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Cultural control of herbicide-resistant *Lolium rigidum* Gaud. populations in winter cereal in Northeastern Spain

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Abstract

Lolium rigidum Gaud. is one of the most common weed species in winter cereals in Northeastern Spain. Herbicide resistance has been growing since the mid 90's and exclusive herbicide use is not enough in many cases, so that it is necessary to combine as many control tools as possible. Six field trials have been conducted during the cropping seasons 2001-02, 2002-03 and 2003-04 on winter cereal infested with herbicide resistant *L. rigidum* in Northeastern Spain testing different cultural control strategies. Sowing delay was conducted at five fields, mouldboard ploughing at four fields, the combination of sowing delay and ploughing at two fields, increasing the cereal sowing density and combined with sowing delay at one field. Sowing delay was confirmed to have an irregular efficacy depending on the *L. rigidum* emergence during the delay period. In the trials, weed emergence was reduced up to 88% in the best case but there was no effect in two cases. Ploughing had a more constant efficacy and reduced weed emergence between 50 and 80% although stoniness impeded in one occasion a correct soil inversion causing a very low efficacy. Increasing the cereal sowing rate did not reduce the weed population. The combination of the different methods did not increase significantly the individual efficacy, and one method was clearly more effective than the other, depending on the trial. In fields with high *L. rigidum* density, these methods are not effective enough and need to be combined with other methods, which are discussed in the text.

Additional key words: cereal density, integrated weed management, mouldboard ploughing, sowing delay.

Resumen

Control cultural de poblaciones de *Lolium rigidum* Gaud. resistentes a herbicidas en cereal de invierno en el nordeste de España

Lolium rigidum Gaud. es una de las especies de malas hierbas más comunes en cereal de invierno en el nordeste de España. La resistencia a herbicidas ha ido aumentando desde mediados de los años 90, haciendo necesaria la combinación de cuantas más técnicas de control sean posibles. Se realizaron seis ensayos de campo desde el año 2001 al 2004 sobre cereal de invierno infestado con *L. rigidum* resistente a diferentes herbicidas en el nordeste de España, para probar diferentes estrategias de control culturales. Se estudió el retraso de siembra en seis campos, laboreo de vertedera en cuatro campos, la combinación de retraso de siembra y laboreo de vertedera en dos campos, incrementar la densidad de siembra y combinarla con retraso de siembra en un campo. El retraso de siembra tuvo una eficacia irregular dependiendo de la emergencia de *L. rigidum* durante el período de retraso. Se alcanzó una reducción de la emergencia del 88% en el mejor de los casos, pero no hubo efecto en otros dos campos. El laboreo tuvo una eficacia más constante y redujo la emergencia de la mala hierba entre el 50 y el 80%, aunque la pedregosidad impidió en un caso una correcta labor. Incrementar la dosis de siembra no redujo la población de la mala hierba. La combinación de los diferentes métodos no aumentó de forma significativa el efecto individual y un método fue claramente más efectivo que el otro, dependiendo del ensayo. En campos con densidades elevadas de *L. rigidum* estos métodos no la reducen de forma suficiente y necesitan ser combinados con otros métodos que son discutidos en el texto.

Palabras clave adicionales: densidad de cereal, laboreo de vertedera, manejo integrado de malas hierbas, retraso de siembra.

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Abbreviations used: HRAC (Herbicide Resistance Action Committee), LSD (least significant differences), LSM (least square means), NS (not significant).

Introduction

Lolium rigidum Gaud. is one of the most common weed species in winter cereals in Northeastern Spain. Herbicide resistance of *Lolium rigidum* Gaud. to chlortoluron and diclofop-methyl has been reported in Catalonia since 1995 (Taberner *et al.*, 1995). The problem has continued growing and more populations have been found resistant to tralkoxydim, fluazifop and chlorsulfuron (Taberner, 2005). The estimated affected area is still less than 0.5% of the 6 million hectares of winter cereal in Spain (Díaz and Gorrochategui, 2005) but the affected fields require costly management.

Low cereal yields and selling prices have encouraged Spanish farmers to invest minimum efforts in their cereal crops spraying expensive graminicides only when the cheap ones failed. However, the current high cereal price situation may introduce new elements in this scenario modifying the prospects for herbicide resistance.

The great capacity of *L. rigidum* for developing resistance adapting to many different compounds has led to the development of multiple resistant populations in Australia (Powles, 1993) and to the existence of biotypes resistant to herbicides belonging to 10 different mode of action groups (Heap, 2005). Taking into account that climatic and edaphic conditions of some regions in Australia and Spain are similar, the herbicide resistance problem can potentially grow in Spain. In order to prevent and control this problem it is necessary to develop non-chemical control strategies, adapted to the local farmers' practices (Matthews, 1996; Gill and Holmes, 1997; Nalewaja, 1999). Out of these options, probably the easiest to be adopted in the Spanish context are delayed sowing, increasing weed density and ploughing. Stubble burning and crop topping are not authorised, pastures are not sown, and the resistance problem is probably not serious enough to justify modifying the external combine harvesters for seed catching as proposed by Matthews *et al.* (2004). If the problem grows, as it occurred in Australia, Spanish farmers will probably also adopt more non-chemical management strategies, improving these methods even years after the outcome of the problem, as exemplified with the seed burner presented by Matthews *et al.* (2004), thus showing that there is still interest in offering new alternatives to be combined with herbicides.

Two main aspects of the seed biology of *L. rigidum* offer opportunities for its control. First, it is known that the viability of the seeds in the soil is short (Gramshaw and Stern, 1977; Taberner *et al.*, 1992) so that burying them by ploughing can reduce their viability rapidly. For seeds buried at 0, 5 or 20 cm depth, Taberner *et al.* (1992) found that one year afterwards only around 5% of the seeds remained viable in Spanish conditions. This behaviour opens the possibility of burying the seeds with a deep ploughing.

A second important characteristic of *L. rigidum* is that main germination occurs after rainfall in the beginning of the season (Gramshaw and Stern, 1977). Cheam *et al.* (1998) observed main emergence in the two weeks after crop sowing and up to 93% emergence concentrated in the 5-6 first weeks, while Matthews (1996) (using data of Heap, 1988) describes how 60-80% of the *L. rigidum* seeds emerged in the initial germination flush in Australian conditions. This fact offers the opportunity of delaying the sowing date controlling the first *L. rigidum* emergence flush before sowing. However, depending on the climatic conditions, germination can also be staggered. In some cases, in Spanish conditions, there is a concentrated germination flush during the first 40 days after cereal sowing (Planes *et al.*, 1999) but in other cases the germination period can start 2-4 weeks after sowing and last 4-7 weeks (Recasens and Kuc, 1998). Sowing delay aiming a reduction in weed populations can thus be very variable, depending on the climatic conditions of that year. An important inconvenient of sowing delay is the possible yield decrease (Planes *et al.*, 1999; Anderson, 2007).

Lolium rigidum control caused by increased sowing density has been scarcely reported. Gill and Holmes (1997) stated that Australian farmers are usually not willing to increase wheat plant density above 100-150 plants m^{-2}. In Central Spain, Lacasta *et al.* (2004) tested the effect of sowing barley at three different densities (80, 160 and 240 kg ha^{-1}) during eleven years in a monocrop situation finding that the intermediate rate (160 kg ha^{-1}) generally yielded the most. In irrigated winter cereal, Moreno *et al.* (2002) recommended using more than 100 kg ha^{-1} in barley, as they did not find any significant yield increase in any of the three years after testing five different rates up to 200 kg ha^{-1} in the semi-arid Spain. In different experiments at variable *L. rigidum* density, Izquierdo *et al.* (2003) did not find significant differences in barley yield for densities between 75 and 300 kg ha^{-1}.

Liebman and Gallandt (1997) recommended combining several control techniques to have additive effects, the so called 'many little hammers'. Similarly, Anderson (2007) proposed the dualistic approach of prevention and control, which is apparently effective in the semiarid steppe of the United States. However, little work on these techniques have been conducted in our area.

The objectives of this work were to test the effect of sowing delay, ploughing, increased cereal rate and the combination of these methods on *L. rigidum* control in winter cereal. The final aim was to provide new data on the effects of these methods, which should be combined in an Integrated Weed Management Programme to control herbicide resistant *L. rigidum*.

Material and methods

Plant material

Field trials were conducted on different herbicide-resistant populations at different locations of the Lleida province (Table 1). All experiments were conducted on commercial fields using the varieties chosen by the farmer and applying conventional fertilization. The resistance to herbicides was checked before treatment using a seed-based quick-test and confirmed in herbicide field trials (data not shown). All the populations were resistant to chlortoluron, diclofop-methyl and tralkoxydim at the same time, excepting the population of barley in Sarroca, which was only resistant to chlortoluron. *Lolium rigidum* plant density in the control plots was high in all cases (Table 1). Plots were placed perpendicular to the straw swaths, where this weed emerges predominantly (Blanco-Moreno *et al.*, 2004) so that *L. rigidum* distribution was similar between plots.

Cultural control methods

Sowing delay was conducted at five fields; mouldboard ploughing at four fields; the combination of both practices at two fields; increasing the cereal density and increasing the cereal density combined with sowing delay at one field (Table 2). The experimental design was a split-plot with ploughing type as a main factor at Ferran 1, Verdú and Concabella. At Santa Maria and Ferran 2, the treatments were arranged as a randomised complete block design with two factors. At Sarroca, the experiment was a randomised complete block design with one factor. Elementary plots measured 4 x 5 m in all cases.

Ploughing was conducted with a five-furrow-mouldboard plough at Ferran 1, Concabella and Verdú at 15, 20 and 25 cm depths, respectively. At Ferran 2 a four-furrow plough was used inverting the soil approximately at 18 cm depth. Commercial ploughs were used in all cases. The dates of the ploughing treatments are shown in Table 3. At Santa Maria, normal sowing density was 175 kg ha^{-1} corresponding to 439 seeds m^{-2} and high sowing density was 1.5 fold the normal rate, that is, 250 kg ha^{-1} corresponding to 627 seeds m^{-2}. Normal densities in the area were used in the rest of locations.

Early sowing time varied in the various experiments, ranging from October 9 in Sarroca to November 5 in

Table 1. Characteristics of the six field trials located at different locations in the Lleida province. *Lolium rigidum* density (± standard error) in the control plots was assessed in April-May 2001, 2002 and 2003 (end of February at Concabella)

Year, Site	Crop, Variety	Coordinates		Density (plants m^{-2})
		Latitude (ºN)	Longitude (ºE)	
2001-02				
Ferran 1	Wheat, Soissons	41.743	1.413	1344 ± 613.5
Concabella	Barley, Graphic	41.917	1.238	94 ± 42.2
2002-03				
Verdú	Wheat, Soissons	41.616	1.077	359 ± 122.7
Santa Maria	Wheat, Marius	41.730	1.109	536 ± 17.1
2003-04				
Sarroca	Barley, Graphic	41.461	0.577	211 ± 43.8
Ferran 2	Wheat, Soissons	41.733	1.421	387 ± 23.9

Table 2. Different cultural treatments made at the different trials

	Sowing delay	**Mouldboard ploughing**	**Sowing delay and ploughing**	**Cereal density**	**Sowing delay and increased cereal density**
2001-02					
Ferran 1	+	+	+	-	-
Concabella	+	+	+	-	-
2002-03					
Santa Maria	+	-	-	+	+
Verdú	+	+	+	-	-
2003-04					
Sarroca de Lleida	+	-	-	-	-
Ferran 2	-	+	-	-	-

Concabella. The sowing delay ranged from 18 days in Verdú to 68 days in Sarroca (Table 3).

Assessments

Lolium rigidum density was assessed at weed and crop heading (BBCH scale 56-59, BBCH Working Group, 1997) to describe the final effect on the weed population. Assessments included number of *L. rigidum* plants, number of *L. rigidum* ears and total fresh biomass in 0.1 m^2 squares. Biomass was determined immediately after cutting in the field. Crop plant density per linear meter was assessed three times in each plot at heading at Santa Maria (28th May 2003), Verdú (17th June 2003) and at Sarroca (27th April 2004) to describe the effect of the cultural methods on the crop.

Data analysis

Data were transformed when necessary to satisfy normality and variance homogeneity following the indications of the Box-Cox Transformation (Bowley, 1999) using $(x + 1)^{0.5}$ for most cases, excepting weed weight per plant at Ferran 1 where $x^{0.5}$ was used.

Analyses of variance were performed using the SAS GLM procedure (SAS Institute, 1991) for each location separately considering the different models. Least sig-

Table 3. Timing of the ploughing, sowing and assessment dates at the different trials. Rainfall (mm) recorded between the two sowing dates at Pinós (41.83ºN, 1.54ºE) for Ferran, Tornabous (41.70ºN, 1.05ºE) for Concabella and Santa Maria de Montmagastrell, Tàrrega (41.65ºN, 1.146ºE) for Verdú, and Castelldans (41.49ºN, 0.77ºE) for Sarroca. Data from the Meterological Service of Catalonia (Servei Català de Meteorologia)

	Ploughing	**1st sowing date**	**2nd sowing date**	**Time gap (days)**	**Rainfall between both dates (mm)**	**Plant counts**
Ferran 1	16/10/01	17/10/01	08/11/01	22	36.6	28/03/01 + 17/04/01
Concabella	03/11/01	05/11/01	28/11/01	23	41.0	03/06/02
Santa Maria	-	15/10/02	04/11/02	20	4.2	26/05/02
Verdú	18/10/02	18/10/01	05/11/02	18	5.2	29/05/02
Sarroca	-	9/10/03	16/12/03	68	142.9	31/05/04
Ferran 2	11/10/03	14/11/03	-	-	-	19/05/04

nificant differences (LSD) were calculated for pairwise comparisons. Mean values are shown as least square means (LSM) and differences between means were analysed on the basis of ordinary *t*-tests considering $P < 0.05$ in the case of significant interactions.

Results

Mouldboard ploughing

Mouldboard ploughing reduced significantly *L. rigidum* density at Concabella and Verdú (Table 4). This difference was particularly remarkable at Concabella, where ploughing reduced 96% weed density. Although ploughing reduced 55% weed density at Ferran 1, this difference was not significant. Similar results were obtained for weed biomass in these three sites. No significant differences in densities and biomass were observed at Ferran 2. The lack of efficacy of ploughing at this site is probably due to the high stoniness at this location, which impeded deep enough ploughing without damaging the tool. Ploughing did not affect wheat density at Verdú, the only site where this parameter was measured (Table 5).

Table 4. Mean values of different parameters of *Lolium rigidum*. Values in parentheses indicate the transformed means corresponding to each of the back-transformed values (see text for details). LSD values are given on the transformed scale. Ns: not significant.

Experiment	Treatment	Plants m^{-2}	Ears m^{-2}	Fresh biomass (g m^{-2})
Ferran 1	No plough	651.3 (25.5)	-	319.2 (17.9)
	Plough	292.0 (17.1)	-	187.5 (13.7)
	LSD	27.34	-	10.7
	1st sowing	607.7 (24.7)	-	461.3 (21.5)
	2nd sowing	320.8 (17.9)	-	105.5 (10.3)
	LSD	7.27	-	4.45
Ferran 2	No plough	386.7	1798.3	2187.9
	Plough	286.7	1962.5	2730.4
	LSD	159.01	734.05	912.18
Santa Maria	1st sowing date	547.2	918.9	1485.2
	2nd sowing date	358.8	627.1	929.4
	LSD	66.54	161.71	262.85
	Single sowing rate	434.1	806.5	1227.5
	Double sowing rate	476.1	749.4	1203.0
	LSD	66.54	161.71	262.85
Verdú	No plough	417.1 (20.4)	772.3 (27.8)	719.8 (26.8)
	Plough	39.3 (6.3)	99.4 (10.0)	91.2 (9.6)
	LSD	14.48	20.83	24.15
	1st sowing	167.6 (13.0)	389.4 (19.8)	401.9 (20.1)
	2nd sowing	221.4 (14.9)	386.8 (19.7)	328.3 (18.1)
	LSD	2.71	36.55	4.13
Sarroca	1st sowing		732.5 (27.1)	
	2nd sowing		82.4 (9.1)	
	LSD		9.52	
Concabella	No plough	106.7 (10.4)		
	Plough	4.1 (15.5)		
	LSD	2.69		
	1st sowing	53.0 (7.4)		
	2nd sowing	49.3 (7.1)		
	LSD	2.69		

Table 5. Mean values of cereal plants per linear meter at Sarroca, Santa Maria and Verdú. Values in parentheses indicate the transformed means corresponding to each of the back-transformed values. Least significant differences (LSD) values are given on the transformed scale

Location	Treatment	Plants m^{-1}
Santa Maria	1st sowing	6.8
	2nd sowing	16.1
	LSD	2.53
	Single sowing rate	10.2
	Double sowing rate	12.7
	LSD	2.53
Verdú	1st sowing	13.1 (0.0059)
	2nd sowing	13.9 (0.0052)
	LSD	0.0011
	No plough	13.2 (0.0058)
	Plough	13.8 (0.0053)
	LSD	0.0031
Sarroca	1st sowing	7.8
	2nd sowing	18.8
	LSD	3.9

Sowing delay

Sowing delay affected significantly *L. rigidum* density at Ferran 1, Santa Maria and Sarroca (Table 4). At Ferran 1 and Sarroca, rainfall between both sowing dates allowed new weed emergences, which were mechanically controlled, prior to the second sowing date (Table 3). At Santa Maria, although little rainfall fell between both sowing dates the soil remained moist due to the abundant rainfall in the months before sowing and to the foggy days, allowing weed emergence. Total weed biomass was also significantly lower in the second sowing date at these three locations. In the other two trials located at Verdú and Concabella, there were no differences in either plant weed density and weed biomass between the two sowing dates. At these two locations too little rainfall fell before the first sowing date and between the two sowing dates to allow *L. rigidum* emergence (Table 3). The overall efficacy of sowing delay in these trials was lower than the control obtained by ploughing.

The effect of sowing delay on crop density was not statistically significant at Verdú, but at Santa Maria and at Sarroca significantly more crop plants established at the second sowing date ($P < 0.05$) (Table 5).

Sowing density

Increasing sowing density had no effect on crop density and on *L. rigidum* density and biomass at Santa Maria, the only site where this comparison was conducted (Tables 4 and 5).

The combination of different techniques

The combination of sowing delay with ploughing or with sowing density did not improve the effect of the individual treatments significantly at any of the three sites (Table 6) but had some effect at Ferran 1, where *L. rigidum* density was reduced. At Ferran 1 and Verdú, ploughing was the most important control method. At Santa Maria, the main weed reduction was due to sowing delay.

Concerning the effect of these techniques on the crop, at Santa Maria, increasing the sowing rate at the second sowing date gave significantly higher wheat density than the other treatments (Table 5). However, no effect was observed at Verdú on the crop due to the combination of both techniques.

Discussion

Efficacy on weed plants due to ploughing was not considerable at Ferran 2, around 50% at Ferran 1, 81% at Concabella and 93% at Verdú. These values are similar to those obtained by Recasens *et al.* (2001b) (90 and 81%) and by (Recasens *et al.*, 2003) (65 and 92%) in Northeastern Spain, a bit higher to those obtained by Gill and Holmes (1997) (13 and 64%) and a bit lower to those found by Matthews *et al*. (1996) (98%), in Australia. The variation between the experiments suggests that ploughing needs a precise implementation. It should be mentioned that a correct ploughing can be difficult in stony soils like the one in Ferran 2. High fuel consumption justifies its use only in extremely high-infested fields or if cereal price is high enough to compensate the ploughing costs.

Trial results confirm that climatic conditions in the time gap between the normal and the delayed sowing date are crucial for efficacy and should allow maximal *L. rigidum* emergence. Efficacy on weed plants was not considerable at Concabella and Verdú, 35% at Santa Maria, 54% at Ferran 1, and 88% at Sarroca. The highest efficacy was achieved in the field with the highest

Table 6. Mean values of different parameters of *Lolium rigidum*. Values in parentheses indicate the transformed means corresponding to each of the back-transformed values (see text for details). Different letters within each location and parameter refer to statistically significant differences following the *t*-test at $P < 0.05$

Experiment	Treatment	Plants m^{-2}	Ears m^{-2}	Fresh biomass (g m^{-2})
Ferran 1	no plough 1st sowing	1055.3 (32.5) a	-	682.5 (26.1) a
	no plough 2nd sowing	394.2 (19.9) bcd	-	112.8 (10.7) b
	plough 1st sowing	331.3 (18.2) cd	-	304.5 (17.5) a
	plough 2nd sowing	255.0 (16.0) d	-	98.5 (10.0) b
Santa Maria	1st sowing normal rate	518.9 a	906.7 a	1447.8 a
	1st sowing double rate	575.6 a	931.1 a	1522.8 a
	2nd sowing normal rate	337.6 b	700.0 ab	994.2 b
	2nd sowing double rate	376.7 b	567.8 b	884.4 b
Verdú	no plough 1st sowing	330.5 (18.2) b	807.3 (28.4) a	864.5 (29.4) a
	no plough 2nd sowing	513.8 (22.7) a	738.3 (27.2) a	588.5 (24.3) a
	plough 1st sowing	16.1 (4.1) c	35.4 (6.0) c	41.4 (6.5) b
	plough 2nd sowing	50.0 (7.1) c	147.8 (12.2) b	142.0 (12.0) b
Concabella	no plough 1st sowing	141.4 (11.9) a		
	no plough 2nd sowing	76.8 (8.8) ab		
	plough 1st sowing	6.7 (2.8) bc		
	plough 2nd sowing	27.7 (5.4) c		

rainfall and the longest time gap between both sowing dates, i.e. Sarroca. In Australia, a delay of three weeks caused a reduction of *L. rigidum* emergence of 82 and 51% in barley and wheat, respectively (Powles and Matthews, 1996) and an 11-30% reduction in the *L. rigidum* density with each week's delay (Gill and Holmes, 1997). In Spain, Aibar *et al.* (2005) obtained 62% efficacy after a two-month sowing delay. In the same region but further East, Recasens *et al.* (2001a) found a reduction of 89% *L. rigidum* emergence by delaying two weeks the wheat sowing but found no apparent efficacy in another field trial due to lack of *L. rigidum* emergence in the time gap between both sowing dates. In a trial conducted by Planes *et al.* (1999) in the same area, delaying wheat sowing 13 days, weed density was reduced only 27% despite there was sufficient moisture for *L. rigidum* emergence. The main inconvenient of sowing delay is that it has a non-predictable effect on weed control in the semi-arid climatic conditions of Northeastern Spain.

At Santa Maria, no significant differences and even no clear tendencies on *L. rigidum* were detected due to increased sowing rate, so that probably wheat plants were not more competitive when sown in 1.5-fold the normal density (Table 4). A possible explanation is that the field at Santa Maria was irrigated, consequently, water was not a limiting factor. Increasing sowing density could have a more important effect on weeds in rainfed environments as found by Izquierdo *et al.* (2003) in a barley crop infested with *L. rigidum* who describe a lower weed biomass for the same number of weed plants. Taking into account the yield results of Moreno *et al.* (2002) and Lacasta *et al.* (2004), probably it is not worth to increase the sowing rate more than 160 kg ha^{-1} in these semi-arid environments.

The combination of different techniques

The theory of using 'many little hammers' to suppress weeds (Liebman and Gallandt, 1997) was partly confirmed at Ferran 1 and also by Recasens *et al.* (2001a). However, the experience of Anderson (2007) in the semiarid steppe of the United States shows that more than two cultural control tactics may be necessary to be effective enough. In the semi-arid conditions of Spain, lack of water in the drylands hinders to integrate other tools proposed by Anderson (2007) as crop rotations of cold- and warm-season crops. In line with the experiences in his situation, no-till could be also used as an effective tool under Spanish conditions. Because seeds remain on the soil surface, they are vulnerable to specific mortality factors that act on surface lying seeds. Seed mortality could contribute declinining the weed seedbank. For example**,** Baraibar *et al*. (2008) found that predation by harvester ants (*Messor barbarus*) of *L. multiflorum* seeds was significantly higher in no-till than in conventional tilled fields.

In case of combining sowing delay with herbicide use, an additional benefit of delayed sowing is that later emerged *L. rigidum* plants are weaker and probably more susceptible to herbicides or to other control strategies (Recasens *et al.*, 2001a).

The starting situation of the fields in the trials described in this work is of highly-infested fields with resistant weeds, which could not be controlled with the conventional herbicide use. In this context, weed density after combining two cultural control methods was still very high ranging between 35 and 450 *L. rigidum* plants m^{-2} depending on the field. Thus, in highly-infested fields with herbicide resistant *L. rigidum*, it will probably be necessary to combine these cultural methods with other more drastic tools as leaving the field fallow for one year, depleting the seed bank by repeating cultivation as suggested by Gramshaw and Stern (1977), or combining them with the use of those herbicides that are still active on the populations. As commented previously, the new high cereal prices will probably favour the use of more expensive active ingredients, which should be used correctly in combination with other techniques without relying exclusively on them.

Taking into account that delayed sowing date can have negative consequences on yield due to lack of rainfall and that the effect on *L. rigidum* is more variable, mouldboard ploughing can be a more secure strategy for its control than sowing delay, with more constant effects on weed plant reduction and with a lower impact on yield. The main problem of this technique is the high fuel consumption, which needs to be compensated by the cereal price and by the *L. rigidum* control. Taking into account the fast decline of the seed bank of this species, it is probably useful to plough every 2-3 years, only, to reduce the resistant populations. As the highest reductions were achieved by combining ploughing with sowing delay, it is probably worth to practice both, though high densities of *L. rigidum* will require additional control methods.

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