Soil activity of post-emergent herbicides recommended for black-grass and loose silky-bent grass control in winter wheat

Bodenwirkung von empfohlenen Nachauflaufherbiziden gegen Acker-Fuchsschwanz und Windhalm in Winterweizen

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Summary

The natural emergence of black-grass (*Alopecurus myosuroides*) was observed on a wheat field over two growing seasons in 2009 and 2010. Under shallow tillage conditions, *A. myosuroides* emerged steadily between the months September and May. Peak emergence occurred after sowing until the middle of October followed by continuous emergence until winter. Another peak of emergence took place in spring through the beginning of May. Under conventional tillage conditions (ploughing) in 2010, almost no germination of *A. myosuroides* could be observed after the first herbicide treatment in autumn. In order to evaluate the soil activity of recommended post-emergence herbicides, two pot experiments with sterilized soil were carried out outdoors and under greenhouse conditions. The results show that all tested grass herbicides, ACCase-inhibitors and ALS-inhibitors, demonstrated strong soil efficacy against *A. myosuroides* and *Apera spica-venti* in most cases. Especially the herbicides propoxycarbazone, pyroxsulam and mesosulfuron-methyl showed a high soil activity even at low doses. While the soil activity was consistent for clodinafop-progagyl, variable results were observed for fenoxaprop-P-ethyl and pinoxaden in the two experiments. We conclude that the soil activity of the tested herbicides is very variable and dependent on many factors which make it difficult to predict their activity especially under field conditions.

Keywords: *Alopecurus*, *Apera*, cereals, dormancy, pre-emergence activity, weed germination

Zusammenfassung

Das natürliche Auflaufverhalten von Acker-Fuchsschwanz (*Alopecurus myosuroides*) wurde auf einem Weizenfeld über zwei Vegetationsperioden in 2009 und 2010 beobachtet. Bei Minimalbodenbearbeitung lief *A. myosuroides* stetig zwischen den Monaten September bis Mai auf. Dabei fand ein Hauptauflauf von *A. myosuroides* zwischen Weizenaussaat und Mitte Oktober statt, gefolgt von kontinuierlichem Auflauf bis in den Winter und einem erhöhten Auflauf im Frühling bis Anfang Mai. Bei konventioneller Bodenbearbeitung (Pflügen) im Jahr 2010 wurde dagegen nach erster Herbizidbehandlung im Herbst kaum noch Auflauf beobachtet. Um die Bodenwirkung von empfohlenen Nachauflaufherbiziden zu bewerten, wurden Gefäßversuche mit sterilisiertem Boden unter Freiland- und Gewächshausbedingungen durchgeführt. Die Ergebnisse zeigen, dass alle getesteten Grasherbizide, ACCase-Inhibitoren und ALS-Inhibitoren, in den meisten Fällen eine hohe Bodenwirkung gegenüber *A. myosuroides* und *Apera spica-venti* aufweisen. Sogar bei niedrigen Dosierungen zeigten besonders die Wirkstoffe Propoxycarbazone, Pyroxsulam und Mesosulfuron-methyl eine hohe Bodenwirkung. Während die Bodenwirkung von Clodinafop-Progagyl beständig war, kam es bei Fenoxaprop-P-Ethyl und Pinoxaden in den zwei Experimenten zu unterschiedlichen Ergebnissen. Wir schlussfolgern, dass die Bodenwirkung von Herbiziden sehr variabel ist und von vielen Faktoren abhängt, so dass es an dieser Stelle schwierig ist, Vorhersagen zur Wirkung, besonders unter Feldbedingungen, zu machen.

Stichwörter: *Alopecurus*, *Apera*, Dormanz, Getreide, Unkrautkeimung, Vorauflaufwirkung

1. Introduction

The most important weeds of winter cereals in Germany are *Alopecurus myosuroides* HUDS. and *Apera spica-venti* (L.) P. B.. These weeds are well adapted to current agricultural production systems because they respond positively to reduced tillage, early sowing dates and high nitrogen levels (AMANN, 1991; AMANN et al., 1992; PULCHER-HÄUßLING and HURLE, 1986). Their growth behaviour is well adapted to winter-sown crops and they are very competitive. Therefore, grass weeds are controlled regularly and in most cases with herbicides. Currently, *A. myosuroides* and A. *spica-venti* can be controlled by either pre- or post-emergent herbicide applications. However, the most efficient application timing has not yet been defined due to varying biological, agronomic and climatic factors. In many cases, the efficacy of post-emergence herbicides is not maintained long enough to provide sufficient control. Late flushes of weeds such as *A. myosuroides* occur especially in years with a high level of seed dormancy. *A. myosuroides* dormancy varies every year and is highly influenced by the weather conditions during maturation (FENNER, 1991, MOSS et al., 2006). MEINERS et al. (2011) report that *A. myosuroides* is capable of slow emergence over a longer period of time and that the emergence is dependent on the cropping practice. Further, it is reported that *A. myosuroides* is able to emerge at very low temperatures such as 2 °C (MENCK, 1968) or 3 °C (COLBACH et al., 2002). COLBACH et al. (2002) even estimated a minimum temperature requirement of 0 °C for germination of *A. myosuroides*. The importance of herbicides with residual activity to cover the prolonged period of weed emergence becomes obvious in years with mild winters and a high level of seed dormancy.

The objectives of the present study were (i) to characterize the natural emergence of *A. myosuroides* in a field over two seasons and (ii) to evaluate soil activity of post-emergence herbicides under different conditions.

2. Materials and methods

2.1 Emergence of black-grass (*Alopecurus myosuroides* HUDS.)

The experiment was carried out at the research station Rauischholzhausen of the Justus-Liebig-University Gießen in Hessen, Germany. Using natural weed infestation, the emergence of *A. myosuroides* was observed over two seasons on an agricultural field where no ploughing has been conducted since over 20 years. For our investigations, the field was partially ploughed in 2010. In October 2009, two areas with a size of 5 m^2 were sprayed within the winter wheat field using the non-selective and non-residual herbicide Roundup UltraMax (Glyphosate 450 g/l). Within these plots, the natural emergence of *A. myosuroides* was regularly observed in eight marked plots with a size of 0.1 m^2. The following year (2010), plots with a size of 1.5 m^2 were used for countings and already emerged individuals of A. myosuroides were clearly labelled with coloured plastic rings at each counting. Additionally, Roundup UltraMax was reapplied in these plots in early spring.

2.2 Pot experiments on the residual activity of post-emergent herbicides

In order to investigate the residual activity of different post-emergence herbicides, a pot experiment was carried out in May - June 2010 at the outdoor facilities of Bayer CropScience AG in Frankfurt (Germany) to simulate field conditions. Seeds of *A. myosuroides* (50-55 per pot) and *A. spica-venti* (80-90 per pot) were sown in plastic pots (diameter 10.5 cm, depth 8 cm) with sterilized silty clay loam (sand 10.6 %, silt 65.7 %, clay 23.6 %, pH 7.5, C-org 2.46 %) and a range of herbicide treatments were applied pre-emergent on a track sprayer fitted with a flat fan nozzle delivering 300 l/ha water. The post-emergence herbicides, based on recommended field rates, were: Mesosulfuron-methyl at 10, 5 and 2.5 g/ha (WG, 750 g a.i./kg); iodosulfuron-methyl at 5, 2.5 and 1.25 g/ha (WG, 100 g a.i./kg); pyroxsulam at 10, 5 and 2.5 g/ha (WP, 200 g a.i./kg); propoxycarbazone-sodium at 80, 40 and 20 g/ha (Attribut SG, 700 g a.i./kg); flupyrsulfuron-methyl at 10, 5 and 2,5 g/ha (Lexus DF, 500 g a.i./kg); fenoxaprop-P-ethyl at 80, 40 and 20 g/ha (Ralon Super, 69 g a.i./l); clodinafop-propagyl at 80, 40 and 20 g/ha (Topik, 100 g a.i./l) and pinoxaden at 80, 40 and 20 g/ha (Axial EC, 50 g a.i./l). The individual herbicide treatments used in each experiment are shown in Tab. 3. After sowing and spraying, pots were placed outdoors and either irrigated lightly from above using a hose with a sprinkler or watered by natural rainfall to moisten the soil. Each experiment was comprised of four replicates per treatment. Herbicide activity was assessed 47 days after pre-emergence spraying by weighing the upper biomass of the weeds.

In addition, another pot-experiment was conducted with three different ACCase-inhibitors under glasshouse conditions in August and September 2011. The grass herbicides used were: Fenoxaprop-P-ethyl at 82.8 g/ha (Ralon Super, 69 g a.i./l); clodinafop-propagyl at 60 g/ha (Topik, 100 g a.i./l) and pinoxaden at 60 g/ha (Axial, 50 g a.i./l). These rates were equivalent to the maximum recommended field rates. After application, the plants were grown in a glasshouse with average 20 °C day and 12 °C night temperature regimes. The herbicide activity was assessed 35 days after pre-emergence spraying by weighing the upper biomass of the weeds per pot. For all received data an ANOVA was conducted. Multiple comparisons were made using the Tukey-test at a $\alpha = 0.05$ level of significance. Statistical analyses were conducted using SPSS 16.0 (SPSS, Chicago, IL, USA).

3. Results

3.1 Natural emergence of black-grass (*A. myosuroides*) in the field

Emergence of *A. myosuroides* amounted to around 80 % of the total emergence during the four week period between sowing (22.09.09) and application of post-emergence herbicides including Roundup UltraMax (Tab. 1). Further, slight emergence of *A. myosuroides* individuals occurred in November and had its peak in December 2009, followed by continuous emergence of *A. myosuroides* individuals from March until the beginning of May.

Tab. 1 Germination of *Alopecurus myosuroides* individuals per m² during the field season 2009/2010 in Rauischholzhausen after Roundup UltraMax (6 l/ha) application on 21.10.2009.

Tab. 1 *Auflauf von Alopecurus myosuroides-Pflanzen pro m² während der Feldsaison 2009/2010 in Rauischholzhausen nach Applikation von Roundup UltraMax (6 l/ha) am 21.10.2009.*

Date	21.10.	27.11.	14.12.	24.03.	07.04.	05.05.	25.05.
Newly emerged - low tillage	990	25	140	58	50	50	0

Newly emerged: Individuals in BBCH 11-12

In the second year, the emergence of *A. myosuroides* followed a similar, though less extensive pattern (Tab. 2). Peak emergence occurred after sowing (22.09.10) followed by continuous emergence with a peak in November 2010, no emergence until March and another peak in April through to the beginning of May. In comparison, total emerged individuals of *A. myosuroides* were reduced by around 90 % by ploughing. Further there was close to 0 % emergence in late fall and no emergence observable in the spring of 2011.

Tab. 2 Germination of *Alopecurus myosuroides* individuals per m² during the field season 2010/2011 in Rauischholzhausen after Roundup UltraMax (6 l/ha) application on 14.10.2010 and 25.01.2011.

Tab. 2 *Auflauf von Alopecurus myosuroides-Pflanzen pro m² während der Feldsaison 2010/2011 in Rauischholzhausen nach Applikation mit Roundup UltraMax (6 l/ha) am 14.10.2010 and 25.01.2011.*

Date	14.10.	05.11	17.11.	25.01.	23.03.	20.04.	03.05.	30.05
Newly emerged - low tillage (n = 2)	347	28	37	X	0	23	3	0
Newly emerged - ploughing (n = 2)	37	1	6	X	0	0	0	0

Newly emerged: Individuals in BBCH 11-12

3.2 Soil activity of post-emergence herbicides in pots

In this experiment, there were 16-20 *A. myosuroides* plants and 20-25 *A. spica-venti* plants in untreated pots. Treatment effects are shown in Table 3 as average fresh weights per pot after 47 days and in % relative to the untreated pots. All used post-emergence herbicides showed certain levels of pre-emergence weed control which were in almost all cases significant ($p < 0.05$) to the untreated control. All ALS-inhibitors (mesosulfuron-methyl, iodosulfuron-methyl, pyroxsulam, propoxycarbazone and flupyrsulfuron-methyl) applied at the highest dose showed good to very good weed control, ranging from 69-95 % control for *A. myosuroides* and from 74-100 % control for *A. spica-venti*. Even at low doses, especially for propoxycarbazone, pyroxsulam and mesosulfuron-methyl, the soil activity was still on a decent to high level (64-92 %). The ACCase-inhibitors fenoxaprop-P-ethyl and clodinafop-propagyl at the highest dose showed a relatively high level of pre-emergence weed control, ranging from 68-88 % control for *A. myosuroides* and from 64-83 % control for *A. spica-venti.* As expected, the pre-emergence efficacy was reduced at lower doses. In contrast, the ACCase-inhibitor pinoxaden showed a low level of soil activity in this experiment.

Tab. 3 Biomass production (fresh weight per pot and relative data, untreated = 100) of *Alopecurus myosuroides* and *Apera spica-venti* after different pre-emergence applications of post-emergence herbicides in an outdoor pot experiment 2010.

Tab. 3 *Biomassebildung (Frischgewicht pro Gefäß und Relativwerte, unbehandelt = 100) von Alopecurus myosuroides und Apera spica-venti nach Behandlung mit Nachauflaufherbiziden im Vorauflauf unter Freilandbedingungen in 2010.*

		A. myosuroides				***A. spica-venti***			
Herbicide	**Rate g ai/ha**	**Fresh weight g per pot**	**SE ±**		**Fresh weight %**	**Fresh weight g per pot**	**SE ±**		**Fresh weight %**
Mesosulfuronmethyl	10	0.23	0.04	AB	8	0.00	0.00	A	0
	5	0.83	0.20	CDEF	28	0.71	0.17	ABCD	27
	2.5	1.16	0.10	FG	39	0.89	0.26	ABCD	34
Iodosulfuronmethyl	5	1.21	0.09	FG	41	0.00	0.00	A	0
	2.5	1.27	0.07	FGH	43	0.40	0.26	ABC	15
	1.25	1.46	0.14	GHI	50	1.23	0.12	CDEF	46
Pyroxsulam	10	0.20	0.04	A	7	0.00	0.00	A	0
	5	0.27	0.03	ABC	9	0.03	0.03	A	1
	2.5	0.44	0.05	ABCDE	15	0.21	0.08	AB	8
Propoxycarbazonesodium	80	0.14	0.05	A	5	0.05	0.02	A	2
	40	0.17	0.05	A	6	0.26	0.09	AB	10
	20	0.35	0.03	ABCD	12	0,47	0.03	ABCD	18
Flupyrsulfuronmethyl	10	0.80	0.06	BCDEF	27	0.69	0.10	ABCD	26
	5	1.39	0.12	FGH	47	1.31	0.21	DEF	49
	2.5	1.54	0.16	GHI	52	1.91	0.36	FGH	72
Fenoxaprop-P-ethyl	80	0.93	0.09	DEFG	32	0.45	0.16	ABCD	17
	40	1.24	0.27	FG	42	1.06	0.11	BCDE	40
	20	1.85	0.16	HIJ	63	1.99	0.20	FGH	75
Clodinafoppropagyl	80	0.36	0.02	ABCD	12	0.95	0.19	BCDE	36
	40	0.98	0.16	EFG	33	0.77	0.16	ABCD	29
	20	2.16	0.10	J	73	1.75	0.29	EFG	66
	80	2.70	0.24	KL	92	2.48	0.28	GH	93
	40	2.30	0.10	JK	78	2.70	0.15	H	102
Pinoxaden	20	2.02	0.05	IJ	69	2.36	0.24	GH	89
Untreated	-	2.95	0.17	L	100	2.65	0.19	H	100

SE = standard error; mean values within a given column followed with the same letter are not significantly different according to Tukey-test (α = 0.05).

The results for this experiment, which was conducted under greenhouse conditions, are shown in Table 4 as average fresh weights per pot after 35 days and in % relative to the untreated pots. As in the previous experiment, there were 16-20 *A. myosuroides* plants in untreated pots. The ACCase-inhibitors applied at their maximum recommended field dose showed very different soil efficacy values. While clodinafop-propagyl and pinoxaden showed a highly significant ($p < 0.05$) pre-emergence efficacy against *A. myosuroides* (88 % and 85 %), the fresh weights of plants treated with fenoxaprop-P-ethyl showed no significant difference to the untreated control ($p > 0.05$).

Tab. 4 Biomass production (fresh weight per pot and relative data, untreated = 100) of *Alopecurus myosuroides* and *Apera spica-venti* after different pre-emergence applications of post-emergence herbicides in an outdoor pot experiment 2010.

Tab. 4 *Biomassebildung (Frischgewicht pro Gefäß und Relativwerte, unbehandelt = 100) von Alopecurus myosuroides und Apera spica-venti nach Behandlung mit Nachauflaufherbiziden im Vorauflauf unter Freilandbedingungen in 2010.*

Herbicide	Rate g ai/ha	Fresh weight g per pot	SE ±		Fresh weight %
Fenoxaprop-P-ethyl	82.8	6	1.05	A	81
Clodinafop-propagyl	60	0.9	0.17	B	12
Pinoxaden	60	1.1	0.22	B	15
untreated	-	7.4	0.8	A	100

SE = standard error; mean values within a given column followed with the same letter are not significantly different according to Tukey-test (α = 0.05).

4. Discussion

In general, soil activity of herbicides can only occur when the active ingredient is able to be taken up by either the roots or the hypocotyls of the weed. It is essential that there is a high availability of the herbicide in the root zone of the plants. On the one hand, this is highly dependent on characteristics of the chemical itself like its mobility, soil absorption, water solubility (logKoW) and the degradation stability (dt_{50}). On the other hand, a lot of environmental factors such as soil characteristics (organic matter content, biological activity, temperature, clay content and structure), precipitation and plant growth have an important impact on herbicide performance (DEVINE et al., 1993; ALDRICH and KREMER, 1997, FRYER and MAKEPEACE, 1977).

In our pot experiments, we showed that all tested post-emergence herbicides can have a certain soil activity against *A. myosuroides* and *A. spica-venti*. CORNES et al. (1989), RAFFEL et al. (2006) and FORTMEIER et al. (2006) mention that ACCase-inhibitors such as fenoxaprop-P-ethyl, clodinafop-progagyl as well as pinoxaden are entering the plant entirely or mainly through the foliage.

In contrast to the field, plants grown in the glasshouse usually find optimal growth conditions due to controlled temperature and water regimes. For instance, higher temperatures, when soil moisture is not limited, will result in more active plant growth and probably increased herbicide entry. This can be used as an explanation for the two different results for pinoxaden in our pot experiments. The first pot experiment was conducted under cold and wet conditions when almost no soil activity could be expected, while under relatively warm greenhouse conditions, the soil activity was high for pinoxaden. On the contrary, clodinafop-propagyl showed a high soil activity in both experiments. CORNES et al. (1989) also reported that the activity of clodinafop was not dependent on temperature although symptoms were slower to develop in cool temperatures. Our results for fenoxaprop-P-ethyl were inconsistent as well, which is probably the effect of the different growing conditions. In addition, soil moisture has been shown to be important for the activity of isoproturon on *A. myosuroides* in pot experiments in a greenhouse (BLAIR, 1985). HEWSON and READ (1985) concluded from their series of field trials carried out over 12 years on different farms that good control of larger plants by isoproturon generally coincided with moist soil conditions. On the other hand, excessive watering or rainfall after spray application could cause leaching below the rooting zone of small target plants which could lead to their survival (ALDRICH and KREMER, 1997). Furthermore, plants also show higher susceptibly to residual herbicides in pot experiments because the root growth is limited and the chemical is highly concentrated in the root zone in a pot. In addition, sown *A. myosuroides* in pot experiments emerge simultaneously from the same depth, while continuous emerging can be observed in the field (MEINERS et al., 2011). KRÄHMER et al. (1994) reported that several factors like the crop and pest genome, the environmental conditions, physiochemical properties of the applied compounds and crop-pest interactions are causing variability in data generated from greenhouse and field trials. Their data with chlortoluron and isoproturon showed a high variability in glasshouse and field trials. The effect of weather conditions on the performance of isoproturon and clodinafop-progagyl to control *A. myosuroides* were investigated in field experiments by COLLINGS et al. (2003). They concluded that the weather conditions affected the herbicide performance more than the growth stage of the weed. This may explain variable results.

The long lasting emergence of *A. myosuroides* that we observed in our field trials is also reported by MENCK (1968) who proved that sown *A. myosuroides* can emerge during the whole year. However, the percentage of the emerged seeds is highly dependent on the seed dormancy. He suggested that a secondary dormancy, according to its natural endogenous germination rhythm, is induced by cool and wet conditions during the winter which will be reversed as soon as temperatures increase and the soil is drying in spring. The natural seed dormancy is different every year and is highly influenced by the weather conditions during maturation (FENNER, 1991; MOSS et al., 2006). It seems obvious that late flushes of weeds such as *A. myosuroides* occur especially in years with a high level of seed dormancy. We will demonstrate in a later publication that individuals of *A. myosuroides* which are still emerging in the spring after herbicide applications usually do not affect the yield as drastically as in the autumn because of crop competition. But these plants still produce seeds and might cause weed problems in future growing seasons.

The data shown (Tab. 1 and 2) also demonstrate that the emergence of *A. myosuroides* varies within the years and is difficult to predict. The optimal timing for herbicide applications is therefore not always easy. A warning system which can give predictions of emergences of weeds could help farmers to determine optimal herbicide strategies. Most post-emergence herbicides do have a soil activity under certain circumstances but soil activity in the field and its influencing factors remain to be investigated in future studies. In general, the soil activity of herbicides is variable and dependent on many factors which make it difficult to make recommendations at this point.

References

ALDRICH, R. J. AND R. J. KREMER, 1997: PRINCIPLES IN WEED MANAGEMENT. SECOND EDITION, IOWA STATE UNIVERSITY PRESS/AMES, 295-329.

AMANN, A., 1991: EINFLUSS VON SAATTERMIN UND GRUNDBODENBEARBEITUNG AUF DIE VERUNKRAUTUNG IN VERSCHIEDENEN KULTUREN. DISSERTATION, UNIVERSITÄT HOHENHEIM.

AMANN, A., P. ZWERGER AND K. HURLE, 1992: EINFLUSS VON SAATTERMIN UND GRUNDBODENBEARBEITUNG AUF DIE POPULATIONSDYNAMIK VON *ALOPECURUS MYOSUROIDES* HUDS. IN VERSCHIEDENEN KULTUREN. ZEITSCHRIFT FÜR PFLANZENKRANKHEITEN UND PFLANZENSCHUTZ **SONDERHEFT XIII**, 269-276.

BLAIR, A. M, 1985: INFLUENCE OF SOIL MOISTURE ON ISOPROTURON ACTIVITY AGAINST *ALOPECURUS MYOSUROIDES*. WEED RESEARCH **25**, 141-149.

COLBACH, N., B. CHAUVEL, C. DÜRR AND G. RICHARD, 2002: EFFECT OF ENVIROMENTAL CONDITIONS ON *ALOPECURUS MYOSUROIDES* GERMINATION. I. EFFECT OF TEMPERATURE AND LIGHT. WEED RESEARCH **42**, 210-221.

COLLINGS, L.V., A.M. BLAIR, A.P. GAY, C.J. DYER AND N. MACKAY, 2003: THE EFFECT OF WEATHER FACTORS ON THE PERFORMANCE OF HERBICIDES TO CONTROL *ALOPECURUS MYOSUROIDES* IN WINTER WHEAT. WEED RESEARCH **43**, 146-153.

CORNES, D.W., T. SCOTT, E.J. HENDERSON AND P.J. RYAN, 1989: THE EFFICACY AND CROP SAFETY OF A HERBICIDE + SAFENER COMBINATIONS IN CEREALS UNDER UK CONDITIONS. PROCEEDINGS 1989 BRIGHTON CROP PROTECTION CONFERENCE – WEEDS, BRIGHTON, UK, 729-734.

DEVINE, M., S.O. DUKE AND C. FEDKE, 1993: PHYSIOLOGY OF HERBICIDE ACTION. PTR PRENTICE HALL, 441 PP.

FENNER, M., 1991: THE EFFECTS OF THE PARENT ENVIRONMENT ON SEED GERMINABILITY. SEED SCIENCE RESEARCH **1**, 75-84.

FORTMEIER, R., B. BELITZ, B. GLASER AND M. KONRADT, 2006: RALON SUPER-HERBSTANWENDUNG GEGEN *ALOPECURUS MYOSUROIDES* (ACKERFUCHSSCHWANZ) IN WINTERGERSTE. JOURNAL OF PLANT DISEASES AND PROTECTION **SPECIAL ISSUE XX**, 997-1003.

FRYER, J.D. AND R. J. MAKEPEACE, 1977: WEED CONTROL HANDBOOK, VOLUME 1/ PRINCIPLES, INCLUDING PLANT GROWTH REGULATORS. SIXTH EDITION, BLACKWELL SCIENTIFIC PUBLICATIONS.

HEWSON, R.T. AND M.A. READ, 1985: CONTROL OF *ALOPECURUS MYOSUROIDES* (BLACK-GRASS) IN WINTER CEREALS WITH ISOPROTURON - A SUMMARY OF TRIALS CARRIED OUT OVER TWELVE YEARS IN THE UK. PROCEEDINGS 1985 BRITISH CROP PROTECTION CONFERENCE - WEEDS, BRIGHTON, UK, 901-908.

KRÄHMER, H. AND P. E. RUSSEL, 1994: COMPARING GLASSHOUSE AND FIELD PESTICIDE PERFORMANCE II, BCPC MONOGRAPH NO 59, 2-16.

MENCK, B. H., 1968: BIOLOGIE DES ACKERFUCHSSCHWANZES UND SEINE VERBREITUNG. DISSERTATION, UNIVERSITÄT KIEL.

MEINERS, I., B. HONERMEIER AND H. KRÄHMER, 2011: WEED ABUNDANCE DOCUMENTATION IN WINTER WHEAT – THE EMERGENCE OF BLACKGRASS (*ALOPECURUS MYOSUROIDES* HUDS.) WITH AND WITHOUT WEED CONTROL MEASURES AND THE RESULTING VARIATION OF BIODIVERSITY PARAMETERS FOR ARABLE LAND. EWRS WEED MAPPING WORKSHOP, JOKIOINEN, FINNLAND.

MOSS, S.R., A.J. SWAIN, Z.S. HUGHES AND S.K. COOK, 2006: QUANTIFYING THE DORMANCY OF *ALOPECURUS MYOSUROIDES* SEEDS PRODUCED BY PLANTS EXPOSED TO DIFFERENT SOIL AND MOISTURE AND TEMPERATURE REGIMES. WEED RESEARCH **46**, 470-479.

PULCHER-HÄUßLING, M. AND K. HURLE, 1986: EINFLUSS DER N-DÜNGUNG AUF DIE KONKURRENZ ZWISCHEN UNKRÄUTERN UND WINTERWEIZEN. PROCEEDINGS EWRS SYMPOSIUM ON ECONOMIC WEED CONTROL, 137-144.

RAFFEL, H., P. NIELSEN AND W. RÜEGG, 2006: AXIAL-EINFLUSS DES ANWENDUNGSZEITPUNKTES AUF DIE WIRKUNGSSICHERHEIT GEGEN SCHADGRÄSER IN GETREIDE. JOURNAL OF PLANT DISEASES AND PROTECTION **SPECIAL ISSUE XX**, 1039-1046.