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Effect of reduced doses of mesosulfuron + iodosulfuron to control weeds in no-till wheat under Mediterranean conditions

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Abstract

Field experiments were carried out over three years (2004-05, to 2006-07) to study the efficacy of a post-emergence dual-purpose herbicide (mesosulfuron – methyl (3%) + iodosulfuron – methyl – sodium (0.6%) + mefenpyr – diethyl (9%) to control *Lolium rigidum* Gaud. and broad-leaved weeds in no-till wheat (*Triticum aestivum* L.). A ready herbicide mixture was used at three doses (6+1.2, 9+1.8 and 12+2.4 g a.i. ha^{-1}) on two dates (beginning of tillering for *L. rigidum* and 2-3 pair of leaves for broad-leaved weeds, and complete tillering for *L. rigidum* and 5-6 pair of leaves for broad-leaved weeds) with three different application volumes (100, 200 and 300 L ha^{-1}). The results of the present study reveal that using lower than the recommended dose (12+2.4 g ha^{-1}), the herbicide mixture controls *L. rigidum* better than it controls some broad-leaved weeds. Effective weed control, which was achieved mainly through the application at the first weed development stage, provided higher grain yields. The lower control efficacy of more developed *L. rigidum* and broad-leaved weeds and a longer period of competition between crop and weeds are responsible for the significantly lower crop yields for the delayed application. Within each application timing significant differences were obtained among the dose/volume combinations, with the exception of the first application regarding *L. rigidum* control, indicating that a reduction in herbicide dose is possible, but only for certain dose/volume combinations. Nonetheless, weed control was maintained across an array of dose/volume combinations, especially with *L. rigidum*, thus, our results demonstrate that reduced doses can effectively control weeds if applied early.

Additional key words: application timing, application volume, broad-leaved weeds, herbicide dose, *Lolium rigidum* Gaud, weed control.

Resumen

Efecto de la reducción de dosis y volúmenes de aplicación en un herbicida de post-emergencia para controlar malezas en trigo de siembra directa en condiciones mediterráneas

Se llevaron a cabo ensayos de campo durante tres años (2004/2005, 2005/2006 y 2006/2007) en una finca en la región de Évora (Alentejo), en el sur de Portugal, para estudiar la eficacia de un herbicida [mesosulfuron metil (3%)+iodosulfuron metil sodio (0,6%)+mefenpir dietil (9%)] en aplicaciones de post-emergencia en el control de *Lolium rigidum* Gaud. (Ballico) y de otras malezas de hoja ancha, en un cultivo de trigo en siembra directa. Se aplicó el herbicida a tres niveles (6+1,2, 9+1,8 y 12+2,4 g a.i. ha^{-1}), en dos fechas (comienzo de ahijamiento y ahijamiento completo para *L. rigidum* y 2-3 pares de hojas frente a 5-6 pares para malas hierbas de hoja ancha), y con tres volúmenes de aplicación (100, 200 y 300 L ha^{-1}). Con dosis de herbicida más bajas de lo recomendado (12+2,4 g ha^{-1}), se controla con más eficacia *L. rigidum* que las malezas de hoja ancha. Para todas las combinaciones dosis/volumen, las aplicaciones tempranas en los primeros estadios de desarrollo proporcionaron las más elevadas producciones de grano. Para cada una de las fechas de aplicación no se han registrado diferencias significativas para cualquiera de las combinaciones dosis/volumen, lo que nos lleva a concluir que es posible una reducción en las dosis de aplicación del herbicida pero solamente para algunas combinaciones dosis/volumen. Sin embargo, el control de las malezas se realizó con varias combinaciones dosis/volumen especialmente con *L. rigidum,* por lo que nuestros resultados nos muestran que dosis reducidas de herbicida, cuando son aplicadas temprano, pueden controlar eficazmente las malezas.

Palabras clave adicionales: dosis de herbicida, estadios de desarrollo de las malezas, fechas de aplicación, malezas de hoja ancha, volúmenes de aplicación.

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Introduction

Wheat (*Triticum aestivum* L.) is the most important winter cereal grown in Portugal and is severely limited by grass and broad-leaved weeds. Annual ryegrass (*Lolium rigidum* Gaud.) is one of the most troublesome weeds in cereals in Mediterranean climates (Recasens *et al*., 1997; González-Andújar and Saavedra, 2003). Yield losses in cereal crops due to competition from ryegrass can reach up to 80% depending on the infestation level (Izquierdo *et al*., 2003). Broad-leaved weeds are equally a problem in many wheat growing areas in Portugal. The most common method of controlling weeds is by using herbicides. Experimental results, obtained from numerous experiments in Spain, indicate that the level of ryegrass control achieved with commercial herbicides at recommended doses usually ranges from 57% to 99%, with an average value of 90% (Fernández-Quintanilla *et al*., 1998; Navarrete *et al*., 2000).

At present, the aim of weed management is to keep the weed population at an acceptable level, rather than to keep the crop totally free of weeds. Several studies have demonstrated satisfactory weed control and acceptable crop yields, when herbicides are used at lower than normally recommended doses (Devlin *et al*., 1991; Spandl *et al*., 1997; Stougaard *et al*., 1997; Fernández-Quintanilla *et al*., 1998; Brian *et al*., 1999; Navarrete *et al*., 2000; Zhang *et al*., 2000; Boström and Fogelfors, 2002; Hamill *et al*., 2004). Herbicides at reduced doses are often sufficient to control weed density at or below the threshold levels. Below-labelled herbicide doses in combination with some mechanical weed control have proven to be an effective way of reducing herbicide input in agricultural systems (Hamill and Zhang, 1995).

Belles *et al*. (2000) have reported that a 50% dose of tralkoxydim controls more than 85% of wild oat (*Avena fatua* L.) in barley (*Hordeum vulgare* L.). O'Donovan *et al*. (2001) has also found that tralkoxydim at below-labelled doses often provides good control of wild oat. Zhang *et al*. (2000), using data from different studies in several crops and under different environmental conditions, observed substantial variations in weed control efficacy using different herbicide doses, even recommended ones. Control levels can vary from 20 to 100%, with both recommended and reduced doses. Numerous reasons can account for this variation, but we suggest that application timing and application volume may be two factors affecting herbicide efficacy. Walker *et al*. (2002) in Australia found that clodinafop and tralkoxydim efficacy on wild oat (*Avena ludoviciana* Durieu.) and paradoxa grass (*Phalaris paradoxa* L.) remains high when 50% to 75% of the recommended doses are applied.

Zand *et al*. (2007), studying the effect of different herbicides (fluroxypyr; diflufenican plus MCPA and Clopyralid plus 2, 4-D) and different herbicide doses to control broad-leaved weeds in winter wheat in Iran, reported that the control of *Galium tricornutum* is above 85% for the highest herbicide dose, but drops to below 50% at the lowest dose and these three herbicides applied at the highest dose also control *Lamium amplexicaule* and *Descuraina sophia* at over 82%. However, when herbicide doses are decreased, control of these annual broad-leaved weeds is reduced significantly. According to them, control of *Sinapis arvensis* and *Beta maritime* populations with all herbicide treatments ranges from 91% to 100%, while significant differences are obtained for *Malva neglecta* and *Silybum marianum*.

The practice of no-till in cereal production has been increasing worldwide as well as in Portugal, in order to reduce production costs and prevent soil erosion. As reported by Bernoux *et al*. (2006), at present, about $63 \cdot 10^6$ ha are under no-till worldwide, with the largest area, about $21 \cdot 10^6$ ha, in the USA, followed by about $20 \cdot 10^6$ ha in Brazil. The adoption of this tillage system changes the weed flora, weed seed distribution in upper soil layers and the timing of weed emergence. Tuesca *et al*. (2001) reported that annual broad-leaved weed species in wheat show higher population densities under conventional tillage and that annual and perennial grass weed species have an erratic response to tillage systems. According to Wrucke and Arnold (1985), annual grass weed populations usually increase in no-till systems, while annual broad-leaved weeds decrease (Buhler and Daniel, 1988).

Gill and Arshad (1995), Hakansson (1995) and Jensen (1995) have reported a reduced late emergence of annual weeds with decreasing soil tillage intensity. In no-till systems, where the soil remains undisturbed and the soil surface is covered by plant residues, weed densities are reduced when compared with other tillage systems (Zanin *et al*., 1997; Streit *et al*., 2002). Soil disturbance is considered an important factor in breaking dormancy and might explain lower weed densities under no-tillage compared to the other tillage systems (Yenish *et al*., 1992). Under Mediterranean conditions, a high initial weed emergence rate can be expected after the first rainfalls, as most weed seeds remain at or near the soil surface in no-till. Thus, spraying before sowing eliminates an important proportion of potential weeds and reduces the subsequent weed pressure in the established crop. The lower weed densities and the advantage of a much better bearing capacity of no-till soil during the rainfall period, allows a much better application timing thereby helping in obtaining satisfactory weed control at reduced herbicide doses (Boström, 1999). Earlier application timings, which in many years are not possible in traditional tillage systems due to wet soil conditions on the predominant poorly drained Mediterranean soils, do not only reach the weeds at a more sensitive stage but may also allow the use of lower application volumes to achieve the necessary crop penetration and contact with the weed leaves. Thus the improved bearing capacity of the soil under no-till is a pre-condition for early application timings in many years. Furthermore, as demonstrated by O'Donovan *et al*. (1985), early control of weeds is important to avoid crop yield reductions.

The aim of the present paper is to explore the possibility of reducing the input of a post-emergence herbicide mixture (mesosulfuron + iodosulfuron) to control *L. rigidum* and broad-leaved weeds in wheat under no-tillage, while maintaining acceptable weed population levels and consequently satisfactory crop yields. Therefore, a field experiment was carried out combining reduced doses with different water volumes and application timings.

Material and methods

To study the effect of three doses of a post-emergence herbicide to control *L. rigidum* and broad-leaved weeds in wheat (*Triticum aestivum* L.) in combination with three application volumes and two weed development stages, an experiment was carried out in 2004-05, 2005-06 and 2006-07, on a private farm in the Alentejo region (Évora) in Southern Portugal. The applied dual-purpose herbicide is a commercial mixture formulated as a water dispersible granule of mesosulfuron-methyl (3%), iodosulfuron-methyl-sodium (0.6%) and mefenpyr-diethyl (9%). Mesosulfuron-methyl is a post-emergence grass weed herbicide for wheat, triticale (*Triticosecale* Wittmack) and rye (*Secale cereale* L.) providing some control of various broad-leaved weeds. Iodosulfuron-methyl-sodium is a complement to control broad-leaved weeds. This herbicide mixture belongs to the safened sulfonylureas group. Its recommended application dose is 12+2.4 g a.i. ha^{-1}. Mefenpyr-diethyl is the safener to ensure the highest level of selectivity, without compromising product efficacy. To increase the efficacy of the herbicide, a Tank-mix adjuvant was applied, consisting of 0.5 L ha^{-1} of a concentrate solution of 283 g L^{-1} or 27% of lauril ether diglicol sulfate sodium.

The experimental layout was a randomized complete block design with four replicates. The treatments and their respective levels are summarized in Table 1. For each replication three control plots without any herbicide application were established.

The experiment was carried out over 3 years in different fields of the private farm but all the sites had identical soil characteristics (Luvisol), with a sandy loam texture in the A-horizon and a sandy clay loam in the B-horizon. Soil pH in water was around 6.2 in the top layers increasing up to 7.0 in the subsoil. Organic matter in the topsoil was around 1%.

The study sites are located in a typical Mediterranean climatic region with a concentration of the rainfall during the winter months, which corresponds to the early growing season of the wheat, causing problems for the realization of field operations due to excessive soil moisture conditions.

Wheat was sown in mid-November using the no-till drilling technique. Weeds emerging before sowing were sprayed off with glyphosate at a dose of 360 g ha^{-1}.

The post-emergence herbicide treatments were carried out using a plot sprayer equipped with flat-fan nozzles (110°-10) when about 90% of the *L. rigidum* was at the beginning of tillering (first application timing) or when it had reached complete tillering (second application timing). When *L. rigidum* was at the beginning of tillering, the broad-leaved weeds had

Table 1. Application doses, volumes and times used for *Lolium rigidum* G. and broad-leaved weed control in wheat

Mesosulfuron+iodosulfuron dose (g ha^{-1})	Volume (L ha^{-1})	*Lolium* development stage	Broad-leaved weeds development stage
6+1.2 (0.5 X)	100	Beginning of tillering (early)	2-3 pair of leaves (early)
9+1.8 (0.75 X)	200	Complete tillering (late)	5-6 pair of leaves (late)
12+2.4 (1 X)	300		

about 2-3 pairs of leaves and when *L. rigidum* had reached complete tillering, the broad-leaved weeds had about 5-6 pair of leaves. These two application timings corresponded to the 22-25 and 31-32 Zadoks' stage (Zadoks *et al.,* 1974) of the wheat, respectively. The different application volumes were achieved through varying pressure and speed. The plot size was 10 × 3 m and the net harvested area 15 m^2.

The main broad-leaved weeds present in the experiment in decreasing frequency were *Chamaemelum mixtum* L., *Chrysanthemum segetum* L., *Calendula arvensis* L., *Echium plantagineum* L., *Raphanus raphanistrum* L., *Polygonum aviculare* L., *Silene nocturna* L., *Galium aparine* L., *Anagallis arvensis* L., *Plantago afra* L., *Lactuca serriola* L., *Torilis arvensis* L., *Daucus carota* L., *Lamium amplexicaule* L. and *Scandix pecten-veneris* L. The weeds were identified and counted twice each year, but not removed. The first counting took place immediately before the treatment and the second one about 2 months later. For the countings, quadrates with a side length of 50 cm were used in the central part of all the plots inside the 15 m^2 harvest area. The quadrates were placed in the same position for both countings. The results are presented as the number of weeds per square metre.

Average densities of the broad-leaved weeds and *L. rigidum* were around 20 and 65 plants per square metre, respectively.

Weed control efficacy of the different treatments is expressed as the percentage of weed control obtained and is calculated through the following expression:

$$Ef = 100 - [(C_2 - d)/C_1] \cdot 100$$

where *Ef* is the efficacy of the treatment (%), C_1 the number of weeds per square metre counted before the treatment, C_2 the number of weeds per square metre counted approximately 2 months after the treatment and *d* the difference in the number of weeds per square metre between the first and the second counting in the untreated (control) plots (re-infestation). The *d* value (average of the 3 years) determined for the first weed development stage was 2.0 plants m^{-2} for *L. rigidum* and 4 plants m^{-2} for broad-leaved weeds. For the second weed development stage, the *d* value (average of the 3 years) was 1.0 plants m^{-2} for *L. rigidum* and 5.0 plants m^{-2} for broad-leaved weeds.

A long-duration wheat cultivar (Jordão) was sown at a rate of 180 kg ha^{-1} and N-P-K fertilization was applied according to yearly soil test recommendations, to maintain fertility levels and to achieve a potential crop yield of 2,500 kg ha^{-1}. The harvest of the centre of the plots (10 × 1.5 m) was performed using a plot combine harvester. Grain yields and the 1,000-grain weight were determined based on dry weight. The number of grains m^{-2} was calculated on the basis of grain yield per area and 1,000-grain weight. Before harvest, a crop sample was taken from each plot to determine the total dry matter (grain and straw) for calculating the harvest index.

Analysis of variance (ANOVA) was performed to determine significant differences. The Duncan's Multiple Range Test was used for the separation of means when the F-test revealed an error probability of less than or equal to 5% ($P \leq 5\%$). All statistical analyses were performed using the MSTATC program (version 1.42).

Results and discussion

Weed control

L. rigidum control presents significant differences with regard to the levels of herbicide doses, application volumes and application timings, as well as the interaction of application timings × herbicide doses and broad-leaved weeds showed significant differences with regard to herbicide doses and application timings, as well as the interaction of application timings × application volumes (Table 2). Early herbicide application (beginning of tillering for *L. rigidum* and 2-3 pair of leaves for broad leaved weeds) provided good control of *L. rigidum* even with the reduced doses of the herbicide. However, broad-leaved weeds control efficacy was lower when herbicide doses were reduced compared to recommended rate. In general, the delayed herbicide application provided poor *L. rigidum* and broad-leaved weed control efficacy compared to early application. Only minor or insignificant effects of the variation of the application volume could be observed neither for the different application timings and doses, nor for *L. rigidum* and broad-leaved weeds' control efficacy.

For the first application timing, *L. rigidum* presents high control efficacy even for herbicide doses and application volumes lower than the recommended. For this application timing, broad-leaved weeds show lower control efficacy than *L. rigidum*, when doses are lower than recommended and it seems necessary to increase the herbicide dose to the maximum recommended to achieve satisfactory control efficacy. However, for both

Table 2. Effect of herbicide doses and application volumes on the efficacy (%) of the treatments to contorl *Lolium rigidum* and broad-leaved weeds for two application timings (3 years' average)

Application timing	Dose	Volume (L ha^{-1})			Mean
		100	200	300	
Lolium rigidum					
Early	0.5 X	95^{a}*	96^{a}	95^{a}	95^{A}
	0.75 X	95^{a}	99^{a}	98^{a}	97^{A}
	1 X	97^{a}	98^{a}	93^{a}	96^{A}
	Mean	96^{A}	98^{A}	95^{A}	96^{a}
Late	0.5X	75^{cd}	73^{de}	68^{e}	72^{C}
	0.75X	80^{bd}	78^{bd}	77^{bd}	78^{B}
	1 X	81^{bc}	83^{b}	79^{bd}	81^{B}
	Mean	79^{B}	78^{BC}	75^{C}	77^{b}
Broad-leaved weeds					
Early	0.5X	78^{ef}*	91^{ad}	85^{bf}	85^{BC}
	0.75 X	81^{df}	92^{a}	90^{ae}	88^{B}
	1X	98^{a}	94^{ac}	96^{ab}	96^{A}
	Mean	86^{B}	92^{A}	90^{A}	90^{a}
Late	0.5 X	75^{fg}	66^{g}	74^{fg}	71^{E}
	0.75 X	74^{fg}	77^{fg}	83^{cf}	78^{D}
	1 X	82^{cf}	80^{df}	81^{df}	81^{CD}
	Mean	77^{C}	74^{C}	79^{C}	77^{b}

* Values followed by the same letter or letters are not significantly different at a 5% level (Duncan multiple range test). The comparison of different means is indicated by the different format of the letters used. Doses are indicated as the proportion of the recommended dose (1 X).

types of weeds (*L. rigidum* and broad-leaved) and most treatments, the first application timing is more efficient than the second.

As reported by other authors (Devlin *et al*., 1991; Spandl *et al*., 1997; Stougaard *et al*., 1997; Fernández-Quintanilla *et al*., 1998; Brian *et al*., 1999; Navarrete *et al*., 2000; Zhang *et al*., 2000; Boström and Fogelfors, 2002; Hamill *et al*., 2004) satisfactory control of weeds can be achieved by lower than normally recommended herbicide doses while maintaining acceptable crop yields. The results obtained in this study demonstrate that the success of reduced doses of the herbicide depends not only on early application, when the weeds are more sensitive, but also on the type of weeds present. For *L. rigidum*, the lowest herbicide dose had a same control efficacy compared to the highest dose, but for broad-leaved weeds the difference in control efficacy between the lowest and highest doses was significant. For these weeds, satisfactory control (> 95%) could only be achieved by applying the recommended dose, and even so, only for the first application timing. At doses below the recommended, the herbicide shows some problems in controlling *Silene nocturna*, *Chamaemelum mixtum*, *Polygonum aviculare*, *Anagallis arvensis Plantago afra*, and *Daucus carota*, even at the early application timing (data not shown). These results are in accordance with the results obtained by Zand *et al*. (2007).

No-till seems to contribute in two different ways to the possibility of reducing the quantity of herbicide necessary to guarantee satisfactory weed control in autumn sown cereal crops, under Mediterranean conditions. The first as reported by Boström (1999), is due to the higher soil bearing capacity and the consequent soil trafficability during the rainy season, which makes it possible to apply the herbicide at almost any time, including the development stage when weeds are more sensitive to the herbicide. The second aspect, related to no-till crop establishment, concerns weed emergence as influenced by soil disturbance. The rate of reinfestation found after both application timings can be considered as quite low and seems to be a consequence of the absence of soil disturbance. These results are in accordance with the findings of other authors (Gill and Arshad, 1995; Hakansson, 1995; Jensen, 1995).

Grain yield

Grain yield shows significant differences with regard to application timings and herbicide doses, as well as the interaction of herbicide doses × application timings, but not for the interaction herbicide doses x application volumes × application timings (Table 3). Grain yields were found to be similar for different treatments, however they always decreased when application timing was delayed (complete tillering). For the early application (beginning of tillering), the medium herbicide dose combined with the highest application volume gave the highest grain yield. The use of the lowest herbicide dose and the medium application volume was sufficient to achieve the highest grain yield for the later application timing. Regarding weed control efficacy, only minor or insignificant effects of the variation of the application volume could be observed for the different application timings and doses.

Although we found a lower control efficacy of *L. rigidum* and broad-leaved weeds causing a longer period of competition between crop and weeds and a decrease in grain yield for the second application timing, our data show clearly that practitioners can control *L. rigidum* with a range of doses and volumes, if applied early.

Table 4 shows that the number of grains per square metre and the total dry matter were higher for the first application timing for all treatments, while the mean grain weight was higher for some treatments for the second application timing, as a result of the lower number of grains per square metre in these treatments.

The results obtained in this study with regard to yield and its parameters are in accordance with several studies mentioned above confirming that lower than recommended herbicide doses are sufficient to achieve satisfactory crop yields. It has also been demonstrated as mentioned by O'Donovan *et al*. (1985), that the early application timing provides higher grain yields for all applied treatments.

Conclusion

L. rigidum and broad-leaved weeds are the major problem weeds in wheat, under Mediterranean conditions, and their control contributes decisively to the total cost of weed control. The results of the present study demonstrate that it is possible to reduce the recommended (12+2.4 g ha^{-1}) dose of the dual-purpose herbicide mesosulfuron-methyl +iodosulfuron-methyl-sodium, and still obtain a high control of *L. rigidum*. In order to achieve this it seems essential to choose an early application timing, which, under the Mediterranean winter rainfall conditions, is often a problem, due to the low machine bearing capacity of the soil, under conventional soil tillage. Crop establishment under no-till makes the application timing much more independent of the variability in both the amount and distribution of the rainfall, and this practice seems to considerably reduce the late re-infestation of *L. rigidum*. However, the herbicide used in this study shows lower control efficacy for broad-leaved weeds as compared to *L. rigidum* for the most favourable application timing. In

Table 3. Effect of herbicide doses and application volumes on grain yield (g m^{-2}) for two application timings (3 years' average)

Application timing	Dose	Volume (L ha^{-1})			Mean
		100	200	300	
Early	Control	177^{g}*	177^{g}	177^{g}	177^{D}
	0.5 X	319^{ac}	322^{ab}	325^{a}	322^{A}
	0.75 X	314^{ac}	333^{a}	336^{a}	327^{A}
	1 X	326^{a}	313^{ac}	317^{ac}	319^{A}
	Mean	284^{A}	286^{A}	289^{A}	286^{a}
Late	Control	177^{g}	177^{g}	177^{g}	177^{D}
	0.5 X	288^{ce}	290^{bd}	256^{ef}	278^{B}
	0.75 X	247^{f}	266^{df}	267^{df}	260^{C}
	1 X	278^{df}	276^{df}	252^{f}	269^{BC}
	Mean	248^{B}	252^{B}	238^{B}	246^{b}

* Values followed by the same letter or letters are not significantly different at a 5% level (Duncan multiple range test). The comparison of different means is indicated by the different format of the letters used. Doses are indicated as the proportion of the recommended dose (1 X).

Table 4. Harvest index, dry matter and yield components of the different treatments (3 years' average)

Stages	Dose	Harvest index	Dry matter (g m^{-2})	No. of grains m^{-2}	Mean grain weight (mg)
Early	Control	0.407	435	4,071	41
	0.5 X	0.435	743	7,285	42
	0.75 X	0.430	749	7,499	41
	1 X	0.412	785	7,263	41
	Mean	0.421[b]*	678[a]	6,530[a]	41[b]
Late	Control	0.407	436	4,131	41
	0.5 X	0.438	631	6,280	42
	0.75 X	0.440	588	5,798	43
	1 X	0.442	602	5,957	42
	Mean	0.431[a]	564[b]	5,542[b]	42[a]

* Values followed by the same letter or letters are not significantly different at a 5% level (Duncan multiple range test). Means are being compared only within a column.

order to obtain high control efficacy for broad-leaved weeds, even for the first application timing, it is necessary to use the recommended dose (12+2.4 g ha^{-1}). This is because this herbicide has limited ability to control some broad-leaved weeds such as: *Silene nocturna*, *Chamaemelum mixtum*, *Polygonum aviculare*, *Anagallis arvensis*. *Plantago afra*, and *Daucus carota* when applied at lower than recommended doses.

The higher efficacy in control of *L. rigidum* and broad-leaved weeds and a shorter period of competition between crop and weeds for the first application timing are responsible for the higher grain yields and it seems that using reduced herbicide doses it is possible to use lower application volumes than those normally recommended, which is in accordance with Steckel *et al*. (1990) and Hamill and Zhang (1995).

The results of these trials also confirm the findings of several studies carried out by various researchers (Devlin *et al*., 1991; Spandl *et al*., 1997; Stougaard *et al*., 1997; Fernández-Quintanilla *et al*., 1998; Brian *et al*., 1999; Navarrete *et al*., 2000; Zhang *et al*., 2000; Boström and Fogelfors, 2002; Hamill *et al*., 2004) that maximum weed control is not always necessary to achieve the yield potential of the crop and that the use of below-labelled doses of herbicides can be an effective way of reducing pesticide input in field crops while maintaining satisfactory weed control.

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