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CONSEQUENCES FOR WEED MANAGEMENT IN CROP ROTATIONS BY INTRODUCING IMIDAZOLINONE-TOLERANT OILSEED RAPE VARIETIES

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*	Significant, $p \leq 0.05$
%	Per cent
®	Registered trademark
$	US Dollar
α	Statistical error, 1st order
AA	Genome of *Brassica campestris*
ACCase	**A**cetyl-**C**oA-**c**arboxyl**ase**
AHAS	**A**ceto**h**ydroxy**a**cid-**s**ynthase
AHAS1	**A**ceto**h**ydroxy**a**cid-**s**ynthase **1**, originating from the C genome (*Brassica oleracea*)
AHAS3	**A**ceto**h**ydroxy**a**cid-**s**ynthase 3, originating from the A genome (*Brassica campestris*)
a.i.	**A**ctive **i**ngredient/s
ALS	**A**ceto-**l**actate-**s**ynthase
ANOVA	**An**alysis **o**f **va**riance
BASF SE	**B**adische **A**nilin- und **S**oda-**F**abrik **S**ocietas **E**uropaea
BBCH	**B**iologische Bundesanstalt, **B**undessortenamt and **Ch**emical Industry
B.C.	**B**efore **C**hrist
°C	Degree **C**elsius
CC	Genome of *Brassica oleracea*
cm	**C**enti**m**etre
CPC	**C**rude **p**rotein **c**ontent
dt	**D**eci **t**onne
E	**E**ast
E.C.	**E**mulsion **c**oncentrate
ED_x	Specific herbicide dose at which the fresh weight is reduced by x %
e.g.	**E**xample **g**iven
EIQ	**E**nvironmental **i**mpact factor
EPSPS	5-**e**nol**p**yruvyl-**s**hikimate-3-**p**hosphate **s**ynthase
EU	**E**uropean **U**nion
F_1	**F**ilial generation **1**
FAO	**F**ood and **A**griculture **O**rganisation of the United Nations

g	**G**ramme
ha	**H**ect**a**re
HET-IT	**Het**erozygous **i**midazolinone-**t**olerant
HOM-IT	**Hom**ozygous **i**midazolinone-**t**olerant
HRAC B	**H**erbicide Resistance **A**ction **C**ommittee, mode of action group **B**
HT	**H**erbicide-**t**olerant
HW	**H**ectolitre **w**eight
IMIs	**Imi**dazolinone**s**
IS	**I**midazolinone-**s**usceptible
IT	**I**midazolinone-**t**olerant
JKI	**J**ulius-**K**ühn **I**nstitut
Kg	**K**ilo**g**ramme
km/h	**K**ilo**m**etres per **h**our
kPa	**K**ilo **pa**scal
L.	**L**inné
l	**L**itre
LSD	**L**east **s**ignificant **d**ifference
m	**M**etre
m^2	Square **m**etre
mm	**M**illi**m**etre
n	**N**umber
N	**N**orth/**N**itrogen
OSR	**O**il**s**eed **r**ape
p	**P**robabillity of error
P1/PM1	**P**oint **m**utation 1
P2/PM2	**P**oint **m**utation 2
pH	**P**otentia **h**ydrogenii
POST-E	**Post-e**mergence crop
PRE-E	**Pre-e**mergence crop
qPCR	**q**uantitative PCR
SB	**S**ugar **b**eet
SCTs	**S**ulfonylamino**c**arbonyl**t**riazolinone**s**
SOSR	**S**pring **o**il**s**eed **r**ape
spp.	**Sp**ecies

ssp.	**S**ub**sp**ecies
SUs	**Su**lfonylurea**s**
SW	**S**pring **w**heat
t	**T**onnes
TKW	**T**housand-**k**ernel **w**eight
TPs	**T**riazolo**p**yrimidine**s**
US	**U**nited **S**tates
var.	**Var**iety
vs.	**V**er**s**us
WOSR	**W**inter **o**il**s**eed **r**ape
WW	**W**inter **w**heat

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<u>PAPER No. 1</u>

1 General Introduction

Oilseed rape (OSR) (*Brassica napus* L. var. *napus*) is a very important arable crop in modern agriculture and is globally grown as spring (canola) and winter oilseed rape (SOSR/WOSR) varieties. Its high value as a preceding crop in rotations with a high proportion of cereals and the high yield potential and economic benefits for farmers, have contributed to it's importance.

The harvested seeds are widely used in human nutrition, animal feeding and in the recent past, as a renewable resource for the production of environmental-friendly paints, varnishes and biodiesel.

The crop is well established in plant breeding and more recently, the use of genetic engineering and transformation has become very important. Generally, the aims of OSR breeding were modification of the oil content and composition (low content of erucic acid and glucosinolates), the increase of yield, resistance to insect pests and different pathogens and the tolerance to pesticides, with **herbicide tolerance** being the most important trait.

Genetically modified glyphosate- and glufosinate-tolerant OSR varieties are commonly used in Northern America and Australia, but are unsuitable for European agriculture due to legal restrictions. A third group of herbicide-tolerant (HT) OSR has a tolerance to the chemical class imidazolinones (IMIs) and was developed with conventional breeding approaches. The patent is held by BASF SE and **imidazolinone-tolerant** (IT) SOSR is sold globally under the **Clearfield®**-label.

The introduction of IT spring and winter varieties has already started in Eastern Europe and will continue comprehensively in 21 out of the 27 member states of the EU, with a focus on winter-grown varieties. The implementation may lead to new possibilities for weed control in OSR, but has to be evaluated precisely for future recommendations in agricultural practice.

Correspondingly, studies have been carried out to highlight specific issues associated with HT crops. Presented in this thesis is an evaluation of the advantages, namely post-emergence (POST-E) weed control in OSR by using the Clearfield® production system, and disadvantages, namely consequences for volunteer OSR management in crop rotations which contain IT OSR.

1.1 Origin and relevance of oilseed rape (*Brassica napus* L. var. *napus*) as a crop

The *Brassicaceae* family contains nearly 3200 species, of which mainly *Brassica* ssp., especially *Brassica napus* L. var *napus* (synonymously OSR, rapeseed, canola), gain economic importance as crops. The botanical relationship between Brassica species was first investigated by U (1935) who showed that *Brassica napus* is an amphidiploid (AA x CC, n = 19) from an intraspecific crossing of *Brassica campestris* (AA, n = 10) and *Brassica oleracea* (CC, n = 9). Brassica species were firstly domesticated by ancient civilisations in Asia and the Mediterranean region and cultivation of oilseed Brassicas have been recorded as early as 4000 B.C. in India (Friedt & Snowdon, 2009). During archaeological extractions, Brassica seeds were found in a 16th-century house in Germany and were identified as *Brassica napus* (Kroll, 1994). At this time, rapeseed was exclusively used for lamp oil and significant cultivation areas were not found until the 18th-century.

A large-scale worldwide OSR production was not realised until the second half of the 20th-century, as breeding approaches led to the development of double-low varieties (low content of erucic acid and glucosinolates) suitable for human consumption and animal feed (Booth & Gunstone, 2004). Today, OSR is grown on all continents, as spring and winter varieties, according to climatic conditions, with a harvested area of 31,680,945 ha and a production quantity of 59,071,197 t (FAO Statistics, 2012). OSR production has gained a great importance across Europe, with a consistent increase in production area and harvest. While production centres are clearly located in Germany and France, with a harvested area of roughly 1,500,000 ha in each country in 2010, significant OSR production can also be found in the United Kingdom and Eastern Europe.

In Germany, approximately 12 % of the arable land is grown with OSR. In the early nineties, the cultivated area remained fairly constant at around 900,000 ha, but increased rapidly to the above mentioned 1,500,000 ha due to OSR production for non-food uses. In recent years the harvest amount averaged 3.5 t ha^{-1}, with a peak of nearly 4.3 t ha^{-1} observed in 2009 (FAO Statistics, 2012).

Generally, OSR is grown in cereal rotations and is considered a valuable preceding crop for wheat due to a positive influence on the soil structure (Scheller, 1987). OSR plants leave behind a highly degradable straw with a high nitrogen content, which can be used by the subsequent crop (Amberger, 1995). Accordingly, OSR is widely grown previous to winter wheat (WW) due to the possibility of a shared use of machinery (Cramer, 1990).

1.2 Weed management in oilseed rape

Generally, plant protection in OSR is necessary to guarantee high yields, without depending on processing the crop for human consumption, livestock or renewable raw material. However, OSR can be considered a quite competitive crop (Radermacher, 1939). Field experiments of Wahmhoff (1990) showed an increased yield of OSR due to weed control for only 56 % of herbicide treatments. According to Schröder *et al*. (2008), 25 % of herbicide applications would have been unnecessary in retrospect of 5-year trials. Nonetheless weed control is widespread and applied to approximately 97 % of OSR areas in Germany to decrease a negative impact on the crop. Overall, rationales for herbicide use are: (i) pre-emergence (PRE-E) treatments without estimation of weed pressure; (ii) the avoidance of infestation with *Galium aparine, Matricaria* spp. and *Sisymbrium* spp. (Werner & Heitefuss, 1996); (iii) the avoidance of increased moisture and dockage in the harvested grain due to weed infestation; (iv) the necessity to control volunteer cereals due to phytosanitary reasons; and (v) the need to decrease the weed seedbank in the soil. A total of 36 important weed species in OSR were identified with *Galium aparine*, *Matricaria* spp., *Stellaria media*, *Capsella bursa-pastoris* and *Viola arvensis* being the most abundant in Germany (Petersen & Hurle, 1998; Goerke, 2007).

With row spacing of 30-40 cm, OSR was a typical root crop before the development of chemical weed control. Weeds were often controlled by using a hoe or harrow (Wahmhoff, 1994). At the beginning of the 1960s, mechanical weed control became unnecessary as it was possible to apply and incorporate herbicides, such as trifluralin (Probst *et al*., 1967), into the soil to control the weed flora. This was done until the beginning of the 1990s as a common weed control treatment, but a shift to PRE-E herbicides, such as clomazone, has been noticeable since then. More recently, weed control measures against dicotyledonous species (including metazachlor, picloram, bifenox, propazamid and pendimethalin) were increasingly used at time of OSR emergence until the rosette stage in autumn. Unfortunately, however, widely used active ingredients (a.i.) can be associated with negative side effects, like volatilisation, crop- and drift damage (clomazone) (Locke *et al*., 1996), as well as water pollution (metazachlor) (Ballanger, 1999). In the future, new products containing dimethachlor and dimethenamid-P may become significant for weed control in OSR (Schröder *et al*., 2008). POST-E herbicides targeting the Acetyl-CoA-carboxylase (ACCase) are applied mostly against volunteer cereals and grass weeds.

1.3 Development of herbicide-tolerant oilseed rape varieties

Both non-transgenic and transgenic breeding programs were followed during the development of HT OSR varieties. In the 1980s, a triazine-resistant biotype of birdsrape mustard (*Brassica campestris* L.) was found in Canada and was used for the breeding of triazine-tolerant canola varieties. The cytoplasm of the weed was transferred into the crop by introgression and backcrossing (Beversdorf *et al*., 1980; Beversdorf & Hume, 1984; Beversdorf & Kott, 1987). A tolerance of OSR to sulfonylureas (SUs) was achieved by Kenyon *et al*. (1987) by using microspore cultures, which were subjected to a range of chlorsulfuron concentrations after embryogenesis. Another non-transgenic approach was realised by Swanson *et al.* (1989). In this study in-vitro microspore mutagenesis and selection was used to gain several fertile double-haploid IT SOSR plants.

The development of HT transgenic OSR varieties occurred with the introduction of genetic methods in plant biotechnology. The development of glyphosate-tolerant crops has been attempted since the early 1980s and was achieved by different approaches, such as overexpression of the target site 5-enolpyruvyl-shikimate-3-phosphate synthase (EPSPS), decreased affinity of EPSPS to glyphosate and herbicide degradation (Padgette *et al*., 1996). The most promising technique was the introduction of glyphosate-tolerance by inserting and expressing EPSPS which is less susceptible to inhibition by glyphosate (Kishore *et al*., 1992.)

Metabolic detoxification of herbicides in crops, as a mechanism of herbicide tolerance, has been successfully realised in the case of glufosinate (Cole & Rodgers, 2000). The genes *bar* and *pat* of the *Streptomyces* species, which were found responsible for enzymatic inactivation of glufosinate, were isolated (Murakami *et al*., 1986; Strauch *et al*., 1988) and transferred to crops to endow tolerance. Glufosinate-tolerant OSR was first planted in Canada in 1995.

Brassica napus canola cultivars were transformed with *Arabidopsis thaliana* acetohydroxyacid synthase (AHAS) genes and afterwards screened for herbicide-tolerance (Miki *et al*., 1990). Transgenic lines of *Brassica napus* varieties ‘Westar’ and ‘Profit’ were found to express the mutant gene *crs1-1* which was essential for tolerance to the sulfonylurea herbicide chlorsulfuron.

Herbicide tolerance to bromoxynil in OSR was conferred by a single transgene (*oxy* gene) (Cuthbert *et al*., 2001). The gene was taken from a soil bacterium and showed the ability to metabolise hydroxybenzonitrile herbicides such as bromoxynil.

1.4 Clearfield®-technology – imidazolinone-tolerant oilseed rape varieties

The imidazolinone herbicides were discovered at the American Cyanamid Company in the 1970s (Novdkov, 1994). Currently, the six a.i. imazapic, imazamethabenz-methyl, imazamox, imazapyr, imazaquin and imazethapyr are registered (HRAC 2012). These herbicides target the acetolactate-synthase (ALS) synonymously with the AHAS gene in chloroplasts of higher plants and are used because of low application rates, reduced environmental impact and good selectivity, as PRE-E or POST-E treatments, to control both monocotyledonous and dicotyledonous weeds (Ramezani, 2007).

IT OSR was discovered in the late 1980s by a research group at Allelix Crop Technologies in Canada (Swanson *et al*., 1989). Microspores of the *Brassica napus* SOSR cultivar 'Topas' were isolated, mutagenised with ethyl nitrosourea and subsequently cultured. Double haploid plantlets were then sprayed with imidazolinone herbicides in the greenhouse. Two semi-dominant mutants (P1 or PM1 and P2 or PM2) were found to be most tolerant to IMIs and were bred to a homozygous F_1-hybrid, which was superior in imidazolinone-tolerance (Shaner *et al*., 1996). All commercially available IT OSR varieties originated from these two lines (Tan *et al*., 2005). The genes PM1 and PM2 are unlinked and additive and therefore Ruthledge et al. (1991) suggested that PM1 and PM2 equate to the AHAS1 and AHAS3 genes of *Brassica napus*. The tolerance to IMIs is linked to two point mutations at codon 653, with serine substituted by asparagine (AHAS1) and codon 574, with tryptophan substituted by leucine (AHAS3). PM1 confers tolerance to IMIs only, while PM2 results in an explicitly higher imidazolinone-tolerance in combination with a cross-tolerance to SUs as described by Hattori *et al*. (1995). The highest level of tolerance is achieved by having both mutations combined in the crop (Tan *et al*., 2005) as realised in commercial plant breeding.

Besides OSR, the Clearfield® production system is also available for the commercial crops maize (*Zea mays*), wheat (*Triticum aestivum*), rice (*Oryza sativa*), sunflower (*Helianthus annuus*) and lentils (*Lens culinaris*) (Pfenning et al., 2008). IT crops are globally grown with production centres in North America, South America, Europe and Australia. In IT OSR, combinations of imazamox + imazethapyr (North America) and imazapyr + imazapic (Australia) are used for weed control. In Europe, the a.i. imazamox is intended to be used in a mixture with metazachlor and quinmerac.

1.5 Problem statement and aim of the thesis

Weed management in OSR was done without HT varieties in Europe in the past. By integrating IT SOSR and WOSR varieties into cropping systems, two novel herbicide-tolerance genes will appear in agricultural ecosystems, potentially causing unwanted changes by spreading HT plants in space and time (Raybold & Gray, 1993). This could lead to essential changes in volunteer OSR management. Therefore, similarly to transgenic glyphosate- and glufosinate-tolerant OSR varieties, which were extensively field-tested by regulatory authorities for a long time (Kleter et al., 2008) but never authorised for growing in Europe, the introduction of OSR with tolerance to IMIs creates concern, although these plants are not genetically modified. Consequently, there is a need for collecting data on the use and behavior of IT OSR in crop rotations in reference to agronomic recommendations, which could be integrated into a Stewardship program for OSR growers.

The hypothesis of the present study was to address and investigate the following aspects, which are likely to arise with a large-scale cultivation of IT OSR:

(i) Does the Clearfield® production system imply the possibility of POST-E weed control, with regard to the use of damage thresholds in OSR? Is it possible to identify benefits compared to common weed management practices?

(PAPER No. 1)

(ii) Does gene transfer between adjacent IT and imidazolinone-susceptible (IS) OSR varieties lead to an IT F_1-generation? What is the genetic outcome of such outcrossing events?

(PAPER No. 2)

(iii) How do IT OSR plants respond to ALS-inhibiting herbicides? Is there a need to adjust herbicide strategies for the control of IT volunteers in subsequent crops in the future?

(PAPERS No. 2, 3 and 4)

(iv) Is there a measurable negative effect of volunteer OSR on yield and quality parameters of wheat, if weedy OSR is not controlled accurately?

(PAPER No. 5)

2 KRATO C & PETERSEN J (2012) Post-emergence weed control in winter oilseed rape (*Brassica napus* L.) using imidazolinone-tolerant varieties. The manuscript is currently *in preparation*.

ABSTRACT

Weed control in OSR is dominated by prophylactic PRE-E or early POST-E treatments without specific knowledge of the occurring weed species and density. However, models for the analysis of economic damage thresholds require this information. A two-year field experiment was conducted at two different locations in Germany in order to evaluate the use of IT WOSR varieties and a corresponding herbicide (metazachlor+quinmerac+imazamox) for POST-E weed control. Randomised blocks were established using both minimum tillage and ploughing as soil management methods. Herbicides were applied in the fall, and the efficacy was determined by weed density and yield. The overall efficacy of metazachlor+quinmerac+imazamox was approximately 90 %, with good results against the volunteer cereals, *Thlaspi arvense, Chenopodium album, Matricaria inodora, Papaver rhoeas, Capsella bursa-pastoris* and *Apera spica-venti*, but a lack of efficacy regarding *Agropyron repens* and *Viola arvensis*. OSR yield was increased significantly in treated plots compared to untreated ones and was between 29.9 dt ha^{-1} and 63.7 dt ha^{-1} according to trial year and location, with an overall yield increase of 50 %. The opportunity for the use of economic damage thresholds in WOSR is shown by growing IT varieties. Herbicide treatments can be applied POST-E with detailed knowledge of the weed spectrum. The higher dose rate of 35 g ha^{-1} a.i. imazamox provides superior weed control.

Keywords: Clearfield®, damage thresholds, herbicide-tolerant crops, herbicide selectivity, imidazolinone herbicides

Introduction

OSR is one of the most important arable crops with a global-scale production volume of 59,071,197 t (FAO, 2012). Weed control is crucial for the maintenance of high yields. Formerly, OSR was planted with a row spacing of 30-40 cm and, although mechanical weed control was common, it was replaced almost completely by chemical weed control (Wahmhoff, 1994). Sufficiently early sown and well-developed OSR is able to tolerate a certain weed density without harmful effects (Gräpel & Schiller, 1988). In order to apply the best management practice in farming, approaches for the use of damage thresholds for weed control in OSR have been developed since the late eighties. Weed thresholds for wild oats were developed for atrazin-tolerant and -susceptible OSR varieties (Forcella, 1987). Küst *et al.* (1988) investigated the economic thresholds for volunteer barley in WOSR. The crop density of OSR played an essential role in the competitive ability of the crop towards the weed. Gräpel and Schiller (1988) found the crop cover in autumn and early spring to be an important factor for the determination of economic damage thresholds. Dingebauer (1990) developed a simple model to evaluate the necessity of herbicide application based on the crop-to-weed coverage parameter. Weed competition depended strongly on the climatic conditions during drilling and only approximately 30 % of herbicide treatments were found to be effective. In the field trials of Wahmhoff (1990), the effect of different weather conditions, crop coverage and weed flora at trial sites were important factors impacting on OSR yield, as well as the actual weed density. A preliminary decision model for the application of damage threshold was described by Küst *et al.* (1990). This model used competition indices based on the relationship between the percentage of grain yield loss and the density of several important weed species together with factors such as crop vigour, relative time of weed emergence and expected yield, in order to predict a possible yield loss. The model was evaluated in field trials and was further improved by correcting the competitive indices of some weeds as well as by including the relative leaf area of weeds in the late autumn to consider crop competition as a factor (Munzel *et al.*, 1992). Based on available data, Bodendörfer *et al.* (1994) developed the computer-based decision support system RAPUS, and all efforts were combined to result in the development of an internet-based decision support system called CEBRUS.

To date, herbicide applications have been dominated by PRE-E and early POST-E treatments as routine treatments (Schröder *et al.*, 2008). The choice of herbicides is mainly based on the expected weed pressure. Models for the use of damage thresholds are rarely accepted in agricultural practice. One of the main reasons is the missing availability of POST-E herbicides, which control a broad weed spectrum in WOSR.

The tolerance to non-selective herbicides has been developed in many crops, including OSR. Approaches were mainly based on the tolerance to glyphosate, glufosinate and IMIs and are commercially used all over the globe (Beckie *et al*., 2006). Glyphosate- and glufosinate-tolerant OSR varieties were field-tested for use in Europe (Sauermann, 2000) but were not adopted due to their genetically modified characteristics and legal restrictions. In contrast, IT OSR varieties were developed using classical breeding methods (Tan *et al*., 2005) and will be widely introduced into European agriculture in the near future. A benefit of HT crops and non-selective herbicides is the ability to control a wide range of weeds and the substitution of PRE-E herbicide treatments by POST-E treatments (Petersen & Hurle, 1998).

The aims of this study were the assessment of the possibility of POST-E weed control in WOSR and the evaluation of the use of economic damage thresholds by growing IT WOSR varieties and their corresponding herbicides. Furthermore, the effect of application timing and dose rate of imazamox on weed control was investigated.

Material and methods

Field trials were conducted in 2009 and 2010 at two different locations in Rhineland-Palatinate (Tab. 1). IT WOSR varieties (experimental hybrids, homozygous for PM1 and PM2), provided by BASF SE, were sown in commercial field sites using a plot-in-plot technique. OSR was planted with 60 seeds m^{-2} while sowing was performed with an Amazone Drillstar RP AD302 using a two-disc coulter and a sowing depth of 2 cm. The row spacing was 12.5 cm. Preceding crops were WW in Bubach and winter barley in Bingen. The trial was carried out in duplicate at each location and for each year using either minimum tillage or ploughing as soil treatments. All trials were set up as randomised blocks with four replications per herbicide treatment (Tab. 2). Herbicides were applied using a one-wheel plot sprayer ‘AgroTop’ with an Airmix 110-025 flat fan nozzle, a pressure of 210 kPa and a speed of 4.5 km h^{-1}. The water volume for herbicide application was 200 l ha^{-1}. Fertiliser and other pesticide applications were conducted consistently over the entire field according to ‘good farming practice’.

Table 1 Trial location with altitude, annual average temperature, annual precipitation and sowing times of WOSR.

Location	Bingen (49°58‘ N, 7°54‘ E)	Bubach (50°4‘ N, 7°33‘ E)
Altitude	89 m	450 m
Annual average temperature	9.9°C	7.8°C
Annual precipitation	548.1 mm	664.6 mm
Sowing date 2009	25/08	01/09
Sowing date 2010	25/08	06/09

Table 2 Herbicide treatments (trade name and a.i.) used to control monocotyledonous and dicotyledonous weeds in IT WOSR.

No.	Herbicide	A.i. [g l^{-1}]	Product rate [l ha^{-1}]	Timing
1	Untreated			
2	Nimbus CS	Metazachlor [250] + Clomazone [33.3]	2.5 l/ha	PRE-E [BBCH 09]
3	Nimbus CS	Metazachlor [250] + Clomazone [33.3]	2.5 l/ha	PRE-E [BBCH 09]
	Focus Ultra*	Cycloxidim [100]	1 l/ha	POST-E [BBCH 13-14]
4	ButisanTop	Metazachlor [375] + Quinmerac [125]	2.0 l/ha	PRE-E [BBCH 09-10]
5	ButisanTop	Metazachlor [375] + Quinmerac [125]	2.0 l/ha	PRE-E [BBCH 09-10]
	Focus Ultra*	Cycloxidim [100]	1 l/ha	POST-E [BBCH 13-14]
6	BAS 79801*	Imazamox [6.25] + Metazachlor [375] + Quinmerac [125]	2.0 l/ha	POST-E [BBCH 10-11]
7	BAS 79801*	Imazamox [6.25] + Metazachlor [375] + Quinmerac [125]	2.0 l/ha	POST-E [BBCH 12-14]
8	BAS 79800*	Imazamox [17.5] + Metazachlor [375] + Quinmerac [125]	1.5 l/ha	POST-E [BBCH 12-14]
9	BAS 79800*	Imazamox [17.5] + Metazachlor [375] + Quinmerac [125]	2.0 l/ha	POST-E [BBCH 12-14]

*applied with aduvant Dash E.C. [1.0 l ha^{-1}]

The weed density was counted with three pseudoreplications per plot [0.25 m^2] after weed emergence and herbicide treatment in the fall and again in the spring of the following season. The plots were harvested on July 15th 2010 and July 5th 2011 in Bingen and on August 4th 2010 and August 11th 2011 in Bubach, using a plot harvester (Type: Hege 140).

Yield loss of OSR was calculated using the prediction model of Munzel *et al*. (1992) as follows: Weed density [plants m^{-2}] x competitive indices [depending on weed species; 0.03-4] x crop vigour [0.5 = very good; 1.0 = good; 1.5 = medium; 2.0 = bad] x relative time of weed emergence [1.0 = simultaneously with the crop; 0.6 = 10 days delay; 0.3 = 20 days delay] x yield expectation x product price = estimated yield loss.

SigmaPlot 11.0 (Sysstat Software, Inc) was used for statistical analysis. All data was tested for normality (Shapiro-Wilks) and homogeneity of variances. Data on weed density was tested by employing a one-way analysis of variance (ANOVA) on the ranks (Kruskal-Wallis).

A non-parametric test was used because data were not normally distributed. The least significant difference was addressed using the Student-Newman-Keuls Method (α = 0.05). Yield data was subjected to ANOVA, and multiple mean pair-wise comparisons were performed using Fishers' least significant difference (LSD) at α = 0.05.

Results

Herbicide efficacy data was combined for the trial years (2009/2010; 2010/2011), the two trial locations (Bingen; Bubach) and different tillages (+/- ploughing). Each herbicide treatment achieved a significant decrease of weed density compared to the untreated control (Fig. 1). Furthermore, the highest efficacy was shown when volunteer cereals were controlled successfully. The Clearfield® herbicide showed an overall efficacy between 85 (BAS 79801 H) and 93 % (BAS 79800 H).

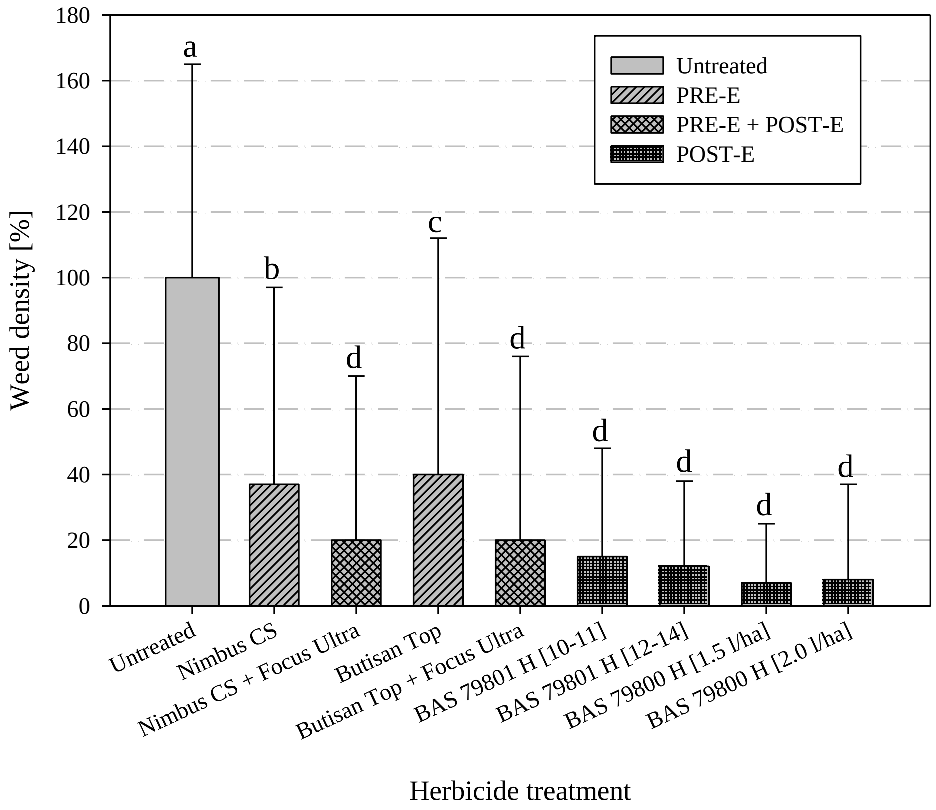

Figure 1 Percentage weed density in plots of IT WOSR depending on the herbicide treatment. Combined data 2009-2011 (n = 7). 100 % equals weed density in the untreated control. Significant differences at p ≤ 0.05 are indicated using small letters.

Yield in untreated plots ranged between 13 dt ha^{-1} and 52 dt ha^{-1} with respect to the trial year, location and weed flora. The average yield of the combined data from weedy plots was 31 dt ha^{-1}. Generally, each herbicide treatment resulted in a significantly higher yield compared to the untreated control (Fig. 2). Regarding the single herbicide treatments, lower yields were measured in plots treated either with Nimbus or Butisan Top compared to the other treatments. An average maximum yield surplus of 53 % was achieved by applying BAS 78900 H with 2.0 l ha^{-1}.

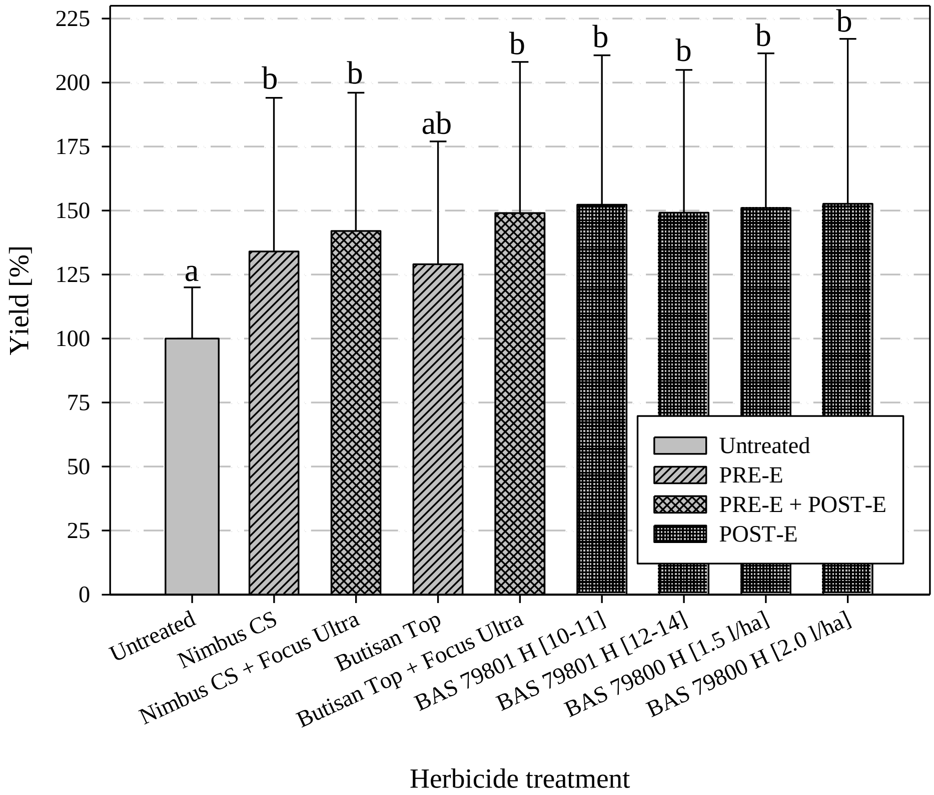

Figure 2 Percentage IT WOSR yield depending on the applied herbicide treatment. Combined data 2009-2011 (n = 7). 100 % equals yield in the untreated control. Significant differences at $p \leq 0.05$ are indicated using small letters.

A more specific view is necessary to evaluate the data with regards to the use of damage thresholds for weed control in IT WOSR. The weed flora was quite diverse at the different trial sites and volunteer barley, volunteer wheat, *Thlaspi arvense*, *Chenopodium album*, *Matricaria inodora*, *Viola arvensis*, *Agropyron repens*, *Papaver rhoeas*, *Capsella bursa-pastoris* and *Apera spica-venti* were identified as the major weeds.

The emergence was most often observed simultaneously with OSR plants with a maximum delay of 10 days in few cases. The weed density differed intelligibly between 3 plants m^{-2} and 150 plants m^{-2}, while the major weed infestations were observed in plots in Bingen 2009 with an overall density of 203 plants m^{-2} and in plots in Bubach 2010 with 144 plants m^{-2} (Tab. 3).
The crop vigour was rated ‘good’ (factor 1) in Bingen 2009 for both soil preparations and for the non-ploughed experiment in 2010, but only ‘moderate’ for the ploughed experiment of the same year. Heavy rainfall shortly after sowing caused aggradations of the soil.
Only one experiment was performed in Bubach in 2009. Here, agronomic measures led to an optimal seedbed. Environmental conditions during drilling and early crop development resulted in well established and quite vigorous OSR plants. The prior conditions in the second year were different. The preceding crop WW was harvested late, at the end of August, and stubble tillage and seedbed preparation unfortunately led to poor starting conditions for the crop. Consequently, the crop vigour was ranked ‘poor’ (factor 2). Soil conditions in the ploughed experiment site were ‘moderate’ and rated with a factor of 1.2.
Herbicide treatments showed a wide range of efficacy in weed control. The PRE-E treatments 2 and 3 controlled *Matricaria inodora*, *Capsella bursa-pastoris* and *Apera spica-venti* but showed incomplete efficacy against the other weeds. PRE-E treatments 4 and 5 showed sufficient control against *Matricaria inodora*, *Papaver rhoeas* and *Apera spica-venti* but almost no efficacy was observed on *Thlaspi arvense*. The efficacy against volunteer cereals and *Agropyron repens* was covered by a subsequent application of the graminicide cycloxidim.
Even the highest density of 150 volunteer cereals was covered by a treatment with metazchlor+quinmerac+imazamox, independent of the application timing (BBCH 10-11 respectively BBCH 12-14). However, a higher dose rate of 35 g ha^{-1} a.i. imazamox increased the efficacy in some cases (Tab. 3). Nevertheless, single plants of volunteer cereals survived the treatment, but most died off during winter. The POST-E herbicide treatment 6 was weak on *Thlaspi arvense*, but the efficacy was significantly increased by an application at BBCH 12-14 of the crop (Treatments 7-9). The response of *Chenopodium album* was also stronger when treated later. The overall efficacy against *Matricaria inodora* was adequate, but the highest level of control was achieved by early application timing (BBCH 10-11) in this case compared to the POST-E treatment at growth stage 12-14. *Papaver rhoeas*, *Capsella bursa-pastoris* and *Apera spica-venti* were included in the range of efficacy but a decrease was detected for *Agropyron repens* and *Viola arvensis*. However, a higher dose rate of imazamox with 35 g ha^{-1} a.i. achieved higher levels of herbicide efficacy in some cases.

Yield data was quite diverse and depended strongly on the year and the location. In 2010, OSR plants showed growth depression and leaf yellowing after the PRE-E treatment with metazachlor+clomazone on the ploughed site in Bingen. However, the plants recovered and yields were still determined to range from 33.2 dt ha^{-1} to 34.2 dt ha^{-1} (Tab. 4). There was no statistically significant difference between the other herbicide treatments.

No significant differences were found for the two 2010 Bingen datasets, which were ploughing and non-ploughing. The differences in the mean values of the treatment groups were not great enough to exclude the possibility that the differences were due to random sampling variability. However, yield of the untreated OSR plants was lower compared to yield of plants which received herbicide treatments.

The other four datasets showed a clear distinction between untreated and treated plots, as well as between different herbicide treatments. Generally, the best results were achieved with a treatment of the herbicide metazachlor+quinmerac+imazamox.

Single-plot data from the seven experimental sites were plotted as estimated yield loss vs. measured yield loss (Fig. 3). The data followed a linear relationship with a significant correlation coefficient of 0.48 ($p = 0.01$). However, some variation was observed between the estimated and measured values, for example, a yield loss of 4 % was calculated to be caused by weed infestation for the ploughed experimental site in Bingen 2010 but an actual loss of 1 % was detected. Conversely, a marginal yield loss of 8 % was calculated for the ploughed experimental site in Bubach in 2010 by the model, but a high yield loss of 66 % was observed de facto.

Table 3 Weed density in plots of IT WOSR depending on the applied herbicide treatment. Mean values are shown.

Tillage	Weed species	Weed density m^{-2} in untreated plots	Herbicide treatments							
			Nimbus CS	Nimbus + Focus Ultra	Butisan Top	Butisan Top + Focus Ultra	BAS 79801 H (BBCH 10-11)	BAS 79801 H (BBCH 12-14)	BAS 79800 H (1.5 l ha^{-1})	BAS 79800 H (2.0 l ha^{-1})
+	*Hordeum vulgare*	13.5	11.0	0.0	10.8	0.0	0.5	1.0	0.0	0.0
	Thlaspi arvense	17.8	5.0	4.0	18.3	15.3	11.0	0.5	0.3	0.0
	Chenopodium album	20.5	2.0	1.0	9.5	6.5	4.5	0.3	0.0	0.0
-	*Hordeum vulgare*	150.3	164.0	0.3	146.8	0.0	1.0	1.8	1.5	0.0
	Thlaspi arvense	14.5	5.3	10.3	13.0	12.3	10.3	0.0	0.0	0.0
	Chenopodium album	32.0	2.8	4.0	7.0	12.5	2.0	0.0	0.0	0.0
	Matricaria inodora	6.3	0.0	0.3	0.0	0.8	0.3	0.8	0.0	0.0
+	*Hordeum vulgare*	2.8	2.4	0.8	3.2	0.3	0.5	1.0	1.0	0.8
	Viola arvensis	11.8	2.8	1.8	5.8	3.3	1.0	4.0	2.0	5.3
	Agropyron repens	25.0	21.2	0.3	14.4	2.3	5.0	6.5	4.3	4.8
+	*Papaver rhoeas*	111.3	58.3	45.7	0.7	2.0	0.0	5.7	1.7	0.7
	Matricaria inodora	4.0	0.0	0.0	0.0	0.0	0.0	2.0	0.7	0.7
-	*Capsella bursa-pastoris*	5.7	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0
	Matricaria inodora	5.3	0.0	0.0	0.3	0.0	1.0	3.7	1.0	0.3
	Papaver rhoeas	19.0	5.0	1.7	4.0	0.3	0.7	0.7	1.0	1.7
	Viola arvensis	38.3	56.3	68.0	68.0	49.7	30.7	19.7	24.0	38.7
	Others	7.7	3.0	2.0	4.0	1.7	1.0	0.0	0.3	0.3
+	*Capsella bursa-pastoris*	67.0	0.7	0.0	4.7	2.7	0.0	0.0	0.3	0.0
	Matricaria inodora	13.3	0.0	0.0	0.0	0.0	0.0	1.3	0.7	2.0
	Apera spica-venti	47.6	1.0	0.6	1.0	0.6	0.4	0.6	0.0	0.5
	Others	16.0	5.0	1.0	2.7	0.0	1.3	1.0	0.0	0.3
-	*Triticum aestivum*	23.3	18.3	0.0	16.0	0.0	1.7	2.3	0.0	0.0
	Matricaria inodora	19.7	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
	Others	9.7	0.7	0.7	1.3	1.0	0.7	1.3	0.3	1.0

Table 4 Yield of IT WOSR depending on the applied herbicide treatment. Yield loss was estimated using the model of Munzel *et al*. (1992). Multiple mean comparisons of yield data were performed using Fisher's LSD. Significant differences at $p \leq 0.05$ are indicated using small letters (+ = with plough, - = without plough; means are shown).

		Herbicide treatments								
Trial	Tillage	Untreated	Nimbus CS	Nimbus + Focus Ultra	Butisan Top	Butisan Top + Focus Ultra	BAS 79801 H (BBCH 09-11)	BAS 79801 H (BBCH 12-14)	BAS 79800 H (1,5 l ha^{-1})	BAS 79800 H (2,0 l ha^{-1})
Bingen Season 2009/2010	+	34.0^{a}	39.7^{a}	41.8^{a}	40.3^{a}	45.9^{a}	42.9^{a}	42.4^{a}	43.3^{a}	44.4^{a}
		Predicted yield loss **3.1 %** / measured yield loss **23 %**								
	-	27.5^{a}	29.1^{a}	46.3^{b}	25.1^{a}	50.1^{b}	48.0^{b}	49.3^{b}	49.3^{b}	47.1^{b}
		Predicted yield loss **24.3 %** / measured yield loss **41 %**								
Bubach Season 2009/2010	+	52.4^{d}	58.0^{abc}	55.7^{bc}	56.3^{bc}	54.5^{c}	63.7^{a}	61.2^{ab}	61.0^{ab}	60.0^{abc}
		Predicted yield loss **2 %** / measured yield loss **13 %**								
Bingen Season 2010/2011	+	33.9^{a}	34.2^{a}	33.2^{a}	34.9^{a}	32.6^{a}	37.8^{a}	35.3^{a}	34.9^{a}	34.8^{a}
		Predicted yield loss **7 %** / measured yield loss **3 %**								
	-	31.6^{a}	32.3^{a}	28.5^{a}	34.0^{a}	30.7^{a}	32.2^{a}	32.0^{a}	29.9^{a}	31.7^{a}
		Predicted yield loss **4 %** / measured yield loss **1 %**								
Bubach Season 2010/2011	+	13.2^{c}	36.1^{ab}	32.6^{ab}	30.6^{b}	34.6^{ab}	35.9^{ab}	34.3^{ab}	36.6^{ab}	38.4^{a}
		Predicted yield loss **8 %** / measured yield loss **66 %**								
	-	24.3^{d}	32.0^{c}	39.7^{a}	34.4^{bc}	40.2^{a}	38.4^{ab}	38.5^{ab}	38.7^{ab}	38.6^{ab}
		Predicted yield loss **10 %** / measured yield loss **38 %**								

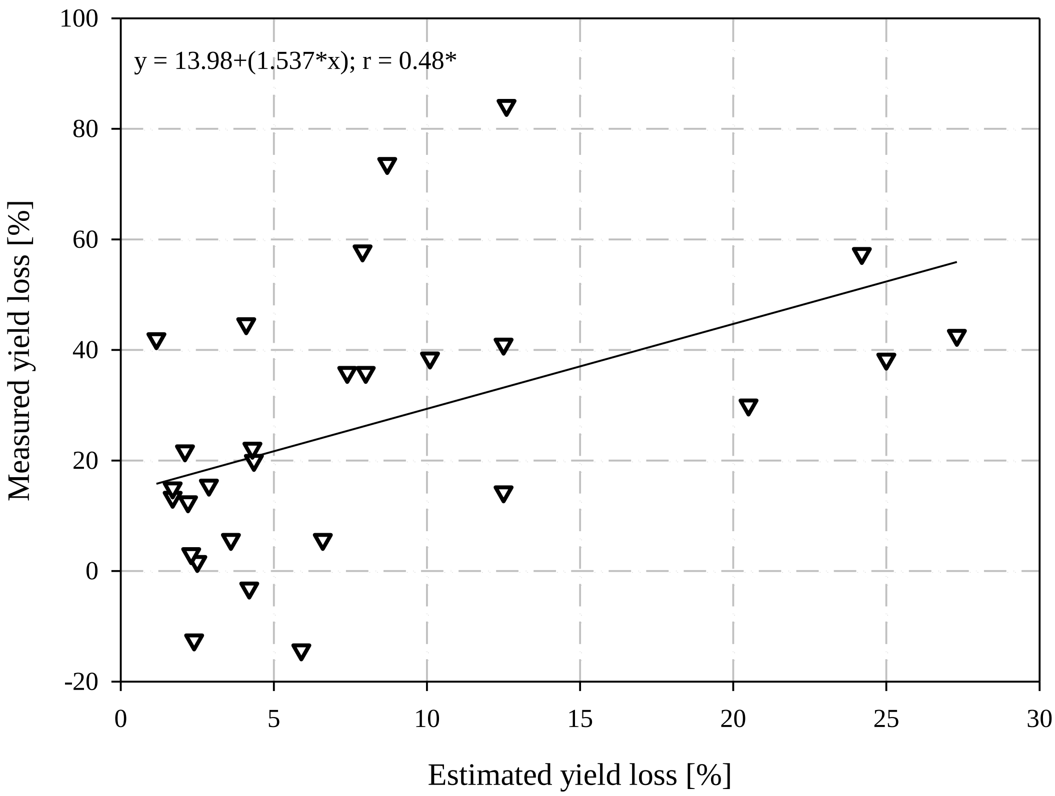

Figure 3 Relationship between the measured yield loss and the estimated yield loss in IT WOSR (model of Munzel *et al*., 1992). Data was plotted from field trials in Bingen and Bubach 2009-2011 (n = 28, * = statistically significant correlation).

Discussion

Metazachlor, quinmerac and clomazone are used with a relative frequency of 63 % to control weeds in OSR crops (Roßberg *et al*., 2002). This emphasises the magnitude of herbicide treatments performed at a time were the actual weed flora cannot be determined exactly. The intention of the Clearfield® production system is to provide a POST-E weed control at growth stage 12-14 of OSR plants. The a.i. imazamox was added to the herbicide Butisan Top (metazachlor+quinmerac) in order to target a wider range of weeds, including volunteer cereals (Blackshaw *et al*., 1998) and weeds from the *Brassicaceae* family. Generally, the field experiments confirmed the possibility of broad spectrum weed control in OSR with POST-E treatments when the combination of IT varieties and the herbicide mixture metazachlor+quinmerac+imazamox was applied.

Damage thresholds for volunteer cereals are found with 50-150 plants m^{-2} (Lutman, 1984; Küst *et al*., 1988). The control of such weeds is currently achieved by a second herbicide application in the fall or spring, mostly with ACCase-inhibiting herbicides. A density of 150 volunteer barley plants m^{-2} resulted in a significant yield loss when left untreated at the Bingen experimental site. The density was significantly decreased by the application of 12.5 g ha^{-1} imazamox. The combination of IT OSR varieties and the corresponding herbicides can be considered a 'single herbicide treatment' solution. Dicotyledonous and monocotyledonous weeds, especially volunteer cereals, can be controlled together in one POST-E treatment even when minimum tillage is applied. This fact could be of benefit to farmers in terms of working management.

Matricaria spp. has become a major weed in WOSR production, with a frequency of 73 % in Germany in 2005 (Goerke *et al*., 2007). Efficacy is best if herbicides are applied until the first true leaf stage (Faber, 2002), which was confirmed by these trials. However, the efficacy was significant when metazachlor+quinmerac+imazamox was applied at growth stage 12-14, but was even higher at growth stage 09-11. *Viola arvensis* was not successfully controlled with imazamox and imazethapyr in field trials in Canada (Degenhardt *et al*., 2005). This corresponds with the results of the field trials in Bingen and Bubach, where *Viola* spp. could not be controlled to an acceptable level when treated with BAS 79801 H or other herbicide treatments, regardless of the application timing. However, for some weeds, a treatment at BBCH 12-14 with the lower dose rate of imazamox can result in lower efficacies. If such weeds occur, the application timing has to be adjusted to BBCH 09-11. Consequently, an early treatment may conflict with the application of damage thresholds.

The most important factor for the use of damage thresholds is the exact knowledge of the weed species which have emerged on a farmers' field. This knowledge can be provided when using HT cropping systems and can be used for the estimation of yield losses. The weed density of two experiments has led to the estimation of yield losses, which were confirmed by the measured yield. In one case, a high yield loss was calculated and subsequently occurred in the field. But for the other four experiments, some discrepancies were found between calculated yield losses and measured yield losses. Yield loss was strongly underestimated between 11 % and 58 %. However, other factors besides weed species and density affected growth and yield of OSR significantly.

According to the environmental impact of plant protection agents, the use of IT OSR varieties can result in a lower quantity of herbicide use. Brimner *et al*. (2005) showed that the Environmental Impact Factor (EIQ) per hectare of grown OSR in Canada, which evaluates pesticides according to their potential to harm non-target organisms and environments, was about three times lower for HT canola, including imidazolinone-, glyphosate- and glufosinate-tolerance, compared to conventional canola. This can be seen as a positive side-effect of HT cropping systems and matches the context of the National Action Plan on the sustainable use of plant protection products forced by the JKI (Julius-Kühn Institut). The use of a lower dose of 12.5 g ha^{-1} imazamox, compared to 35 g ha^{-1} imazamox in most European countries, and the avoidance of unnecessary herbicide applications can contribute to a truly integrated weed management system for OSR.

IT OSR varieties will be bred by the vast majority of OSR breeding companies (Bremer *et al*., 2011). Generally, the yield of WOSR in this study is comparable to the mean yields of currently grown IT-free OSR hybrids, and a tolerance to herbicides may not be associated with negative changes in maturity, seed yield, weight or oil content, as shown by Blackshaw *et al*. (1994) for chlorsulfuron-tolerant canola.

Possible disadvantages arising with the introduction of IT OSR varieties into European cropping systems include outcrossing between tolerant and non-tolerant OSR (Krato & Petersen, 2012), the distribution of IT OSR seeds during and after harvest (data not shown) and the occurrence of IT volunteers within the crop rotation. However, by forcing the communication with both growers using IT crops and growers using IS crops during the stewardship program for HT crops, it should be possible to minimise these disadvantages to a tolerable level. According to Graef *et al*. (2007) the introduction of HT OSR can also result in the selection of herbicide-resistant weeds after several years of cultivating HT OSR. With an adequate rotation length and application of herbicides with different modes of action, it is thought that herbicide-resistant weeds could be avoided.

The present study only provides a first impression on the use of IT OSR, but results indicate that IT OSR can be a tool for the use of economic damage thresholds in integrated weed management in OSR. However, after the introduction of IT varieties together with the knowledge of the actual charge for corresponding herbicides per hectare, large-scale data has to be collected in order to validate the application of a decision-support system for weed control in OSR.

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ABSTRACT

IT spring oilseed rape was developed in 1987 using conventional breeding methods and first marketed in Canada in 1996. Over the coming years, IT WOSR will be introduced into the European market. On the one hand, the IT cropping system provides the possibility of POST-E weed control in OSR. On the other hand, the introduction of a new herbicide-tolerance trait into the European cropping systems may lead to new challenges for weed control in crop rotations containing WOSR. In this study, a two-year field and greenhouse experiment was carried out to determine the transfer frequency of the HT trait from IT WOSR plants to adjacently grown susceptible WOSR plants. Furthermore, cross-resistance to SUs and differences in herbicide response of heterozygous (HET-) and homozygous (HOM-) IT WOSR varieties to triflusulfuron-methyl was examined. The transfer frequency of the resistance trait and zygosity of the F_1-generation was investigated using a real-time quantitative polymerase chain reaction (qPCR). Outcrossing ranged from 2.05 % in a westerly direction and 0.57 % in an easterly direction at the closest distance of 2 m between pollen donor (IT OSR plants) and pollen acceptor (IS plants). Outcrossing decreased significantly with increasing distance from the pollen donor, but IT F_1-plants were still found at a distance of 45 m. 84 % of the analysed F_1-oilseed rape plants showed both independent tolerance genes for imidazolinone-tolerance (PM1 and PM2) and were heterozygous for both genes. IT WOSR plants showed a cross-tolerance against triflusulfuron-methyl and the corresponding resistance factors were much higher for homozygous biotypes compared to heterozygous ones. Consequently, outcrossing can result in IT volunteers with cross-tolerance to triflusulfuron-methyl.

Keywords: Clearfield® production system, herbicide tolerance, imidazolinones, intraspecific gene flow, winter oilseed rape

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ABSTRACT

IT OSR (*Brassica napus* L.) varieties are currently grown in Canada, Northern America, Chile and Australi. A Europe-wide introduction has started and will be pushed further for both spring and winter varieties. The primary aim of this study was to evaluate the impact of imidazolinone-tolerance for future volunteer OSR control in subsequent crops, particularly WW. A greenhouse bioassay showed cross-tolerance of IT OSR towards SUs, triazolopyrimidines (TPs) and sulfonylaminocarbonyltriazolinones (SCTs) (resistance factors between 5 and 775), with a homozygous variety expressing a higher tolerance level compared to a heterozygous variety. Calculated ED_{90}-values suitable to control tolerant plants were always higher than the recommended herbicide dose. Generally, results were confirmed under field conditions, but with higher herbicide efficacies than expected in some cases (e.g. florasulam). Herbicides with an alternative mode of action were found to be effective to control IT volunteers in subsequent WW crops. Herbicide strategies have to be adjusted for volunteer control in subsequent crops if IT OSR varieties will be grown in the future. However, agronomic tools (harvest date, harvest technique, tillage) should to be used conscientiously in the first place to keep volunteer OSR densities at the lowest possible level.

Keywords: acetolactate synthase, CLEARFIELD®, imidazolinone-tolerance, volunteer crops, weed management, weed persistence

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(http://pub.jki.bund.de/index.php/JKA/issue/view/786)

ABSTRACT

Due to a higher proportion of OSR (*Brassica napus*) in sugar beet (SB) rotations, volunteer OSR can occur as a competitive weed in SB. The sulfonylurea triflusulfuron is widely used for broad-leaved weed control in SB, but may no longer be effective to control IT volunteers when IT OSR is grown, which is due to a cross-tolerance to ALS-inhibiting herbicides. Aim of the study was to evaluate 6 different herbicide strategies for the control of tolerant volunteers in the field. As a result, IT OSR showed a distinctive cross-resistance to triflusulfuron. Mean herbicide efficacy was 14 % and was only slightly increased by combination with metamitron. IS and IT OSR varieties showed different response to the herbicide treatments. A significantly higher reduction of plant fresh mass (shoot) > 90 % was caused by herbicide treatments that included the a.i. desmedipham, phenmedipham, ethofumesate, chloridazon and quinmerac. The results showed that triflusulfuron is no longer suitable to control volunteers if they are derived from imidazolinone-tolerance expressing varieties. However, alternative herbicides are available. Generally, increased attention has to be paid to volunteer management within the whole crop rotation if IT OSR is grown. Appropriate tillage strategies after OSR harvest have to be followed by effective herbicide treatments in the subsequent SB, for example a mixture of metamitron, phenmedipham, desmedipham, ethofumesat and lenaciel.

Keywords: Clearfield®, crop rotation, herbicide tolerance, imidazolinones, oilseed rape, triflusulfuron, volunteer management

6 KRATO C & PETERSEN J (2012) Competitiveness and yield impact of volunteer oilseed rape (*Brassica napus* L.) in winter and spring wheat (*Triticum aestivum*). *Journal of Plant Diseases and Protection* 119 (2), 74-82.
(http://www.ulmer.de/51795.html?UID=521784D8300F94522FC90B3CB66028F9770E17BBBFAA6143D5)

ABSTRACT

With the introduction of IT OSR varieties in Europe, herbicide-based control strategies of volunteers in cereals may become ineffective in the future. Experiments were conducted on commercial fields and in outdoor pots in Bingen (Germany) to quantify the effect of OSR volunteers on yield and quality parameters of wheat. To simulate competition, OSR was sown into wheat plots at a range of different densities. Both spring and winter varieties of OSR and wheat were used in the experiments. Crop yield was expressed as the number of heads per m^{-2} and net yield as kg per ha and hectolitre weight (HW). Wheat moisture content, percentage of dockage, wheat thousand-kernel weight (TKW), and crude protein content (CPC) were determined. Significant negative correlations were detected between the yield parameters heads m^{-2}, HW and yield on the one hand, and OSR density on the other hand. Moisture content of wheat and percentage of dockage were positively correlated with the volunteer density. No clear correlation was found between volunteer OSR density and TKW or CPC of wheat. The highest volunteer density of 261 plants m^{-2} caused a maximum yield loss of 68 % in WW. Based on a non-linear regression analysis, a single volunteer OSR plant per m^2 causes a yield loss of between 0.74 and 1.61 % in the field, which corresponds to 26.3 kg ha^{-1} (SOSR x spring wheat (SW)) and 147.3 kg ha^{-1} (WOSR x WW), respectively. Growing of IT OSR varieties will challenge farmers in terms of volunteer management. Accurate, delayed tillage after OSR harvest and control of IT volunteers with alternative modes of action except HRAC B will contribute to the successful avoidance and removal of IT volunteers from subsequent crops.

Keywords: crop-weed competition, imidazolinone-tolerance, volunteer management, yield loss

7 General Conclusions

The consequences of introducing IT OSR varieties and the imidazolinone herbicide imazamox for weed control in OSR production were evaluated by the present thesis. The application of the complementary herbicide imazamox/metazachlor/quinmerac is intended at growth stage 12 to 16 of the tolerant crop to make prophylactic treatments unnecessary and to target the weed flora in a more specific way. The foundation for the decision of potentially avoiding herbicide use and adjusting dose rates is given in IT OSR due to exact knowledge of the occurring weed species, their density and establishment of the crop.

Shifts in the weed flora in OSR were detected in the past due to high cropping intensity and a limited number of herbicides (Hanzlik *et al*., 2012) resulting in the selection of competitive weeds in OSR. Increased abundance of cruciferous weeds, such as *Capsella bursa-pastoris, Thlaspi arvense* and *Sisymbrium officinale* as well as species from other families like *Geranium* spp., *Anchusa* spp. and *Papaver rhoeas,* was observed (Klaasen, 1995; Schröder *et al*., 2008; Lutman *et al.*, 2009). Cruciferous weeds are commonly controlled by the soil herbicide clomazone but imazamox can target these weeds as well and shows efficacy against several other major weed species in OSR as confirmed by our data (Paper No. 1: POST-E weed control in WOSR using IT varieties), Grey *et al.* (2006) and data from BASF SE (Bremer *et al*., 2011; Pfenning *et al*., 2012 as well as unpublished data). Even high densities of volunteer cereals, as a result of minimum tillage, can be controlled with efficacies of > 95 % by imazamox. This indicates that the use of HT OSR and POST-E herbicides can lead to successful weed control with a single treatment. The combination of imazamox/metazachlor/quinmerac is therefore more effective than currently available herbicide solutions. Progress in weed management can consequently lead to other work management benefits in the production process. In particular, in years with late harvest of WW and/or unfavourable environmental conditions prior to sowing of OSR, the use of IT OSR associated with a later use of herbicides can dampen work peaks and bring work relief for growers.

Also, economic-related benefits were identified for OSR production with HT varieties. IT canola was grown in different eco-regions in Canada and yield was higher in two out of three cases compared to two conventional non-tolerant varieties when seeded in one of three or four years (Cathart *et al.,* 2006).

Gianessi (2005) stated that, for example, the adoption of glyphosate-tolerant crops saved roughly US$ 1.2 billion and 17 million kg of herbicides compared to non-tolerant cropping systems. Data from field experiments in Alberta, Canada were evaluated with regard to the economics of weed management in HT OSR (Upadhyay *et al.,* 2006). Major factors influencing the profitability of HT systems were costs for herbicides, variety performance, OSR price and location. The IT production system was profitable at the location Lethridge; at the location Lacombe, however, net returns were almost unaffected when comparing IT and conventional production systems. Moreover, the possibility of minimum tillage before seeding or direct-seeding of IT OSR and reduced or no herbicide applications instead of two can minimise costs for OSR production.

Furthermore, currently grown OSR varieties are highly susceptible to ALS-inhibitors and can be negatively affected by soil residues of ALS-inhibitors that had been applied on preceding crops or by residues in tanks of application technique. In the case of IT OSR, crop tolerance is given. In contrast, the a.i. imazamox used in OSR should not cause harm to other rotational crops. The persistence of polar and loaded molecules such as imazamox strongly depends on the soil pH-value (Koskinen & Harper, 1990). Low pH-values can lead to an adsorption of IMIs to soil particles and a decreased and delayed degradation. SB, which was planted after soybeans with an in-crop treatment of 35 g ha^{-1} imazamox showed no yield effect at a high soil pH-value but did at a low pH (Bresnahan *et al.,* 2002). The same amount of herbicide showed no effect on several vegetables, e.g. cabbage, potatoes, tomatoes and cucumbers that were planted in the following year in Ontario (O'Sullivan *et al*., 1998). The retention time for planting rice, maize and *Sorghum bicolor* after beans treated with 40 g ha^{-1} imazamox was significantly lower on Brazilian soils with a pH of 6.6 compared to 5.4 (Cobucci *et al.*, 1998). Imazamox did not lead to replanting problems in soils in central Italy with pH-values between 7.1 and 8.2 (Panucci *et al*., 2006).

Recently, the introduction of genetically-modified OSR varieties in Europe was extensively assessed and critically discussed. Studies confirmed the possibility of spreading (e.g. Ramsay *et al*., 2003; Funk *et al*., 2006; Deveaux *et al*., 2007) and persistence (Gruber *et al*., 2004; Beckie & Warwick, 2010) of the herbicide-tolerance genes in the soil seed bank and volunteer populations. Clearly, IT OSR is not genetically engineered but results are highly transferable. The persistence of IT volunteers will be due to a high frequency of OSR in crop rotations and inevitable seed losses at harvest. Consequently, IT volunteers will occur, having an impact on the selection and choice of herbicides for in-crop weed control in subsequent crops. Another possible negative effect of IT OSR is associated with the use of an ALS-inhibiting herbicide in an as-yet sulfonylurea-free crop

The use of IT varieties and the ALS-inhibitor imazamox in OSR may cause shifts in the weed flora. Weeds have a high plasticity and are able to adapt to herbicide regimes and to find niches for their development (Burnside, 1996). The use of HT crops and complementary herbicides can improve herbicide efficacy and decrease the weed diversity (Burnside, 1992; Giaquinta, 1992). The weed flora is likely to change due to the use of imazamox. Cruciferous weeds, *Papaver rhoeas* and *Geranium* spp. will decrease in density. In contrast, the density of *Matricaria* spp., *Lamium* spp., *Viola* spp., *Lolium* spp. and *Veronica* spp. will increase due to limited efficacy of imazamox against these weeds (Grey *et al*., 2006; Pfenning *et al*., 2008).

ALS-inhibition as a mode of action to target weeds in OSR has not been used before and will have an impact on the evolution of herbicide resistance in weeds in several rotational crops. Close to 400 weed biotypes evolved resistance against several modes of action (Heap, 2012). In OSR, the selection pressure on *Stellaria media*, *Matricaria* spp., *Papaver rhoeas*, cruciferous species and grass weeds *Apera spica-venti* and *Alopecurus myosuroides* for the development of ALS-resistance (target-site and enhanced metabolism) will consequently increase by the application of the ALS-inhibitor imazamox. A second ALS-inhibitor, ethametsulfuron, will be registered by the company DuPont for the POST-E weed control in OSR (Drobny & Schlang, 2012) and will intensify the problem.

Recently, volunteer cereals have been commonly controlled by a POST-E application of ACCase-inhibiting herbicides, such as aryloxyphenoxypropionates and cyclohexanediones. The evolution of resistance of grass weeds towards ACCase-inhibitors is likely to decrease if weed control in OSR is achieved with the ALS-inhibitor imazamox instead.

Farmers growing IT OSR have to adapt their herbicide strategies in cereals that follow OSR. In conclusion, the potentially increasing avoidance of ALS-inhibitors for weed control in cereals, which have to be substituted by other modes of action to secure efficacy against IT volunteers, can contribute to a decreased selection for ALS-resistance in weeds.

Gene transfer of the tolerance traits PM1 and PM2 to non-tolerant OSR plants and the occurrence of IT volunteers were confirmed (Paper No. 2: Gene flow between IT and IS WOSR varieties). Based on the detected outcrossing frequencies, seed clusters of 1.6 to 82 IT volunteers m^{-2} can appear on adjacent fields when considering an OSR yield of 4 t ha^{-1}, harvest losses of 5 % and a TKW of 5 g, but with high variation between fields and years. Generally, outcrossing was highest at low distances and many studies on genetically-modified OSR have shown gene dispersal to be confined by isolation distances and buffer zones (Morris *et al*., 1994; Scheffler *et al*., 1995; Ingram, 2000; Staniland *et al*., 2000; Reboud, 2003; Damgaard & Kjellsson, 2005).

Generally, genetically-modified crops are embargoed with legal restrictions concerning gene flow but these restrictions would not apply to growing non genetically-modified plants.

Another concern regards the vertical gene transfer from OSR to related species. The sexual compatibility of OSR and related weed species was investigated in several crossing experiments (Raybould & Gray, 1993; Fitzjohn *et al*. 2007). The results lead to the conclusion that the likelihood of transferring the imidazolinone-tolerance from OSR to related species in combination with a stable introgression of the gene into weed populations is present; however, the relevance of outcrossing events relating to the appearance of IT weed species is estimated to be low for agricultural practice.

Seed dispersion of IT rapeseeds between different fields during harvest was confirmed by our own studies, which were not incorporated in the present thesis. The highest dispersion rates were counted with 787 volunteer plants m^{-2}. Thus, seed dispersion by technical equipment - mainly combine harvesters - and the well-reported seed losses before and during OSR harvest (Gruber *et al*. 2004; Lutman *et al*., 2005) are the most relevant sources of IT volunteers in crop rotations. The cross-tolerance to ALS-inhibitors will cause consequences for the chemical control of IT volunteers in subsequent crops, namely significantly decreased efficiency of ALS-inhibitors against volunteers with tolerance to IMIs. Herbicide regimes in WW and SB have to change to ensure high efficacies against IT volunteer OSR (Paper No. 3 & 4: Control of IT volunteer OSR in subsequent crops). With non-observance, significant yield losses have to be expected at high volunteer densities (Paper No. 5: Competitiveness and yield impact of volunteer OSR (*Brassica napus* L.) in WW and SW (*Triticum aestivum*).

IT volunteer OSR should be categorised as a herbicide-resistant weed in consequence. A model to describe the impact of herbicide-tolerance for the characteristics of volunteer OSR was designed using physiological parameters including emergence pattern, volunteer density, seed longevity, death rates, flowering and seeding as well as control parameters such as harvest efficiency, herbicide treatment, soil tillage and crop rotation (Squire *et al*., 1997). In conclusion, seed bank levels of IT volunteers will be considerably more difficult to reduce if the efficacy of ALS-inhibiting herbicides in subsequent crops is compromised. Hence, guidelines for management of herbicide-resistant weeds should be used, e.g. for volunteer control in WW that is grown rotationally after IT OSR. A combination of cultural and herbicidal control measures can lead to successful containment of volunteer populations. According to Moss (2002) and Beckie (2006), an integrated weed management is required to reduce selection pressure. First of all, soil cultivation is a key step in reducing IT volunteers. Tillage should be delayed after OSR harvest to avoid induced dormancy in rapeseeds and to promote emergence of volunteers. A second step is based on stubble hygiene, which can be achieved by destroying the volunteers with effective seedbed preparation and/or application of a non-selective herbicide. A slightly delayed drilling of WW is favourable to widen the time frame for weed-seedling emergence before the crop is sown and to decrease the winter hardness of OSR volunteers.

During the whole crop rotation, it is important to control IT volunteers effectively with alternative herbicides if volunteers occur in the crop stand from the soil seed bank. The major aim has to be the avoidance of maturing IT OSR volunteers in order to prevent the distribution and increased persistence of IT volunteers on arable fields independent of the currently grown crop.

Rationales for using IT OSR varieties depend on various factors including weed spectrum in OSR, tillage regimes and crop rotations. The herbicide clomazone has been an important tool for controlling cruciferous and some other important weeds in OSR since 1997 (Schröder *et al*., 2008). However, the use of clomazone is linked to regulatory requirements in terms of application due to a high potential of volatilization and observed damage on non-target areas (BVL, 2012). The combination of IT varieties and corresponding herbicides is useful to substitute clomazone in future OSR production and to facilitate the control of cruciferous weeds and some invasive weed species like *Sinapis arvensis, Barbarea vulgaris, Bunias orientalis* and *Cardaria draba*.

When applying an isolated view of the rotational crop OSR, the use of minimal tillage (high density of volunteer cereals) and/or stressful working conditions due to unpredictable environmental conditions prior to sowing or shortly after sowing, are reasons for choosing IT OSR. The herbicide combination metazachlor/quinmerac/imazamox is not necessarily dependent on an optimal seedbed and soil moisture to facilitate high levels of weed control. An exception has to be made for e.g. *Alopecurus myosuroides*. Dry conditions in combination with an application at the two-true-leaf stage or later may significantly decrease the efficacy of the soil herbicide metazachlor.

If integrated in crop rotations, the volunteer management in subsequent crops becomes the centre of attention. OSR is mainly grown in one out of three or four years in rotations containing a high amount of winter-sown cereals. If the above mentioned problematic weed species - e.g. cruciferous weeds - occur with high distribution and density in OSR, benefits of using IT OSR will overlap the increased effort of volunteer control.

In contrast, these rotations can be associated with a high proportion of grass weeds that may require a second herbicide application at later time of the growing season and may lead to increased costs. If the weed flora in OSR corresponds with the efficacy range of imazamox/metazachlor/quinmerac, a decision pro IT OSR is expedient. It can be suggested that IT OSR can be integrated in diverse rotations with winter cereals, spring cereals and maize because IT volunteer OSR can be controlled with herbicides for dicotyledonous weed control. However, the main volunteer management will appear in the direct following crop. Nonetheless, growers have to be aware of the fact that volunteer OSR can emerge over the whole growing season and that WOSR is quite competitive in spring crops due to its growing habit.

In crop rotations containing both SB and OSR, the volunteer management is generally problematic and a restriction has to be made. The use of IT varieties cannot be recommended due to complicated volunteer management. OSR as a weed is highly competitive in SB and can cause significant yield losses. An additional risk would be an increasing density of soil pathogens such as *Heterodera schachtii* and *Plasmodiophora brassicae* in SB crop rotations.

There has been, and will be, a lack of innovation regarding new herbicidal solutions for weed control in general. When assessing advantages and disadvantages of the Clearfield® production system, benefits for farmers in terms of working flexibility and broad-spectrum weed control are given and the IT volunteer management can be successfully accomplished with agronomic tools. Ultimately, innovative technologies can only be provided, but choice for adoption has to be made by every single farmer according to the operating conditions. However, a stewardship for Europe has to be implemented by BASF SE to re-allocate information to breeders, users as well as non-users on critical aspects of IT OSR production such as minimising gene flow, avoiding IT weeds, preventing seed dispersion and managing IT volunteers.

8 Summary

OSR (*Brassica napus* L.) is one of the most important arable oil crops globally and is grown on an area of 31,680,945 ha as winter- and spring-sown varieties. The harvest is mainly used in human nutrition, animal feeding and as a renewable resource for the production of paints, varnishes and biodiesel.

OSR can be considered a quite competitive crop but nonetheless weed control is carried out on the vast majority of the grown area. The most common treatments are done PRE-E or early POST-E, mainly as prophylactic treatments without exact knowledge of the weed species or their densities. In order to facilitate a more targeted weed control in OSR, IT varieties combined with the corresponding imidazolinone herbicide imazamox (target-site is ALS) + metazachlor/quinmerac (Clearfield® production system) were developed for the European market by BASF SE and several breeding companies.

By integrating IT plants into cropping systems, herbicide-tolerance genes will appear in agricultural ecosystems. Unless the tolerance is achieved by non-transgenic breeding methods, the introduction creates concerns regarding spreading the herbicide-tolerance in space and time causing unwanted changes for volunteer OSR management.

The hypothesis of the present study was to investigate important aspects, which are likely to arise with a commercial introduction and cultivation of IT OSR in Europe:

(i) Does the Clearfield® production system imply the possibility of POST-E weed control, with regard to the use of damage thresholds in OSR? Is it possible to identify benefits compared to common weed management practices?

POST-E weed control was successful using IT varieties. The total herbicide efficacy of imazamox/metazachlor/quinmerac was about 90 % in the field trials. Good results were achieved against volunteer cereals, *Thlaspi arvense*, *Chenopodium album, Matricaria inodora*, *Papaver rhoeas*, *Capsella bursa-pastoris* and *Apera spica-venti* but a lack of efficacy was observed regarding control of *Agropyron repens* and *Viola arvensis*. Yield was increased significantly in treated plots compared to untreated ones by up to 50 %. IT OSR can be a tool for the use of damage thresholds in integrated weed management in OSR.

(ii) Does gene transfer between adjacent IT and imidazolinone-susceptible (IS) OSR varieties lead to an IT F_1-generation? What is the genetic outcome of such outcrossing events?

Outcrossing between IT and IS OSR varieties was confirmed with outcrossing frequencies between 0.57 and 2.05 % between pollen donors and acceptors that were directly adjacent.

Outcrossing declined significantly with increasing distance but was still found 45 m from IT plants. The transfer of both tolerance genes and heterozygosity was shown by 84 % of analysed F_1-plants.

(iii) How do IT OSR plants respond to ALS-inhibiting herbicides? Is there a need to adjust herbicide strategies for the control of IT volunteers in subsequent crops in the future?

A cross-tolerance of IT OSR to SUs, TPs and SCTs was shown in greenhouse bioassays and field trials with calculated resistance factors between 5 and 775. Furthermore, homozygous IT plants expressed a much higher tolerance level compared to heterozygous ones.

Herbicides with alternative modes of action other than HRAC B (ALS-inhibition) were found to be effective to control IT volunteers in subsequent crops. Pendimethalin, picolinafen, isoproturon, diflufenican, florasulam, flufenacet and flurtamone controlled IT volunteers in WW. In sugar beet, herbicide combinations with metamitron, desmedipham, phenmedipham, ethofumesate, chloridazon and lenacil were able to control IT volunteers but single active ingredients were not.

(iv) Is there a measurable negative effect of volunteer OSR on yield and quality parameters of wheat, if weedy OSR is not controlled accurately?

Significant negative correlations were detected for the independent variable volunteer OSR density and the wheat yield parameters heads m^{-2}, HW and yield. In contrast, moisture content of wheat and percentage of dockage increased with increasing volunteer density. The highest volunteer density of 261 plants m^{-2} caused a maximum yield loss of 68 % in WW. Based on a non-linear regression analysis, a single volunteer OSR plant per m^2 causes a yield loss of between 0.74 and 1.61 %.

In conclusion, the use of IT OSR varieties can substitute the herbicide clomazone in the future and provide POST-E weed control with detailed knowledge of the weed spectrum. This can promote integrated weed management, the use of damage thresholds in weed control and working management benefits for growers.

Clearly, difficulties in volunteer management are a drawback of IT OSR, but with conducting an accurate, delayed tillage after OSR harvest and adjusting herbicide regimes in subsequent crops, IT volunteers should not cause more harm compared to IS OSR volunteers.

Based on the assumption that innovations in development of new active ingredients for weed control cannot be expected, the use of HT crops has to be seen as a major tool to solve issues in weed management.

9 Zusammenfassung

Raps (*Brassica napus* L.) ist eine der weltweit wichtigsten Ölpflanzen und wird auf einer Fläche von 31.680.945 ha als Winter- und Sommerform angebaut. Die geernteten Rapssamen werden vornehmlich in der menschlichen Ernährung, als Futtermittel für Nutztiere oder als Grundlage für die Produktion von Farben, Lacken und Biodiesel verwendet.

Raps ist eine sehr konkurrenzstarke Kultur, aber trotzdem werden auf einem Großteil der Rapsanbaufläche Herbizide zur Unkrautbekämpfung angewendet. Im Wesentlichen werden prophylaktische Maßnahmen im Vorlauf oder sehr frühen Nachauflauf durchgeführt, ohne die genaue Verunkrautungssituation zu kennen. Um eine gezieltere Unkrautkontrolle zu ermöglichen, wurde eine Kombination aus IT Rapssorten und dem korrespondierenden Imidazolinonherbizid Imazamox (Zielort ist ALS) in Mischung mit Metazachlor und Quinmerac von BASF SE und Pflanzenzüchtungsfirmen entwickelt. Dieses System soll unter dem Namen Clearfield® europaweit angewendet werden.

Durch die Integration von IT Rapssorten in Fruchtfolgen werden Herbizidtoleranzgene in Agrarökosystemen auftreten. Die Herbizidtoleranz wurde zwar durch Methoden der konventionellen Pflanzenzüchtung erreicht, nichtsdestotrotz ruft die räumliche und zeitliche Verbreitung dieser Gene Bedenken hervor und könnte wesentliche Veränderungen in der Ausfallrapskontrolle bedingen.

Ziel der vorliegenden Untersuchung was es, wichtige agronomische Askekte zu beleuchten, die mit einer kommerziellen Einführung und dem großflächigen Anbau von IT OSR einhergehen.

(i) Bietet das Clearfield® Produktionssystem die Möglichkeit der Herbizidanwendung im Nachauflauf und die damit verbundenene Verwendung von Schadensschwellen im Rapsanbau? Lassen sich Vorteile im Vergleich zu herkömmlichen Unkrautbekämpfungsverfahren ableiten?

Die Unkrautkontrolle im Nachauflauf in IT Winterraps konnte mit einem Gesamtwirkungsgrad von 90 % erfolgreich durchgeführt werden. Eine sehr gute Wirksamkeit gegen Ausfallgetreide, *Thlaspi arvense*, *Chenopodium album*, *Matricaria inodora*, *Papaver rhoeas*, *Capsella bursa-pastoris* and *Apera spica-venti* und Wirlungslücken gegen *Agropyron repens* und *Viola arvensis* wurden beobachtet. Der Ertrag konnte durch die Herbizidmaßnahme im Vergleich zur unbehandelten Kontrolle um bis zu 50 % gesteigert werden. Die Verwendung herbizidtoleranter Rapssorten kann ein Werkzeug zur Anwendung von Schadensschwellen im Rahmen einer integrierten Rapsproduktion sein.

(ii) Führt Gentransfer zwischen IT und nicht-toleranten Rapspflanzen zu einer herbizidtoleranten F_1-Generation? Welches Zygotielevel weisen die Nachkommen auf?

Intaspezifischer Gentransfer zwischen IT und empfindlichen Rapssorten wurde bestätigt, wobei die Auskreuzungsraten zwischen 0,57 und 2,05 % in unmittelbarer Nachbarschaft beider Rapsgenotypen lagen. Die Auskreuzungsraten verringerten sich signifikant mit steigender Entfernung, aber auch in 45 m Entfernung zum Pollenspender wurde Genübertragung phänotypisch nachgewiesen. Die Übertragung beider Toleranzgene und Heterozygotie bestätigte sich auf genetischer Ebene für 84 % der F_1-Pflanzen.

(iii) Wie reagieren IT Rapspflanzen auf verschiedene ALS-Inhibitoren? Muss die chemische Ausfallrapskontrolle verändert werden, um zukünftig IT Ausfallraps effektiv zu kontrollieren?

Eine Kreuztoleranz der IT Rapspflanzen gegenüber den chemischen Klassen Sulfonylharstoffe, Triazolopyrimidine and Sulfonylamino-Carbonyltriazolinone wurde sowohl in Gewächshausstudien als auch im Feld deutlich. Errechnete Resistenzfaktoren lagen zwischen 5 und 775. Außerdem exprimierten homozygot IT Rapspflanzen höhere Toleranzlevel im Vergleich zu heterozygoten Pflanzen.

Herbizide, die nicht die ALS als Zielenzym angreifen, zeigten eine gute Wirksamkeit zur Bekämpfung von IT Ausfallraps in Winterweizen (Pendimethalin, Picolinafen, Isoproturon, Diflufenican, Florasulam, Flufenacet und Flurtamone) und Zuckerrüben (Metamitron, Desmedipham, Phenmedipham, Ethofumesat, Chloridazon, und Lenacil). Wobei in Zuckerrüben ausschließlich Herbizidmischungen hohe Wirkungsgrade erreichten.

(iv) Gibt es einen negativen Effekt von Ausfallraps auf die Ertrags- und Qualitätsparameter von Weizen, wenn der Ausfallraps nicht erfolgreich bekämpft wurde?

Signifikant negative Korrelationen zeigten sich zwischen der Einflussvariable Ausfallrapsdichte und den Parametern Weizenertrag, Ährendichte m^{-2} und Hektolitergewicht. Die Feuchte und der Besatz des Erntegutes stiegen demgegenüber bei ansteigender Ausfallrapsdichte. Die höchste Ausfallrapsdichte von 261 Pflanzen m^{-2} in Winterweizen führte zu einem Ertragsverlust von 68 %. Basierend auf einer nicht-linearen Regressionsanalyse kann eine Ausfallrapspflanze pro m^2 zu einem Ertragsverlust zwischen 0,74 und 1,61 % führen.

Als Schlussfolgerung lässt sich festhalten, das die Anwendung von IT Rapssorten den umstrittenen Wirkstoff Clomazone ersetzten und zu einer zielgerichteten Unkrautkontrolle im Nachauflauf im Raps führen kann. Verfahren der integrierten Unkrautbekämpfung und die

Anwendung von wirtschaftlichen Schadensschwellen werden unterstützt und Verbesserungen im Arbeitsmanagement der Landwirte sind möglich.

Jedoch ist das Auftreten von IT Ausfallraps ein deutlicher Nachteil des Anbausystems. Wird aber eine effektive und verzögerte Bodenbearbeitung nach der Rapsernte mit der Anpassung von Herbizidstrategien in Folgekulturen verknüpft, sollten IT Ausfallrapspflanzen nicht problematischer sein als momentan auftretende, nicht IT Ausfallrapspflanzen.

Innovationen in der Entwicklung neuer herbizider Wirkstoffe sind nicht zu erwarten. Dementsprechend ist die Verwendung herbizidtoleranter Kulturpflanzen ein bedeutendes Werkzeug zur Lösung wichtiger Probleme in der Unkrautbekämpfung.

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Affirmation

I, Christoph Krato, declare:

The present thesis: ‘Consequences for weed management in crop rotations by introducing imidazolinone-tolerant oilseed rape varieties’ was prepared autonomously and exclusive of using the mentioned additives. Literally or contextually adopted test passages are marked correspondingly. The work has not been submitted to any examination authority in similar or exact profile.

Geisenheim, 21 April 2012

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(Signature)