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Reduced herbicide rates for an effective weed control in competitive wheat cultivars

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Abstract

A study was carried out over 2 years (2008/2009 and 2009/2010) in Greece, in order to evaluate the weed control using reduced rates of the herbicide mesosulfuron-methyl+iodosulfuron-methyl-sodium of four major weeds (*Avena sterilis*, *Phalaris minor*, *Papaver rhoeas* and *Sinapis arvensis*), grain yield and yield components of five wheat cultivars (Bob, Cosmodur, Meridiano, Quadrato and Simeto). The results indicated a significant differentiation between the several wheat cultivars regarding their weed competitive ability, in terms of dry biomass and seed production. In the case of cultivars such as Simeto the efficacy of 50% reduction of the herbicide recommended rate on wild oat remained high, since it resulted to a reduction of biomass and seed production up to 81 and 98% compared with the untreated plots. In most cultivars studied, the reduction of the herbicide rates by 25 to 50% resulted to a no significant reduction of grain yield compared to the recommended rate. The study revealed that some wheat cultivars with enhancing weed competitiveness can improve the efficacy of reduced herbicide rates. Consequently, sustainable cropping systems could be further developed through the integration of such agronomic practices, while in parallel, care on the threat of herbicide resistance development should be also taken.

Keywords: Reduced herbicide rates; Competitive wheat cultivars; Weeds.

Introduction

Negative effects of pesticides in the environment as the risk of food contamination have led in the last years to reduce the use of agrochemicals, mainly herbicides (Barros et al., 2005). Widespread concern about environmental side-effects of herbicides has resulted in the banning of several herbicides in some countries and an increased pressure on farmers to reduce the use of herbicides (Matteson, 1995). Recent studies largely advocate for developing sustainable cropping systems with a reduced reliance on herbicides (Barros et al., 2005). In fact, today the aim of weed management is to keep the weed community at an acceptable level of control rather than to keep the crop totally free of weeds. In many cases, satisfactory control of weeds may be obtained when herbicides are used fewer times and at lower rates than normally recommended (Zhang et al., 2000) and thus maintain satisfactory crop yield (Steckel et al., 1990).

Recommended herbicide rates are selected to ensure a high level of weed control over a wide range of environmental conditions, weed growth stages, and weed species with different degrees of susceptibility. The industry recognizes that there are situations where herbicide efficacy can be maintained at reduced rates, although these situations are difficult to predict (Blackshaw et al., 2006). Considerable research has examined the potential use of lower-than-labeled herbicide rates (Salonen, 1992; Blackshaw et al., 2006). The results of the several approaches are not always similar, and sometimes controversial about the potential practices. As a general principle, a lower rate of herbicide may kill most of the target weeds under favourable conditions; however, under less favourable conditions, a higher rate will be required, and under unfavourable conditions even the highest rate of herbicide may still give unsatisfactory results (Medd et al., 2001). Nevertheless, knowledge about effects of different factors affecting herbicide efficiency, e.g., different weed species, growth stage (Bruce et al., 1996), competitiveness of the crop, variety and weather conditions (Xie et al., 1997), increases the possibility to use herbicide rates below the recommended one while still obtaining adequate weed control and acceptable crop yield (Fogelfors, 1990; Salonen, 1992). Indeed, herbicides at reduced rates are often sufficient to control weed density at or below the threshold levels and below-labeled herbicide rates in combination with some mechanical weed control have proven to be an effective way of reducing herbicide input to agricultural systems (Barros et al., 2005). The combination of reduced herbicide rates with other management practices, such as competitive crops or cultivars, could also markedly increase the odds of successful weed control (Salonen, 1992; Zhang et al., 2000).

Integrated weed management systems help farmers manage rising herbicide costs, herbicide-resistant weeds, and also help mitigate the social, health, and environmental impacts of agriculture. In particular, weed management aimed at the reduction of herbicide use needs to comprise multiple strategies, among them the use of crops and cultivars with improved competitive traits. In addition, some studies revealed large differences between cultivated plant species and cultivars within each species in this ability to suppress weeds (Christensen, 1995). Using the most competitive cultivars under field conditions can be an important component of integrated weed management systems, useful in both conventional and organic (and other low-input) farming systems (Olofsdotter, 2001).

The objective of this study was to evaluate the effects of reduced rates of the herbicide mesosulfuron-methyl+iodosulfuron-methyl-sodium on the growth and fecundity of four major weeds (*Avena sterilis*, *Phalaris minor*, *Papaver rhoeas* and *Sinapis arvensis*), grain yield and yield components of five wheat cultivars (Bob, Cosmodur, Meridiano, Quadrato and Simeto) grown under the field conditions of Greece.

Materials and Methods

Field experiments were conducted during 2008-2009 and 2009-2010 in the Vonitsa region of western Greece. The site was located at 20° 53′ 54″ E, 38° 53′ 38″ N (altitude 60 m asl). The soil was a clay loam, whose physicochemical characteristics (0 to 15 cm depth increment) were clay 283 g kg^{-1}, silt 320 g kg^{-1}, sand 396 g kg^{-1}, organic C content 16.1 g kg^{-1}, pH (1:2 H_2O) 8.1, $CaCO_3$ 12 g kg^{-1} and organic matter content of 27 g kg^{-1}. The previous crop was alfalfa (*Medicago sativa* L.). The aforementioned weeds were the dominant plant species. Total monthly rainfall and mean monthly temperature data recorded near the experimental field are shown in Table 1.

Table 1. Total monthly rainfall and mean monthly temperature for the years 2008/2009 and 2009/2010.

	J	F	M	A	M	J	J	A	S	O	N	D
						Rainfall (mm)						
2008	–	–	–	–	–	–	–	–	–	73	131.1	154.2
2009	290.6	108.5	135.8	54.2	9.1	36.3	0	0.8	24.8	178	150.1	121.1
2010	100.9	115.8	67.8	26.6	72.6	7.9	0.3	–	–	–	–	–
						Temperature (°C)						
2008	–	–	–	–	–	–	–	–	–	19.3	15.2	11.6
2009	10.4	9.8	12.2	15.4	21.3	22.7	26.3	27.5	23.3	18.5	15.7	12.5
2010	10.9	11.1	12.1	16.1	19.6	24.1	26.6	–	–	–	–	–

Nitrogen and phosphorus were applied as ammonium sulpho-phosphate (20-10-0) at 80 and 40 kg ha^{-1}, respectively, and incorporated into the soil before wheat sowing. All wheat cultivars were planted at a seed rate of 170 kg ha^{-1} on 15 November 2008 and 19 November 2009. A split-plot arrangement of treatments was used with five plots and three replicates in a randomized complete block design. The plot size was 5×12 m. In each of the fifteen plots, four subplots of 5×3 m were created and separated by a 1 m wide alley. Wheat cultivars (Bob, Cosmodur, Meridiano, Simeto and Quadrato) were the main plot factor, while herbicide rate (0, 0.063, 0.125 and 0.25 kg ha^{-1} (recommended rate) of the herbicide product Hussar maxx WG) was the subplot factor. The herbicide used (Hussar maxx WG, Bayer CropScience AG, Monheim, Germany) was a commercial mixture formulated as a water dispersible granule of mesosulfuron-methyl (3% w/w) and iodosulfuron-methyl-sodium (3% w/w) and mefenpyr-diethyl (9%). Mesosulfuron-methyl is a post-emergence grass weed herbicide for wheat, triticale and rye, providing also control of some broad-leaved weeds. This herbicide is mixed with iodosulfuron-methyl-sodium to complement the control of broad-leaved weeds. Both herbicides belong to the group of sulfonylureas. This herbicide mixture is applied in combination with the safener mefenpyr-diethyl to ensure the highest level of selectivity without compromising product efficiency. When wheat crop and grass weeds reached the three to five leaf stage (Zadoks stage Z 13-15, following Zadoks et al., 1974), while broad-leaved weeds had 3-5 pairs of leaves, they were treated with the above-mentioned rates of herbicide, using a motorized backpack sprayer delivering 300 l ha^{-1} spray solution at 2.5 kg cm^{-2} pressure. The history of the experimental field showed heavy infestation of wild oat (*Avena sterilis* L.), littleseed canary grass (*Phalaris minor* Retz.), common poppy (*Papaver rhoeas* L.) and wild mustard (*Sinapis arvensis* L.). Shortly after weed emergence, seedlings of the above-mentioned weeds were thinned to the desired densities: 10 seedlings per m^2 for wild oat and littleseed canarygrass and 5 seedlings per m^2 for common poppy and wild mustard. Weeds that emerged within the experimental area after the first target weeds had emerged were removed, remaining the oldest weeds in place. Weeds were counted per m^2 in all subplots at the heading stage six weeks after treatment (6 WAT). Additionally, at the ear emergence growth stage of wheat (Zadoks growth stage 50 according to Zadoks et al., 1974), the four weeds were harvested and their aboveground biomass and seed number were determined. Other weed species were observed at very low densities, therefore they are not reported.

The plots were harvested in late June of each year to determine the grain yield. For this determination, grain yields were combined from an area of 2 m^2 from the centre of each 3×2 m subplot. The crop yield was adjusted to 15% moisture content and the yield components (thousand grain weight) and quality parameters (grains per spike) were determined.

The data were analyzed by ANOVA and means were separated by Fisher's Protected LSD test at a significance level of P=0.05. Because the ANOVA indicated no significant treatment by year interaction, means of all parameters (except weed density) were averaged over years. All statistical analyses were conducted using the Statistica 9 software package (StatSoft, Inc. 2300 East 14th Street, Tulsa, OK 74104, USA).

Results

Weed density was inversely proportional to each herbicide rate, while in 2009 the densities of grass weeds were higher than the second year (Table 2), which occurred possibly due to the significant reduction of the produced seed in the first year of experimentation (data not shown). In all cases, the highest recommended herbicide rate reduced the number of weeds by 77 to 95% compared with the untreated control. On the contrary, the reduction of herbicide rates by 25 and 50% resulted to a weed density reduction ranging from 62 to 89% and from 53 to 67%, respectively, which cannot be characterized as satisfactory.

Table 2. Density of the major weed species of our field experiment and both years (2009 and 2010) for all treatments, averaged across the five wheat cultivars at 6 WAT. LSD values according to Fisher's protected test (P=0.05) are also shown.

Year	Herbicide rates (kg ha^{-1})	Weed species			
		A. sterilis	*Ph. minor*	*P. rhoeas*	*S. arvensis*
		plants m^{-2}			
2009	0	18.3	14.4	10.2	12.6
	0.063	6.3	5.4	3.4	4.2
	0.125	4.4	3.6	1.3	2.6
	0.25	3.0	2.8	0.5	1.9
2010	0	15.3	12.6	10.1	9.8
	0.063	5.4	4.4	3.3	4.6
	0.125	2.7	2.6	2.1	3.7
	0.25	1.3	2.0	1.3	2.3
LSD (P=0.05)		2.42	2.33	2.56	2.27

Regarding weed dry biomass production, Quadrato was the most weed suppressive among the five wheat cultivars that were tested, in the absence of herbicide applications (Table 3). It is noticeable that in the untreated plots the weed biomass with the Quadrato cultivar was from 19 to 35% lower than with the Cosmodur cultivar. Consequently, there is a significant differentiation between the several wheat cultivars regarding their weed competitive ability, while plant height seems to play some role on that, since Quadrato was the tallest cultivar (data not shown). The best weed control was achieved with the highest herbicide rate, but lower rates of mesosulfuron+iodosulfuron often provided adequate weed control. The reduction of the upper recommended rate by 50% decreased the control efficiency on wild oat less than canary grass, common poppy and wild mustard. Simeto was the cultivar with the most efficient weed control at the reduced rates, while the relative weed control in Cosmodur was rather inadequate (Table 3).

Table 3. Shoot dry biomass production for the major weeds of field experiments counted at the ear emergence stage of wheat (Z50). Means were averaged across the two years. LSD values according to Fisher's protected test (P=0.05) are also shown.

Wheat cultivar	Herbicide rates (kg ha^{-1})	Weed species			
		A. sterilis	*Ph. minor*	*P. rhoeas*	*S. arvensis*
		g			
Bob	0	13.4	8.3	7.9	19.9
	0.063	3.6	4.5	3.1	5.3
	0.125	2.4	2.1	2.2	2.6
	0.25	1.2	1.2	0.8	1.8
Cosmodur	0	15.2	8.9	8.7	23.3
	0.063	6.1	5.6	3.2	6.2
	0.125	3.2	2.4	1.8	4.1
	0.25	2.3	0.9	0.5	1.9
Meridiano	0	12.9	8.7	8.2	18.4
	0.063	4.3	4.6	4.2	5.8
	0.125	2.1	2.7	1.9	2.3
	0.25	1.4	1.3	1.1	1.4
Simeto	0	14.9	8.3	7.5	20.8
	0.063	2.8	3.1	2.2	4.8
	0.125	0.9	1.6	0.7	1.7
	0.25	0.6	0.3	0.2	1.2
Quadrato	0	11.3	7.2	5.9	15.2
	0.063	3.1	3.1	1.5	6.2
	0.125	1.4	1.6	1.1	2.9
	0.25	0.5	0.8	0.6	1.8
LSD (P=0.05)		3.05	2.82	2.31	3.82

Another parameter which has to be studied towards a long time efficacy of every weed management practice is its effect on weed seed production. In our study, the differences between the several wheat cultivars were significant, especially in a non-herbicide situation. Indeed, the fecundity of *A. sterilis*, *Ph. minor*, *P. rhoeas* and *S. arvensis* in Quadrato untreated plots was 31, 33, 23 and 21% lower than in Cosmodur, respectively (Table 4). On the other hand, the maximum recommended rate of mesosulfuron + iodosulfuron gave a very efficient weed control in term of their seed production. The herbicide rates reduction also resulted to a satisfactory situation (especially on grassy weeds), since half the recommended rate resulted to a seed production reduction ranging from 92 to 98% for wild oat and from 88 to 95% for canary grass compared to the untreated control, depending on the wheat cultivar.

Table 4. Interaction between wheat cultivars and herbicide rates on seed production of several weed species. Means were averaged across the two years. LSD values according to Fisher's protected test (P=0.05) are also shown.

Wheat cultivar	Herbicide rates (kg ha^{-1})	Weed species			
		A. sterilis	*Ph. minor*	*P. rhoeas*	*S. arvensis*
		seeds m^{-2}			
Bob	0	5820	6345	71500	18500
	0.063	440	740	7540	5540
	0.125	125	270	1780	1240
	0.25	15	79	640	650
Cosmodur	0	6214	6780	73200	21450
	0.063	245	780	8590	6670
	0.125	88	242	920	860
	0.25	14	85	560	310
Meridiano	0	5485	5125	68400	16720
	0.063	204	546	11450	6680
	0.125	81	103	810	1310
	0.25	32	32	385	670
Simeto	0	5960	5840	61500	18440
	0.063	108	320	7650	5520
	0.125	35	87	505	765
	0.25	14	26	210	204
Quadrato	0	4261	4510	56000	15680
	0.063	116	210	7050	4650
	0.125	45	68	665	850
	0.25	18	14	385	345
LSD (P=0.05)		385.5	412.6	7800.5	5420.2

Differences in wheat yield parameters were not observed among growing seasons, therefore the mean values were presented in Table 5. Grain yield, ranged between 3640 and 4140 kg ha^{-1} and between 3920 and 4620 kg ha^{-1} in the least and the most productive cultivar (Cosmodur and Simeto), respectively. Quadrato was the most productive cultivar in the untreated situation, since in the same time it was the most weed competitive cultivar (Tables 3 and 4). In most cultivars, the 50% reduction of the herbicide rates resulted to a no significant reduction of grain yield compared to the recommended dose. In parallel, the resulted yields after the herbicide application with half the rate were significantly higher (by 8 to 12%) than the corresponding values without any herbicide at all.

Table 5. Interaction between wheat cultivar and herbicide rate on grain yield parameters of wheat. Means were averaged across the two years. LSD values according to Fisher's protected test (P=0.05) are also shown.

Wheat cultivar	Herbicide rates (kg ha^{-1})	Grain yield	Thousand grain weight	Number of grains per spike
		kg ha^{-1}	g	
Bob	0	3820	48	36
	0.063	4320	51	41
	0.125	4510	52	45
	0.25	4580	51	47
Cosmodur	0	3640	50	30
	0.063	3800	53	34
	0.125	4190	53	37
	0.25	4140	54	37
Meridiano	0	3670	45	31
	0.063	4010	46	34
	0.125	4170	48	36
	0.25	4230	48	38
Simeto	0	3920	51	38
	0.063	4310	52	43
	0.125	4500	53	48
	0.25	4620	53	51
Quadrato	0	4030	48	36
	0.063	4370	50	40
	0.125	4330	50	42
	0.25	4480	50	44
LSD (P=0.05)		330.5	4.2	8.3

The thousand grain weight ranged between 48 and 54 g without significant differences between the several treatments in each cultivar (Table 5). However, there were some significant differences regarding number of grains per spike (Table 5), since this specific trait was also significantly correlated to the grain yield (r=0.92). In the case of half doses, the number of grains was lower (not significantly) compared with the recommended rates, but still by 9-12% higher than the spikes of the untreated plants (Table 5). It was also noted that the number of grains per spike for the plants of several cultivars (Cosmodur and Meridiano) treated with the recommended rate was at the same level with untreated plants belonging to other cultivars (Simeto and Quadrato). Consequently, it seems that this yield component is primarily dependent on cultivar.

Discussion

The results revealed a significant differentiation between the several wheat cultivars regarding their weed competitive ability, even without any herbicide application. Indeed, several researchers have already reported large differences between cultivated plant species and cultivars within each species in this ability to suppress weeds (O'Donovan et al., 2000; Travlos et al., 2011). In our study, the best weed control was achieved with the highest herbicide rate, but lower rates of mesosulfuron+iodosulfuron often provided good weed control, especially in the most competitive cultivars. This finding is in full accordance with previous studies supporting that competitive cultivars affect herbicide performance and weed dry matter reduction, while they enhance the likelihood of success with reduced herbicide rates (Sharma and Vanden Born, 1983; Salonen, 1992). Lemerle et al. (1996) have also found that diclofop at reduced rates was more effectively controlled rigid ryegrass (*Lolium rigidum*) in competitive (tall) than in non-competitive (short) wheat cultivars. Moreover, in our experiment, the reduction of the upper recommended rate by 50% decreased the control efficacy on wild oat less than common poppy and wild mustard. This variation among weed species on their susceptibility to reduced herbicide rates has also been recognized (Salonen, 1992). Consequently, weed monitoring is a prerequisite for successful adjustment of dose rate, since the dose responses are species-specific (Kudsk, 1989).

For the four weeds assessed, the effects of reduced herbicide rates on their fecundity were similar to the relative effects on weed biomass. This trend is in agreement with previous studies, since weed biomass correlates closely with the seed production of weeds (Wilson et al., 1988). In some cases, herbicide rates lower than the recommended may not prevent weed seed production (Fogelfors, 1977), although other studies revealed no increase in the number of weed seeds in the soil after continuous use of reduced herbicide rates (Salonen, 1992). This is probably also true for our case, since half the recommended rate resulted to a seed production higher than in the plots treated with the recommended rate. Although, the produced seeds were significantly less than the untreated plots, potentially and progressively reducing the soil seed bank. This effect is crucial for sustainable agriculture, since sustainable weed management is closely linked to the development of competitive cropping systems that reduce weed populations over time.

It is well known that herbicides applied at lower than recommended rates can affect weed control and may affect crop productivity and consequently profitability (Harker and Blackshaw, 1991). Past research showed that wild oat biomass was 20 to 400% greater when herbicides were applied at half rather than the full recommended label rate (Barton et al., 1992; Spandl et al., 1997). These same studies showed that cereal seed yield and net returns often were not affected by reduced herbicide rates, despite more wild oat biomass. This was also true for our study, since despite the significant increase of the biomass of the several weeds after the 50% reduction of the herbicide rates (2 to 5 times higher than the corresponding values after the application of the recommended rate), there was not a significant impact on the grain yield of the most cultivars (except the least competitive one, i.e. Cosmodur). Particularly for mesosulfuron+iodosulfuron, there is evidence that their rates could be significantly reduced through integration with other management practices (e.g. sorghum and sunflower extracts) without compromising yield of wheat (Mushtaq et al., 2010). In our experiments, the reduction of the recommended rates to the half resulted to a reduction of the grain yield up to 9%, depending on the cultivar. Similar values were also evident in previous studies when five wild oat herbicides were applied at rates lower than the full label rate (Holm et al., 2000).

Several studies have found substantial variation in weed control efficiency using different herbicide rates (Zhang et al., 2000), while rate reduction higher than 50% might result in high variation in efficacy, depending on many factors (Salonen, 1992). Zhang et al. (2000) reported that registered doses are set to ensure adequate control over a wide spectrum of weed species, weed densities, growth stages, and environmental conditions. In general, researches indicate that in some cases there is good potential to reduce both herbicide rate and the number of herbicide applications when they are used within competitive cropping systems (Blackshaw et al., 2006). Under that point of view, management practices that increase crop competitiveness, such as selection of competitive cultivars or increased crop seeding rates, are viewed as a possible strategy to reduce the negative effect of reduced weed control when herbicide rates are decreased. On the contrary, there are certainly some adverse effects of low herbicide rates such as an evolution or further spreading of herbicide resistant weeds (Vila-Aiub and Ghersa, 2005; Travlos and Chachalis, 2010). Clearly, the risk of using reduced herbicide rates needs to be minimized by providing farmers with information on when (and when not) reduced rates are an available option (Hoverstad et al., 2004), while herbicide resistance cases should be separately managed by means of an integrated weed management system. Therefore, decision support systems might have a critical role to play in this regard (Nordblom et al., 2003), while weed monitoring and cultivar ranking are rather prerequisite for the success of such an approach.

Conclusively, the question is if there is ability for a reduction of inputs in agriculture by reducing herbicide rates below those recommended. Our results revealed a significant differentiation between the several wheat cultivars regarding their weed competitive ability, in terms of dry biomass and seed production. In the case of the most competitive cultivars the efficiency of 50% reduction of the herbicide recommended rate on weeds remained high, resulting to a grain yield not significantly reduced. Therefore, it seems that crop cultivars with enhancing weed competitiveness can improve the efficiency of reduced herbicide rates and the sustainability of cropping systems through less reliance on herbicides. On the contrary, in the case of less competitive cultivars such a rate reduction might be rather risky and unprofitable, while several other problems (such as herbicide resistance) may also occur. Clearly, extended studies should be conducted towards the direction of a complex evaluation of the productivity of several crop cultivars and the growth and fecundity of important weeds as a response to treatments with reduced rates of a wide range of herbicides under different soil and climatic conditions. Reduced reliance on herbicides continues to be an aspect of agriculture that requires further attention, but only combined with agronomic practices such as growing of highly suppressive cultivars could result in effective and sustainable weed management.

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