Validation of yellow nutsedge (*Cyperus esculentus*) control strategies in maize in an on-farm, large-scale field trial

Validierung verschiedener Strategien zur Bekämpfung von Erdmandelgras (Cyperus esculentus) anhand eines on-farm Großparzellenversuchs

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DOI 10.5073/jka.2018.458.028

Abstract

A large on-farm field trial was carried out between 2013 and 2015 to investigate the effect of repetitive maize cropping on *Cyperus esculentus* infestation over time. Intensive control strategies, developed and investigated in small-scale trials, were validated. Four *C. esculentus* treatment strategies were installed. Soil samples were taken each year put in the greenhouse and the number of *C. esculentus* sprouts was assessed.

Initial infestation was patchy. Field areas were flooded several times due to heavy rainfall. Despite the inherent variability and the adverse weather conditions following conclusions can be drawn: Growing maize combined with intensive weed control (2-4 passes), reduced infestation on average by 80%. Principal components for *Cyperus esculentus* control strategies are hoeing, the active substances S-metolachlor, mesotrione, terbuthylazine, rimsulfuron, bentazone, and a herbicide containing foramsulfuron, thiencarbazone and iodosulfuron.

Growing maize combined with high intensity weed control is an effective approach to manage and reduce *C. esculentus* infestation. Yield depressions due to this highly intensive weed control cannot be rule out. Nevertheless, farmers in the affected region have adopted these approaches.

Keywords: Control strategy, dropleg, hoeing, late under leaf application, mechanical weed control

Zusammenfassung

Es wurde ein Großparzellenversuch von 2013 bis 2015 durchgeführt, um die Wirkung von Maisanbau während mehrerer Jahre auf den *Cyperus esculentus* Befall in einem Feld zu untersuchen. Dabei wurden Bekämpfungsstrategien, die zuvor in Kleinparzellenversuchen entwickelt und geprüft worden waren, validiert. Der Versuch beinhaltete vier Bekämpfungsverfahren. Jedes Frühjahr wurden Bodenproben gezogen, im Gewächshaus ausgelegt und angetrieben. Anschließend wurde die Anzahl der sich entwickelnden Erdmandelgrastriebe gezählt.

Der Ausgangsbesatz war heterogen verteilt. Zudem standen einzelne Feldbereiche aufgrund starker Regenfälle mehrmals unter Wasser. Trotz der Variabilität und der schwierigen Wetterbedingungen konnten folgende Schlussfolgerungen gezogen werden: Maisanbau kombiniert mit intensiver Bekämpfung (2-4 Bekämpfungsmaßnahmen) über mehrere Jahre ermöglichte eine Reduktion der *Cyperus esculentus*-Dichte um rund 80 %. Es zeigte sich, dass Hacken, die Wirkstoffe S-Metolachlor, Mesotrione, Terbuthylazin, Rimsulfuron und Bentazon sowie das Kombinationsprodukt mit den Wirkstoffen Foramsulfuron, Thiencarbazone und Iodosulfuron wichtige Komponenten einer *Cyperus esculentus*-Bekämpfungsstrategie in Mais sind.

Maisanbau mit einer intensiven Unkrautbekämpfung ist ein wirksamer Ansatz, um *C. esculentus* unter Kontrolle zu halten und den Besatz zu reduzieren. Aufgrund der intensiven Bekämpfung können Ertragsdepressionen jedoch nicht ausgeschlossen werden. Landwirte in der betroffenen Region setzen diese Bekämpfungsansätze bereits um.

Stichwörter: Bekämpfungsstrategie, Dropleg, Hacken, mechanische Unkrautbekämpfung, späte Unterblattbehandlung

Introduction

Yellow nutsedge (*Cyperus esculentus* L.) is considered one of the worst weeds (HOLM et al., 1991). In Switzerland it has become a serious threat to arable and vegetable crop production. It spreads and reproduces mainly vegetatively via tubers in the soil. However, we could show recently that in Switzerland seed production had been underestimated and that the risks of dispersal via seeds should not be further neglected (e.g. KELLER et al., 2015; KELLER et al., 2016). Apart from preventing its further spread via tubers and seeds, it is crucial to provide farmers with control strategies allowing reducing *C. esculentus* levels in highly infested fields. Such strategies need to be developed, tested and validated. In Switzerland several herbicides with efficacy against *C. esculentus* are registered for use in maize (*Zea mays* L.). Apart from the availability of herbicides, maize is also suited as an eradication crop, because it can be hoed and the germination requirements of *C. esculentus* and maize are similar (RIEMENS et al., 2008). This allows optimizing the timing of weed control. Further, after canopy closure the soil is well shaded and thus fewer *C. esculentus* tubers germinate (KELLEY, 1987). In addition, the risk of further spreading is low, when this crop is grown. We had determined and tested different, highly intensive *C. esculentus* control strategies in small plot trials in maize from 2011 to 2013 (KELLER et al., 2014a; KELLER et al., 2014b). The next step was to validate the most promising strategies under practical farming conditions on a larger area: We installed a large-scale plot trial in a farmer's field (2013 to 2015). Thus, the aim of the study was to validate these control strategies over several years and provide farmers with hands-on experiences and with adoptable strategies against *C. esculentus*.

Materials and Methods

The field trial was initiated in spring 2013 in a *C. esculentus* infested field in the eastern part of Switzerland. The soil was a sandy loam with an organic matter content of 3% and a pH of 6.9. Average temperature was 10.5 °C, average annual precipitation was 1.25 m (averages 2013-2015, nearest weather station, http://www.agrometeo.ch). The site was chosen due to its known *C. esculentus* infestation. Maize was grown according to regional practices; sowing date was between late April and early May.

The design was a randomized complete bloc design for the *C. esculentus* control treatments: 4 *C. esculentus* control strategies i.e. treatments (TR1 to TR4) with 4 replicates and 3 small untreated control plots (TR5) were included in the trial. Treatment plot size was 15 m by 100 m; untreated control plot size was 15 m by 10 m. These 3 untreated control plots were randomly put in 3 of the large treatment plots. Plot width corresponded to the boom width of the farmer's sprayer (15 m). Four soil samples (10L, sampling depth: 0.2 m) were taken each 20 m in the middle of each treatment plot every year before field season (T_0: 15 April 2013, T_1: 6 February 2014, T_2: 10 March 2015, T_3: 25 February 2016). For the 3 plots within which the small untreated control plots had been allocated only 3 soil samples were taken, as one sampling point was located within the respective untreated control plot. Thus, in the untreated control plots only 1 soil sample was taken per plot. In total 64 samples were taken in the whole field trial. Sampling sites were geo-referenced with a precise Trimble device (precision: 0.02 m) allowing to re-establish plot borders and sampling sites at the same position over the years. The soil samples were stored at a temperature of 4 °C for maximal 3 months; then they were put in shallow trays (0.35 by 0.55 m) in the greenhouse. Other weeds were removed from time to time to prevent competition effects. The number of *C. esculentus* sprouts germinated after 8 weeks was determined. These values were considered to be a good measure of the extent of *C. esculentus* infestation. *Cyperus esculentus* infestation level per m^2 soil was calculated based on sampling volume and sampling depth.

Treatment 3 (TR3) and 4 (TR4) had been successfully tested in the small plot trials and thus could be applied without problems (Tab. 1, Tab. 2). In treatment 3, 2 L ha^{-1} Dual Gold (Syngenta, EC, S-metolachlor 960 g L^{-1}) was sprayed and incorporated (incorporation depth: 0.06-0.08 m) before sowing followed by 2 hoeing passes (post-emergence), followed by a late under leaf (i.e. under canopy) application with 1.1 kg ha^{-1} Basagran SG (Leu + Gygax, SG, bentazone 870 g kg^{-1}). In treatment 4, 20 g ha^{-1} Titus (DuPont, WG, rimsulfuron 250 g kg^{-1}) and 0.75 L ha^{-1} Callisto (Syngenta, SC, 100 g L^{-1}) were applied twice post-emergence followed by a late under leaf treatment identical to treatment 3.

Treatment 1 (TR1) and 2 (TR2) hadn't been tested before in the small plot trials. In treatment 1, 1.5 L ha $^{-1}$ Equip Power (Bayer, OD, foramsulfuron 30 g L^{-1}, thiencarbazone 10 g L^{-1}, iodosulfuron-methyl 1 g L^{-1}, safener: cyprosulfamide 15 g L^{-1}) was tested followed by a late under leaf application as described above. Due to high weed pressure, especially lady's thumb (*Persicaria maculosa*) and common barnyard grass (*Echinochloa crus-galli*), the efficacy of Equip Power was not lasting long enough to control these weeds until canopy closure. Treatment 2 was planned as an organic treatment, controlling *C. esculentus* only by hoeing. This idea was quickly abandoned also due to high weed pressure (especially intra-row). In both treatments a late under leaf application was carried out as described above. The 2 treatments were adjusted the following year (Tab. 2). In treatment 1, 0.2 L ha^{-1} Adengo (Bayer, SC, isoxaflutole 225 g L^{-1}, thiencarbazone 90 g L^{-1}, safener: cyprosulfamide: 150 g L^{-1}) and 1.5 L ha^{-1}Aspect (Bayer, SC, terbuthylazine: 333 g L^{-1}, flufenacet 200 g L^{-1}) were applied additionally early post-emergence to control other weeds. In 2015, all post-emergence herbicides were applied accidentally at the same date. In treatment 2, 4 L ha^{-1} Lumax (Syngenta, SE, S-metolachlor 375 g L^{-1}, terbuthylazine 125 g L^{-1} and mesotrione 37.5 g L^{-1}) was applied early post-emergence followed by a late under leaf application as described above.

Tab. 1 Control measures and used active substances (a.i.) applied in the treatments (TR) 2013: post-emergence (POST), pre sowing with incorporation (PSI), late under leaf treatment (UL).

Tab. 1 *Bekämpfungsmassnahmen und eingesetzte Wirkstoffe (a.i.) in den Verfahren (TR) 2013: Nachauflauf (POST), Vorsaat mit Einarbeitung (PSI), späte Unterblattbehandlung (UL).*

TR	Control measure a.i. g ha^{-1}	Timing	2013 Date
1	Foramsulfuron, 45 Thiencarbazone, 15 Iodosulfuron-methyl, 1.5	POST	June, 7, BBCH 13-14
	Bentazon, 957	UL	July, 12
2	Hoeing	POST	June, 7
	Hoeing	POST	June, 18
	Bentazon, 957	UL	July, 12
3	S-metolachlor, 1920	PSI	May, 1
	Hoeing	POST	June, 7
	Hoeing	POST	June, 18
	Bentazon, 957	UL	July, 12
4	Rimsulfuron, 5 Mesotrione, 75	POST	June, 7, BBCH 13-14
	Rimsulfuron, 5 Mesotrione, 75	POST	June, 14, BBCH 15-16
	Bentazon, 957	UL	July, 12
5	Untreated control		

The pre-sowing and the post-emergence applications were carried out with the farmer's tractor mounted sprayer (nozzles: Teejet 110 04, spray volume: 300 L/ha).

The late under leaf application was done by a contractor with a self-propelled sprayer with a boom width of 24 m equipped with droplegs (Kuhn Landmaschinen AG, Dintikon, Switzerland). The nozzles of the droplegs were oriented downwards to avoid spraying the leaves of the maize plants. Spray volume was 400 L ha^{-1}. The late under leaf application was applied on the whole field except the 3 small, untreated control plots of TR5 (Tab. 1 and 2).

Hoeing was done twice per year in the respective treatment(s) using a tool carrier (FOBRO-Mobil, Bärtschi-FOBRO AG, Hüswil, Switzerland). Hoeing was done according to weather conditions and adjusted to crop height: First pass at a height of 0.2 to 0.3 m, second pass at a height 0f 0.7 to 0.8 m. Two rows at a time were hoed with goose-foot blades. In the first pass about 77 to 87% of the area could be hoed (distance to maize plants: 0.05 to 0.08 m). During the second pass the crop was also earthed up to bury weeds and to promote crop growth.

The trial was set up to allow elaborate statistical analyses using linear mixed models accounting for spatial auto-correlation (e.g. GERHARDS et al., 2012). However, the initial infestation level was very patchy and we had many samples without *C. esculentus* infestation at all (38 of 64). Thus, we decided to only consider the sampling points at which *C. esculentus* was present in the initial year to determine the reduction over the years. For the yearwise comparison of the treatments TR1, TR2, TR3 and TR4 a simple ANOVA was carried out omitting the trial design. To compare infestation levels between the initial and the last trial year a paired t-test was carried out treatmentwise. The analyses were carried out in R (R CORE TEAM, 2016). The samples without *C. esculentus* infestation in the initial year were considered as a measure of the further spread of *C. esculentus* within the field. It is often stated that *C. esculentus* spreads rapidly and exponentially within a field by mechanical weed control, cultivation etc. We hypothesized that a lack a spread within the field is also a good indicator of the efficacy of the control strategies and cropping strategies.

Tab. 2 Control measures and used active substances (a.i.) applied in the treatments (TR) 2014 and 2015: post-emergence (POST), pre sowing with incorporation (PSI), late under leaf treatment (UL).

Tab. 2 *Bekämpfungsmaßnahmen und eingesetzte Wirkstoffe (a.i.) in den Verfahren (TR) 2014 and 2015: Nachauflauf (POST), Vorsaat mit Einarbeitung (PSI), späte Unterblattbehandlung (UL).*

TR	Control measure a.i. g ha^{-1}	Time	2014 Date	2015 Date
1	Isoxaflutole, 45 Thiencarbazone, 18 Terbuthylazine, 500 Flufenacet, 300	POST	June, 2, BBCH 13-14	May, 18, BBCH 12
	Foramsulfuron, 45 Thiencarbazone, 15 Iodosulfuron-methyl, 1.5	POST	June, 10 BBCH 14-16	
	Bentazon, 957	UL	July, 4	July, 3
2	S-metolachlor, 1500 Terbutylazine, 500 Mesotrione, 150	POST	May, 26, BBCH12	May, 18, BBCH 12
	Bentazon, 957	UL	July, 4,	
3	S-metolachlor, 1920	PSI	April, 24	April, 21
	Hoeing	POST	June, 6	
	Hoeing	POST	June, 20	
	Bentazon, 957	UL	July, 4	July, 3
4	Rimsulfuron, 5 Mesotrione, 75	POST	June, 2, BBCH 13-14	May, 18, BBCH 12
	Rimsulfuron, 5 Mesotrione, 75	POST	June, 10 BBCH 14-16	June, 2, BBCH 14-16
	Bentazon, 957	UL	July, 4	July, 3
5	Untreated control			

Results

C. esculentus was present in only 26 samples in the initial year (2013); and absent in 38 samples. In the soil samples taken 2016, we found *C. esculentus* in 3 of the 38 initially non-infested samples. Whereas in 19 of the 26 samples taken at sites initially infested in 2013, no *C. esculentus* plants were found anymore in 2016.

The average density of *C. esculentus* in soil samples taken in initially infested field areas was 1.8 ±1.6 *C. esculentus* L^{-1} soil, which corresponds to a density of 366±315 *C. esculentus* plants per m^2. There were no significant differences in the infestation levels in the TR1 to TR4 treatments, neither in the initially taken samples, nor in the samples taken the following years (Tab. 3).

Tab. 3 Development of the *C. esculentus* infestation levels of the different treatments over the years (means are reported). *Cyperus esculentus* control treatments were compared by ANOVA. Only samples with initial *C. esculentus* infestation were considered. The success of *C. esculentus* control in the respective year was determined, by sampling in the subsequent winter/spring. The columns are named according to year of control and not the year the sampling took place.

Tab. 3 *Entwicklung des durchschnittlichen Erdmandelgrasbefalls (*C. esculentus*) in den verschiedenen Verfahren über die Versuchsjahre. Die Verfahren 1 bis 4 wurden mit einer ANOVA verglichen. Es wurden nur die Beprobungsstellen mit einem Anfangsbefall berücksichtigt. Der Erfolg eines Bekämpfungsjahres wurde anhand von gezogenen Bodenproben im Folgejahr bestimmt. Die Spalten sind gemäss Bekämpfungsjahr und nicht gemäss Beprobungsjahr beschriftet.*

Treatment TR	samples	2013 T_0	2013 T_1	2014 T_2	2015 T_3	change $T_3 - T_0$ 2015-2013	paired t-test $T_3 - T_0$
	N	------------ *C. esculentus* plants m^{-2}			----------	%	p-value
1	6	460	143	227	40	-85	0.03
2	10	428	282	312	66	-55	0.01
3	4	310	110	130	0	-100	0.02
4	5	240	148	260	16	-91	0.16
p-value		0.64	0.24	0.85	0.45		
5	1	40	160	400	0	-100	

A decrease in infestation levels could be observed after the first year and after the third year, whereas infestation levels had increased after the second year. For the *C. esculentus* control strategies i.e. treatments (TR1 to TR4) we could observe a decrease in infestation levels of 55 to 100% over 3 years (Tab. 3). On average a reduction of about 80% could be achieved with these strategies. Paired t-tests, comparing the initial infestation level with the infestation level at the trial end, were significant for treatment 1, 2 and 3.

3 small, untreated plots (TR5) had been randomly installed within the large plot trial. Only in 1 of the plots *C. esculentus* was initially present (40 plants m^{-2}). Strong weed growth especially of *P. maculosa* and *E. crus-galli* suppressed crop growth completely in the untreated plots. After an increase of the *C. esculentus* infestation level in 2013 and 2014, no *C. esculentus* plants were found anymore in the soil sample at the trial end (Tab. 3).

Discussion

The employed strategies allowed a reduction of *C. esculentus* infestation levels of 55 to 100%. In treatment 2, the time elapsed between the early post-emergence and the late under leaf application was too long. Most likely, an additional application in between the 2 applications would further reduce *C. esculentus* infestation. The intensive control strategies in 2013 and 2015 resulted in a reduction of *C. esculentus* infestation, whereas in 2014 the strategies were less successful i.e. infestation levels increased. In each trial year, the conditions during the early growth phase were not favorable for maize due to heavy rainfall and cool temperatures. In 2014, the summer was also rainy (especially in July) (www.agrometeo.ch; ANONYMOUS, 2015). This might have further favored *C. esculentus* growth and proliferation. STOLLER et al. (1979) also carried out trials in maize over 3 years to control *C. esculentus* almost 40 years ago. They worked with EPTC, alachlor, ametryn and bentazone. The former 3 are not (anymore) approved for use in the European Union, neither in Switzerland (ANONYMOUS, 2017a and 2017b). We could achieve similar reduction levels as STOLLER et al. (1979) with currently registered herbicides and under the described adverse weather conditions. Cropping maize over years using S-metolachlor to control *C. esculentus* is also recommended by a draft data sheet on *C. esculentus* of the EPPO (ANONYMOUS, 2004). In our trial, 2 control strategies (TR1 and TR 4) which were not based on S-metolachlor allowed also a reduction of *C. esculentus* over the years. Further, strategies - in accordance to the respective registration situation - are recommended by other extension oriented services (e.g. FOUCART et al., 2017 in Belgium and ANONYMOUS, 2016 in the Netherlands).

In the first year a slight growth depression could be observed early in the season in treatment 3 (presowing herbicide incorporation treatment) due to heavy rainfall. However, the plants recovered fast and no treatment differences could be further observed. The maize was harvested with a standard combine harvester. Thus, yield could not be determined treatmentwise. According to the farmer, yields were generally lower compared to previous years and fields in the region in which weed control was less intensive. Thus, if maize is cropped to reduce infestation levels of *C. esculentus* in field, yield depressions have to be accepted to a certain extent.

The results of the untreated control plot in which *C. esculentus* was initially present have to be interpreted with caution, as they are based on one replicate. They mainly showed that without weed control, maize could not be successfully grown. They confirmed once more that weeds out-compete *C. esculentus* in the long run (e.g. KELLER et al. 2014a, b; BRYSON and CARTER, 2008). The removal of other weeds by hand would have been very difficult to achieve due to the high weed pressure in the field. A nearby field can be seen as a more meaningful control. This field was also infested, but weed control was done without focus on *C. esculentus* control over the years. In 2015, maize was also grown. End of May *C. esculentus* coverage was around 80% in that field. In the field trial, *C. esculentus* plants were very rare and later on mostly controlled by the late under leaf application. Retrospectively, it would have been better to determine the infestation levels in the first year, optimize the trial design based on that information and start with the trial in the second year.

Growing maize has been adopted by farmers in the region to manage and to reduce *C. esculentus* infestation levels in their fields. In order to successfully reduce infestation levels control measures have to be carried out carefully and consistently. Emerging *C. esculentus* plants have to be controlled several times over the season to prevent new tuber formation, to exhaust the "tuber bank" in the soil and to reduce infestation levels in the fields.

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