increase has been observed in variants 2 and 3 since the second crop rotation in 2001 (figure 2). In the case of *V. arvensis*, the abundance levels registered during the first rotation persisted during the second crop rotation in all variants (figure 3). *Polygonum spp.*, another frequent weed genus, showed a trend similar to that of *C. album*.

In maize variant 1, *C. album* and *V. arvensis* coverage has remained very low 4 weeks after herbicide treatment since 1997 (table 1), and a small degree of diversity and abundance of associated floral species has persisted until the September harvest each year. New *C. album* emerged after glufosinate application in maize variants 2 and 3. In 2 of 3 years, *C. album* was almost as abundant 4 weeks after treatment as before treatment (table 1). In most cases, *V. arvensis* was not satisfactory controlled by glufosinate (table 1). The high degree of coverage by *V. arvensis* 4 weeks after treatment was usually attributable to growing plants which had already emerged before glufosinate treatment. The degree of coverage of *Polygonum* spp. in all maize variants did not exceed 0.2 % until 4 weeks after treatment.

Beginning with the second rotation in 2001, glufosinate-resistant volunteer oilseed rape emerged in maize variants 2 and 3; these plants predictably survived glufosinate treatment. Glufosinate was successfully supplemented with nicosulfuron or rimsulfuron in 2001 and 2002, respectively. Both of these herbicides and variable doses of glufosinate have adequately controlled weed growth in the HR crops during last 7 years. Yields of rape and maize variants 2 and 3 were comparable to those of the respective standard crop (variant 1), i.e. no significant differences observed. The pretty higher percentage of crude fibre observed in maize variants 2 and 3 in certain years was not significant.

Table 1. Effect of herbicide on *Chenopodium album* and *Viola arvensis* coverage (% ± SE) in maize 0 and 28 days after treatment (DAT).

Variant	*Chenopodium album*		*Viola arvensis*	
	0 DAT	28 DAT	0 DAT	28 DAT
Variant_1_2001	1.00 ± 0.204	0.08 ± 0.025	0.75 ± 0.144	0.08 ± 0.025
Variant_2_2001	1.25 ± 0.323	0.88 ± 0.125	0.50 ± 0.000	1.13 ± 0.125
Variant_3_2001	0.68 ± 0.197	0.75 ± 0.166	0.50 ± 0.000	1.00 ± 0.000
Variant_1_2002	1.13 ± 0.375	0.00	1.00 ± 0.204	0.03 ± 0.025
Variant_2_2002	0.88 ± 0.125	0.10 ± 0.000	1.00 ± 0.204	1.88 ± 0.315
Variant_3_2002	1.50 ± 0.204	0.20 ± 0.100	0.88 ± 0.125	1.50 ± 0.204
Variant_1_2003	0.30 ± 0.000	0.00	0.30 ± 0.000	0.00
Variant_2_2003	0.53 ± 0.165	0.40 ± 0.058	0.40 ± 0.058	0.53 ± 0.165
Variant_3_2003	1.15 ± 0.202	0.58 ± 0.149	0.53 ± 0.103	0.45 ± 0.050

The proportion of out-crossing of HR transgenic rape into the conventional rape cultivated as a catch crop strip around the experimental fields ranged from a mean 0.026 % to 0.13 % (table 2).

The distance between the transgenic pollen donor and the nearest recipient was roughly 25 m, 35 m and 15 m in 1998, 1999 and 2001, respectively. In the isogenic rape (variant 1), the percentage of out-crossing ranged between 1 % and 3 %.

Table 2. Occurrence of transgenic HR rape seeds in isogenic rape harvested in a pollen catch crop strip (approx. 0.5 ha) in 1998, 1999 and 2001.

Season	Number of sampling points	Seeds per sample	Plants treated (total)	Surviving plants (total)	Out-crossing rate [%]
1997/98	187	200	35,599	31	0.090
1997/98	14	1,000	13,396	18	0.130
1998/99	222	ca. 200	ca. 42,000	11	0.026
1998/99	14	1,000	13,641	10	0.070
2000/01	116	1,000	107,957	37	0.034

DISCUSSION

Allowing a pretty wide period for herbicide application in all HR crops increases the flexibility of weed control and enables better compliance with herbicide thresholds (Hommel & Pallutt, 2000). The addition of glufosinate to the list of post-emergence herbicides for oilseed rape and maize is therefore in the interest of IPM. Nevertheless, a second application of glufosinate is often required about 2 to 3 weeks after initial treatment for adequate weed control in maize. This increase in treatment intensity prevents the excessive accumulation of *C. album* seeds in the soil. The unsatisfactory effect of glufosinate on *V. arvensis* was reflected by a moderate to high abundance of this weed species in oilseed rape and maize. However, this gap in glufosinate activity in these crops is ecologically desirable because of the low competitive ability of *V. arvensis* (Schulte, 1999).

Except for the occurrence of HR volunteer rape in maize as a new competitive weed, the different glufosinate treatment intensities (from 0 litre/ha to 14.5 litres/ha) in the three rape and maize variants did not lead to differences in weed species diversity in any of the 7 years studied (Hommel & Pallutt, 2002).

The volunteer rape made it necessary to supplement glufosinate with another herbicide (Stelling, et al., 2000), which naturally offsets the economic and ecological advantages of HR crops. Therefore, when cultivating HR rape according to the principles of IPM, another crop resistant to the same herbicide should not be used within a given crop rotation.

Neither the dead mulch in maize nor the newly emerged weeds that survived 1 or 2 glufosinate treatments reached coverage levels capable of protecting the soil from wind or water erosion. None the less, the diversity and abundance of epigeous fauna in HR maize fields was probably still greater than that in conventional maize. The use of HR crops in special erosion-prevention systems with conservation tillage has some advantages over the use of conventional crops. For example, the intensity of herbicide use (e.g. dose, number of active compounds) is often lower, and the wider spraying window gives the farmer increased flexibility in selecting an optimum spraying date.

The out-crossing of transgenic HR rape to conventional rape can not be entirely prevented (Dietz-Pfeilstetter, et al., 2003). Therefore, practicable thresholds like 0.5 % for non-commercialised and 0.9 % for commercialised transgenic varieties, as recommended by the EC, are absolutely necessary. Abstention from transgenic rape growing in certain regions also seems to be an acceptable solution. Because of the long dormancy of oilseed rape (Pekrun, et al., 1997), the occurrence of volunteer transgenic rape in conventional rape fields poses an important obstacle to their coexistence. However, this problem is still less often investigated because the pollen donor plants can probably cause higher proportions of out-crossing than transgenic pollen originating from outside the field.

Compared to conventional oilseed rape and maize managed with herbicides such as metazachlor, quinmerac, carbetamide, dimefuron, fluazifop-P, metolachlor, pyridate, and terbuthylazin, the use of glufosinate in herbicide-resistant transgenic rape and maize has distinct ecotoxicological advantages because of glufosinate's lack of effect in the soil, the often later need for herbicide application, and the subsequently higher degree of crop and weed coverage, which reduces the biological risks of chemical weed control (Hommel & Pallutt, 2000).

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REFERENCES

Burth U; Freier B (1996). The development of the concept of integrated plant protection and what it includes. Plant Research and Development **43**, 7-15.

Dietz-Pfeilstetter A; Bübl W; Stelling D (2003). Occurrence of transgenic progenies in the harvest of winter oilseed rape variety trials. Nachrichtenbl. Deut. Pflanzenschutzd. **55**, 134-137.

Gutsche V; Rossberg D (1997). Die Anwendung des Modells SYNOPS 1.2 zur synoptischen Bewertung des Risikopotentials von Pflanzenschutzmittelwirkstoffgruppen für den Naturhaushalt. Nachrichtenbl. Deut. Pflanzenschutzd. **49**, 273-285.

Hommel B; Pallutt B (2000). Bewertung der Herbizidresistenz für den integrierten Pflanzenschutz im System einer 4-feldrigen Fruchtfolge mit Glufosinat-resistentem Raps und Mais. Z. PflKrankh. PflSchutz, Sonderh. XVII, 411-420.

Hommel B; Pallutt B (2002). Bewertung der Glufosinatresistenz bei Raps und Mais aus der Sicht des integrierten Pflanzenschutzes – Ergebnisse eines 1996 begonnenen Langzeitversuchs unter besonderer Berücksichtigung von Veränderungen in der Ackerbegleitflora. Z. PflKrankh. PflSchutz, Sonderh. XVIII, 985-994.

Pekrun C; Potter T C; Lutman P J W (1997). Genotypic variation in the development of secondary dormancy in oilseed rape and its impact on the persistence of volunteer rape. Brighton Crop Protection Conf. – Weeds, 243-248.

Schulte E (1999). LibertyLink im Winterraps. Ein Beitrag zur Entwicklung unweltfreundlicher Anbauverfahren. Report. Aventis CropScience, 79 pp.

Stelling D; Schulte M; Amann A (2000). Strategien der Unkrautbekämpfung mit Liberty® in LibertyLink® Mais. Mitt. Biol. Bundesanst. Land- Forstwirtsch. **376**, 154-155.