

Impact of site-specific weed management on herbicide savings and winter wheat yield

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ABSTRACT

An aggregated distribution pattern of weed populations provides opportunity to reduce the herbicide application if site-specific weed management is adopted. This work is focused on the practical testing of site-specific weed management in a winter wheat and the optimisation of the control thresholds. Patch spraying was applied to an experimental field in Central Bohemia. Total numbers of 512 application cells were arranged into 16 blocks, which allowed the randomisation of four treatments in four replications. Treatment 1 represented blanket spraying and the other treatments differed by the herbicide application thresholds. The weed infestation was estimated immediately before the post-emergence herbicide application. Treatment maps for every weed group were created based on the weed abundance data and relevant treatment thresholds. The herbicides were applied using a sprayer equipped with boom section control. The herbicide savings were calculated for every treatment and the differences in the grain yield between the treatments were tested using the analysis of variance. The site-specific applications provided herbicide savings ranging from 15.6% to 100% according to the herbicide and application threshold used. The differences in yield between the treatments were not statistically significant ($P = 0.81$). Thus, the yield was not lowered by site-specific weed management.

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

There is much documentation in the scientific literature (e.g. Clay et al. 1999, Hamouz et al. 2006, Gerhards et al. 2012) that weeds are distributed in a patchy manner throughout agricultural fields. An aggregated distribution pattern of weed populations provides opportunity to reduce the herbicide application if site-specific weed management is adopted. Gerhards et al. (2002) achieved herbicide savings of 60% and 92% for dicotyledonous and monocotyledonous weeds, respectively, in spring barley (*Hordeum vulgare* L.) cultivation, and savings of 11% and 81% were achieved for the same weed groups for maize (*Zea mays* L.). In two winter wheat fields, Häusler et al. (1998) found that herbicide applications were necessary for 24% and 35% of the area for *Galium aparine* L., for 25% and 31% for other dicotyledonous weeds

and for 55% and 7.5% for grasses. Using a simulation, Christensen and Heisel (1998) estimated a 40% reduction of herbicide consumption, and Nordmeyer and Häusler (2000) calculated the need for herbicide application from 7% to 64% of the total area in various fields.

Site-specific weed management is based on the threshold concept: the aim is to adjust the intensity of management practices to the actual degree of weed infestation, with only those areas having a weed density exceeding the predefined control threshold typically being treated. However, site-specific weed management requires the precise setting of control thresholds for effectiveness and reliability. Furthermore, both areas that are treated superfluously and unsprayed areas that will show increases in weed infestation should be

minimised. The optimisation of control thresholds is, therefore, the main condition for implementing this technology in practice.

The economic threshold is considered as the weed abundance at which the cost of weed control is equal to the crop yield increase caused by this control. Thus, the control is economically profitable for higher weed abundances (Coble and Mortensen 1992). In the last decades, much research effort was devoted to the proper setting of weed economical thresholds. For cereals, most authors provide values between 0.1 and 2 plants/m² for *G. aparine*, 40–50 plants/m² for other dicotyledonous weeds and 20–30 plants/m² for grass weeds (Beer and Heitefuss 1981, Wahmhoff and Heitefuss 1985, Gerowitt and Heitefuss 1990, Zanin et al. 1993). Häusler et al. (1998) used the following application thresholds for the modelling of site-specific weed control in cereals: *Elytrigia repens* (L.) Nevski – 0.1 plants/m²; other monocotyledonous weeds – 20 plants/m²; *G. aparine* – 0.2 plants/m²; *Cirsium arvense* (L.) Scop. – 0.1 plants/m² and other dicotyledonous weeds – 40 plants/m².

However, the actual economic threshold values may vary considerably depending on crop density, crop and weed stage and other factors. There is little experience with the use of above mentioned thresholds for the site specific weed management applications. This work is focused on the practical testing of site-specific weed management in a winter crop sequence and the optimisation of the control thresholds for this system.

MATERIAL AND METHODS

Site specific weed management was applied to an experimental field in Central Bohemia near Kolín in 2011. The annual average air temperature

at the experimental site is 9.0°C, and the annual average precipitation is 560 mm. The elevation ranges from 280 to 285 m a.s.l. The soil type is modal Greyzem on loess. The field was sown with winter wheat (*Triticum aestivum* L.), the forecrop and the following crop was winter rape.

The entire area of 3.07 ha (320 × 96 m) was split into 512 cells of 60 m² (6 × 10 m). The cell represents the smallest area individually surveyed and treated with herbicides. The weed infestation was estimated before the post-emergence herbicide application at the growth stage of wheat 24–31 of BBCH scale. The abundance of all of the weed species was analysed manually by counting individuals in four sampling quadrats placed in the central part of each cell. An area of 4 × 1.5 m² was analysed for *G. aparine*; *C. arvense* and *E. repens*, and the other weed species were evaluated in an area of 4 × 0.5 m². The coverage of each species was estimated visually in the same samples. The Patchiness index (PI) of Lloyd (1967) was calculated for the most abundant weed species to quantify the aggregation of their populations:

$$PI = \frac{m + \left(\frac{s^2}{m}\right) - 1}{m}$$

Where: m – sample mean; s^2 – sample variance. PI value higher than 1 indicates an aggregated population.

All the cells were arranged into 16 blocks, which allowed the randomisation of four treatments in four replications (Figure 2a). Treatment 1 represented blanket spraying, regardless of the weed infestation, and the other treatments differed by the application threshold used for the individual weed groups. The threshold values are listed in Table 1.

Treatment maps for every weed group were created based on the weed abundance data and relevant treatment thresholds. The herbicides were

Table 1. Application thresholds for individual weed groups

Weed group	Thresholds (plants/m ²)			
	treatment 1	treatment 2	treatment 3	treatment 4
<i>Galium aparine</i>	–	0.1	0.2	0.5
<i>Cirsium arvense</i>	–	0.2	0.5	1
<i>Tripleurospermum inodorum</i>	–	5	10	15
Other dicotyledonous weeds	–	10	20	30
Annual monocotyledonous weeds	–	5	10	20

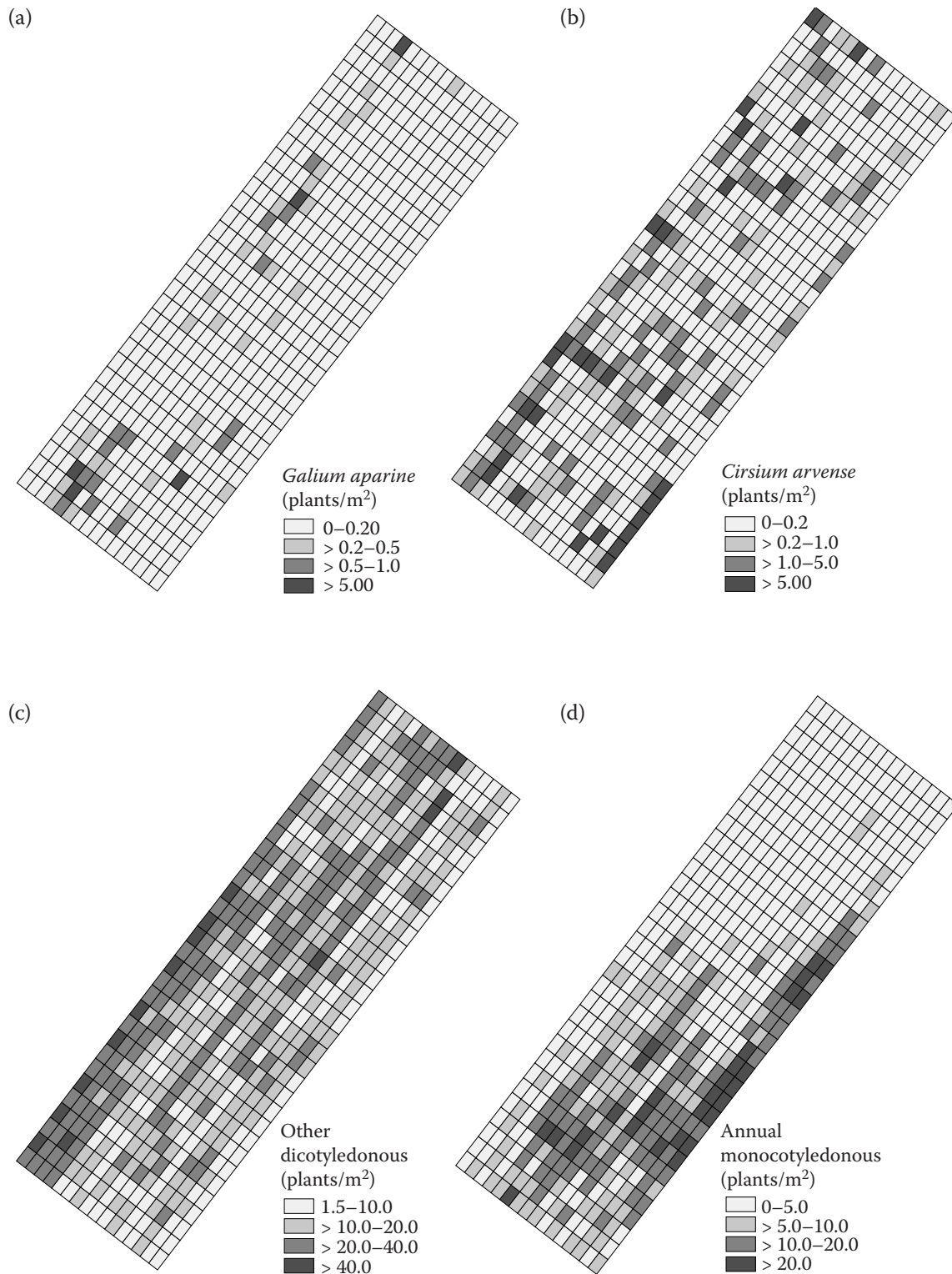


Figure 1. Distribution maps of following weed groups: *G. aparine* (a); *C. arvense* (b); other dicotyledonous weeds (c) and annual monocotyledonous weeds (d)

applied using a 36 m boom sprayer equipped with boom section control (every section 6 m wide). The positioning of the sprayer was ensured using real time kinematic (RTK) navigation system with

a horizontal error of less than 0.1 m. The sprayer was adjusted prior to the herbicide application, ensuring a horizontal error of application lower than 1 m and providing reasonable accuracy for

Table 2. Herbicides used in winter wheat in 2011, their dosage and target weed group

Herbicide	Active ingredient	Herbicide dose per ha	Water (L/ha)	Application date	Target weed group
Axial + Adigor	pinoxaden 100 g/L + rape oil – methyl ester 440 g/L	0.4 L + 1.8 L	300	19.4. 2011	annual monocotyledonous weeds
Biplay SX	metsulfuron-methyl – 110 g tribenuron-methyl – 222 g	40 g	300	19.4. 2011	other dicotyledonous weeds
Lontrel 300	clopyralid 300 g/L	0.4 L	300	28.4. 2011	<i>Cirsium arvense</i>
Starane 250 EC	fluroxypyr 250 g/L	0.5 L	300	28.4. 2011	<i>Galium aparine</i>
Roundup Klasik	glyphosate-IPA 480 g/L	3 L	300	15.7. 2011	<i>Elytrigia repens</i>

the selective spraying of individual cells. The herbicide application against individual weed groups was performed separately; the herbicides were selected according to the actual weed spectrum and are listed in Table 2. The glyphosate-IPA herbicide was applied as pre-harvest treatment to the whole trial field in order to control *E. repens*. The site-specific treatment was avoided in this case to maintain a homogeneous maturing of the crop.

The savings were calculated for every herbicide as a percentage ratio between the site-specific treatments and blanket spraying. The yield of the winter wheat was analysed by the harvest of 1.5 m strips in each cell and corrected for the standard grain moisture. The differences in the wheat grain yield between the treatments (i.e., application thresholds) were analysed using an analysis of variance (ANOVA) at a probability level of $\alpha = 0.05$. All statistical analyses were performed with Statistica 9.0 software (StatSoft Inc. 2010)

RESULTS AND DISCUSSION

Weed distribution. The experimental field showed a relatively high weed density, however

the coverage of weeds was generally low. The mean weed abundance reached 32.01 plants/m². *Viola arvensis* Murray showed the highest abundance (15.51 plants/m²), followed by *Tripleurospermum inodorum* (L.) Schultz-Bip. (4.91 plants/m²) and *E. repens* (2.89 stems/m²). The distribution of most of the weed species was patchy, and significantly large areas with a low weed infestation were found. The total weed density varied between 6.5 and 94.67 plants/m². The annual grass weeds were concentrated in the southern part of the field, whereas patches of the annual dicotyledonous weeds were more evenly distributed throughout the area. *C. arvense* occurred in very small patches and covered a small area, but it was present in many of the application cells. *G. aparine* occurred in only a few cells and was of the marginal importance. The values of the mean density, mean coverage and Patchiness index for the most abundant weed species are listed in Table 3. Distribution maps of *G. aparine*, *C. arvense*, other dicotyledonous weeds and annual monocotyledonous weeds are presented in Figure 1.

Herbicide savings. The site-specific applications of the herbicides provided herbicide savings ranging from 15.6% to 100% according to the her-

Table 3. Mean abundance, mean coverage and Patchiness index of the most abundant weed species

Weed species	Mean abundance (plants or stems/m ²)	Mean coverage (%)	Patchiness index
<i>Viola arvensis</i>	15.51	0.20	1.23
<i>Tripleurospermum inodorum</i>	4.91	0.08	1.98
<i>Elytrigia repens</i>	2.89	0.12	5.49
<i>Papaver rhoeas</i>	1.00	0.12	4.71
<i>Cirsium arvense</i>	0.90	0.15	7.72
<i>Lamium amplexicaule</i>	0.11	0.01	8.43
<i>Galium aparine</i>	0.10	0.02	11.71

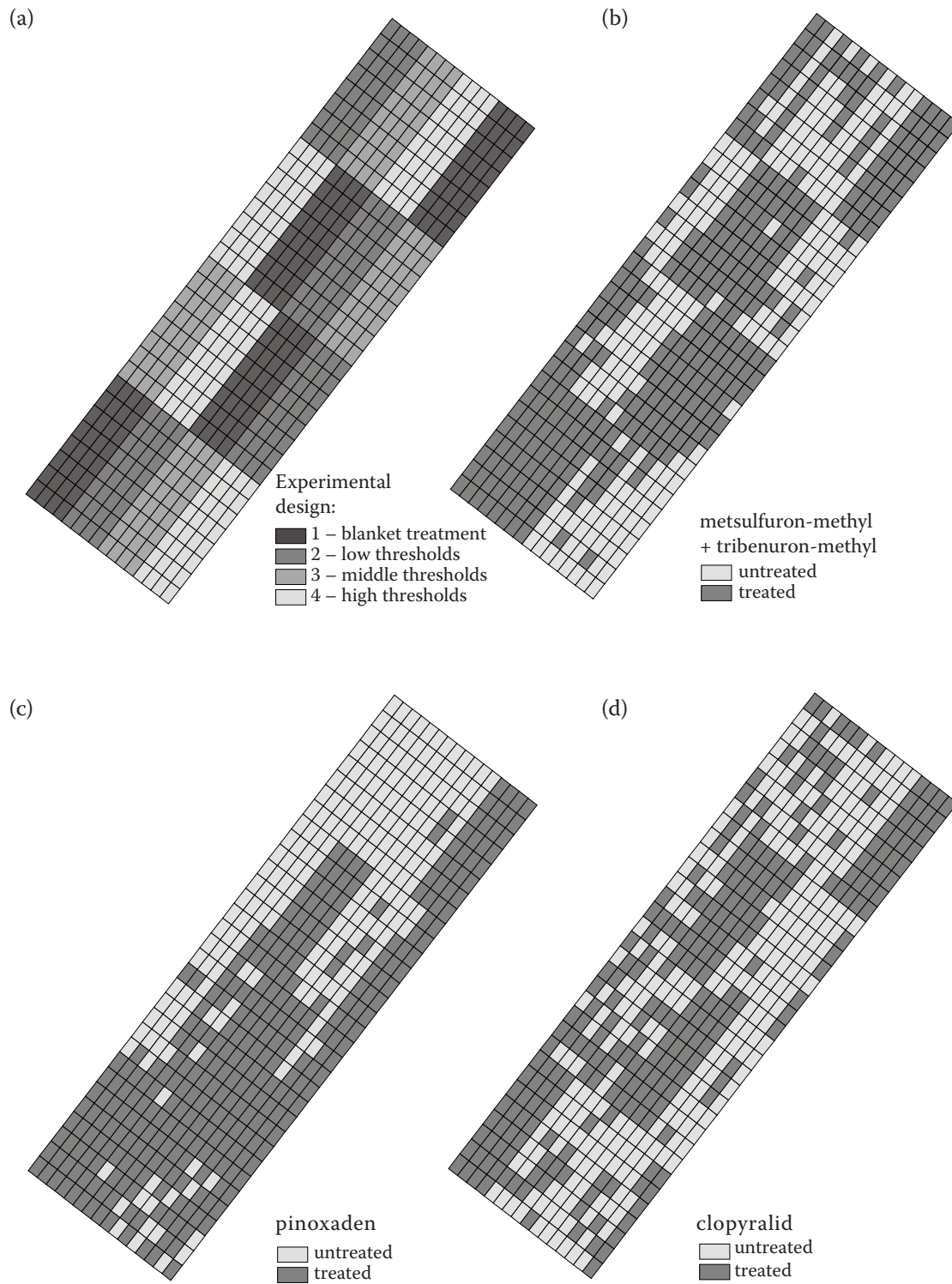


Figure 2. Experimental design (a) and application maps for metsulfuron-methyl + tribenuron methyl (b); pinoxaden (c) and clopyralid (d)

bicide and application threshold used. The highest savings (85.94–100%) were achieved in the case of the fluroxypyr application, because only small number of cells was infested with *G. aparine*. In

contrast, lower savings of metsulfuron-methyl + tribenuron-methyl herbicide (15.63–84.38%) were caused by relatively high abundance and homogeneous distribution of *V. arvensis* and *T. inodo-*

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

Herbicide active ingredient	Number of treated cells				Herbicide savings (%)			
	1	2	3	4	1	2	3	4
Pinoxaden	128	63	31	12	0	50.78	75.78	90.63
Metsulfuron-methyl + tribenuron-methyl	128	108	50	20	0	15.63	60.93	84.38
Fluroxypyr	128	18	3	0	0	85.94	97.66	100
Clopyralid	128	35	26	28	0	72.66	79.69	78.13
Glyphosate-IPA	128	128	128	128	0	0	0	0

rum. As expected, higher application thresholds generally resulted in higher herbicide savings. The application maps for pinoxaden, clopyralid and metsulfuron-methyl + tribenuron-methyl are shown in Figure 2. All of the herbicide savings for the individual treatments are listed in Table 4. The results confirm the patchy distribution of weed populations in crop fields and show that, even if the mean weed infestation is relatively high, site-specific weed management can provide a good potential for herbicide savings. Wallinga et al. (1998) showed that actual herbicide saving is considerably affected by spatial resolution of the sprayer. In this research, a 6 × 10 m grid was used for weed sampling and herbicide application. Increasing the spatial resolution will probably result in a higher reduction of herbicide use.

Winter wheat yield. The mean grain yield of the entire experimental field was 8664 kg/ha. The lowest yield (8497 kg/ha) was achieved at treatment 1 (blanket spraying). All site-specific treatments resulted in higher yields although the differences between treatments are relatively low. When compared with treatment 1, the treatment 2 resulted in 160 kg/ha yield increase, whereas treatments 3 and 4 provided 247 and 254 kg/ha yield

increase respectively. The ANOVA analysis showed that the differences between the treatments were not statistically significant ($P = 0.81$). The yields of all of the treatments are presented in Figure 3. The results show that grain yield was little affected by the herbicide treatment, and, although the differences between the treatments were not statistically significant, the yield tended to be higher in all of the site-specific treatments compared to the blanket spraying. Therefore, even the highest thresholds (treatment 4) are acceptable for site-specific weed control in this case. A similar result was reported also by Ritter et al. (2008) who partially explained this by the absence of a negative side effect of the herbicide on the crop. The statistical insignificance was caused by high total variance of the analysed data, suggesting that the grain yield could be affected by other factors. Ritter et al. (2008) also mentioned that a high variance of the data can limit the statistical analyses of single effects but that the variance is crucial for the effective utilisation of precision farming techniques.

At present, site-specific weed management is still limited by the mapping costs, and automated weed sampling and mapping methods are being developed to reduce these costs (e.g. Gerhards and Oebel 2006, Gebhardt and Kühbauch 2007, Martín et al. 2011). Clearly, once the availability of rapid and reliable mapping methods allows the practical application of site-specific weed control, research analysing the impact of site-specific weed management on crop yield and weed populations, such as that presented here, will become more important.

The economic threshold does not take into account the changes in the weed species populations in the ensuing years. Indeed, using the above-mentioned thresholds could lead to an increase in the weed populations in the untreated portions

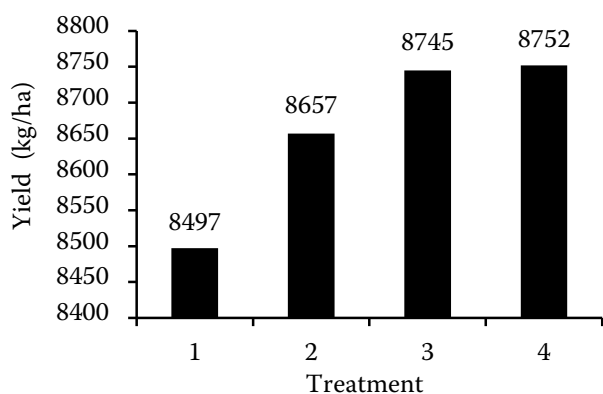


Figure 3. Wheat grain yield of all the tested treatments

of the field in the years following the application. Our experiment will continue to study the impact of site-specific weed management and crop rotation on weed population dynamics. Other environmental factors will be also measured and involved in the statistical analyses.

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