Effect of site-specific weed management in winter crops on yield and weed populations

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ABSTRACT

Site-specific weed management (SSWM) methods allow spatially variable treatment of weed populations according to actual weed abundance, thus offering the opportunity for herbicide savings. However, SSWM's effect on weed population dynamics is not sufficiently understood. In this study, SSWM was conducted based on various application thresholds to analyse the effects on crop yield and weed infestation in the succeeding crop. SSWM was used on a 3.07 ha experimental field in winter wheat (2011) and winter oilseed rape (2012). The whole area was split into application cells of 6 × 10 m and abundance of all weed species was evaluated manually in each cell. Four different herbicide treatments were tested. Standard whole-field herbicide application (blanket spraying) was treatment 1. Treatments 2, 3 and 4 comprised SSWM using different thresholds for post-emergent herbicide application. SSWM resulted in savings of post-emergent herbicides ranging from 71.9% to 100%, depending on the application threshold. Differences in winter rape yield among treatments were generally small and statistically insignificant ($P = 0.989$). Although some minor changes in weed abundances were observable, the experiment showed that none of the site-specific herbicide treatments caused a significant ($\alpha = 0.05$) increase of weed species abundance compared to the standard treatment.

Keywords: economic thresholds; patch spraying; weed control; yield loss; *Brassica napus* L.; *Triticum aestivum* L.

Although it is still widely ignored in practice, the spatial variability of weed infestation offers significant opportunity for reducing pesticide application in agricultural fields. For example, Rew et al. (1996) calculated the potential reduction in herbicide use from patch spraying of *Elytrigia repens* (L.) Nevski to be up to 97% compared with the whole-field application. Nordmeyer (2006) found in five cereal fields that herbicide treatment was needed against grass weeds on 39% of the area, against *Galium aparine* on 49%, and against other broadleaved species on 44%.

Site-specific weed management (SSWM) methods have been developed in recent decades to take advantage of this potential. SSWM demands precise information as to the spatial distribution of weeds, and decision making is based on the threshold concept. Usually, only those areas are treated where weed density exceeds a predefined or calculated control threshold (e.g. Nordmeyer 2006, Wiles 2009) or the application rate is modified step-wise according to a set of thresholds (Timmermann et al. 2003). Therefore, optimal setting of threshold values has a crucial impact on the effectiveness and reliability of SSWM.

Economic thresholds have been a subject of interest in many studies. The economic threshold is considered to be that weed abundance at which the cost of weed control is equal to the value of the increased crop yield produced by this control. For higher weed abundances, control is economically profitable (Coble and Mortensen 1992). Many research studies focused on cereals, where the authors reported values between 0.1 and

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2 plants/m^2 for *G. aparine*, 40–50 plants/m^2 for other dicotyledonous weeds, and 20–30 plants/m^2 for grass weeds (e.g. Gerowitt and Heitefuss 1990, Zanin et al. 1993).

Recent research has established that SSWM based on threshold values that are close to the economic threshold did not cause loss of crop yield (e.g. Ritter et al. 2008). The economic threshold does not, however, take into account weed reproduction and possible changes of weed species populations in subsequent years. The concept of using long-term thresholds, such as economic optimum threshold, where the effect of weed reproduction is taken into account, seems to be more appropriate (Cousens 1987). Doyle et al. (1986) showed that the long-term threshold for control of *Alopecurus myosuroides* Huds. should be considered significantly lower than the standard economic threshold calculated for single years. However, estimation of long-term economic thresholds is a difficult task and requires knowledge of such additional factors, among others, as reproduction and dispersal biology of weed species, and crop rotation effects. Such thresholds are therefore rarely available.

In this study, SSWM was carried out on the basis of various application thresholds to analyse the effects on crop yield and weed infestation in the succeeding crop.

MATERIAL AND METHODS

A practical experiment was conducted on a 3.07 ha field in Central Bohemia near Kolín during 2011 and 2012. The elevation of the experimental site ranges from 280 to 285 m a.s.l. and the annual average air temperature is 9.0°C. The soil type is modal Greyzem on loess. The field was sown with winter wheat (*Triticum aestivum* L.) in 2011 and with winter oilseed rape (*Brassica napus* L.) in 2012. The crop preceding the wheat was also winter rape. Shallow tillage without ploughing was used after harvest and before seeding in both years.

The experimental field of 3.07 ha was split into 512 cells of 6 × 10 m in size (Figure 3a). Weed abundance was estimated in each cell before the post-emergence herbicide application. The abundance of all weed species was evaluated manually by counting the individual weeds in four sampling quadrats placed regularly in the central part of each cell (Figure 1). A 4 × 1.5 m^2 area was evaluated for *G. aparine*, *Cirsium arvense* (L.) Scop., and *E. repens* in each cell, and a 4 × 0.5 m^2 area for the other weed species.

The total amount of 512 cells was arranged into 16 blocks, which allowed the randomization of four treatments in four replications. The complete arrangement of cells and treatments is shown Figure 3a. Standard whole-field herbicide application (blanket spraying) was conducted as treatment 1, whereas treatments 2, 3 and 4 consisted of SSWM with different thresholds used for post-emergent herbicide application. The threshold values used in winter rape are listed in Table 1. The threshold values and herbicides used in winter wheat are presented in Hamouz et al. (2013).

The herbicides were applied using a self-propelled 36 m boom sprayer equipped with boom section control (every section 6 m wide) and RTK (real time kinematic) navigation system. After cali-

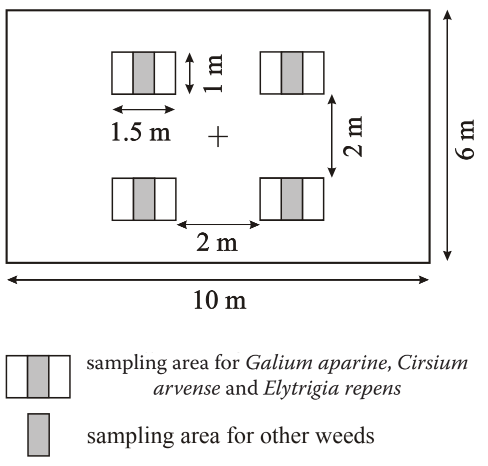

Figure 1. Sampling schema for weed abundance used in each cell

Table 1. Application thresholds (plants/m^2) for individual weeds and weed groups and treatments in winter oilseed rape

Weed or group	Treatment 1	2	3	4
Galium aparine	–	0.2	0.5	1
Cirsium arvense	–	0.2	0.5	1
Tripleurospermum inodorum	–	5	10	15
Other dicotyledonous weeds	–	10	20	30
Annual monocotyledonous weeds	–	5	10	15

1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

Table 2. Herbicides used in winter oilseed rape in 2012, their application rates and target weed groups

Herbicide	Active ingredient (g/L)	Herbicide rate (L/ha)	Water rate (L/ha)	Application date	Target weed group
Butisan 400 SC	metazachlor 400	1.5	300	1.9. 2011	annual monocot and dicot weeds
Command 36CS	clomazone 360	0.25	300	1.9. 2011	annual dicot weeds
Galera	clopyralid 267, picloram 67	0.35	250	5.4. 2012	annual dicot weeds and *Cirsium arvense*
Garland Forte	propaquizafop 100	1.5	250	10.4. 2012	monocot weeds

bration, the sprayer allowed horizontal error of application less than 1 m in the direction of its movement. In oilseed rape, pre-emergent herbicides (metazachlor and clomazone) were applied uniformly over the entire experimental field. The post-emergent site-specific herbicide applications were performed separately against individual weed groups (Table 2). Treatment maps for each weed group were created based on the weed abundance data and relevant treatment thresholds. No post-emergent treatment of *Viola arvensis* Murray was conducted in winter rape because of low efficacy of registered post-emergent herbicides against this species.

The herbicide savings in winter rape were calculated as a percentage of the untreated area in the site-specific treatments. The yield of the winter rape was evaluated by harvesting 1.5 × 10 m strips in each cell and correcting for the standard rape seed moisture of 10%. The differences in crop yields between the treatments were analysed using analysis of variance (ANOVA) at probability level $\alpha = 0.05$. The weed distribution, herbicide application and crop yield in winter wheat (2011) are presented in a previous publication (Hamouz et al. 2013).

The effect of SSWM on weed abundance in the succeeding crop was tested as an important part of this study. After the site-specific herbicide application in winter wheat (2011), weed abundance differences between the four treatments were compared in winter rape (2012) using ANOVA at probability level $\alpha = 0.05$. All statistical analyses were performed using Statistica 9.0 software (StatSoft, Inc. 2010). Weed abundances in 2011 and 2012 were compared graphically, but the statistical comparison of mean values was not reasonable because of the different crops and herbicide treatments involved. The spatial stability of weed populations between years 2011 and 2012 was evaluated using the Pearson's correlation coefficient.

Table 3. Mean abundances (plants or shoots/m^2) with standard deviation (SD) of the most important weed species depending on treatment in 2012 and probability values (P) of the null hypothesis on differences among treatments

Weed species	Treatment 1		Treatment 2		Treatment 3		Treatment 4		Mean	P
	mean	SD	mean	SD	mean	SD	mean	SD		
Viola arvensis	26.19	3.67	21.80	10.6	23.03	3.9	24.67	15.00	23.93	0.921
Tripleurospermum inodorum	2.69	1.54	3.43	2.58	2.95	3.04	1.97	1.24	2.76	0.824
Papaver rhoeas L.	0.15	0.30	0.23	0.42	0.15	0.26	0.24	0.45	0.19	0.972
Elytrigia repens	0.13	–	0.16	–	0.13	–	0.08	–	0.13	0.878
Cirsium arvense	0.06	0.02	0.04	0.03	0.03	0.01	0.03	0.01	0.04	0.158
Apera spica-venti	0.03	–	0.02	–	0.02	–	0.06	–	0.03	0.608
Galium aparine	0	0	0	0	0.001	0.002	0.006	0.01	0.002	0.270

1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

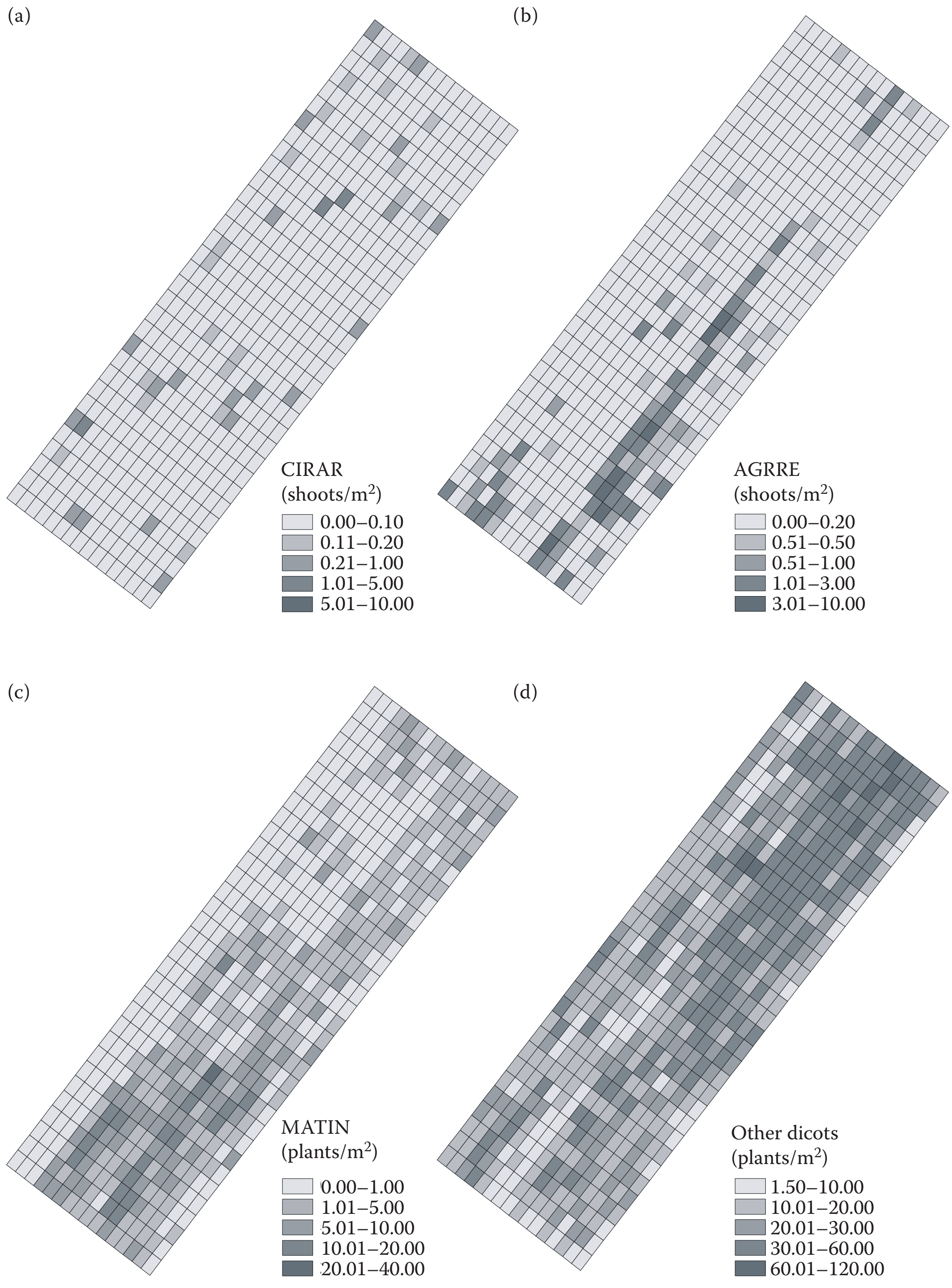

Figure 2. Distribution maps for the following weed groups: *Cirsium arvense* (a); *Elytrigia repens* (b); *Tripleurospermum inodorum* (c), and other dicotyledonous weeds (d) in winter oilseed rape (2012)

RESULTS AND DISCUSSION

Distribution of weed populations. The mean total weed density of the experimental field reached 30.35 plants/m^2 in 2012, but the distribution of weed populations was patchy. The density varied between 3.66 and 141.83 plants/m^2. *V. arvensis* (23.93 plants/m^2) and *Tripleurospermum inodo-*

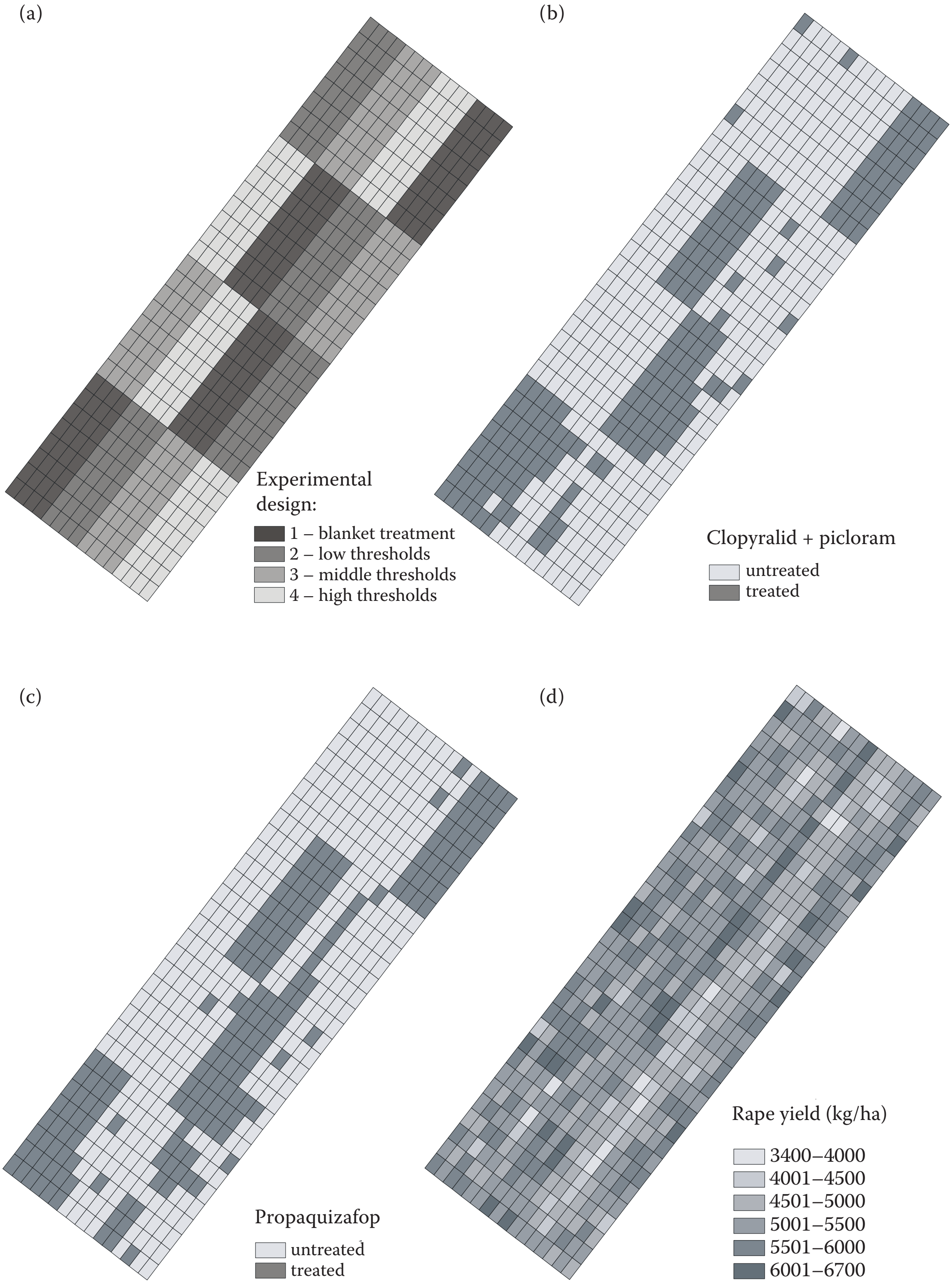

Figure 3. Experimental design (a); application maps for clopyralid + picloram (b); for propaquizafop (c), and winter oilseed rape yield map (d)

rum (L.) Schultz-Bip. (2.76 plants/m^2) were the dominant species. *V. arvensis* was distributed over the entire experimental field with the highest abundance in its north-eastern part, whereas large patches of *T. inodorum* were localized mainly in the southern half of the area. Other species were present at mean densities lower than 1 plant/m^2. Mean density values for the important weed spe-

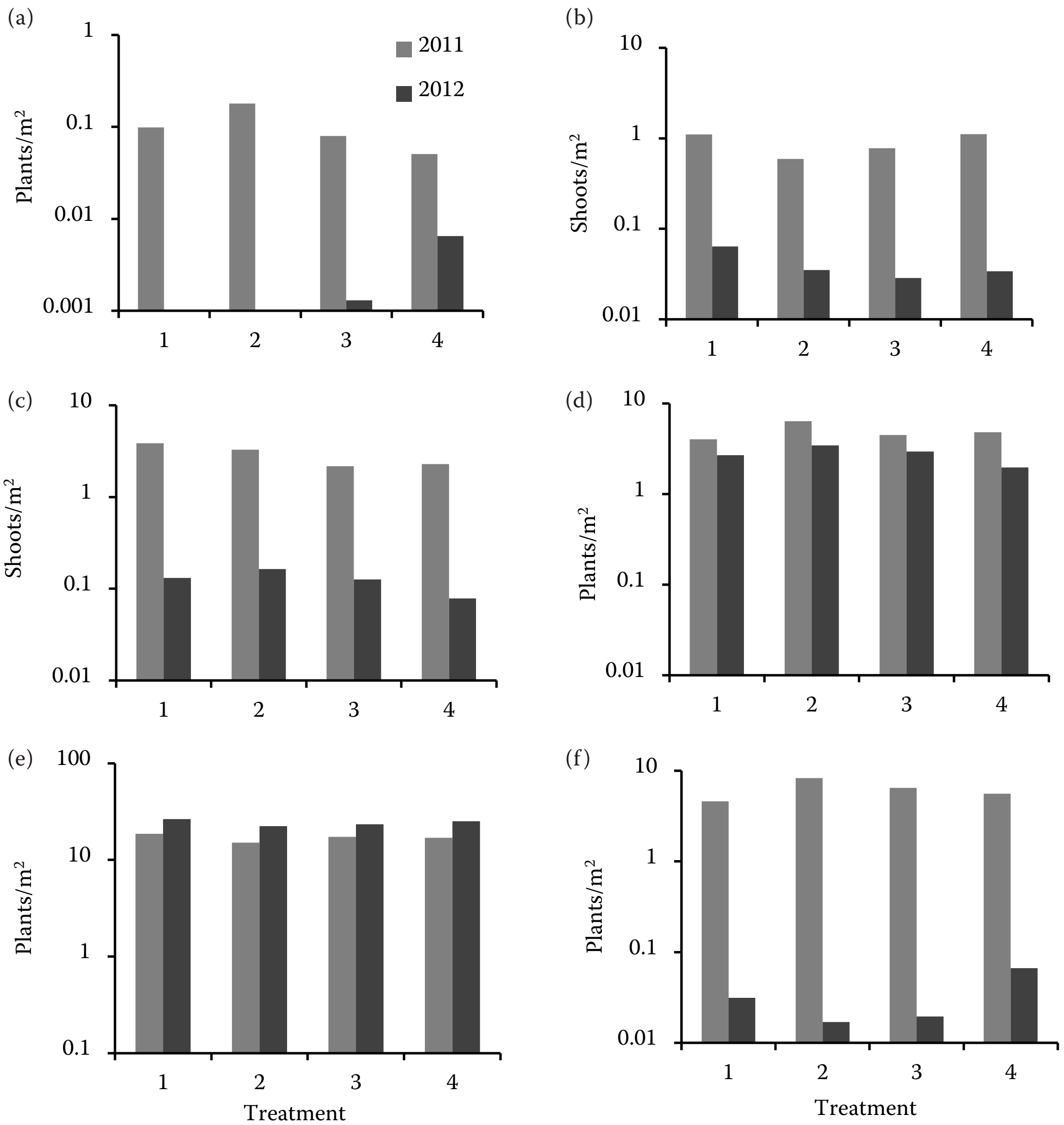

Figure 4. Comparison of weed abundance in 2011 (winter wheat) and 2012 (winter oilseed rape): (a) *Galium aparine*; (b) *Cirsium arvense*; (c) *Elytrigia repens*; (d) *Tripleurospermum inodorum*; (e) other dicots, and (f) annual monocots. 1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

cies are listed in Table 3 and distribution maps for *C. arvense*, *E. repens*, *T. inodorum*, and a group of other dicotyledonous weeds are presented in Figure 2.

The abundance of most weed species was lower in 2012 compared to 2011 (Figure 4), with the exception of *V. arvensis*. This should not, however, be attributed fully to the effect of site-specific weed treatment. The overall decrease in 2012 could have been affected also by the different sowing dates for the crops and by pre-emergent application of herbicide in late summer 2012. Low infestation with *Apera spica-venti* (L.) P.B. could have been caused also by its preference for later germination and/or by year effect. On the other hand, increase in the abundance of *V. arvensis* can be caused by its lower sensitivity to the clomazone + metazachlor herbicide combination. Compared to the preceding crop, noticeable decrease in the abundance of *E. repens* and *C. arvense* was observed in winter rape. This control was probably attained by blanketed pre-harvest spraying of winter wheat with glyphosate. A strong effect on weed abundance can be expected due to differences in weather conditions in individual years. Significant changes in density of annual weeds among the years were reported

Table 4. Number of treated cells and herbicide savings (%) for the individual herbicides and by treatments (1–4)

Herbicide	Number of treated cells				Herbicide savings			
	1	2	3	4	1	2	3	4
Metazachlor	128	128	128	128	0	0	0	0
Clomazone	128	128	128	128	0	0	0	0
Clopyralid + picloram	128	36	10	0	0	71.9	92.2	100
Propaquizafop	128	26	12	11	0	79.7	90.6	91.4

1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

(e.g. Walter 1996). Variations may occur even in the case of perennial weed species. Jurado-Expósito et al. (2004) documented that patches of *Convolvulus arvensis* L. varied considerably over a four-year crop rotation despite conventional weed management.

Direct comparison of weed abundances in individual treatments after one year of SSWM provides better information about the effect of SSWM on the development of weed populations. For 2012, there is some tendency towards higher abundances of *G. aparine* and annual grasses observable in treatment 4. That is in contrast to the previous year, when treatment 4 showed the lowest infestation with *G. aparine* and the abundance of annual grasses was about evenly balanced for all treatments. Nevertheless, the differences in abundances between treatments were not statistically significant ($P = 0.270$ and $P = 0.608$ for *G. aparine* and annual grasses, respectively). Other weed groups showed relatively balanced distribution among treatments in 2012, with no significant differences. ANOVA probability values for the null hypothesis on abundance differences among treatments for all important weed species are summarized in Table 3.

Although some minor changes in weed abundances are observable, the experiment showed that none of the site-specific herbicide treatments caused significant increase of weed density compared to the standard treatment. This is in accordance with other research studies, such as that by Christensen et al. (2003), which showed in a five-year experiment that 45–66% reduction in herbicide use achieved by SSWM did not lead to a significant reduction in crop yield or to an increase of weed abundance. Gerhards et al. (2002) also reported a minor effect of SSWM on weed populations. They found that the absence of herbicide control in unsprayed parts of the field did not cause a systematic increase of *A. myosuroides* density at those locations in subsequent years.

Herbicide savings. A previous paper by Hamouz et al. (2013) demonstrated that when using SSWM in winter wheat herbicide savings of 51–91% were possible for grass weeds and of 16–84% for dicotyledonous weeds in the same field. In winter rape, SSWM provided even greater post-emergent herbicide savings, ranging between 71.9% and 100%, depending on treatment (Table 4). This result was expected, considering the preceding application

Table 5. Pearson's correlation coefficients for weed species abundance between years 2011 and 2012 calculated for individual treatments ($n = 128$) and for total experimental field ($n = 512$)

Weed species	Treatment				Total
	1	2	3	4	
Cirsium arvense	0.494*	0.730*	0.236*	0.273*	0.442*
Elytrigia repens	0.526*	0.374*	0.661*	0.272*	0.479*
Viola arvensis	0.139	0.484*	0.342*	0.248*	0.295*
Tripleurospermum inodorum	0.257*	0.595*	0.569*	0.460*	0.484*
Apera spica-venti	–0.037	0.000	0.030	0.092	0.024

Significant coefficients at probability level α = 0.05 (two-tailed test) are marked with asterisk. 1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

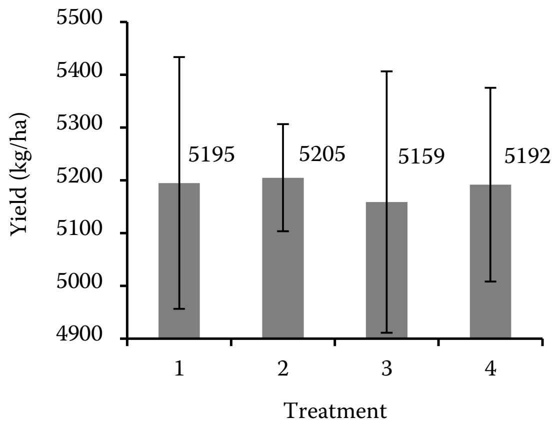

Figure 5. Winter oilseed rape yield of all tested treatments in 2012. Vertical lines represent standard deviations. 1 – blanket treatment; 2 – low thresholds; 3 – middle thresholds; 4 – high thresholds

of pre-emergent herbicide in all treatments. In all cases, higher application thresholds resulted in greater herbicide savings. Application maps for post-emergent herbicides are depicted in Figure 3. On the other hand, no savings of pre-emergent herbicides were achieved because of the blanket spraying of all treatments. While elimination of pre-emergent treatment could provide higher total savings, this was not a suitable solution here due to the lack of highly efficient post-emergent herbicides.

The results achieved are generally in accordance with those from other studies, although there is only scant information available on savings in winter rape. Gerhards and Oebel (2006) calculated total herbicide savings in winter rape of 20% against broadleaved species and 22% against grass weeds. Greater savings are reported for other winter crops. For example, Häusler et al. (1998) found that herbicide applications in two winter wheat fields were necessary for 24% and 35% of the area against *G. aparine* L., for 25% and 31% of the area against other dicotyledonous weeds, and for 55% and 7.5% of the area against grasses. Gutjahr et al. (2012) calculated herbicide savings in 11 winter wheat fields treated with SSWM. Average untreated area was 70% for broad-leaved species and 59% for grass weeds.

Spatial stability of weed patches. Pearson's correlation coefficients calculated for weed species abundance between years 2011 and 2012 are summarized in Table 5. In general, relatively high correlations were found in some species which indicates high stability of their patches. As expected, the highest correlations were found in case of perennial weeds whereas low correlations were calculated for annual species producing short living seeds such as *A. spica-venti*. Surprisingly, there is no general trend toward higher correlations in treatment 1 (blanket spraying) when compared to other treatments. This result suggests that changes in weed abundance between years are not strongly affected by herbicide treatment. For *G. aparine* and other less frequent species, calculation of correlation coefficients was not meaningful because of large amount of zero values in the data.

Winter rape yield. An average oilseed rape yield of 5187 kg/ha was achieved in 2012. Treatment 2 exhibited the highest yield (5205 kg/ha), although it was only 10 kg/ha higher compared to that for treatment 1 (the standard treatment). Similarly, the lowest yield, found in treatment 3, was only 36 kg/ha less than that for the standard treatment. The differences among treatments were generally small and statistically insignificant ($P = 0.989$). The yields of all treatments are compared in Figure 5 and the yield map of the entire experimental field is presented in Figure 3.

Ritter et al. (2008) reported a similar effect of SSWM on crop yield, as site-specific treatments caused no significant decrease of wheat yield compared to the whole-field herbicide application. Other studies (e.g. Gerhards et al. 2012) showed that herbicide application may significantly increase grain yield only if the competitive effect of weeds is strong. At lower weed densities, the positive effect of herbicide treatment is smaller and may be cancelled out by the effect of herbicide phytotoxicity on the crop.

In practical use of SSWM, both optimal setting of treatment thresholds and reliable estimation of weed abundance are important. As demonstrated by Wallinga et al. (1998) and Cousens et al. (2004), the spatial aggregation of weed populations occurs at many scales, including the scale of sampling, which thus increases sampling requirements to obtain reliable treatment maps. Although a relatively large sampling area was analysed in this research, the risk of undetected small patches nevertheless still exists. This can contribute to an increase of weed abundance in untreated cells in subsequent years. Considering the relatively small area of treatment cells, the dispersal of weed seeds must also be taken into account. The field experiment will be continued in order to analyse the overall long-term effect of SSWM on the development of weed populations.

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