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Field study on the occurrence of ground beetles and spiders in genetically modified, herbicide tolerant corn in conventional and conservation tillage systems

A. SCHIER
Business Economics Environment University, Nürtingen-Geislingen, Fakultät II, Studiengang Agrarwirtschaft, FG Phytomedizin / Biotechnologie, Neckarsteige 6-10, 72622 Nürtingen, Germany, e-mail: schier@fh-nuertingen.de

Summary

The habitat choice and population dynamics of arthropods depends highly on microclimate (particular combinations of temperature, humidity and light) and food availability. In agro-ecosystems, abundance can differ locally according to small scale characteristics, influenced in particular by the soil cultivation methods. There are various ways to cultivate soil, including conventional ploughing (PL) and conservation tillage (CT). The latter is a more protective of soil and friendlier to arthropods. Under ct conditions, the crop can be directly planted into a mulch layer which contains varying elements of macro- and mesofauna, thus providing a wide choice of prey for beneficial arthropods.

The objective of this study was to analyse and compare the impact on weed control and arthropod abundance of conventional and conservation tillage methods under different herbicide regimes. The study was conducted between 2002 and 2005 on continuously planted Roundup Ready® (RR) corn. Due to the very good efficacy of the active ingredient Glyphosate, weeds can be controlled in a more flexible time frame compared to e.g. the use of residual herbicides. Weed ground cover might be higher in RR crops for a longer period of time, thus providing favourable environmental conditions for a lot of arthropods.

Pitfall trapping was used to determine the abundance of ground-dwelling arthropods (carabids and spiders). The results show a clear difference between the two soil cultivation methods with regard to the number of individuals per species and the total number of species present. In the ct system, more individuals were trapped than under ploughed conditions, probably due to the higher ground cover of weeds (GUD) and higher food availability.

Weed control is necessary in agricultural fields to obtain maximum crop yield. Irrespective what method is used, highly efficacious weed control may diminish arthropod density due to habitat loss. In CT systems there is per se a longer period of favourable conditions for arthropods.

The results of this multi year study indicate that the combination of ct and herbicide tolerant corn has a positive impact on biodiversity. On the other hand, even though weeds and winter rye as intercrop are well controlled with the herbicide treatments, yield in the CT plots could not always reach the level in the ploughed system. The reason for this effect might be the higher water consumption of the winter-hardy intercrop that leads to less available water for corn in spring.

Keywords: Arthropods, biodiversity, corn, herbicide resistance, conservation tillage, genetically modified plants, GMHT, complementary herbicide, glyphosate, ground beetle, spiders, weeds, weed control

Zusammenfassung

Feldversuch zum Auftreten von Laufkäfern und Spinnen in herbizidresistentem, gentechnisch verändertem Mais unter den Bedingungen der konventionellen und pfluglosen Bodenbearbeitung

Die Biotopwahl und Populationsdynamik von Arthropoden wird in hohem Maße durch das Mikroklima (besonders die Kombination von Temperatur, Luftfeuchtigkeit und Licht) bestimmt. Ihr Auftreten im Agro-Ökosystem hängt von kleinräumigen Strukturen ab, die besonders durch die Art der Bodenbearbeitung beeinflusst werden. Es gibt viele Möglichkeiten der Bodenbearbeitung einschließlich der konventionellen Pflugbearbeitung (PL) und Mulchsaat (CT), wobei die Mulchsaat das bodenschonendere und nützlingsförderndere Anbauverfahren ist. Bei dieser Anbaumethode wird die Kulturpflanze direkt in die Mulchschicht der Zwischenfrucht eingesät. Diese Mulchschicht weist unterschiedliche Anteile an Makro- und Mesofauna auf, was zu einem breit gefächerten Nahrungsangebot für die Arthropoden führt.

Ziel der vorliegenden Studie war es, das Auftreten von Laufkäfern und Spinnen in herbizidresistenten, gentechnisch veränderten Roundup Ready® Mais unter den Bedingungen verschiedener Herbizidvarianten in den konventionellen und pfluglosen Bodenbearbeitungsvarianten zu vergleichen. Dabei wurde der Roundup Ready Mais von 2002 bis 2005 als Monokultur angebaut. Glyphosathaltige Herbizide zeichnen sich durch einen hohen Wirkungsgrad gegenüber wichtigen Unkräutern aus; deswegen können diese in einem relativ weiten Zeitfenster flexibel bekämpft werden. Der Bodenbedeckungsgrad kann deshalb über einen längeren Zeitraum höher sein und damit einer Vielzahl von Arthropoden günstige Lebensbedingungen bieten.

Mit Hilfe der Bodenfallen-Methode wurde die Aktivitätsdichte von Laufkäfern und Spinnen erfasst. Die Ergebnisse zeigen einen deutlichen Einfluss der Bodenbearbeitungsverfahren auf das Auftreten der Bodenarthropoden. In den Mulchparzellen (CT) wurden mehr Individuen gefangen als in den Pflugparzellen (PL). Dies ist zum einen auf den höheren Gesamtunkrautdeckungsgrad (GUD) und zum anderen auf das differenziertere Nahrungsspektrum der Mulchschicht zurückzuführen. Diese Anbaumethode wirkt sich nicht nur positiv auf die Individuenzahl sondern auch auf die Artenanzahl aus.

Die Unkrautbekämpfung ist notwendig, um landwirtschaftliche Erträge zu sichern. Unabhängig von der gewählten Methode führt der Rückgang des Unkrautdeckungsgrades zu einer Verminderung der Arthropodendichte durch Habitatverluste. Insofern bieten Mulchsaatverfahren über einen längeren Zeitraum vorteilhaftere Lebensbedingungen für Arthropoden. Die Ergebnisse dieser mehrjährigen Untersuchungen weisen darauf hin, dass der Anbau von herbizidresistenten Mais unter den Bedingungen der Mulchsaat einen positiven Einfluss auf die Biodiversität der untersuchten Spinnen und Laufkäfer ausübt. Die Unkräuter und der Bodendecker Winterroggen konnten mit den eingesetzten Herbiziden gut bekämpft werden. Der Ertrag in den Mulchvarianten (CT) konnte nicht das Ertragsniveau der Pflugvarianten (PL) erreichen. Die Ursache dafür liegt möglicherweise in einem erhöhten Wasserverbrauch des winterharten Bodendeckers, infolgedessen kann es im Frühjahr zu einem Wassermangel für den Mais kommen.

Stichwörter: HR-Technology, Roundup Ready® Mais, Mulchsaat, GVP, Laufkäfer, Spinnen, Arthropoden, Biodiversität, Unkrautbekämpfung, Bodenbearbeitung, gentechnisch veränderte Pflanzen, Glyphosat, GMHT, Unkräuter

Introduction

Conservation tillage (CT) systems are becoming increasingly important in the further development of sustainable agricultural production. There are many publications that describe the environmental benefits of CT, such as lower impacts on soil organisms, water saving, minimizing erosion of soil, organic carbon content increase, etc (LI *et al.* 2005, SANCHEZ-GIRON *et al.* 2004, DITTMER and SCHRADER 2000, RASMUSSEN 1999). Genetically modified herbicide tolerant (GMHT) crops favour the use of CT methods. However, although there are several studies looking at the effects of GMHT crops on biodiversity under conventional production systems (for example the Farm Scale Evaluations, http://www.pubs.royalsoc.ac.uk/phil_bio/news/fse_toc.html, or ELMEGAARD and PEDERSEN (2001), STRANDBERG and PEDERSEN (2002), little work has been conducted combining both CT and GMHT crops.

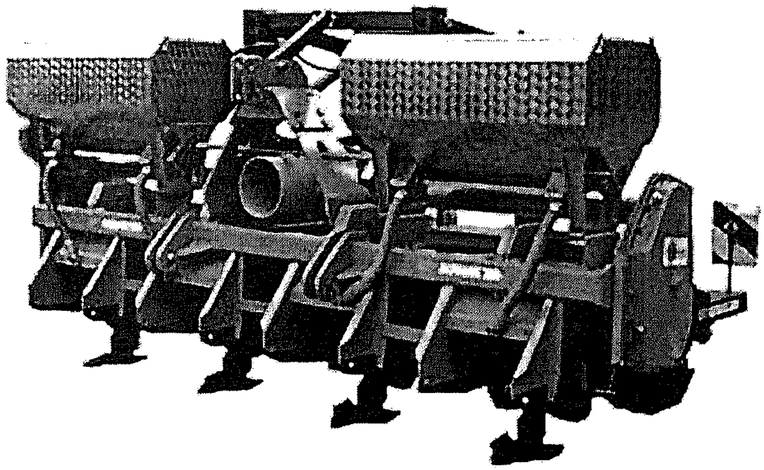

Fig. 1: Left: Althaus Oecosem-2 strip rotary hoe for seeding corn.
Right: Mulched winter rye cover crop with 33 cm milled strips 5.5.2003
Abb. 1: Linkes Bild: Althaus Oecosem-2 Breitbandfräse für die Streifenfrässaat von Mais.
Rechtes Bild: Gemulchter Bodendecker Winterroggen mit 33 cm breiten Frässtreifen 5.5.2003.

Roundup Ready® maize tolerant to the broad spectrum herbicide glyphosate has been commercialised since 1997. The Roundup Ready® crop presents a cost-effective weed control system, with estimated saving for maize growers in the US of 10$/acre (GIANESSI *et al.*, 2002; MARRA *et al.*, 2002) and the opportunity to replace several selective herbicides by a single broad-spectrum herbicide with a favourable human health and environmental profile. Glyphosate is non-persistent and has limited mobility as it binds tightly to soil. The compound presents very low toxicity to humans. Furthermore, it does not bioaccumu late and presents minimal risk to terrestrial and aquatic species including fish, birds, mammals an invertebrates (GIESY *et al.* 2000, WILLIAMS *et al.* 2000).

Tab. 1: Planting and harvest data from 2002 to 2005.
Tab. 1: Aussaat- und Erntedaten von 2002 bis 2005.

	2001/2002	2002/2003	2003/2004	2004/2005
Cover Crop	phacelia	winter rye	winter rye	winter rye
Planting Rate kg/ha	12	110	110	110
Planting Date	15.07.	29.10.	24.10.	29.10.
Mulching Date	02.05.	29.04.	30.04.	03.05.
Planting Rate /m²	9	9	9	9
Planting Date	09.05.	05.05.	04.05./27.05.	12.05.
Emergence Date	21.05.	13.05.	15.05./02.06.	25.05.
Harvest	silage maize	corn maize	corn maize	corn maize
Harvest Date	10.10.	14.10.	19.10.	17.10.
Plot Size m²	30	36	36	54

Post emergence applications of glyphosate is an effective and flexible way to control weeds in corn, where weed competition affects yield mainly between the 3 and 8 leave stage of the crop. The concept of the "weed sensitive phase" of corn was the basis for the development of this study in Roundup Ready® corn. Additionally the establishment of winter-hardy intercrops in autumn would reduce leaching and runoff losses (HALL *et al.* 1984, HALL *et al.* 1991, LEONARD 1988) and cover crops can also suppress the development of weeds (SCHILLING 1997) in sugar beets and (ZINK 1990) in corn.

Materials and methods

The study was conducted at the "Tachenhausen Agricultural Experiment Station" of the Nürtingen-Geislingen University. The geographic and meteorological data can be summarised as following: slight incline, 380 m above sea level, average rainfall of 750 mm/m² and a mean annual temperature of 8 °C. The soil is a weakly pseudogleyic loam. The field experimental design was a split-plot with two PL and two CT large plots with a dimension of 10 m by 54 m.

Different herbicide treatments with 4 replicates were tested in the course of the study. The following Herbicides were applied at the trail: Callisto (Mesotrione, 100g/l), Mikado (Sulcotrion, 300g/l) and MON 78044 (Glyphosate, 360g/l)

In the CT treatment the cover crop was mulched approximately one week before planting the corn in 33 cm wide strips prepared with an Althaus Oecosem-2 seeder (Fig. 1). Fig. 2 shows the different growing conditions of PL and CT plots 16 days after planting.

Fig. 2: Left: Corn in the PL plots 16 days after planting 21.5.2003. Right: Corn in the CT plots 16 days after planting in the strips between the winter rye cover crop 21.5.2003.

Abb. 2: Linkes Bild: Mais in den gepflügten Parzellen (PL) 16 Tage nach der Saat 21.5.2003. Rechtes Bild: Mais 16 Tage nach der Saat in den Parzellen mit konservierender Bodenbearbeitung (CT) zwischen dem Bodendecker Winterroggen 21.5.2003.

Pitfall traps were used to survey populations of soil dwelling arthropods (BARBER 1931). Traps consisted of 8 cm diameter plastic cups with their top level on the same level as the soil surface. Each cup was one-third filled with a 4 % formalin solution with detergent. One trap was positioned in the centre of each plot. All species of ground beetles und spiders were counted and identified. During the trapping period, the pitfall traps were emptied on a weekly basis. Samples were preserved in 70 % alcohol and later identified under a binocular microscope. In 2002, the sampling interval for pitfall trapping was 3^{rd} June to 7^{th} July. The samples were taken from the treatments 1, 2, 3 and 8 as well as from PL and PL and CT areas (see Table 7). In 2003, the sampling interval for pitfall trapping was 3^{rd} June to 4^{th} August. The samples were taken from the treatments 1, 5 and 6 as well as from PL und CT areas. In the night from 23^{rd} to 24^{th} May 2004 one half of the experiment was destroyed. Therefore no pitfall trapping was done anymore. To ensure consistent results and to avoid side effects, all plants of the two interior rows were harvested and chaffed. The results (see Table 8) were transformed into 100 % dry material.

Results

In 2002, the following results are summarized from 32 pitfall traps per sampling interval. The number of ground beetles is split into 874 individuals in the PL area und 1,095 individuals in the CT area. The number of trapped spiders was more than twice as high, namely in total 5,181 individuals from 3 families, 2,312 from the conventional area and 2,869 individuals from the CT area were trapped. In 2002, the results are summarized from 32 pitfall traps per sampling interval. The number of ground beetles is split into 874 individuals in the PL area und 1,095 individuals in the CT area. In comparison to the trapped beetles the number of spiders was more than twice as high, namely in total 5,181 individuals from 3 families, 2,312 from the PL area and 2,869 individuals from the CT area were trapped.

In 2003, treatments were reduced in number and therefore only 24 pitfall traps were used from 3rd June to 4th August. The samples were taken from the treatments 1, 5 and 6 as well as from und PL and CT areas. A total of 3,850 ground beetles were captured in the pitfall traps representing 39 species (Table 3). *Carabus granulatus* L. was the most abundant with 526 and 352 specimens collected in the CT and the PL plots respectively. The total abundance of ground beetles fluctuated through the sampling period with populations peaking at the end of June and end of July in the PL plots; and at the end of June, beginning of July and end of July in the CT plots (Tab. 4).

The "red list" species (TRAUTER *et al.* 1996) *Abax carinatus* (DUFT.) (3, s, !), *Carabus auratus* L. (h, !), *Notiophilus aquaticus* (L.) (v*, mh) were only found in the CT plots. The species *Pterostichus diligens* (STURM) (v, h) was found in the CT and PL plots. The red list species *Pterostichus quadrifoveolatus* LETZN. (v, mh) was only found in a PL plot. It seems the „red list" species prefer the CT plot habitat (Tab. 4).

Tab. 2: Density of activity of ground beetles and spiders in PL and CT plots, average number of individuals caught per day and trap (IDT) 2002.

Tab. 2: Aktivitätsdichte der Laufkäfer und Spinnen, durchschnittliche Individuenfänge pro Tag und Falle (IDT) 2002.

	PL 1	CT 1	PL 2	CT 2	PL 3	CT 3	PL 8	CT 8	PL average	CT average	PL total	CT total
ground beetles												
10.06.	-	-	0.33	0.50	0.26	0.38	0.27	0.30	0.29	0.39	117	161
17.06.	0.57	1.24	0.68	0.76	0.24	0.23	0.48	0.65	0.49	0.72	253	357
01.07.	0.55	1.05	0.32	0.37	0.27	0.4	0.43	0.37	0.39	0.55	197	267
07.07.	1.24	1.62	0.63	0.3	0.29	0.31	0.35	0.38	0.63	0.65	307	310
	2.36	3.91	1.96	1.93	1.06	1.32	1.53	1.70	1.80	2.31	874	1.095
spiders												
10.06.	-	-	0.21	0.35	0.17	0.30	0.18	0.13	0.14	0.19	76	105
17.06.	2.26	3.48	1.39	2.07	1.27	2.50	1.36	2.68	1.57	2.68	791	1.362
01.07.	1.94	1.57	0.85	1.65	1.04	0.86	1.69	1.10	1.38	1.30	697	661
07.07.	1.50	1.72	1.74	1.66	0.85	1.24	1.72	1.18	1.45	1.45	748	741
	5.70	6.78	4.19	5.74	3.33	4.90	4.95	5.07	4.54	5.62	2312	2.869

Tab. 3: Number of ground beetles species in PL and CT plots and red list category ranking (RLCR), 2003 (v = species of the prewarning list, 3 = endangered species, s = seldom, mh = moderate frequent, h = frequent, sh = very frequent, ! = special responsibility of protection in cause of distribution).

Tab. 3: Anzahl der Laufkäferarten in den Pflug- und Mulchvarianten, sowie die „Rote Liste" Einstufung (RLCR) 2003 (v = Arten der Vorwarnliste, 3 = gefährdete Art, s = selten, mh = mäßig häufig, h = häufig, sh = sehr häufig, ! = besondere Schutzverantwortung aufgrund der Verbreitung).

Taxonomy	PL	CT	RLCR
Abax carinatus (DUFT.)	0	1	3, s, !
Abax parallelepipedus (PILL. MITT.)	66	43	h
Agonum muelleri (HERBST)	22	103	sh
Amara aenea (DEGEER)	4	10	sh
Amara familiaris (DUFT.)	15	23	sh
Amara plebeja (GYLL.)	0	1	h
Amara similata (GYLL.)	64	53	h
Anisodactylus signatus (PANZER)	5	4	v*, s
Anchomenus dorsalis (PONT.)	363	130	sh
Bembidion lampros (HERBST)	41	35	sh
Bembidion properans (STEPH.)	24	38	sh
Bembidion quadrimaculatum (L.)	184	248	sh
Carabus auratus L.	0	1	h, !
Carabus auronitens F.	0	1	h
Carabus cancellatus ILL.	20	21	vh
Carabus granulatus L.	352	526	h
Diachromus germanus (L.)	1	0	mh
Harpalus affinis (SCHRK.)	9	53	sh
Harpalus anxius (DUFT.)	0	1	mh
Harpalus distinguendus (DUFT.)	3	2	mh
Harpalus latus (L.)	1	0	h
Harpalus rubripes (DUFT.)	0	1	h
Harpalus tardus (PANZ.)	1	0	h
Loricera pilicornis (FABR.)	36	46	sh
Limodromus assimilis (PAYK.)	4	0	h
Microlestes minutulus (GOEZE)	17	13	h
Nebria brevicollis (F.)	26	3	sh
Notiophilus biguttatus (FABR.)	6	2	h
Notiophilus aesthuans MOTSCH.	1	1	v*, mh
Notiophilus aquaticus (L.)	0	1	v*, mh
Poecilus cupreus (L.)	72	301	h
Pseudoophonus rufipes (DEG.)	244	334	sh
Pterostichus diligens (STURM)	1	2	vh
Pterostichus burmeisteri HEER	1	0	mh, !
Pterostichus melanarius (ILL.)	147	102	sh
Pterostichus quadrifoveolatus LETZN.	1	0	v, mh
Pterostichus vernalis (PANZ.)	0	1	h
Stomis pumicatus (SCHALL.)	1	0	h
Trechus quadristriatus (SCHRK.)	13	4	sh
Total	1,745	2,105	

Tab. 4: Density of activity of ground beetles in PL and CT plots, average number of individuals caught per day and trap (IDT) 2003.

Tab. 4: Aktivitätsdichte der Laufkäfer, durchschnittliche Individuenfänge pro Tag und Falle (IDT) 2003.

	Herbicide Treatment						Tillage System	
Date	PL 1	CT 1	PL 5	CT 5	PL 6	CT 6	PL average	CT average
10.06.	0.89	3.39	2.21	1.89	1.07	2.18	1.39	2.49
16.06.	1.50	2.67	1.83	2.13	1.92	3.08	1.75	2.63
23.06.	2.86	3.43	3.71	3.54	3.25	4.11	3.27	3.69
30.06.	2.50	2.50	2.39	1.93	1.64	1.50	2.18	1.98
07.07.	3.11	3.54	2.21	2.93	0.79	3.32	2.04	3.26
14.07.	2.50	2.32	2.04	2.75	2.46	3.29	2.33	2.79
21.07.	2.07	3.04	2.07	2.21	4.32	3.18	2.82	2.81
28.07.	3.14	3.54	3.75	3.75	3.54	3.21	3.48	3.50
04.08.	2.00	2.04	1.93	2.29	1.36	2.57	1.76	2.30
Average	2.29	2.94	2.46	2.60	2.26	2.94	2.34	2.83

In 2003, a total of 3,436 spiders were captured in the pitfall traps, i.e. 30 species belonging to 8 families (Table 5). The Linyphiidae had the largest share of the spider population, with 11 species. The number of identified species was lower in the PL plots (23 species) and higher in CT plots (25 species). The spider dynamics were similar in all CT plots. In July, the maximum values reached 8.36 IDT (see Table 6, CT 6). Generally, higher activities were reported in mulched plots, with an average of 3.15 IDT than in ploughed plots with an average of 1.45 IDT (VOLKMAR and SCHIER 2005).

In all variants, the eudominant species (> 32 %, ENGELMANN 1978) was the xerophilous, eu-rychrone miniature spider *Oedothorax apicatus*. It colonized mainly open biotopes, fields and persistent ruderal places (MAURER and HÄNGGI 1990). A higher activity of *O. apicatus* (1.80 IDT) was observed on the untreated control plots (CT) compared to variant CT 5 with 1.33 IDT and CT 6 with 1.15 IDT. Higher activity levels were also recorded in the untreated control plots (PL 1) with 1.10 IDT compared to 0.91 IDT in the PL 5 and 0.77 IDT in the PL 6 plots.

Typical open-land inhabitants were abundant (*Pardosa agrestis*, *Erigone dentipalpis*, *Erigone atra*), shown in Table 5. The lycosids (*P. agrestis, P. palustris*) profited more than any other spider families from reduced soil tillage (*P. agrestis*: CT, average 0.92 IDT); PL, average 0.15 IDT). The two species *Microlinyphia impigra* (O.P.-CAMBRIDGE), and *Drassyllus lutetianus* (L. KOCH) were listed in the Red Data Book of Baden-Württemberg and Germany (PLATEN *et al.* 1996).

To summarize, the results suggest that reduced soil tillage does have a positive effect on epigeous spiders. Since spiders feed on aphids, these results might also be interesting in terms of natural pest control.

Weed control and yields from 2002 to 2005 are outlined from Tab. 7 to Tab. 9. Because of the low weed pressure in the PL plots in 2002, none of the herbicide treatments showed any significant increase in yield. In the CT plots, the herbicide treatments increased yield. STEME (*Stellaria media)* represented the major part (70 %) of the weed population. Glyphosate-treated plots showed best weed control in PL and CT situations. But the treatment with the conventional herbicides reached only 88.1 to 90 % STEME control. In any case, this did not translate into yield loss. When comparing the untreated plots of PL and CT the latter yielded lower due to increased competitive effect from the cover crop, but each herbicide treatment compensated this impact to a level comparable to PL plots.

Corn seedlings within the strips of the cover crop winter rye are protected against cold winds in early May 2003 (Fig. 2). In PL plots emerged corn plants showed even chlorosis due to cold stress. This was not the case in CT; there young plants were more vigourus.

Tab. 5: Number of spider species in PL and CT plots and red list category ranking (RLCR), 2003, sh = very common, h = common, s = rare, v = pre warning list, sv = special responsibility due to a limited population.

Tab. 5: Anzahl der Spinnenarten 2003, sh=sehr häufig, h = häufig, s = selten, v = Vorwarnliste, sv = Besondere Schutzverantwortung aufgrund der Verbreitung.

Taxonomy	PL	CT	RLCR
Gnaphosidae			
Drassyllus lutetianus	0	1	h
Drassyllus pusillus	1	0	sh
Micaria pulicaria	0	1	sh
Zelotes subterraneus	1	0	h
Linyphiidae			
Bathyphantes gracilis	1	1	sh
Diplostyla concolor	18	8	sh
Erigone atra	48	64	sh
Erigone dentipalpis	94	141	sh
Lepthyphantes tenuis	8	3	h
Meioneta rurestris	44	30	sh
Microlinyphia impigra	0	1	sv
Oedothorax apicatus	681	1067	sh
Oedothorax fuscus	0	2	h
Porrhom. microphthalmum	1	2	h
Walckenaeria vigilax	0	1	v
Lycosidae			
Alopecosa (Juvenile)	1	0	
Aulonia albimana	0	1	sh
Lycosidae (Juvenile)	0	14	
Pardosa agrestis	144	693	h
Pardosa palustris	19	231	sh
Pardosa prativaga	1	1	h
Pirata latitans	1	3	h
Trochosa ruricola	22	55	sh
Xerolycosa miniata	1	4	v
Pisauridae			
Pisaura mirabilis	1	0	sh
Salticidae			
Salticidae (Juvenile)	0	1	
Theridiidae			
Enoplognatha thoracica	2	0	sh
Robertus lividus	4	0	sh
Tetragnathidae			
Pachygnatha clercki	1	0	sh
Pachygnatha degeeri	15	26	sh
Thomisidae			
Thomisidae (Juvenile)	0	1	
Xysticus kochi	1	4	sh
Total	1,080	2,356	

Tab. 6: Density of activity of spiders in PL and CT plots, average number of individuals caught per day and trap (IDT) 2003.

Tab. 6: Aktivitätsdichte der Spinnen, durchschnittliche Individuenfänge pro Tag und Falle (IDT) 2003.

	Herbicide Treatment						Tillage System	
Date	PL 1	CT 1	PL 5	CT 5	PL 6	CT 6	PL average	CT average
10.06.	3.00	4.96	2.61	6.68	1.89	2.79	2.50	4.81
16.06.	1.75	2.63	1.46	1.54	1.29	1.29	1.50	1.82
23.06.	1.68	3.32	1.21	2.46	1.07	2.04	1.32	2.61
30.06.	3.57	6.54	1.50	4.57	2.00	4.57	2.36	5.23
07.07.	1.96	4.11	1.36	2.64	1.68	3.71	1.67	3.49
14.07.	1.50	5.18	1.75	3.75	1.14	8.36	1.46	5.76
21.07.	0.57	1.54	0.46	1.14	0.64	1.39	0.56	1.36
28.07.	1.04	2.93	0.89	0.89	0.61	1.18	0.85	1.67
04.08.	1.14	2.82	0.82	0.86	0.61	1.04	0.86	1.57
Average	1.80	3.78	1.34	2.73	1.21	2.93	1.45	3.15

In 2003, good weed control was achieved in all PL and CT plots regardless of the timing of the herbicide treatment. Due to the extremely dry season weed pressure was very low. CHEAL and STEME represented 90 % of the weed population. In Table 7 the KDG (ground cover of crop) in the CT plots was lower because of the cover crop competition to corn. All treatments in the PL and CT plots (Table 9) showed significant higher yields compared to the untreated control. Within the PL treatments no significant differences were recorded but in the CT plots smaller yields were found in CT 2 and CT 6. In CT 6 the 3.0 l Roundup treatment was applied 9 days later than the other herbicides. Obviously this delayed weed control caused a significant decrease in yield of 13.5 to 15.9 dt/ha. The conventional corn herbicides from CT 2 stopped growth of winter rye only very slowly. In CT 2 the rye could even form ears, but without grains. This also results in significant yield losses that are comparable with delayed herbicide application in CT 8. The efficiency of weed control and yield in CT 2 (28.05.) und CT 6 (06.06.) is nearly on the same level but the herbicide in plot CT 6 was applied 9 days later. Under these circumstances fast weed control is very important as water might become the limiting factor for corn development. Because of the slower herbicide activity of CT 2 (1.5 C + 1.5 M) against the cover crop this resulted in an significant yield loss even compared to CT3, where Roundup was applied twice in very low doses (1.0 R) + (1.0 R).

In 2004 in the night from 23rd to 24th May 2004 all the PL plots were destroyed by unknown individuals. So corn in the PL plots was planted on 27th May for a second time. Apart from this in all PL and CT plots good weed control was achieved regardless of the timing of the herbicide treatment.

In 2005, PL 3 received only 1.5 R at the 2nd herbicide treatment due to low weed pressure.

Tab. 7: Herbicide treatment, ground cover of the crop (KDG), weedcover (UDG) in the control plot (Treatment 1) and efficiency (% eff.) in the treated plots, 2002, 2003, 2004 und 2005 (herbicides: C = Callisto (Mesotrione, 100g/l), M = Mikado (Sulcotrion, 300g/l), R = Roundup (Glyphosate, 360g/l)).

Tab. 7: Herbizidbehandlungen, Kulturdeckungsgrad (KDG), Unkrautgeckungsgrad (UDG) in der unbehandelten Kontrolle (treatment 1) und Wirkungsgrade der Herbizidbehandlungen (% eff.), 2002, 2003, 2004 und 2005 (Herbizide: C = Callisto (Mesotrione, 100g/l), M = Mikado (Sulcotrion, 300g/l), R = Roundup (Glyphosate, 360g/l)).

2002	application (crop growth stage related)			23.07.02 (PL)		23.07.02 (CT)	
Treatment	BBCH 13 31.05.	BBCH 16 11.06	BBCH 18 17.06.	GUD (1) % eff	KDG	GUD (1) % eff.	KDG
1				75.0	53.8	83.8	47.5
2	1.5 C + 1.5 M			90.0	60.0	88.1	56.3
3	2.0 R		2.0 R	98.7	65.0	98.4	65.0
4	3.0 R		3.0 R	98.7	65.0	98.7	66.0
5		3.0 R		98.0	60.0	97.6	62.5
6		1.0 R		96.3	62.5	93.4	63.8
7		2.0 R		98.0	60.0	97.9	63.8
8		1.5 R		98.0	61.3	97.6	66.3
9		3.0 R + 0.75 C		98.7	63.8	98.8	63.8
2003	application (crop growth stage related)			17.06.03 (PL)		17.06.03 (CT)	
	BBCH 13 28.05.	BBCH 16 04.06	BBCH 18 11.06.	GUD (1) % eff	KDG	GUD (1) % eff.	KDG
1				48.8	47.0	56.3	18.8
2	1.5 C + 1.0 M			98.0	50.0	98.2	27.5
3	1.0 R		1.0 R	98.0	50.0	98.2	31.3
4	2.0 R		2.0 R	98.0	50.0	98.2	30.0
5	3.0 R		3.0 R	98.0	50.0	98.2	29.3
6		3.0 R		98.0	50.0	98.2	28.8
2004	application (crop growth stage related)			destroyed (PL)		05.07.04 (CT)	
	BBCH 13 28.05. 21. 06. (PL)	BBCH 16 09.06. 26. 06. (PL)	BBCH18 21.06. 30. 06. (PL)			GUD (1) % eff.	KDG
1				-	-	77.5	32.0
2	1.5 C + 1.0 M			-	-	99.5	43.8
3	1.0 R		1.0 R	-	-	97.7	52.0
4	3.0 R		3.0 R	-	-	99.9	38.8
5		1.5 R		-	-	99.7	43.8
6		3.0 R		-	-	98.5	46.8
2005	application (crop growth stage related)			29.06.05 (PL)		29.06.05 (CT)	
	BBCH 13 02.06.	BBCH 16 13.06.	BBCH 18 23.06	GUD (1) % eff.	KDG	GUD (1) % eff.	KDG
1				47.5	48.8	60.0	30.0
2	1.5 C + 1.0 M			99.2	50.0	72.8	45.0
3	3.0 R		1.5 R (PL) 2.0 R (CT)	99.8	50.0	77.0	50.0
4		3.0 R		98.3	50.0	54.2	43.0

Tab. 8: Yield silage maize (t/ha, 100 % dry material) in the ploughing and CT plots, 10th October 2002 [herbicides: C = Callisto (Mesotrione, 100g/l), M = Mikado (Sulcotrion, 300g/l), R = Roundup (Glyphosate, 360g/l)].

Tab. 8: Erträge Silomais (t/ha, 100 % Trockenmasse) in den Pflug- und Mulchparzellen, 10. Oktober 2002 [Herbizide: C = Callisto (Mesotrione, 100g/l), M = Mikado (Sulcotrion, 300g/l), R = Roundup (Glyphosate, 360g/l)].

2002	application (crop growth stage related)			PL			CT		
	BBCH 13	BBCH 16	BBCH 18						
	31.05.	11.06.	17.06.	t/ha	rel.		t/ha	rel.	
1				18.0	100.0	a	14.4	100.0	b
2	1.5 C + 1.5 M			17.0	94.8	a	17.5	122.0	a
3	2.0 R		2.0 R	17.7	98.8	a	16.1	112.0	ab
4	3.0 R		3.0 R	16.9	94.4	a	17.9	124.8	a
5		3.0 R		17.0	94.8	a	18.1	125.7	a
6		1.0 R		16.3	90.7	a	16.2	112.6	ab
7		2.0 R		16.5	91.6	a	17.0	118.4	ab
8		1.5 R		17.9	99.9	a	16.6	115.4	ab
9		3.0 R + 0.75 C		17.5	97.6	a	16.9	117.6	ab
LSD (P=.05)				1.55			1.92		
Standard Deviation				1.07			1.31		

Discussion

Looking at the results of 2003, one has to take into account the climatic extremes of this year. Precipitation was only slightly more than half of the average annual precipitation. The average-temperature in August was 6 °C higher than normal. Between May and September 2002 the rainfall was 550 mm compared with only 214 mm in the same period the year 2003. This had a negative influence on the development of corn. Particularly corn in the CT plots could only develop very slowly. Before sowing winter rye was mulched down but then generated further on and was thus competing with corn with regard to water. Due to the dry weather there were fewer weeds in 2003 than in an average year. Besides that, in the untreated control CHEAL developed very well.

Abundance of ground beetles in 2003 was similar between the CT 1 (no herbicide) and the CT 6 (one application at the 6 the leaf stage); however, abundance was lower at the CT 5 (two applications of herbicide). Abundance of spiders was greater in the CT 1 treatment followed by CT 6, with the lower abundance in CT 5. Abundance of epigeal arthropod is usually correlated to ground cover (HUMMEL *et al.* 2002; BUCKELEW *et al.* 2000). Toxicological data have shown no effects of the herbicide glyphosate on insects (GIESY *et al.* 2000). In this study, weed control efficiency between treatments varied between years. In 2003, there was no difference between CT 5 and CT 6; however, in 2002, the CT 5 treatment was more efficient than CT 6. One possible explanation for the observed lower abundance of ground beetles and spiders in the treatments that received herbicide might have been a slighter larger cover crop in the CT 5 treatments not perceived by the observer collecting data on ground cover.

Tab. 9: Yield grain maize (dt/ha, 100 % dry material) in the ploughing and CT plots, 2003, 2004 and 2005.
Tab. 9: Ertrag Körnermais (dt/ha, 100 % Trockenmasse) in den Pflug- und Mulchparzellen, 2003, 2004 und 2005.

2003	application (crop growth stage related)			14.10. (PL)			14.10. (CT)		
	BBCH 13 28.05.	BBCH 16 05.06.	BBCH 18 28.06.	dt/ha	rel.		dt/ha	rel.	
1				64.9	100.0	b	10.4	100.0	c
2	1.5 C + 1.5 M			77.3	119.1	a	48.4	465.4	b
3	1.0 R		1.0 R	74.6	115.0	a	61.3	589.7	a
4	2.0 R		2.0 R	75.2	115.8	a	63.5	611.1	a
5	3.0 R		3.0 R	76.3	117.5	a	62.6	601.8	a
6		3.0 R		75.9	116.9	a	47.8	459.6	b
LSD (P=.05)				5.36			5.92		
Standard Deviation				3.56			3.93		
2004	application (crop growth stage related)			19.10. (PL)			19.10. (CT)		
	BBCH 13 28.05. 21. 06. (PL)	BBCH 16 09.06. 26. 06. (PL)	BBCH18 21.06. 30. 06. (PL)	dt/ha	rel.		dt/ha	rel.	
1				69.8	100.0	a	30.6	100.0	b
2	1.5 C + 1.5 M			69.9	100.1	a	59.1	193.0	a
3	1.0 R		1.0 R	71.4	102.3	a	57.5	187.7	a
4	3.0 R		3.0 R	72.0	103.1	a	57.2	186.5	a
5		1.5 R		70.5	100.9	a	54.9	179.0	a
6		3.0 R		69.8	100.0	a	55.2	180.2	a
LSD (P=.05)				4.38			11.99		
Standard Deviation				2.91			7.98		
2005	application (crop growth stage related)			17.10. (PL)			17.10. (CT)		
	BBCH 13 02.06.	BBCH 16 13.06.	BBCH 18 23.06.	dt/ha	rel.		dt/ha	rel.	
1				81.9	100.0	b	64.3	100.0	b
2	1.5 C + 1.5 M			93.2	113.8	a	82.7	128.8	a
4	3.0 R		1.5 R	94.1	114.9	a			
4	3.0 R		2.0 R				87.8	136.8	a
5		3.0 R		90.1	110.0	ab	82.8	128.5	a
LSD (P=.05)				8.74			7.39		
Standard Deviation				5.47			4.62		

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