Impact of site-specific weed management in winter crops on weed populations

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ABSTRACT

This work is focused on evaluating the effects of site-specific weed management (SSWM) on weed populations over a 4-year period. SSWM was used on a 3.07 ha experimental field during 2011–2014 in a rotation of winter wheat and winter oilseed rape. The area was split into application cells of 6 × 10 m and weed abundance 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 applications. SSWM resulted in herbicide savings of 6.3–100% for *Galium aparine*, 0–84.4% for other dicotyledonous weeds, and 31.3–90.6% for annual monocotyledonous weeds. SSWM led to significantly increased density of *G. aparine* and *Tripleurospermum inodorum* in the final experimental year when compared to the blanket treatment. Negative correlation coefficients between 2011 and 2014 plant densities found in SSWM treatments (–0.237 to –0.401) indicate that *Apera spica-venti* does not establish a long-term soil seed bank.

Keywords: weed thresholds; patch spraying; population dynamics; *Brassica napus* L.; *Triticum aestivum* L.

Increasing public pressure to ensure the sustainability of agricultural ecosystems requires the reduction of pesticides use. In weed management, herbicide use could be substantially decreased by adoption of site-specific weed management (SSWM) because weed populations are distributed unevenly across fields (e.g. Nordmeyer 2006, Gerhards et al. 2012). Of course, accurate threshold values are needed for reliable adoption of this method.

Many research studies have focused on estimating weed economic thresholds in recent decades. The economic threshold is considered to be that weed abundance at which the cost of weed control equals the increased benefit on yields which it would bring (Cousens 1987). All economic benefits of weed control should be taken into account, however, including the likes of easier harvests and less product contamination by weed seeds. In cereals, economic threshold values have been estimated between 0.1 and 0.5 plants/m^2 for *Galium aparine* L. 40–50 plants/m^2 for other dicotyledonous weeds and 20–30 plants/m^2 for grass weeds (e.g. Beer and Heitefuss 1981). Zanin et al. (1993) reported an economic threshold for *G. aparine* between 1.5 and 5.4 plants/m^2. Keller et al. (2014) reported even 4–14 plants/m^2, although they did not take into account harvest difficulties and grain contamination.

By definition, economic thresholds vary with commodity price and with the cost of weed control, but they vary also by crop and weed stage and other factors. The most important disadvantage of the economic threshold concept is that threshold values are typically calculated on a 1-year basis and do not reflect changes in weed species populations in subsequent years. Long-term weed management strategies require taking into account the future effects of management decisions (Wallinga and van Oijen 1997). Long-term thresholds (or economic optimum thresholds) which provide maximum profitability over long periods need to be developed (Cousens 1987). Unfortunately, the calculation of such thresholds is even more

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complex and requires large quantities of data. Weed population dynamics are affected not only by herbicide application but by many other factors, such as crop rotation and soil conditions. For this reason, reliable long-term thresholds are not yet available for most species. Some studies, however, suggest that the values may be substantially lower than the short-term economic thresholds (Bauer and Mortensen 1992).

In previous work (Hamouz et al. 2013, 2014), it was shown that SSWM applied to winter cereals and winter oilseed rape had no significant effect on crop yields. The present work evaluates the effect of SSWM on weed populations over a 4-year period based on various threshold values.

MATERIAL AND METHODS

Site-specific weed management was applied on an experimental field in Central Bohemia (49.999'N, 15.166'E) during 2011–2014. The field was sown with winter wheat in 2011, 2013 and 2014 and with winter rape in 2012. The experimental area of 3.07 ha was split into cells of 6 × 10 m. These cells constituted the smallest area individually surveyed and treated with herbicides. A total of 512 cells were arranged into 16 blocks, which allowed the randomized placing of four treatments in four replications (Figure 1). Blanket spraying regardless of weed infestation was performed in treatment 1 whereas the other treatments consisted of SSWM with various thresholds used for individual weed groups (Table 1).

Figure 1. Experimental design

Weed infestation was evaluated in spring of each year prior to post-emergence herbicide application. The density of each weed species was evaluated manually by counting individual weeds in four samples taken in the central part of each cell. An area of 4 × 1.5 m^2 was evaluated for *G. aparine*, *Cirsium arvense* (L.) Scop. and *Elytrigia repens* (L.) Nevski. Other weeds were sampled in an area of 4 × 0.5 m^2.

Treatment maps for each weed group were created based on weed abundance data and relevant treatment thresholds. Herbicide application against individual weed groups was performed separately using a sprayer equipped with boom section control and real time kinematic GPS. Herbicides and their application rates are specified in Table 2. Water was applied at rates between 250 and 300 L/ha. In addition to the SSWM treatments, winter oilseed rape was treated by a pre-emergent application of herbicides after sowing and *E. repens* was treated by a blanket pre-harvest application of a non-selective herbicide in 2011.

Differences in population density among treatments (i.e. application thresholds) were analysed by one-way ANOVA. Because of high intra-group variance of the data, a significance level of $\alpha = 0.1$ was chosen for this analysis. To evaluate the spatial stability of weed populations, Pearson's correlation coefficient was calculated for densities of weed groups between 2011 and 2014. Other details on methods can be found in Hamouz et al. (2014).

RESULTS AND DISCUSSION

The experimental field showed moderate initial weed abundance in 2011. The mean weed

Table 1. Treatment thresholds (plants/m^2) for individual weed groups

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

Table 2. Herbicides used during the 4-year research period, their application rates, treatment time and target weed groups

Herbicide	Herbicide rate (g/ha)				Treatment time (BBCH stage)	Target weed group
	2011	2012	2013	2014		
Pinoxaden + rape oil – methyl ester	40 + 792	–	–	–	31	annual monocot weeds
Pinoxaden	–	–	30	30	31	
Metsulfuron-ethyl + tribenuron-methyl	4.4 + 8.8	–	4.95 + 9.99	4.95 + 9.99	29	other dicotyledonous weeds
Clopyralid	120	–	–	120	31	*Cirsium arvense*
Fluroxypyr	125	–	175	175	29	*Galium aparine*
Glyphosate-IPA	1440	–	–	–	87	*Elytrigia repens*
Metazachlor	–	600	–	–	pre-emergence	annual monocot and dicot weeds
Clomazone	–	90	–	–	pre-emergence	annual dicot weeds
Clopyralid + picloram	–	93.5 + 23.5	–	–	32	annual dicot weeds and *C. arvense*
Propaquizafop	–	150	–	–	33	monocot weeds

density reached 32.01 plants/m^2. *Viola arvensis* Murray showed the highest abundance, followed by *Tripleurospermum inodorum* (L.) Schultz-Bip. and *E. repens*. The distribution of most of the weed species was patchy, and significantly large areas with a low weed infestation rates were

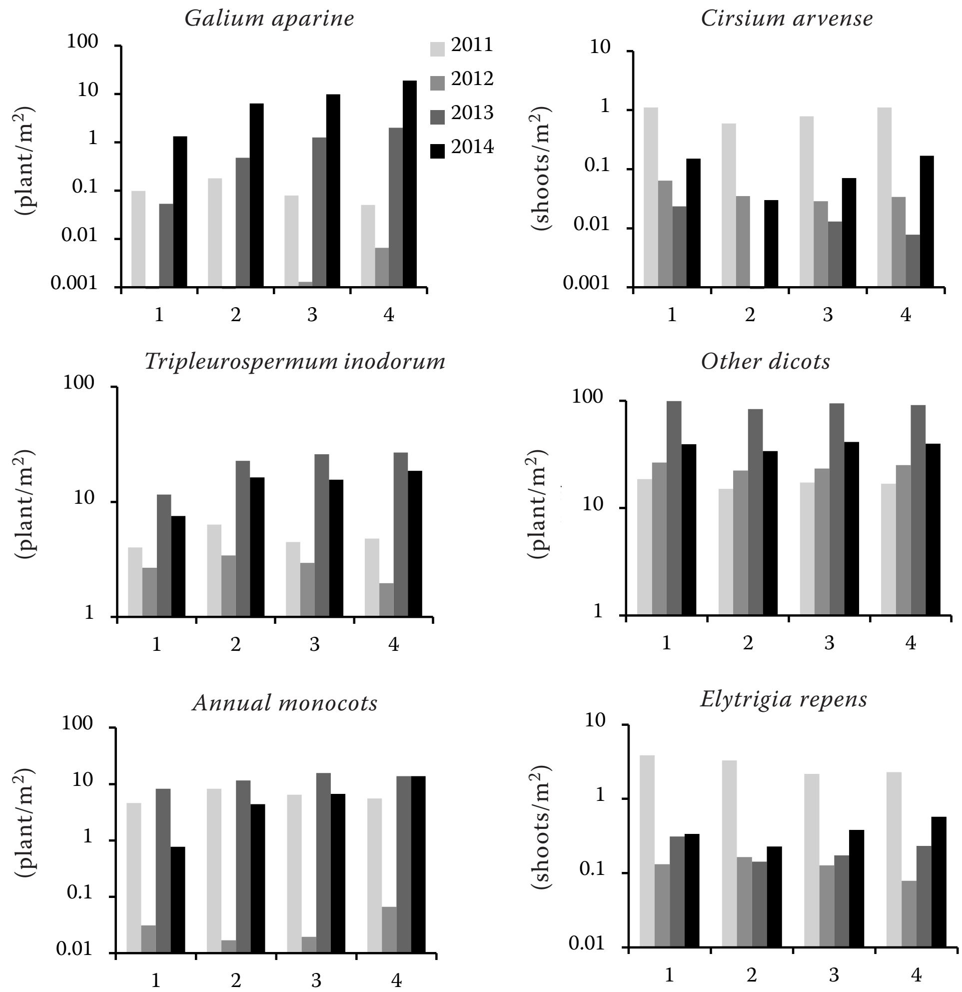

Figure 2. Comparison of population density for most important weeds in all experimental years

found. Because of the randomized trial design, the mean weed densities of individual treatments were mostly comparable (Figure 2), although the variations between replications were rather high. Therefore, the initial differences among treatments were statistically insignificant in all cases (P = 0.569–0.875). In the following sections, changes in weed density over the 4 years will be compared for blanket and SSWM treatments and will be described separately for individual weed groups.

Galium aparine. Initial infestation of *G. aparine* in all plots in spring 2011 was low and mean density varied between 0.05 and 0.18 plants/m^2 among treatments. Pre-emergent blanket herbicide application in winter rape assured a very low occurrence of *G. aparine* in all treatments in spring 2012. Infestation with *G. aparine* was higher for SSWM treatments in 2013 and 2014, however, and its abundance increased with rising threshold value (Figures 2 and 3). Significant differences were found between treatments 1 and 4 in 2013 (P = 0.076) and 2014 (P = 0.007).

The overall increase in *G. aparine* density cannot be attributed solely to the SSWM, because higher densities were also found with the blanket treatment. The causes of this rise can be attributed to the limited crop rotation of winter crops sequenced in combination with minimum tillage practice. The high infestation in 2014 on all plots can be accounted in part also to the lower efficacy of fluroxypyr used in the preceding year.

Due to the gradual increase of *G. aparine* population, herbicide savings in SSWM treatments decreased from 85.9–100% in 2011 to 6.3–12.5% in 2014 (Table 3). A relatively high correlation coefficient between 2011 and 2014 was found in treatment 1 (Table 4). The low correlations in treatments 2 and 3 are related to the increase of abundance in low density areas. The higher correlation in treatment 4 is caused by the fact that no cells were treated here in 2011 because the threshold was not exceeded.

Cirsium arvense. A relatively high initial abundance of *C. arvense* was suppressed by site-specific treatment combined with blanket pre-harvest application of glyphosate in 2011. Low *C. arvense* densities were maintained in subsequent years by SSWM (Figure 2) when herbicides were applied to relatively small areas. None of the SSWM treatments differed significantly from blanket treatment in 2013 and 2014 (P = 0.523 and P = 0.115, respectively).

Due to the high efficacy of the applied herbicides, high herbicide savings exceeding 90% were still possible in the final experimental year (Table 3). Low correlations between first and final year density were due to low densities and high relative sampling error rather than to the expansion of *C. arvense* in untreated cells (Table 4). Based on these results, even the highest threshold used in treatment 4 (1 shoot/m^2) can be recommended for SSWM.

Tripleurospermum inodorum. A medium infestation of *T. inodorum* was observed in 2011, varying between 4.01 and 6.35 plants/m^2 depending on treatment. The whole-field treatment of pre-emergent herbicide applied in August 2011 affected the abundance of *T. inodorum* in 2012, which was overall low. In the third and fourth experimental years, density of the *T. inodorum* population increased substantially, and mainly on SSWM plots. The high abundance in the third year prompted herbicide application on nearly all plots in SSWM treatments, and *T. inodorum* subsequently declined slightly in 2014 (Figures 2 and 3).

The overall population trend appears to be moderately increasing with higher thresholds. The occurrence of *T. inodorum* was greatest in treatment 4, although the initial population density was comparable with that for other treatments in the first experimental year. For statistical analysis, only three replications were taken into account for each treatment while excluding outlier values coming from a *T. inodorum*-free strip. Evaluated in this manner, treatment 1 was found to be significantly different from treatments 3 and 4 in 2013 (P = 0.053 and P = 0.034, respectively) and from treatment 4 in 2014 (P = 0.075).

The herbicide savings from SSWM treatments cannot be related only to *T. inodorum* in this case, because the same herbicide was used also against other dicotyledonous weeds. Correlations between first and final year density were higher in SSWM treatments, probably due to higher densities and therefore lower relative sampling errors.

Considering these results, the thresholds applied in treatments 3 and 4 (10 and 15 plants/m^2, respectively) cannot be recommended for SSWM. Even the lowest threshold used in this study (5 plants/m^2) could result in higher infestation by *T. inodorum* in subsequent years.

Other dicotyledonous weeds. The group of other dicotyledonous weeds was dominated by *V. arvensis*. Initial abundance of this group was similar for all treatments in 2011 and varied between 15.1 and 18.6 plants/m^2. Site-specific treat-

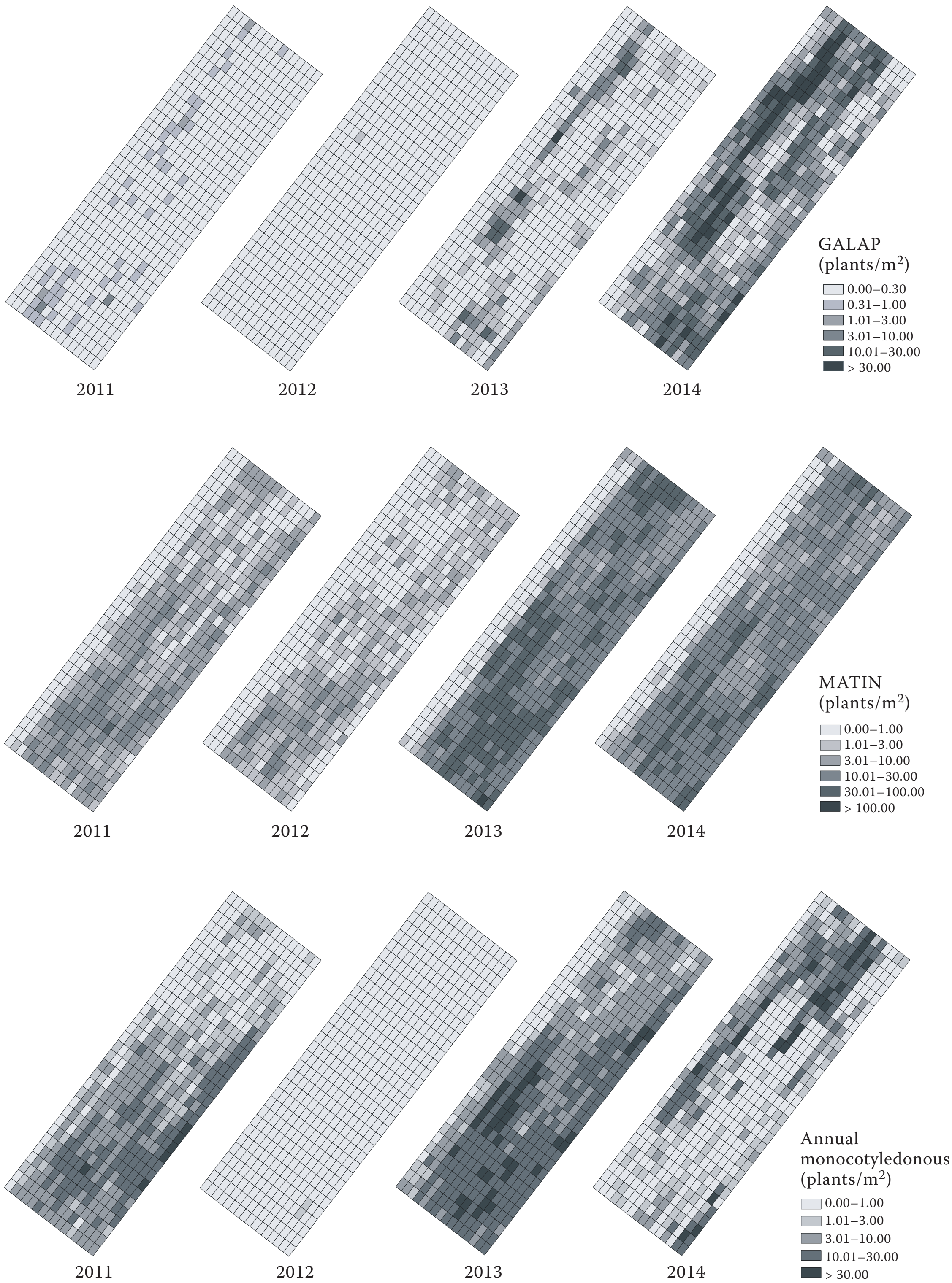

Figure 3. Distribution maps of *Galium aparine* (GALAP), *Tripleurospermum inodorum* (MATIN) and annual monocotyledonous weeds in all experimental years

ment according to thresholds did not cause an increase in weed density in the following year, and the highest infestation was found on blanket treatment plots. In the second experimental year, only pre-emergent blanket spraying against *V. arvensis* was used, because the post-emergent herbicides did not provide sufficient control. This led to an increase in the other dicotyledonous group in

Table 3. Herbicide savings (%) for individual herbicides and by treatments (1–4) in winter wheat. Savings in winter rape (2012) are reported in Hamouz et al. (2014)

Herbicide	2011				2013				2014			
	1	2	3	4	1	2	3	4	1	2	3	4
Pinoxaden	0	50.8	75.8	90.6	0	31.3	39.8	58.6	0	80.5	74.2	64.1
Metsulfuron-methyl + tribenuron-methyl	0	15.6	60.9	84.4	0	0	0	0	0	0	3.9	19.5
Fluroxypyr	0	85.9	97.7	100	0	69.5	71.1	75.0	0	9.3	12.5	6.3
Clopyralid	0	72.7	79.7	78.1	–	–	–	–	0	96.9	96.1	93.8
Glyphosate-IPA	0	0	0	0	–	–	–	–	–	–	–	–

2013, with *V. arvensis* again being the dominant species. Because of the increase of this group in 2013, treatment thresholds were exceeded in all cases and no savings were achieved by SSWM in this year. In 2014, the abundance of this group decreased slightly, but the realized herbicide savings were small (Table 3).

A considerably higher abundance of other dicotyledonous weeds was found not only on site-specifically treated plots, but also on blanket-sprayed plots. Therefore, this effect cannot be attributed to site-specific weed control. There were no significant differences among treatments in any experimental year (P = 0.633–0.927).

Annual monocotyledonous weeds. Annual monocots were represented on the experimental field almost exclusively by *Apera spica-venti* (L.) P.B. The plant density of this group was comparable among treatments in 2011, ranging between 4.58 and 8.58 plants/m^2. The occurrence of monocots was very low in 2012 because of pre-emergent herbicide application in oilseed rape. Annual monocots were not individually treated by herbicides in this year, although some of them could have been affected by the treatment for *E. repens*. The density of annual grasses was relatively balanced in 2013 and similar to the initial state with only a slightly higher abundance on SSWM treatments. Differences between treatments grew in 2014, and the population density decreased substantially in treatment 1. SSWM plant densities remained higher and increased slightly with increasing threshold values (Figure 2). A significant difference was found between treatments 1 and 4 only in 2014 (P = 0.034).

Pinoxaden herbicide savings remained at an acceptable level throughout the trial period (Table 3). Significant negative correlation coefficients in SSWM treatments (–0.237 to –0.401) indicate that *A. spica-venti* does not establish a long-term soil seed bank. This is apparent also from Figure 3.

Despite higher weed densities in SSWM compared to blanket treatment, SSWM can be recommended for *A. spica-venti*. Excellent herbicide efficacy together with the absence of a long-term soil seed bank in this species allowed for sustainable long-term use of SSWM of this species.

Elytrigia repens. The initial level of *E. repens* infestation was high in 2011 (2.16–3.85 shoots/m^2 depending upon treatment). Considering the application of other herbicides and the risk of crop injury, spring management of *E. repens* was avoided. This species was controlled by a pre-harvest application of a non-selective herbicide. Site-specific weed control against *E. repens* was carried out in oilseed rape in spring 2012 with 79.7–91.4%

Table 4. Pearson's correlation coefficients for weed species density between 2011 and 2014

Weed species	Treatment			
	1	2	3	4
Galium aparine	0.565*	–0.025	0.056	0.476*
Cirsium arvense	0.172	0.125	0.257*	0.295*
Tripleurospermum inodorum	0.369*	0.483*	0.466*	0.537*
Other dicots	0.503*	0.318*	0.316*	0.194*
Annual monocots	–0.057	–0.261*	–0.401*	–0.237*
Elytrigia repens	0.281*	–0.020	0.394*	0.026

Significant coefficients (α = 0.05) are marked with an asterisk herbicide savings in SSWM treatments. It had no significant effect on shoot density in 2013 and 2014 when compared to the blanket treatment (0.821 and 0.816, respectively). Changes in the *E. repens* population are shown in Figure 2.

Weed competition research studies are focused mostly on single species. Multiple weed species interference is difficult to study and research in this area is not frequently undertaken (e.g. Hume 1989, van Acker et al. 1997). Only a few studies, too, have focused on long-term thresholds or thresholds for site-specific weed management (e.g. Wallinga and van Oijen 1997, Keller et al. 2014).

Even in this practical testing of SSWM, the effect of individual herbicides is difficult to distinguish because of the large number of weed groups present and therefore the complexity of weed management systems. Some weed groups were treated using the same herbicide and some herbicides could have side effects on other weeds. However, some effects of SSWM are apparent. This study shows that the population response of individual weed species to SSWM is diverse and it is apparently related to soil seed banks. The species *G. aparine* and *T. inodorum* proved most problematic in this case. Although the seed persistence in the soil of both species is not extremely long, it was enough to increase species infestation for several years in sub-threshold cells.

Regarding possible seed production from sub-threshold weed populations, the low thresholds used in treatment 2 can be recommended for most weed species or groups. From the viewpoint of yields, higher thresholds can be used, but a decrease in herbicide savings should be expected in subsequent years or SSWM could be discontinued for some period. It is also apparent from this research that even if weed control is intensive, an increase in some weed populations may occur in a field due to repeated cultivation of the same crop. Crop sequence or rotation should therefore be considered an integral part of a weed control system.

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