Weed harrowing in winter cereal under semi-arid conditions

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Abstract

Five field experiments on barley and wheat have been carried out in North-Eastern Spain on the same field during the cropping seasons 1999-00 to 2003-04 to compare the effect of different harrowing adjustments on weed control, weed biomass and cereal yield. The variables considered were harrowing timing (pre- or early post-emergence), one or two passes, travelling direction, harrowing depth and speed compared with an untreated control and herbicide. Excepting year 2001, with very little weed emergence, mechanical control as a whole caused a significant weed plant reduction compared to the untreated plots in all years. No influence of harrowing depth and travelling speed and of pre-emergence harrowing were found in the trials. A single harrowing treatment conducted across the sowing direction gave the same or less control compared to harrowing along the sowing direction. Two harrowing passes achieved a higher efficacy than one single pass and little differences were detected if the second pass was conducted the same day, across the sowing direction or 15 days later. Despite herbicide had generally a higher efficacy than the harrowing treatments, in three out of five years it was found a mechanical control with the same control than herbicide. The effect of the different treatments on weed biomass was lower than on weed number and no significant differences were found for grain yield. Considering that an herbicide treatment in the present conditions is three times more expensive than harrowing, a single post-emergence harrowing can be considered a valid option for low and medium-infested cereal fields.

Additional key words: barley, durum wheat, flex-tine harrow, mechanical weed control.

Resumen

Control mecánico de malas hierbas en cereal de invierno en condiciones semiáridas

En este trabajo se muestran los resultados de cinco experimentos de campo localizados en el noreste de España desde 1999-00 hasta 2003-04. En ellos se comparó el efecto de distintas formas de control mecánico de la flora arvense con grada de varillas flexibles sobre la densidad y biomasa de la misma y sobre la producción de cereal comparado con un control sin tratar y el uso de herbicidas. Las variables consideradas fueron: momento y número de pases de grada, profundidad, dirección y velocidad de los pases. Excepto en 2001, con una baja infestación, el control mecánico redujo la densidad de arvenses en comparación con las parcelas sin tratar. La profundidad y la velocidad de la labor no tuvieron influencia clara y realizar el pase en preemergencia del cereal resultó ineficaz probablemente debido a la falta de humedad. Dos pases resultaron más eficaces que uno y se encontraron pocas diferencias si el segundo se hacía en el mismo día, perpendicular o 15 días después. Aunque el herbicida tuvo generalmente mayor eficacia que los tratamientos mecánicos, en tres años se encontró un tratamiento mecánico con eficacia similar. El efecto de los distintos tratamientos sobre la biomasa de arvenses fue menor que sobre el número de las mismas y no hubo diferencias significativas sobre la producción. Dado que el tratamiento herbicida en las condiciones del ensayo fue tres veces más caro que el tratamiento mecánico, un único pase en post-emergencia puede ser una opción válida con infestaciones medias o bajas de malas hierbas.

Palabras clave adicionales: cebada, grada de varillas flexibles, trigo duro.

Introduction

Herbicides have played a key role in the advancement of agriculture in industrialised countries since they are efficient controlling weeds, are selective, fast-acting and relatively cheap. However, nowadays there is a need to consider alternatives to chemical control because weeds may develop resistance against almost any herbicide (Heap, 2008) and an abusive use can contribute to environmental contamination (Garrido *et al.,* 1998). The important reduction of accepted active ingredients in the European Union leads to consider alternative weed control methods. In addition, the general public is more concerned about agrochemical residues in the environment and, more recently, in the agricultural products itselves. To reduce these problems, mechanical weeding is an alternative tool which can be used in combination with herbicides, with other cultural methods as rotations or alone. Moreover, the changes in the European Common Agriculture Policies enhance farmers to adopt more environmentally-friendly practices.

The flex-tine harrow is widely used for mechanical weed control in organically grown cereals. It tills the soil surface superficially, so that weed seedlings are uprooted and covered by soil. Some authors have suggested that the most important effect is covering (Jones *et al.,* 1995), while in other experiments uprooting was probably the main cause (Kurstjens and Kropff, 2001; Cirujeda *et al.*, 2003). Uprooting and covering may not completely kill the weeds, but the damage caused may be enough to slow down their growth (Lambain *et al.*, 1993) although Rasmussen (1992) did not find that surviving weeds had a lower competitive ability.

Authors agree in the large amount of factors affecting harrowing efficacy. Some are the weed species, phenological stages of the weed and crop, soil type and moisture, weather conditions and the way tillage is carried out (Böhrnsen, 1993) including driving speed, tine angle, etc. However, contradictory results can be found in the literature for many of these parameters. For example, concerning the effect of speed on weed control, Rasmussen and Svenningsen (1995) and Kurstjens and Perdock (2000) related efficacy with higher speed. Rasmussen (1990), however, did not find a clear relationship between both. Also Cirujeda *et al*. (2003) did not find efficacy increases when comparing 2, 5 and 8 km h^{-1} and Rydberg (1993) described the biggest weed reduction at 5 km h^{-1} and increasing harrowing speed up to 9 or 13 km h^{-1} did not improve weed control but could affect grain yield.

Concerning the direction of harrowing, most trials have been conducted along the crop plant rows. Few experiments reported results of trials harrowing across the sowing direction. Neururer (1977) quoted by Rydberg (1994) found more weed reduction harrowing across but Rydberg (1994) did not find any differences.

The flex-tine harrow can be used at pre-emergence, early post-emergence and selective harrowing can be conducted at late tillering of the cereal (Rasmussen and Svenningsen, 1995). Efficacy in pre-emergence is only expected if the majority of weeds germinate earlier than the crop (Rasmussen, 1996). Most of the trials described in the literature have been conducted in early post-emergence of both the weeds and the crop and it is often recommended to harrow in early stages of the weeds, especially when tap-rooted weeds dominate (Wilson *et al.*, 1993; Welsh *et al.*, 1997; Cirujeda *et al.*, 2003). Selective harrowing is not usually conducted as weeds are better controlled at early stages. Repeating post-emergence harrowing the same day usually increases efficacy and crop damage (Rasmussen, 1991; Wilson *et al.*, 1993) and no additional effect is observed in some cases (Welsh *et al.*, 1997).

The tine angle of the harrow should have an effect on weed control and yield. However, Bàrberi *et al.* (2000) combined four different positions which corresponded to different aggressiveness with single and go-and-back treatments on durum wheat and did not find significant effects on weeds and crop.

In addition to controlling the weeds it is necessary to do the adjustments in order to avoid crop damage, as it happens with chemical treatments (Kurstjens and Perdock, 2000). The relationship between weed control and crop damage is very important (Rasmussen, 1991), since control is normally improved by deeper harrowing or more passes, even though both factors may increase crop damage (Rasmussen and Rasmussen, 1995). The selectivity of weed control is mostly determined by the difference between the root system and/or stiffness of the crop versus the weed, where the weeds should be less developed than the crop for the treatment to be effective and selective.

With the exception of the work conducted in Italy (Bàrberi *et al.*, 2000) and some conducted in Spain (Lacasta *et al*., 1997; Moyano *et al.*, 1998; Cirujeda and Taberner, 2006), most of the research on weed harrowing has been conducted in Northern countries (Denmark, Netherlands, Great Britain, Sweden, Germany, etc.). In a semi-arid environment as found in Southern Europe, Northern Africa, huge parts of North America

and other parts of the world rainfall is very irregular. In the semi-arid conditions of North-Eastern Spain drought periods in autumn or winter are frequent but also wet years occur. It is thus important to conduct field trials during several years in order to assess the limitations given by the climatic conditions in the present locations. Pre-emergence harrowing can be effective if moisture enhances germination but if sowing is conducted in dry conditions the effect is probably very little. Dry soils in autumn are expected to be more common in the semi-arid conditions, opposite, survival of weeds should be more difficult in the semi-arid climates after harrowing. On one hand, more continuous moisture in Northern Europe allows recovery of weeds, but on other hand, moisture favours crop development and competition potentially suppressing weeds.

The cropping cycle is also shorter in the semi-arid conditions compared to Northern Europe, as cereal is normally sown in mid autumn (November) to benefit from autumn and winter rain or rarely at the end of winter (February) if too wet conditions did not allow earlier sowing. Harvest is made in mid June so that the cropping cycle comprises around 7 months, compared to the 8 or 9 months in Northern European conditions. Despite sowing density for winter cereal is similar (150-200 kg ha^{-1}) a normal yield in Spanish rainfed areas is 2500 kg ha^{-1}, compared to the 5000 or 6000 kg ha^{-1} in Northern Europe. Specially, in low-yield areas harrowing can be an interesting weeding technique as costs are lower compared to any herbicide application (Pardo *et al.*, 2004).

In Spain, this type of weeding is poorly developed but adopted by some organic growers. The typical treatment tested in winter cereal in semiarid zones is one pass during the tillering phase (Lacasta *et al.,* 1997; Moyano *et al.*, 1998; Zaragoza *et al.,* 1999; Lezáun *et al.*, 2001). The studies carried out by Cirujeda and Taberner (2006) included repeated passes but focused on one weed species, namely *Papaver rhoeas*. Due to the scarce information available in semi-arid conditions it was considered necessary to do harrowing experiments in winter cereal crops during several years on a mixed weed flora, searching optimising the use of the flex-tine harrow by adjusting variables such as the number of passes, harrowing depth, direction and travelling speed, as well as the time of intervention (pre- or post-emergence of the crop).

The objective of this work was to study the effect of different adjustments of the flex-tine harrow on weed control in winter cereals under semi-arid conditions on a mixed weed population assessing both effects on weeds and on crop yield.

Material and methods

Site

Trials were carried out in Zaragoza (the township of Montañana, latitude 41º43' N and longitude 2º52' W; 225 m above sea level) on a soil with a loamy texture (37.75% sand, 49.08% silt and 13.17% clay) and with 3.37% organic matter, which is high for the area and caused by the previous crop, which was an orchard. Monthly data on rainfall and temperatures for the period of the experiment are shown in Figure 1.
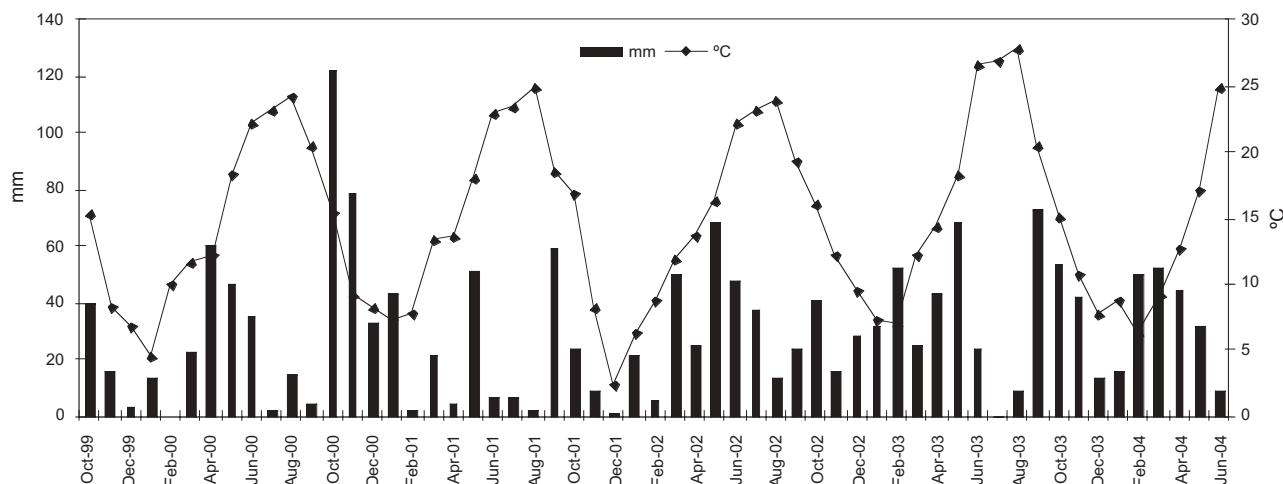

Figure 1. Monthly rainfall and temperature data at the trial.

Sowing and crop management

Barley was sown in November in the first and third year of the study (1999-00, 2001-02) and in February in the second year (2000-01) due to heavy rainfall in autumn and winter impeding earlier sowing. The wheat was sown in November in 2002-03 and in January in 2003-04 due to technical problems. Sowing rate was 150 and 175 kg ha^{-1} in 1999, 2001 and 2002, and 200 kg ha^{-1} on the second and last year in anticipation of a scarce tillering (Table 1).

Fertilization consisted in 120-60-60 N-P$_2$O$_5$-K$_2$O kg ha^{-1}. Phosphorus, potassium and a third of the nitrogen were applied preplant. The rest was applied as side dress at tillering (Table 1). The crop was harvested in June-July each year.

Treatments

The experimental design was a randomized block with three replicates and elemental plots measuring 18 x 5 m. Ten treatments were tested in the first two years and eight in the other three seasons considering only those with the most interesting results (Table 2). Pre-emergence harrowing was considered since 2002. Trials included every year herbicide control plots and non-weeded plots.

The treatments varied in terms of the number of passes (one or two, either on the same day or with an interval of 15 days), of the direction (parallel and/or across to the sowing lines), harrowing depth [changing the angle of the tines on the soil following Bàrberi *et al.* (2000) low β = -70, middle β = -60º, high β = -50º and α= 135º] and of the travelling speed (low 9 km h^{-1} or high 12 km h^{-1}).

Most passes were carried out during the tillering phase in BBCH stage 21-22 (BBCH Working Group, 1997) except for the second pass in treatment 8, which was done during the stem elongation phase (stage BBCH 30) and treatment 0, performed in pre-emergence. The herbicides were chosen depending on the flora composition and considering the phenological stage of the weeds: 2,4-D (2,4-dichlorophenoxyacetic acid) + MCPA (2-methyl-4-chlorophenoxyacetic acid) (0.33 + 0.33 kg a.i. ha^{-1}, Horma, Key) in year 2000, diflufenican + MCPA (0.05 + 0.5 kg a.i. ha^{-1}, Yard, Bayer) in year 2001, chlortoluron + terbutrine + triasulfuron (0.795 + 0.161+0.00375 kg a.i. ha^{-1}, Tricuran 64 WG, Syngenta) in year 2002, MCPA (0.8 kg a.i. ha^{-1} Agroxone, Syngenta) in year 2003 and 2,4-D (0.6 kg a.i. ha^{-1} Primma Din, Agrodan) in year 2004.

Weed plants were counted 15-20 days after the last harrowing in three 0.27 m^2 squares and the weed number was added to evaluate the effectiveness of the different treatments. Efficacy was calculated comparing weed density (plants m^{-2}) with the untreated plots following: [(density untreated plots - density treated plots) (density untreated plots)$^{-1}$*100]. Crop and weed dry weight at flowering of the crop were also assessed to evaluate selectivity. Aboveground biomass was cut in

Table 1. Sowing date, crop density and cereal varieties sown in the different trials and dominant weed species

Year	Crop	Variety	Sowing date	Density (kg ha^{-1})	Dominant weed species
1999-00	Barley	Camelot	15/11/99	150	*Sinapis arvensis, Capsella bursa-pastoris, Polygonum aviculare, Anacyclus clavatus, Senecio vulgaris, Rumex crispus.*
2000-01	Barley	Graphic	15/2/01	200	*Convolvulus arvensis, S. arvensis, Chenopodium vulvaria, R. crispus, Hordeum murinum.*
2001-02	Barley	Hispanic	8/11/01	150	*Galium aparine, Fumaria officinalis, P. aviculare, Stellaria media, Veronica hederifolia, S. arvensis.*
2002-03	Durum wheat	Mellaria	15/11/02	175	*S. arvensis, Diplotaxis erucoides, C. bursa-pastoris, R. crispus, G. aparine, A. clavatus, Taraxacum officinale.*
2003-04	Durum wheat	Ionio	20/1/04	200	*C. vulvaria, C. arvensis, S. arvensis, Veronica hederifolia, R. crispus, Malva spp., C. bursa-pastoris.*

Table 2. Summary of the treatments carried out in the trials

Treatment number	Number of passes	Harrowing direction regarding sowing direction	Harrowing depth	Speed (km h^{-1})	Harrowing date Barley 2000	2001	2002	Wheat 2003	2004
0- Pre-emergence	1 [a]	Parallel	Middle	9	-	-	27/11	4/12	9/2
1- Single pass at low depth	1	Parallel	Low	9	29/2	27/3	-	-	-
2- Single pass at medium depth	1	Parallel	Middle	9	29/2	27/3	11/2	14/2	4/3
3- Single pass at high depth	1	Parallel	High	9	29/2	27/3	-	-	-
4- Single pass at high speed	1	Parallel	Middle	12	29/2	27/3	-	-	-
5- Two parallel passes the same day	2 [b]	Parallel	Middle	9	29/2	27/3	11/2	14/2	4/3
6- Two passes: one parallel, one across	2 [b]	First parallel, second across	Middle	9	29/2	27/3	11/2	14/2	4/3
7- Single pass across the sowing line	1	Across	Middle	9	29/2	27/3	11/2	14/2	4/3
8- Two parallel passes. The second 15 days later	2 [c]	Parallel	Middle	9	29/2 14/3	27/3 10/4	11/2 27/2	14/2 28/2	4/3 22/4
9- Herbicide		Only herbicide treatment			13/3	2/4	17/1	21/2	14/4
10- Untreated control		Unweeded control			nh [d]	nh	nh	nh	nh

[a] Pre-emergence. [b] Treatment repeated at the same day. [c] Treatment repeated 15 days after. [d] Nh: not harrowed.

two 0.27 m^2 squares and dried at 60ºC during 96 hours. Grain yield was obtained at 86% dry mater with an experimental harvester harvesting 27.9 m^2 per plot.

Statistical analysis

To satisfy normality and variance homogeneity, efficacy was *arcsin* [$\sqrt{(x/100)}$] transformed and weed biomass needed $\sqrt{x}$ transformation. Block was nested with year, which was taken into account in the ANOVA model, assigning the correspondent error terms. A contrast analysis was performed to compare the different treatments in a more detailed way using the statistic package SAS (SAS Institute, 1991).

Results and discussion

Effect on weed number

The average weed infestation was highest in 2000 and 2004 with more than 200 plants m^{-2} in the non-weeded plots, moderate in 2002 and 2003 with 42 and 105 plants m^{-2}, respectively and very low in 2001 with only 12 plants m^{-2}, probably due to the delayed sowing. Concerning the effect of harrowing on the different weed species, no efficacy was appreciated on *Sinapis arvensis* and *Rumex crispus* even in the repeated harrowing treatments. In the first case the plants and especially the rooting system developed faster than the crop, and in the second case the perennial weed was strongly anchored.

The interaction *year x treatment* was significant for percentage weed control (Table 3). Percentage weed control of the mechanical treatments was very irregular ranging from 1 to 80% (Table 4). Therefore the results were considered for each year individually. The interaction was not significant for weed biomass so that the mean of all five years was considered (Table 4). The contrast analysis showed that the mechanical treatments considered as a whole were effective for weed density reduction in relation to the untreated control in all years excepting 2001 where the infestation was very low (Table 5, contrast a).

Table 3. Results of the standard ANOVA on the percentage of weed control (*arcsin* ($\sqrt{(x/100)}$ transformed), on weed biomass in kg ha^{-1} ($\sqrt{x}$ transformed) and on yield in kg ha^{-1}

	d.f.	F	P>F
Weed control			
Year	4	1.86	0.1717
Treatment	10	10.69	<0.0001
Year x Block	10	5.10	<0.0001
Year x Treatment	29	2.12	0.0048
Weed biomass			
Year	4	40.30	<0.0001
Treatment	10	6.42	<0.0001
Year x Block	10	1.48	0.1620
Year x Treatment	29	0.95	0.5440
Yield			
Year	4	6.92	0.0047
Treatment	10	1.84	0.0984
Year x Block	10	9.62	<0.0001
Year x Treatment	29	1.50	0.0815

Influence of harrowing depth and speed

These parameters were analysed during the first two years (Table 5, contrasts e, f, g, h). In year 2000 weed control did not increase by increasing working depth or speed and in 2001 only significant differences were detected between middle and high depth (Table 5, contrast g), so that these treatments were not included in the next field trials. Instead, a pre-emergence treatment was tested since 2002 (Table 5, contrast i).

Number of harrowing passes

Concerning the number of passes, as a whole, two harrowing passes achieved better efficacy than only one, with significant differences during the years 2002 and 2004 (Table 4 and Table 5, contrast b). Little differences were detected due to conducting the second harrowing pass in a different direction or at a different date. Only in 2004 harrowing the second pass across the sowing line controlled significantly more weeds than performing the second pass in the same direction (Table 5, contrast j) and only in 2000 doing the second pass in the sowing direction the same day was more effective than repeating the treatment 15 days later (Table 5, contrast k). This last observation is coincident with the findings of Bàrberi *et al.* (2000) who observed that weeds surviving the first harrowing treatment can not be con-trolled with the second treatment as they are bigger then. In fact, best efficacy by weed harrowing is generally achieved when weeds are small so that if it is aimed to do two passes, following the results in semiarid conditions, better efficacy is generally not achieved if the treatment is repeated 15 days after. It is probably different in areas with constant moisture and with new weed emergences during the cropping cycle where harrowing at different moments can be more effective (Rasmussen and Rasmussen, 1999).

Harrowing direction

A single harrowing treatment conducted across the sowing direction gave the same control compared to harrowing along the sowing direction excepting in 2000, where harrowing across was significantly less efficient than harrowing along the sowing direction (Table 5, contrast d). This tendency was also observed in 2002 and 2004, but differences were not significant. Probably the crop was small enough in the trials to avoid that tines were guided between the rows and impeding correct tine vibration, which does occur when harrowing after tillering as described by Rasmussen and Svenningsen (1995).

Harrowing moment

Pre-emergence harrowing was not effective any year in the tested conditions. In 2004, control was even significantly lower compared to a single post-emergence harrowing treatment (Table 5, contrast i). Weeds should be starting germination in order to move pre-emerged weeds so called 'white threads' in pre-emergence (Rasmussen and Svenningsen, 1995) and probably this did not happen in the experiments, as soil moisture was low. Another negative aspect of pre-emergence harrowing is the risk of breaking dormancy (Grundy *et al.,* 2003) as the soil is refined again, but this is an issue that has not been covered in the current study.

Comparing with the herbicide efficacy

Excepting the results of year 2001 herbicide had a significantly higher efficacy compared to harrowing overall (Table 5, contrast l) but in three out of five years it was possible to find a harrowing treatment that had statistically the same efficacy than the herbicide treatment (Table 5, contrast o) but in no case harrowing had a superior weed control than herbicide. At high-density weed infestations and also with highly-aggressive weeds probably the use of herbicide is a more effective solution.

Table 4. Mean weed control (%), weed biomass (kg ha^{-1}) and cereal yield (kg ha^{-1}) for the different years. Data are back-transformed after analysis from *arcsin* ($\sqrt{(x/100)}$). No means are shown for weed control due to the significant interaction *year x treatment*.

	Weed control					Weed biomass	Yield
						Mean	Mean
	2000	**2001**	**2002**	**2003**	**2004**	**2000-04**	**2000-04**
0- Pre-emergence [1]	-	-	29.2	3.3	0.5	914.0	2561.3
1- Single pass at low depth [2]	38.1	25.0	-	-	-	236.9	2761.5
2- Single pass at medium depth	48.6	4.3	38.9	7.2	18.8	456.3	2839.0
3- Single pass at high depth [2]	46.3	41.9	-	-	-	159.1	3060.7
4- Single pass at high speed [2]	53.4	14.9	-	-	-	186.7	2346.3
5- Two parallel passes the same day	64.4	26.5	60.5	21.1	19.5	281.6	2326.9
6- Two passes: one parallel, one cross	36.0	13.8	58.1	50.0	63.1	290.0	2416.0
7- Single pass across the sowing line	20.9	30.1	35.3	18.4	11.4	506.7	2564.5
8- Two parallel passes. The second 15 days later	20.1	25.3	66.7	22.1	37.8	412.0	2558.9
9- Herbicide	75.2	19.5	79.7	83.2	84.0	149.6	2857.5
10- Untreated control	0.0	0.0	0.0	0.0	0.0	749.2	2178.3

[1] Conducted in 2002-2004, only. [2] Conducted in 2000 and 2001, only.

Effect on weed biomass

Weed biomass at the end of the cropping cycle had a similar behaviour than weed control but less significant differences were found (Table 5). This is probably due to the fact that a good control caused by mechanical weeding generally leads to bigger surviving individual plants due to lower competition, hiding part of the control effect as found by Rasmussen (1992). Statistically significant differences were found only when comparing mechanical control as a whole or herbicide with untreated control (Table 5, contrasts a, p) and when choosing the best mechanical control treatment concerning weed biomass with the untreated control (Table 5, contrast s). These results suggest that a good harrowing is able to reduce weed density and also weed biomass.

As commented previously, a significantly higher weed control was found in the plots treated with herbicide compared to the overall mechanical methods in four out of five years as too little weeds were found in 2001, but herbicide did not achieve a higher weed biomass reduction (Table 5, contrast l). Weed biomass was statistically the same even when comparing herbicide treated plots with the mechanical control treatment, which lead to the lowest weed biomass (i.e. harrowing twice at the same date) (Table 5, contrast p). Thus, probably the weeds found in the herbicide-treated plots were big plants grown with little competition.

Cereal yield

Highest mean yield was obtained in 2000 and 2002 (3,511 and 3,284 kg ha^{-1}). Lowest yield were obtained in 2001 (1,586 kg ha^{-1}) and 2004 (1,944 kg ha^{-1}), which is coincident with the delayed sowing in the latter years. However, the interaction *year x treatment* was not significant for percentage weed control. Considering the mean of all five years, despite the mechanical treatments as a whole achieved a significantly better weed control compared to the non-weeded control, this did not lead to a yield increase for any of the tested treatments (Table 5). No differences were found even when choosing the best treatments considering yield (Table 5, contrasts r, s).

Weed competition is probably not the limiting factor in cereal crops in the tested conditions, as significant differences in yield were not found even when comparing untreated plots with treated plots with the highest

Table 5. Results from the contrast analysis

	Mean weed control					Weed biomass Mean	Yield Mean
	2000	2001	2002	2003	2004		
a) mechanical *vs.* unweeded control	**	ns	**	*	**	**	ns
b) two passes in any form *vs.* one pass at any depth, any speed and direction	ns	ns	**	ns	*	ns	ns
c) any parallel pass *vs.* one pass across	**	ns	ns	ns	ns	ns	ns
d) one parallel pass *vs.* one pass across middle depth and 9 km h^{-1} both	**	ns	ns	ns	ns	ns	ns
e) middle *vs.* low depth	ns	ns	-	-	-	ns	ns
f) high *vs.* low depth	ns	ns	-	-	-	ns	ns
g) high *vs.* middle depth	ns	*	-	-	-	ns	ns
h) 12 km h^{-1} *vs.* 9 km h^{-1}	ns	ns	-	-	-	ns	ns
i) harrowing at tillering *vs.* pre-emergence	-	-	ns	ns	*	ns	ns
j) two parallel passes *vs.* one parallel and the second pass across	ns	ns	ns	ns	** (-)	ns	ns
k) two parallel passes *vs.* repeating the second parallel pass 15 days after	**	ns	ns	ns	ns	ns	ns
l) herbicide *vs.* mechanical as a whole	**	ns	**	**	**	ns	ns
m) herbicide *vs.* untreated control	**	ns	**	**	**	*	ns
n) best mechanical concerning weed control *vs.* unweeded control	**	**	**	**	**	-	-
o) herbicide *vs.* best mechanical concerning weed control	ns	ns	ns	*	*	-	-
p) best mechanical concerning weed biomass *vs.* unweeded control	-	-	-	-	-	*	-
q) herbicide *vs.* best mechanical concerning weed biomass	-	-	-	-	-	ns	-
r) best mechanical concerning yield *vs.* unweeded control	-	-	-	-	-	-	ns
s) herbicide *vs.* best mechanical concerning yield	-	-	-	-	-	-	ns

(-) means that the first term is statistically lower than the second; in the other cases, the first term is higher than the second. **: P<0.01; *: P<0.05; ns: not significant. a) in 2000 and 2001: 1, 2, 3, 4, 5, 6, 7, 8 *vs.* 10; in 2002-04: 0, 2, 5, 6, 7, 8 *vs.* 10; b) in 2000 and 2001: 5, 6, 8 *vs.* 1, 2, 3, 4, 7; in 2002-2004: 5, 6, 8 *vs.* 2, 7. c) in 2000 and 2001: 1, 2, 3, 4 *vs.* 7; in 2002-2004: 2 *vs.* 7; d) 2 *vs.* 7 all years; e) in 2000 and 2001: 2 *vs.* 1; f) in 2000 and 2001: 3 *vs.* 1; g) in 2000 and 2001: 3 *vs.* 2. h) in 2000 and 2001: 4 *vs.* 2; i) in 2002-2004: 2 *vs.* 0; j) 5*vs.* 6 all years; k) 5 *vs.* 8 all years l) 9 *vs.* 0, 1, 2, 3, 4, 5, 6, 7, 8; m) 9 vs. 10; n) 5 (2000), 3 (2001) 8 (2002), 6 (2003,2004) *vs.* 10; o) 9 *vs* 5 (2000), 3 (2001) 8 (2002), 6 (2003,2004); p) 5 *vs.* 10 q) 9 *vs.* 5; r) 2 *vs.* 10; s) 9 *vs.*2.

yield. However, weed control is necessary to avoid increasing the weed seed-bank.

In the trials performed the tendency that harrowing across the sowing line gave yielded less than harrowing along the sowing line (Table 4) probably due to crop plant damage. Considering that weed control was the same or lower in one case (Table 5, contrasts c, d), harrowing across the sowing line is probably not a good practice in the present conditions.

Lack of significance on crop yield when comparing the treatments (Table 3) suggests that in the present con-

ditions no important damage was caused due to repeated treatments, but the tendency was lower yield for the repeated harrowing treatment (Table 4), similar to the results of Rasmussen (1991) who also observed just a tendency in reduction.

The above results reveal that a single pass at middle depth at tillering of the cereal can be considered an interesting mechanical option when weed pressure is low or medium. Moreover, although the weed control was lower compared to herbicide use, the yield was almost the same. Taking into account that the cost of the herbicide

treatment (39.7 € ha⁻¹ as an average of the seven years) in the trial conditions is three times more expensive than a single harrowing treatment (12.1 € ha⁻¹, average of the seven years) (Pardo *et al*., 2004), a single harrowing can be a good option from an economic perspective not only when herbicides are not permitted.

Conclusions

Harrowing efficacy was irregular but can be considered a valid option for weed control in cereal fields in the present conditions, because it reduces weed density significantly compared to the untreated plots and because no significant yield differences were found when comparing the harrowing treatments with herbicide use. Moreover, its cost is inferior to herbicide use.

Harrowing at higher speed or higher depth did generally not lead to a higher weed control. Harrowing across the sowing direction of the cereal did not increase efficacy, either and tended to decrease cereal yield.

Concerning repeating harrowing, the best option was to do the second pass the same day and in the sowing direction. However, yield tended to decrease with repeated harrowing so that doing the second pass will be justified with high infestations, only.

Few harrowing treatments achieved a similar efficacy than herbicide use. Out of the tested treatments in semiarid conditions, one single harrowing pass at a normal depth and at 9 km h⁻¹ is probably the best option.

Finally, the convenience of any weed control method can be discussed in the present areas as yield decreases in the non-weeded control plots were not significant compared to any of the mechanical methods not even compared to the herbicide treatment, probably due to the fact that weed competition was not the most limiting factor in these conditions. However, reducing the weed flora in any way is always beneficial to prevent infestations the following years.

Acknowledgements

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