Sektion 2: Klimawandel, Populationsdynamik und Biodiversität

Section 2: Climate change, population dynamics and biodiversity

Use of the crop maize to reduce yellow nutsedge (*Cyperus esculentus* L.) pressure in highly infested fields in Switzerland

Mais als mögliche Sanierungskultur für stark mit Erdmandelgras (Cyperus esculentus L.) verseuchte Flächen in der Schweiz

Martina Keller[1]*, Jürgen Krauss[1], Reto Neuweiler[1] and René Total[1]

[1] Forschungsgruppe Extension Gemüsebau Forschungsanstalt Agroscope Changins-Wädenswil/ Schloss 1, 8820 Wädenswil, Schweiz

*Corresponding author, martina.keller@agroscope.admin.ch

DOI 10.5073/jka.2014.443.013

Abstract

Cyperus esculentus L. causes high yield losses in many crops worldwide. In Switzerland it was observed for the first time about 30 years ago. Since then it has become a serious weed in several regions - especially where vegetables are produced. Growing vegetables in heavily infested fields should be abandoned due to their low competitiveness and the lack of available, effective herbicides. Contrarily, in maize several herbicides with a partial effect on *C. esculentus* are registered. Thus, continuous cultivation of maize including the use of the most effective herbicides against *C. esculentus* could help reducing infestation levels in heavily infested fields.

Field trials were carried out at two sites in maize during 2011 and 2012. Different herbicide combinations, hoeing and herbicide applications combined with hoeing were the applied treatments. Split application was compared with one single application of the same amount of product. The effect of an additional, late under leaf herbicide application was determined as well.

Cyperus esculentus coverage was estimated in the fields in 2011. Plots were sampled in spring 2011, autumn 2011 and autumn 2012. The Number of *C. esculentus* sprouts germinated from the soil samples was determined under greenhouse conditions.

The most effective herbicide combination of registered active ingredients was rimsulfuron and mesotrione. *S*-metolachlor was effective as well, especially if combined with mechanical weed control. Halosulfuron-methyl applied twice provided the best *C. esculentus* control. Split application tended to be more effective than a single application. Control of *C. esculentus* could be improved considerably with an additional herbicide application in late June (under leaf).

The treatments with highest *C. esculentus* control determined in the field trials and combinations thereof are effective treatment options for *C. esculentus* control in maize. These findings indicate and confirm that maize cropped for several years with intensive weed control could successfully decrease *C. esculentus* infestation levels in farmers' fields.

Keywords: Halosulfuron-methyl, late application, mechanical weed control, *S*-metolachlor, splitting

Zusammenfassung

Cyperus esculentus verursacht in vielen Kulturen weltweit erhebliche Ertragsausfälle. In die Schweiz wurde es etwa vor 30 Jahren eingeschleppt. Seither ist es in mehreren Regionen zu einem Problemunkraut geworden – besonders in Gemüsebauregionen. Der Anbau von Gemüsekulturen auf betroffenen Flächen ist jedoch nicht sinnvoll, da deren Konkurrenzkraft gering ist und keine wirksamen Herbizide zur Verfügung stehen. Im Gegensatz dazu sind im Mais mehrere Herbizide mit einer Teilwirkung auf *C. esculentus* zugelassen. Daher könnte Maisanbau über mehrere Jahre kombiniert mit intensivem Einsatz von Herbiziden den Befallsdruck in stark befallenen Flächen reduzieren.

Feldversuche wurden an zwei Standorten 2011 und 2012 in Mais durchgeführt. Verschiedene Herbizidkombinationen, Hacken sowie Herbizide kombiniert mit Hacken wurden untersucht. Zudem wurde die Wirkung einer Splittingapplikation mit einer einmaligen Anwendung derselben Aufwandmenge verglichen und die Wirkung einer Spätapplikation (unter Blatt) untersucht.

Die *C. esculentus* Bedeckung wurde im Sommer 2011 im Feld bonitiert. Die Parzellen wurden im Frühjahr 2011, Herbst 2011 und Herbst 2012 beprobt. Die Bodenproben wurden im Gewächshaus angetrieben und anhand der Anzahl der Erdmandelgraskeimlinge wurde die Wirkung der Versuchsglieder bestimmt.

Die wirksamste Herbizidmischung zugelassener Wirkstoffe war Rimsulfuron und Mesotrione. *S*-metolachlor war auch wirksam, besonders in Kombination mit mechanischer Unkrautkontrolle. Mit Halosulfuron-methyl wurde die beste Wirkung auf *C. esculentus* erzielt. Grundsätzlich war eine Splittingapplikation wirksamer als eine einmalige Behandlung. Die Bekämpfung von *C. esculentus* konnte noch verbessert werden, wenn zusätzlich eine Spätapplikation (Ende Juni, Unterblatt) erfolgte.

Aus unseren Ergebnissen können Landwirte mehrere wirksame Optionen zur Bekämpfung von Erdmandelgras in Mais ableiten. Die Ergebnisse der wirksamsten Versuchsglieder zeigen und bestätigen, dass ein intensiver Maisanbau kombiniert mit konsequenter Bekämpfung über die Jahre den Befallsdruck zu reduzieren vermag.

Stichwörter: Halosulfuron-methyl, mechanische Unkrautkontrolle, S-metolachlor, Spätapplikation, Splitting

Introduction

Cyperus esculentus (yellow nutsedge) causes high yield losses in many regions and many crops worldwide (KEELEY, 1987). Originally, *C. esculentus* was confined to warmer regions and its natural habitat were riparian areas. Today it is found also in regions with colder climate (RIEMENS *et al.*, 2008; ANONYMOUS). In Switzerland it was observed for the first time about 30 years ago. In the meantime it has spread to several regions and has become a difficult to control weed especially in vegetable growing areas. *C. esculentus* reproduces vegetatively by forming tubers in the soil (RIEMENS *et al.*, 2008). These tubers are the overwintering plant parts and are easily transported mainly with machinery, infested soil, planting material or harvesting remains. The former is becoming more and more relevant because of the region-wide operating contractors. Infested fields should be managed last and neither soil, nor planting material nor harvesting remains should be transported from affected fields to other fields. The thorough cleaning of machinery at the spot further reduces the risk of dispersal (these advices can be found in leaflets of different extension services, reports or articles *e.g.* KELLER *et al.* (2013)).

It is crucial to stop further dispersal of *C. esculentus*. If *C. esculentus* is carried to a new field, early detection is of high importance. Small patches can still be removed with moderate effort. For already highly infested fields strategies need to be found to reduce infestation pressure of *C. esculentus* to a steadily low level. In the long run the eradication of *C. esculentus* in these fields should be aimed at. Vegetable crops, sugar beet and potatoes should not be grown in infested fields, because these crops are of low competitiveness, little effective control measures are available and the risk of transporting tubers to new fields is high.

Several herbicides with some efficacy are registered for use in Switzerland, the majority of them in maize (*Zea mays* L.). Several aspects suggest the planting of maize to reduce *C. esculentus* pressure in heavily infested fields: i) the range of herbicides available (ANONYMOUS), ii) the possibility to hoe, iii) the similar germination requirements of yellow nutsedge and maize (RIEMENS *et al.*, 2008) allowing to optimize timing of weed control, iv) the strong shading of maize plants after canopy closure (KEELEY, 1987), and v) the low risk of further spreading.

Thus, the aims of this study were i) to test different herbicides and herbicide combinations for their efficacy against *C. esculentus* in maize, ii) to investigate the effect of splitting and a late herbicide application, iii) to investigate the effect of mechanical control and the combination of it with chemical control measures.

Material and Methods

Field trials were installed at site A (47.386358°; 9.635847°, 406m) and site B (47.187080°, 7.723559, 260m) in 2011 and 2012. The trials were carried out at the same coordinates in both years to investigate the effect over years in promising treatments. The soil at site A is a loamy clay and has a high organic content, average temperature in 2011 was 11.7 °C and in 2012 10.2 °C. Annual precipitation was 1302 mm in 2011 and 1322 mm in 2012 (nearest by weather stations, www.agrometeo.ch). At site B soil type is loam, average temperature was 9.9 °C in 2011 and 9.2 °C in 2012. In 2011 annual precipitation was 1819 mm and in 2012 1937 mm (nearest by weather station, www.agrometeo.ch). The sites were chosen because *C. esculentus* infestation was relatively high and the farmers were willing to participate. Maize was cropped according to regional practices.

At site "A three trials with a randomized complete block design each were carried out: In experiment 1 mainly single herbicide treatments and the effect of splitting were investigated. There were 4 replicates; plot size was 6 m by 10 m. For splitting the plot of the respective herbicide combination was split in two subplots: in subplot "a" the herbicide was applied as a single application and in subplot "b" as split application (two applications). In experiment 2, hoeing and herbicide application combined with hoeing was tested with two replicates. Plot size was 6 m by 20 m. In experiment 3, different herbicides were combined and up to three applications were carried out. Plot size was 6 m by 10 m with three replicates. At site B, experiment 1 and experiment 2 were carried out, accordingly.

Treatment levels carried out in 2011 are given in Table 1. In treatment $12_{\_2011}$, a third application with bentazon was scheduled, but could not be carried out. Thus, treatment $11_{\_2011}$ and 12_{2011} were identical. Some of the treatments were replaced by more promising herbicide treatments in 2012 (Tab. 2).

Herbicide application took place at the 3 leaf stage of maize (first split or single application) and at the 6 leaf stage (second split) with an experimental plot sprayer (1.7 bar, IDK 12002 nozzles, 3.6 km/h, nozzle distance 0.25 m, 400 L/haL/ha). Late herbicide application was carried out at a maize height of about 2 m in late June with a backsprayer (Foxmotori.IT, IDK 12002 nozzles, 2 bar, 400 L/ha). 0.5 L/ha Excell (anionic surfactants) (2011) and 0.5 L/ha Break-thru (trisiloxane based) (2012) were added to the post-emergence applications (POST) to enhance spreading and wetting of the *C. esculentus* plants. For treatment $C_{\_2011}$, *S*-metolachlor was applied after sowing and one day before sowing in treatment B and C_{2012}. The combined sowing machine ensured incorporation of the herbicide into the soil. Hoeing was carried out twice using a tool carrier (FOBRO-Mobil, Bärtschi-FOBRO AG) according to weather condition of the respective year. Two rows at a time were hoed. Plot length of these treatments was doubled to ensure optimal working conditions in the inner part of the plots where samples were taken.

Before initiation of the trials in spring 2011, and after experimentation in autumn 2011 and in autumn 2012, 4 soil samples were taken within each plot and subplot (treatments in which splitting was compared) and pooled to a bulk sample (10 L soil). Soil samples were stored for some weeks at 0°-1°C to mimic the cold season. Thereafter, they were transferred into shallow pots in the greenhouse. The number of *C. esculentus* sprouts emerged after 8 weeks were counted ($N_{\_CE}$) in the greenhouse. For the initially taken soil samples in spring 2011 the number of *C. esculentus* sprouts emerged after 4 weeks was only recorded. For experiment 3 no initial soil samples could be taken.

To investigate the relationship between $N_{\_CE}$ determined in the greenhouse and *Cyperus esculentus* coverage estimated in the field, *Cyperus esculentus* coverage estimated in the fields 8 weeks (site A) and 7 weeks (site B) after the second split application in 2011 and $N_{\_CE}$ of the soil samples taken in autumn 2011 were correlated.

Due to the low number of sites and years, trials were analyzed separately. In experiment 1 two treatment levels were exchanged after the first year of experimentation (2011). In experiment 2, one treatment was replaced. In experiment 3, five treatments were modified. To account for the different plot history due to different infestation levels at trial start and due to these changes in the treatments (compare Tab. 1 and Tab. 2), number of *C. esculentus* sprouts counted in the greenhouse in the soil samples of the previous year in the respective plot or subplot were included as co-variable in the model, if data was available. The model presented in the syntax according to PIEPHO *et al.* (2004) in equation 1 was employed for analyses.

$N_{\_CE} = treatment + N\_{CE\_year\_before} + block: \underline{e}$ 1)

Where $N_{\_CE}$ denotes number of emerged *C. esculentus* sprouts after 8 weeks in the greenhouse per 10-L soil, *treatment* denotes the factor treatment. For the trial year 2012, $N\_{CE\_year\_before}$ is the number of emerged *C. esculentus* sprouts after 8 weeks in the greenhouse per 10 L soil in the same plot/subplot the year before. For 2011, the number of *C. esculentus* sprouts emerged after 4 weeks in the greenhouse from the initially taken soil samples served as co-variable for the analyses; block codes for the replicates and $\underline{e}$ denotes the error. Block was taken as fixed effect. Subplot error was not accounted for. The co-variable $N\_{CE\_year\_before}$ was dropped from the model if its estimate was positive and clearly above zero and lack of fit test indicated that the two models were not significantly different. Analyses were carried out in R (R CORE TEAM, 2012), using the default packages and the 'lsmeans' package (LENTH, 2013). If lsmeans (least-squares means) estimates were below zero, value was adjusted to zero. For the relationship between *C. esculentus* coverage and $N_{\_CE}$ a simple linear model was employed for site A and site B.

Results

At the beginning of the trials, $N_{\_CE}$ averaged 6.2 and 14.9 per 10 L soil at site A and site B, respectively. Infestation of *C. esculentus* was highly variable and patchy within the fields. This resulted in considerable variation within the trials. Apart from *C. esculentus* main weeds were *Polygonum persicaria* and millets (mainly *Echinochloa crus-galli*).

The linear models explained only 3.5% (site A) and 16% (site B) of the variance (adjusted R^2 in %) and no clear relationship could be found between *C. esculentus* coverage and $N_{\_CE}$ (Fig. 1).

In experiment 1, there was a trend of lower $N_{\_CE}$ in the split treatment of mesotrione (3b) compared with single application of mesotrione (3a) in three out of four trials (Tab. 1 and Tab. 2). In contrast, for nicosulfuron ($4a_{\_2011}$, $4b_{\_2011}$) and the herbicide containing isoxaflutole and thiencarbazone ($4a_{\_2012}$, $4b_{\_2012}$) no difference could be observed between single application and splitting. For $4b_{\_2011}$ and $4a_{\_2012}$, $N_{\_CE}$ was found to be significantly higher compared with the halosulfuron-methyl treatment at site A. This treatment was the most effective in experiment 1.

The late application of bentazon tended to decrease $N_{\_CE}$ independent of the control methods applied before: Treatment $C_{\_2012}$ versus B (2012); $13_{\_2012}$ versus $11_{\_2012}$. In experiment 2 (2012), treatment efficacy was increased if *S*-metolachlor was incorporated in the soil before sowing and hoed twice thereafter compared with the mechanical treatment (A). If an additional application of bentazon was carried out late in the season $N_{\_CE}$ was even lower. At site A the incorporation of *S*-metolachlor tended to be more effective than the PRE-emergence application, whereas at site B it was vice versa in 2011.

In experiment 3, the high efficacy of applying bentazon could be clearly observed in 2011. Several applications and the combination of different active ingredients resulted in low values of $N_{\_CE}$. In 2012, $N_{\_CE}$ was significantly higher in treatment $12_{\_2012}$ compared with the other treatments of experiment 3. In treatment $12_{\_2012}$, the herbicides were applied in sequence and not in combination, and no bentazon was applied late in the season.

Tab. 1 Treatment levels and lsmeans of the number of *C. esculentus* germinated in the greenhouse, counted after 8 weeks, site A and B (2011).

Tab. 1 *Versuchsvarianten und lsmeans der Anzahl gekeimter* C. esculentus *nach 8 Wochen im Gewächshaus 2011, Standort A und B.*

	treatment description			**N_CE (N germinated per 10 l soil)**	
	mechanical / applied herbicides	**active ingredient, g/ha**	**application time (BBCH)**	**site A**	**site B**
Trial 1					
1	untreated control	-		15.4 (4.8)4	23.6 (5.4)
2_2011	Dual Gold	S-metolachlor, 1920	PRE[2]	3.1 (3.1)	4.0 (6.1)
3a	Callisto	mesotrione, 150	13	18.0 (4.9)	4.4 (5.5)
3b	Callisto	mesotrione, 2 x 75	13,16	7.2 (4.9)	5.4 (5.5)
4a_2011	Dasul	nicosulfuron, 60	13	18.9 (4.8)	6.9 (5.2)
4b_2011	Dasul	nicosulfuron, 2 x 30	13, 16	26.1 (4.8)	7.9 (5.2)
5	Permit	halosulfuron-methyl[1], 2 x 15	13, 16	2.4 (4.7)	5.6 (5.3)
p-value				0.03	0.18
Trial 2					
A	Harrowing		13, 16	13.1 (0.5)	7.0 (13.5)
B	Dual Gold,	S-metolachlor, 1920	IBS[3]	0.0 (0.5)	20.0 (13.5)
	harrowing		13, 16		
C_2011	Dual Gold,	S-metolachlor, 1920	PRE	3.8 (0.4)	6.0 (16.5)
	harrowing		13, 16		
p-value				0.06	0.76
Trial 3					
10_2011	Permit	halosulfuron-methyl[1], 2 x15	13, 16	6.3 (2.4)	
	Titus	rimsulfuron, 2 x 5	13, 16		
	Basagran	bentazon, 960	63		
	Callisto	mesotrione, 75	63		
11_2011	Basagran	bentazon, 2 x 960	16, 63	6.3 (2.4)	
	Callisto	mesotrione, 75	63		
12_2011	Basagran	bentazon, 2 x 960	16, 63	2.7 (2.4)	
	Callisto	mesotrione, 75	63		
13_2011	Titus	rimsulfuron, 2 x 5	13, 16	0.7 (2.4)	
	Callisto	mesotrione, 3 x 75	13, 16, 63		
	Basagran	bentazon, 960	63		
14_2011	Callisto	mesotrione, 150, 75	16, 63	3.7 (2.4)	
	Basagran	bentazon, 960	63		
p-value				0.46	

[1] not registered for use in Switzerland [2] PRE-emergence [3] incorporated before sowing [4] standard error

Tab. 2 Treatment levels and lsmeans of the number of *C. esculentus* germinated in the greenhouse, counted after 8 weeks, site A and B (2012).

Tab. 2 *Versuchsvarianten und lsmeans der Anzahl gekeimter* C. esculentus *nach 8 Wochen im Gewächshaus 2012, Standort A und B.*

	mechanical / applied herbicides	**active ingredients , g/ha**	**application time** (BBCH)	**N_{CE} (N germinated per 10 l soil)** site A	site B
Trial 1					
1	untreated control	-		36.2 (10.2)[4]	61.9 (11.8)
2_{2012}	Adengo	isoxaflutole, 2 x 37.1; thiencarbazone, 2 x 14.85;	13, 16	30.4 (10.0)	1.6 (13.4)
	Callisto	cyprosulfamide[1], 2 x 24.8 mesotrione, 2 x 75	13, 16		
3a	Callisto	mesotrione, 150	13	29.8 (10.0)	24.7 (11.3)
3b	Callisto	mesotrione, 2 x 75	13,16	20.0 (10.5)	10.0 (11.3)
$4a_{2012}$	Adengo	isoxaflutole, 74.2; thiencarbazone, 29.7; cyprosulfamide[1], 49.6	13	60.9 (10.1)	25.5 (11.3)
$4b_{2012}$	Adengo	isoxaflutole, 2 x 37.1, thiencarbazone, 2 x 14.85; cyprosulfamide[1], 2 x 24.8	13, 16	54.2 (11.4)	32.0 (11.3)
5	Permit	halosulfuron-methyl[2], 2 x 15	13, 16	4.7 (11.0)	1.5 (11.3)
p-value				0.05	0.03
Trial 2					
A	Harrowing		13, 16	23.0 (9.6)	15.1 (2.9)
B	Dual Gold, harrowing	*S*-metolachlor, 1920	IBS[3], 13, 16	13.0 (9.6)	9.8 (3.6)
C_{2012}	Dual Gold, harrowing, Basagran SG	*S*-metolachlor , 1920 bentazon, 960	IBS, 13, 16 63	5.0 (9.6)	0.0 (2.3)
p-value				0.53	0.26
Trial 3					
10_{2012}	Permit	halosulfuron-methyl, 2 x 15	13, 16	3.1 (3.1)	
	Titus	rimsulfuron, 2 x 5	13, 16		
11_{2012}	Titus, Callisto	rimsulfuron, 2 x 5; mesotrione, 2 x 75	13, 16	10.6 (3.2)	
12_{2012}	Titus	rimsulfuron, 10	13	21.5 (3.0)	
	Callisto	mesotrione, 150	16		
13_{2012}	Titus, Callisto	rimsulfuron, 2 x 5; mesotrione, 2 x 75	13, 16	1.7 (3.1)	
	Basagran SG	bentazon, 960	63		
14_{2012}	Titus	rimsulfuron, 10	13	1.8 (2.9)	
	Callisto	mesotrione, 150	16		
	Basagran SG	bentazon, 960	63		
p-value				0.01	

[1] safener [2] not registered for use in Switzerland [3] incorporated before sowing [4] standard error

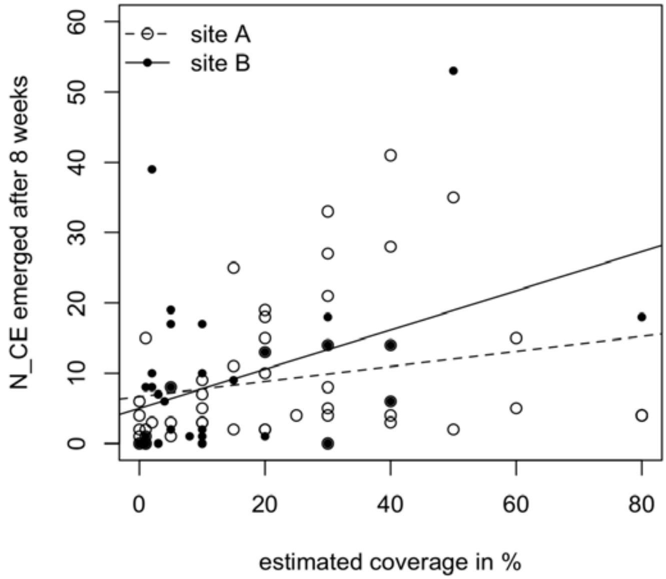

Fig. 1 Number of emerged *Cyperus esculentus* sprouts in 10 L soil after 8 weeks in the greenhouse versus *Cyperus esculentus* coverage 7-8 weeks after the second split application (2011). Lines indicate the modeled linear relationship between the two parameters. Adjusted R^2 in % was 3.5% at site A and 16% at site B.

Abb. 1 *Anzahl gekeimter* Cyperus esculentus-*Keimlinge in 10 l Boden nach 8 Wochen im Gewächshaus gegen* Cyperus esculentus-*Bedeckung 7-8 Wochen nach der zweiten Splitapplikation (2011). Ein lineares Model wurde verwendet, um den Zusammenhang zwischen den beiden Parametern zu zeigen. Adjustiertes R^2 in % betrug 3.5 % am Standort A und 16 % am Standort B.*

Discussion

Weeds often occur in patches (NORDMEYER and ZUK, 2002; GERHARDS and OEBEL, 2006). Due to its means of dispersal and vegetative growth (ANONYMOUS), this is even more the case for *C. esculentus*. This patchiness resulted in high variability within the trials, thus merely trends can be stated in this study.

FELIX and NEWBERRY (2012) found a clear relationship between coverage and number of tubers in the soil, their analyses were based on aggregated data yet. In this study $N_{\_CE}$ was used to compare efficacy of different treatments. However, no clear relationship between *C. esculentus* coverage and $N_{\_CE}$ could be found. This implies that ratings of *C. esculentus* control based on estimated coverage should be interpreted with caution as they lack predictive power for the seasons to come. This confirms the statement of BOHREN and WIRTH (2013) who stated that there is no clear relationship between above ground biomass and the number of tubers formed. They favour the use of number of tubers to rank herbicide efficacy. Compared with rinsing, sieving soil samples and counting tubers directly, our approach requires less working hours. Generally, soil sampling may introduce more variation due to intraplot variability, whereas coverage estimates give a more general rating. With the soil samples technical difficulties were encountered in 2011, which were solved the next year. This may have contributed to the generally higher level of $N_{\_CE}$ in samples taken 2012 which rendered comparison between years difficult.

For further experimentation apart from the untreated control, a treatment with a herbicide controlling present weeds in the field but with no or marginal effect on *C. esculentus* should be included. This is necessary, because in the untreated control emerging weeds strongly compete with *C. esculentus* which is not the case neither in the herbicide treatments nor under normal field conditions.

Splitting improved *C. esculentus* control compared with a single herbicide application provided that the herbicide was at least partially effective in controlling *C. esculentus*. A further application of bentazon late in the season improved *C. esculentus* control. In contrast, applying a herbicide with no or marginal effect on *C. esculentus*, but with complete control of other weeds, resulted in high *C. esculentus* infestation levels. By applying herbicides and removing other weeds competing with *C. esculentus,* the proliferation of *C. esculentus* seems even to be promoted. This was also observed in the southeastern United States, where the broad use of herbicides controlling grasses and broadleaved weeds opened a niche which was readily filled by sedge weeds (BRYSON and CARTER, 2008).

The most effective treatments were the ones with halosulfuron-methyl showing consistent low infestation levels thereafter. Halosulfuron-methyl is not registered for use in Switzerland (compare official online database http://www.blw.admin.ch/psm). In Italy it is registered in rice (compare official online database http://www.salute.gov.it. Several products containing halosulfuron-methyl are registered in the US in turfs, other non-crop sites and many arable (corn, grain sorghum, rice, sugarcane etc.) and many vegetable crops (asparagus, dry beans, pumpkin etc.) (compare official online database http://www.epa.gov/pesticides/). FELIX and NEWBERRY (2012) found high *C. esculentus* control if S-metolachlor was incorporated into the soil before sowing and halosulfuron-methyl was applied after emergence with dicamba and at a later stage glyphosate was applied (glyphosate tolerant maize). This corresponds to a rather intensive control program comparable with the treatments in experiment 3 in our study.

S-metolachlor incorporated into soil before sowing, combined with mechanical weed control and application of bentazon at later growth stage was also a promising treatment. The high efficacy of *S*-metolachlor was also found in other studies, and the EPPO data sheets on quarantine pests suggests for *C. esculentus* a yearlong use of this active ingredient to reduce infestation levels in highly infested fields (ANONYMOUS, 2013).

Herbicide combinations, working with split application and late application or mechanical control combined with herbicides and late application of e.g. bentazon may suppress and control *C. esculentus* infestation to a similar extent as halosulfuron-methyl. However, this requires much more effort of the farmers and costs more. Halosulfuron-methyl did not control millet weeds, which strongly competed with emerging *C. esculentus* and the crop in 2012. The addition of a herbicide controlling these weeds would be mandatory for further experimentation.

In maize, the critical period for weed control cannot be applied to heavily infested *C. esculentus* fields, if the aim is to reduce *C. esculentus* infestation (BOHREN, 2012). Even late application (under leaf, patchwise) should be considered. Generally, the number of applications and amount of herbicides being applied and being released in the environment increases considerably in *C. esculentus* infested fields. This counteracts the general aim to reduce herbicide release in the environment (e.g. MOSER, 2012; ANONYMOUS 2013). However, the scattered pattern of emerging *C. esculentus* requires several herbicide applications. Therefore, the prevention of the further spread of this difficult to control weed is of high importance.

In Switzerland, the national subsidy systems require a minimal crop rotation. Farmers can choose between two protocols: in one protocol, the number of years until the same crop is allowed to be grown on the same field again are given by the regulation. In the other protocol the farmer has to grow at least four crops (to count as a crop, the crop must be grown on more than 10% of the cropped area of the farm), upper limits of the allowed share of the cropped area with distinct crops is also given. Yet, the single field can be cropped continuously with maize in this system (http://www.agrigate.ch/de/pflanzenbau/943/944/950/).

Thus, cropping maize for some years with intensive and continuous control measures is possible and farmers may achieve to decrease infestation levels in highly infested fields in Switzerland. The effective treatments tested in these field trials provide a "small toolbox" for farmers trying to reduce infestation levels in their fields.

Acknowledgement

We thank the farmers providing the area for experimentation and the cantonal administration for the support.

References

ANONYMOUS, 2013: *Cyperus esculentus* (European/non-european). 05-11809 Draft EPPO quarantine pest, Data Sheets on Quarantine Pests, http://www.eppo.int last retrieved 16.10.2013.

ANONYMOUS, 2013: Nationaler Aktionsplan zur nachhaltigen Anwendung von Pflanzenschutzmitteln (National action plan for sustainable use of plant protection products). Bundesministerium für Ernährung; Landwirtschaft und Verbraucherschutz. http://www.bmelv.de/SharedDocs/Standardartikel/Landwirtschaft/Pflanze/Pflanzenschutz/AktionsplanPflanzenschutzmittel.html last retrieved 14.10.2013.

BOHREN, C., 2012: *Cyperus esculentus*, une adventice particulièrement dangereuse (*Cyperus esculentus*, a particular dangerous weed). Présentation des projets (Project presentation).

BOHREN, C. and J. WIRTH, 2013: Aktuelles zu Erdmandelgras (*Cyperus esculentus* L.) (News about yellow nutsedge (*Cyperus esculentus* L.)). AGRARFORSCHUNG SCHWEIZ **4**, 460-467.

BRYSEN, C.T. and R. CARTER, 2008: The Significance of Cyperaceae as Weeds. In: Sedges: Uses, Diversity and Systematics of the Cyperaceae. Naczi, R.F.C. and B.A. Ford, B. A. Monogr. Syst. Bot. Missouri Bot. Garden **108**.

FELIX, J. and G. NEWBERRY, 2012: Yellow Nutsedge Control and Reduced Tuber Production with *S*-metolachlor, Halosulfuron plus Dicamba, and Glyphosate in Furrow-Irrigated Corn. Weed Technol. **26**, 213-219.

GERHARDS, R. and H. OEBEL, 2006: Practical experiences with a system for site-specific weed control in arable crops using real-time image analysis and GPS-controlled patch spraying. Weed Research **46**, 185-193.

KEELEY, P.E., 1987: Interference and Interaction of Purple and Yellow Nutsedges (*Cyperus rotundus* and *C. esculentus*) with crops. Weed Technol. **1**, 74-81.

KELLER, M., R. TOTAL, C. BOHREN and B. BAUR, 2013: Problem Erdmandelgras: früh erkennen - nachhaltig bekämpfen (Problem yellow nutsedge: early detection - sustainable control). Leaflet, http://www.agroscope.admin.ch/publikationen/einzelpublikation/index.html?aid=32393&lang=de&pid=32365 last retrieved 16.10.2013.

LENTH, R.V., 2013: Package 'lsmeans'.

MOSER, T.A., 2012: Postulat Aktionsplan zur Risikominimierung und nachhaltigen Anwendung von Pflanzenschutzmitteln (postulate for an action plan for the minimization of risks and sustainable use of plant protection products). http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20123299 last retrieved 14.10.2013.

NORDMEYER, H. and A. ZUK, 2002: Teilflächenunkrautbekämpfung in Winterweizen (Site-specific weed control in winter wheat). J. Plant Dis. Protect. **XVIII**, 459-466.

PIEPHO, H.P., A. BÜCHSE and C. RICHTER, 2004: A Mixed Modelling Approach for Randomized Experiments with Repeated Measures. J. Agron. Crop Sci. **190**, 230-247.

R CORE TEAM, 2012: R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing. Vienna, Austria, http://www.R-project.org/.

RIEMENS, M.M., R.Y. VAN DER WEIDE and W.T. RUNIA, 2008: Nutsedge Biology and Control of *Cyperus rotundus* and *C. esculentus,* review of a literature survey. PPO Report, Plant Research International B.V.