Soil was quite moist at both the sowing date and at pre-emergence harrowing. Soon after the pre-emergence harrowing the soil dried out and it was quite cold so that *P. rhoeas* germination was probably not enhanced by this soil disturbance. Additionally, independently from the harrowing, *P. rhoeas* could have hardly started to germinate due to the same reasons, so that pre-emergence harrowing did probably kill few *P. rhoeas* seedlings starting to germinate.

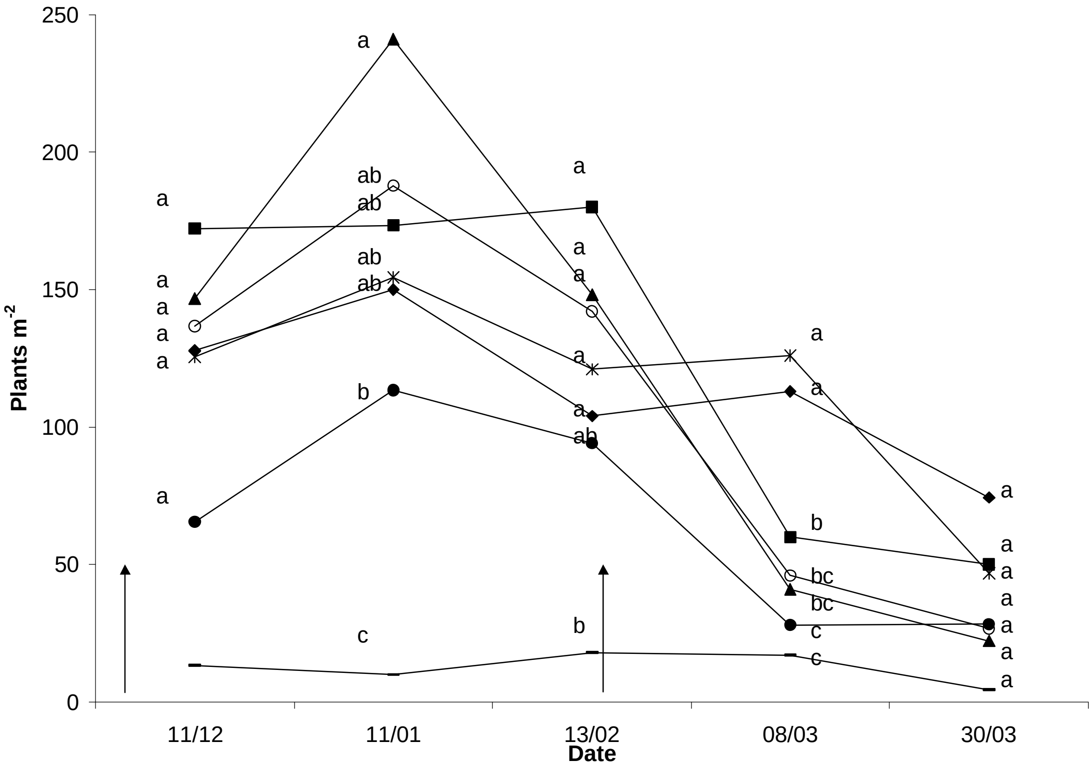

Figure 7.17. a. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Baldomar in 2000-01. The arrows indicate the harrowing moments. ? Untreated, - herbicide, * pre-emergence, ? post-emergence at 2 km h^{-1}, ? post-emergence at 4 km h^{-1}, ¦ post-emergence at 6 km h^{-1}, ? post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.015.

The **post-emergence** harrowing was conducted in a correct moment taking into account that no new *P. rhoeas* germination was observed since the harrowing date. Initial plant density immediately before the post-emergence harrowing was moderate ranging between 100 and 180 plants m^{-2} (Figures 7.17. a-d) and differences between plots were no more as important as before.

There was a statistical significant plant number reduction in the post-emergence treatments after harrowing (P<0.01) (Figure 7.17. a) and at the first assessment after post-emergence harrowing, *P. rhoeas* plant number was significantly lower in all harrowed plots compared to the untreated and pre-emergence harrowed plots (Figure 7.17. a).

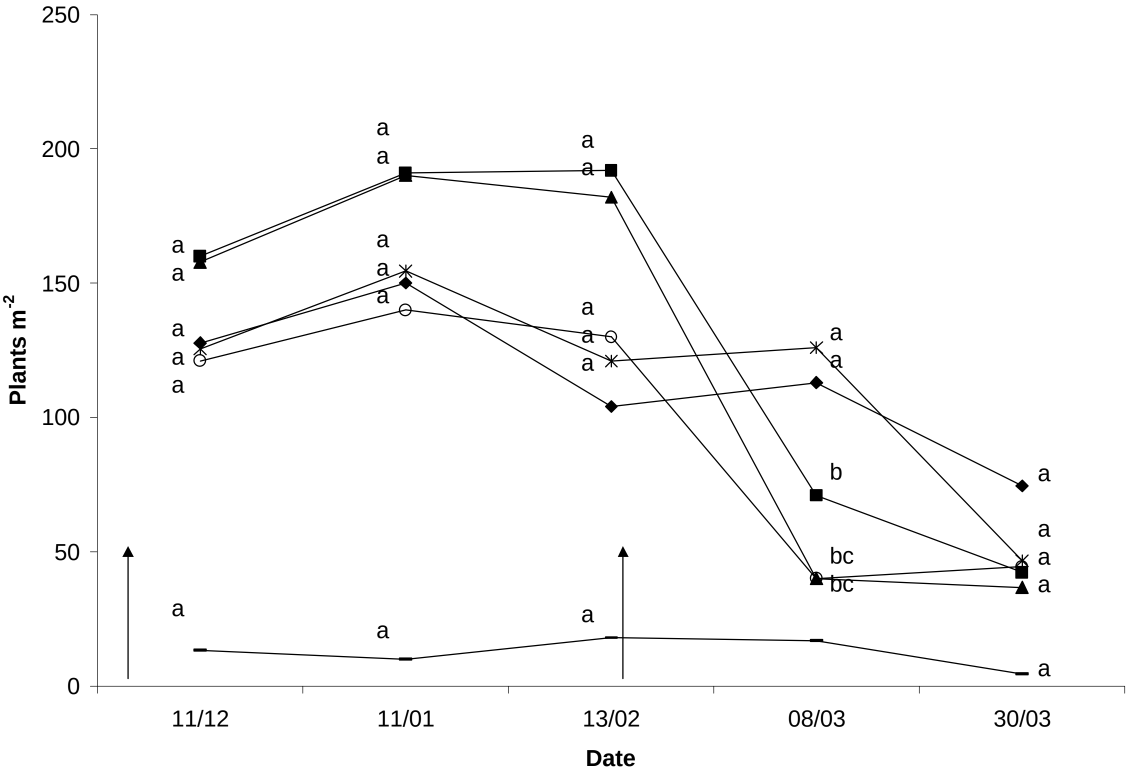

Figure 7.17. b. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Baldomar in 2000-01. The arrows indicate the harrowing moments. ? Untreated, - herbicide, * pre-emergence, ? pre- and post-emergence at 4 km h^{-1}, ¦ pre- and post-emergence at 6 km h^{-1}, ? pre- and post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.05.

Efficacy at this date ranged from 66 and 80% (72±4.4). At the last assessment date, however, no significant differences between any treatment were detected any more and efficacy ranged between 52 and 79% (67±9.6). This approach of plant number in treated and untreated plots is probably again on one hand due to the partial recover of plants in the harrowed plots and on the other hand due to the natural mortality, which mainly occurred in the untreated plots. At the end of the cropping cycle, however, no significant differences in weed plant number were detected any more.

Post-emergence harrowing conducted after pre-emergence harrowing finished in similar plant densities than when conducted alone (Figure 7.17. a, b). Analysing plant evolution throughout the season treatment by treatment, however, it was noticed that the plots harrowed in pre- and in post-emergence behaved in a different way than the only post-emergence harrowed plots. In the first case, no significant variations throughout the cropping period were detected, neither immediately after the post-emergence harrowing. In the second case, *P. rhoeas* plant number decreases after the harrowing were significant, as commented previously, despite the plant density immediately before harrowing was similar in all these treatments. So, these data suggest that even if the effect of pre-emergence harrowing could not be detected comparing the different treatments, a slight control effect seem to having occurred.

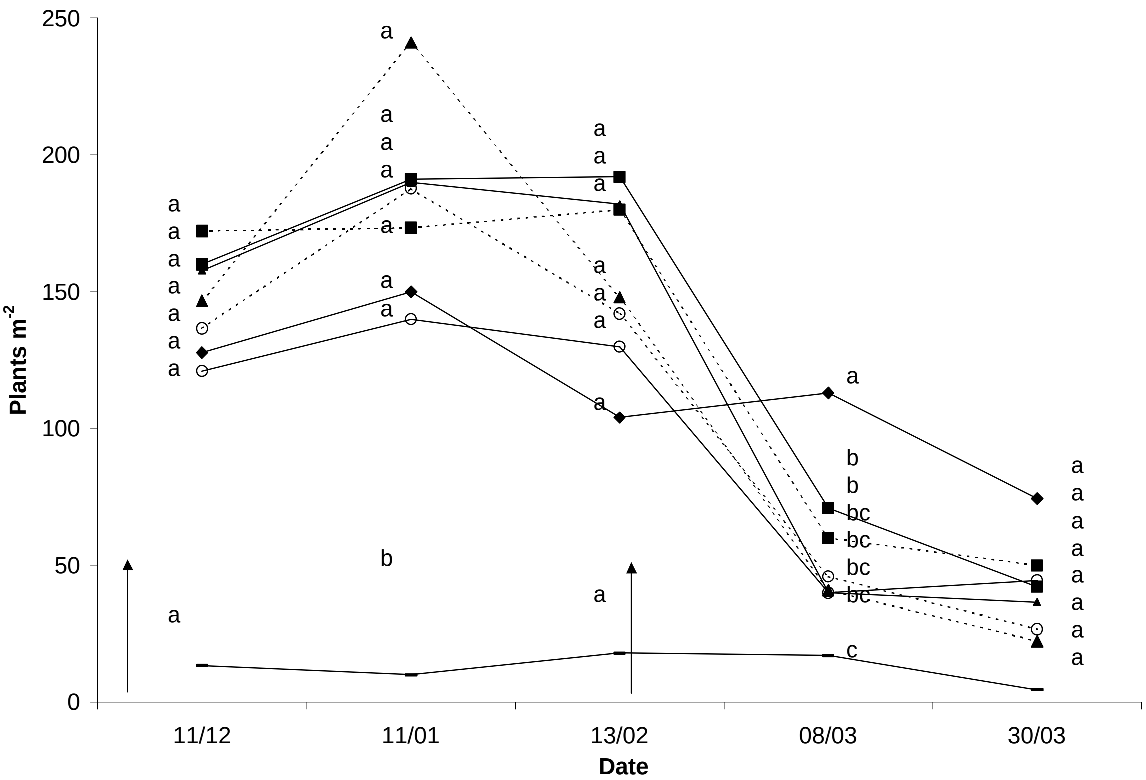

Figure 7.17. c. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Baldomar in 2000-01. The arrows indicate the harrowing moments. ? Untreated, - herbicide, ? pre- and post-emergence at 4 km h^{-1}, ¦ pre- and post-emergence at 6 km h^{-1}, ? pre- and post-emergence at 8 km h^{-1}, --? -- post-emergence at 4 km h^{-1}, --¦ -- post-emergence at 6 km h^{-1}, --? -- post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.01.

With the aim of clarifying the results, Figure 7.17. d shows plant density evolution in the most representative treatments: untreated, pre-emergence, post-emergence and (pre + post-emergence (at the most effective speed).

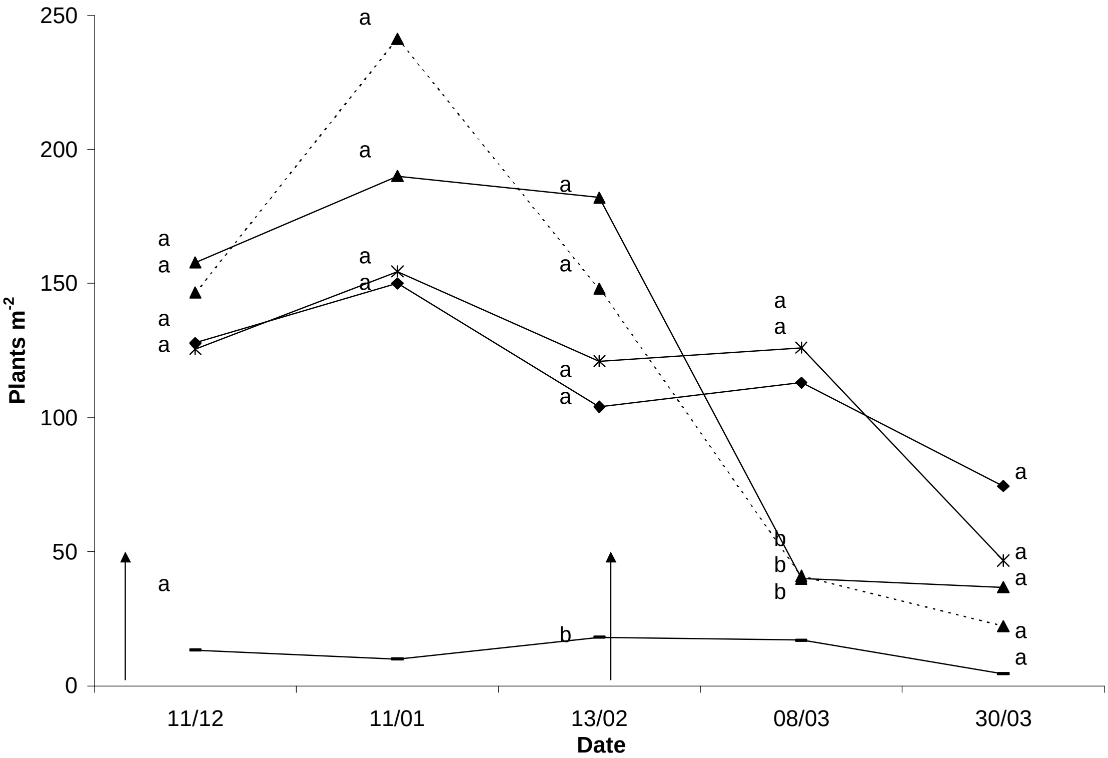

Figure 7.17. d. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Baldomar in 2000-01. The arrows indicate the harrowing moments. ? Untreated, - herbicide, * pre-emergence, ? pre- and post-emergence at 4 km h^{-1}, --? -- post-emergence at 4 km h^{-1}. Different letters correspond to statistically significant differences at P<0.01.

Table 7.5. shows the evolution of weed control efficacy for the different speed treatments.

Table 7.5: Evolution of control efficacy (%) of *Papaver rhoeas* in the trial conducted in Baldomar in 2000-01. Efficacy was calculated taking into account the evolution of plant number in the untreated control plots. DAT = days after treatment.

Treatment	Speed (km h^{-1})	Efficacy 23 DAT	Efficacy 45 DAT
Pre- and post-emergence	2	79.8	71.9
	4	66	69.3
	6	71.7	52.2
Post-emergence	2	72.6	57.9
	4	74.5	79
	6	69.3	61.2
	8	70.2	73.8

Reduction in plant number was similar for the different speed treatments in the post-emergence harrowing, as well as in the plots, which were harrowed in pre-emergence and again in post-emergence. There were no significant differences between the final *P. rhoeas* plant number in the plots harrowed in pre- and post-emergence compared to the post-emergence harrowing alone regardless of the speed influence. Also the efficacy was similar for all the treatments (Table 7.5.). In half of the cases a reduction of efficacy in time was observed, but there was no a clear relationship between the efficacy evolution and speed. The sandy soil in Baldomar had probably an important influence on the lack of response to speed increases.

Nalec 2000-01

Pre-emergence harrowing was conducted both after rolling and without using this tool 15 days after sowing. The soil was quite moist at harrowing but windy and sunny weather afterwards dried the soil surface out. Very young *P. rhoeas* seedlings had already emerged at this date and some cereal plants were already visible. No clear effect of pre-emergence harrowing was observed in this trial, either (Figures 7.18. a-d). The untreated plots as well as the pre-emergence harrowed plots kept high weed densities until the end. In the plots harrowed in pre- and in post-emergence, very variable plant density after pre-emergence harrowing was observed, as it also occurred in Baldomar.

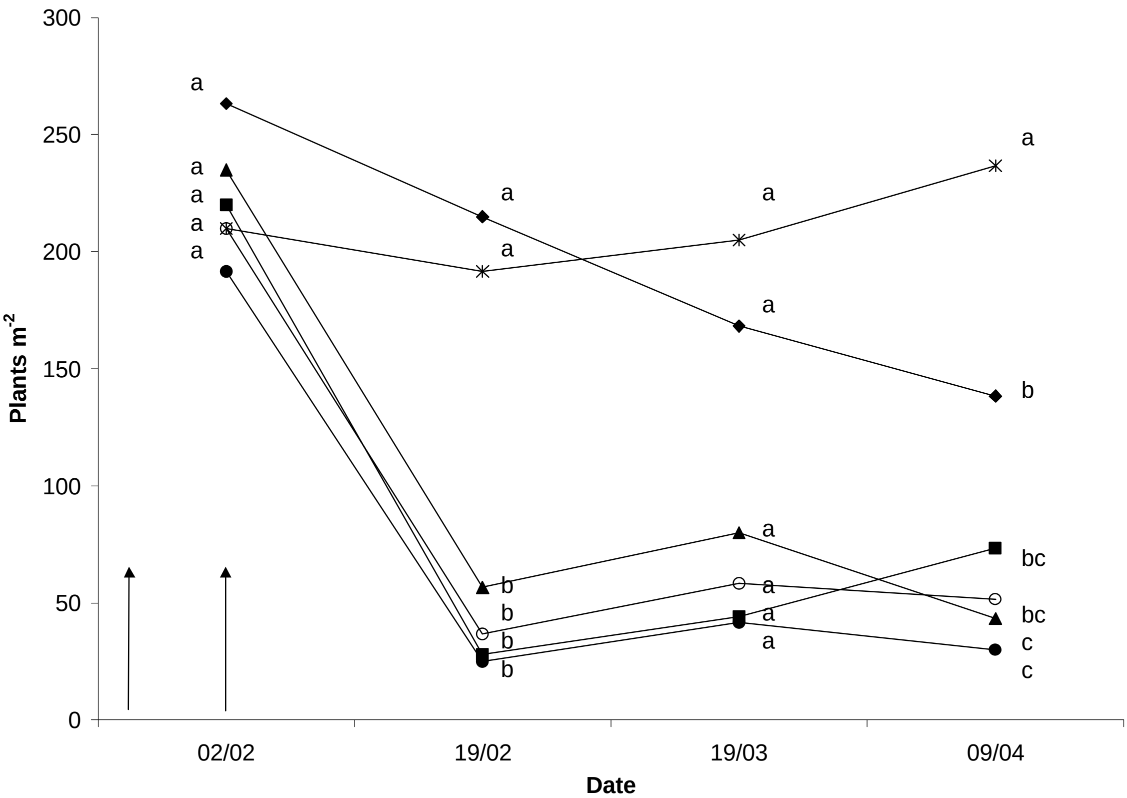

Figure 7.18. a. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Nalec in 2000-01. The arrows indicate the harrowing moments. ? Untreated, * pre-emergence, ? post-emergence at 2 km h^{-1}, ? post-emergence at 4 km h^{-1}, ¦ post-emergence at 6 km h^{-1}, ? post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.01.

The soil was dry at **post-emergence** harrowing. Initial *P. rhoeas* plant number at this time was quite irregular ranging from 70 to 250 plants m^{-2}, even if these differences were not statistically different if the treatments were separed. (Figures 7.18. a, b).

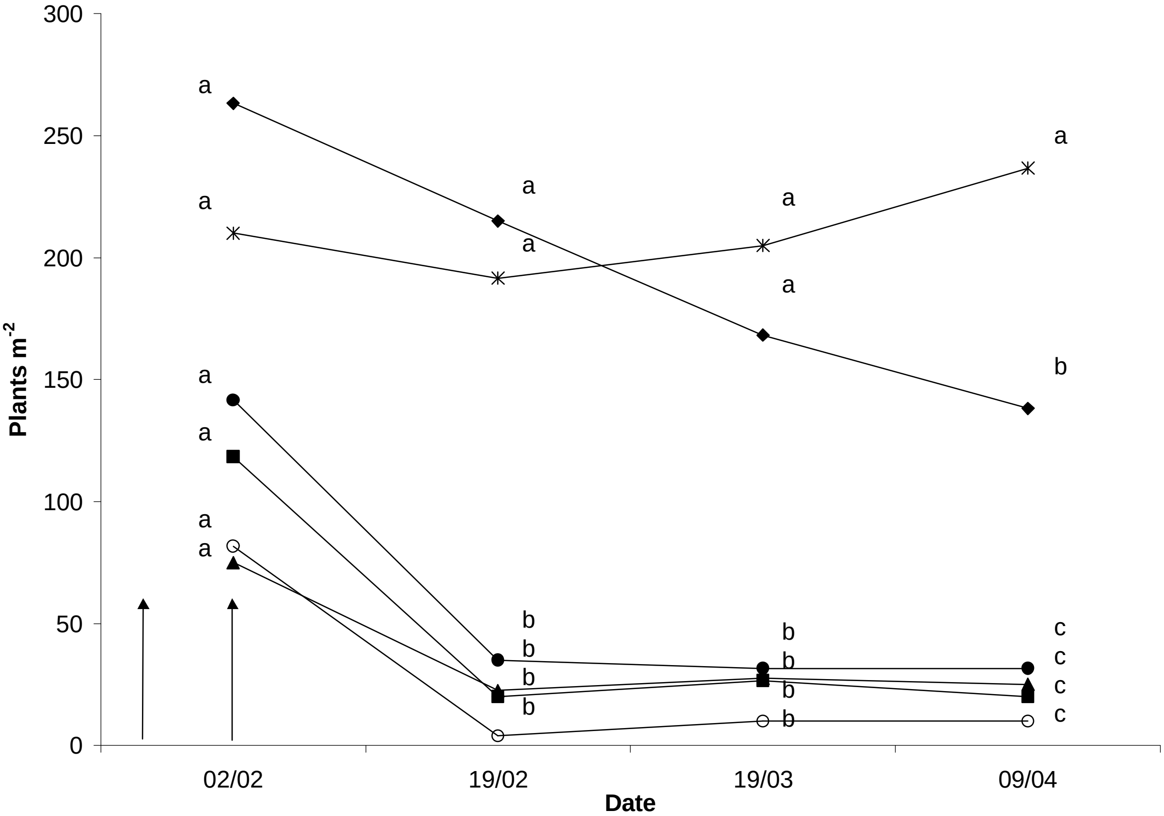

Figure 7.18. b. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Nalec in 2000-01. The arrows indicate the harrowing moments. ? Untreated, * pre-emergence, ? pre- and post-emergence at 2 km h^{-1}, ? pre- and post-emergence at 4 km h^{-1}, ¦ pre- and post-emergence at 6 km h^{-1}, ? pre- and post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at $P<0.01$.

Statistically different initial densities, however, were detected when all the treatments were compared (Figure 7.18. c). The post-emergence harrowing strongly reduced *P. rhoeas* plant number and statistically significant differences occurred until the end of the cropping season even if the combination of plant recover and mortality in the untreated plots led to a reduction of these differences (Figure 7.18. a).

Analysing plant number evolution in time, for all speed treatments plant density before harrowing was statistically lower than at the rest of assessments ($P<0.01$). Speed increase tended to lead to bigger plant number reduction. Efficacy decreased in time, sot that efficacy 66 days after treatment ranged between 37 and 70% (Table 7.6.). As no new germination was observed this decrease was probably mainly due to plant recover.

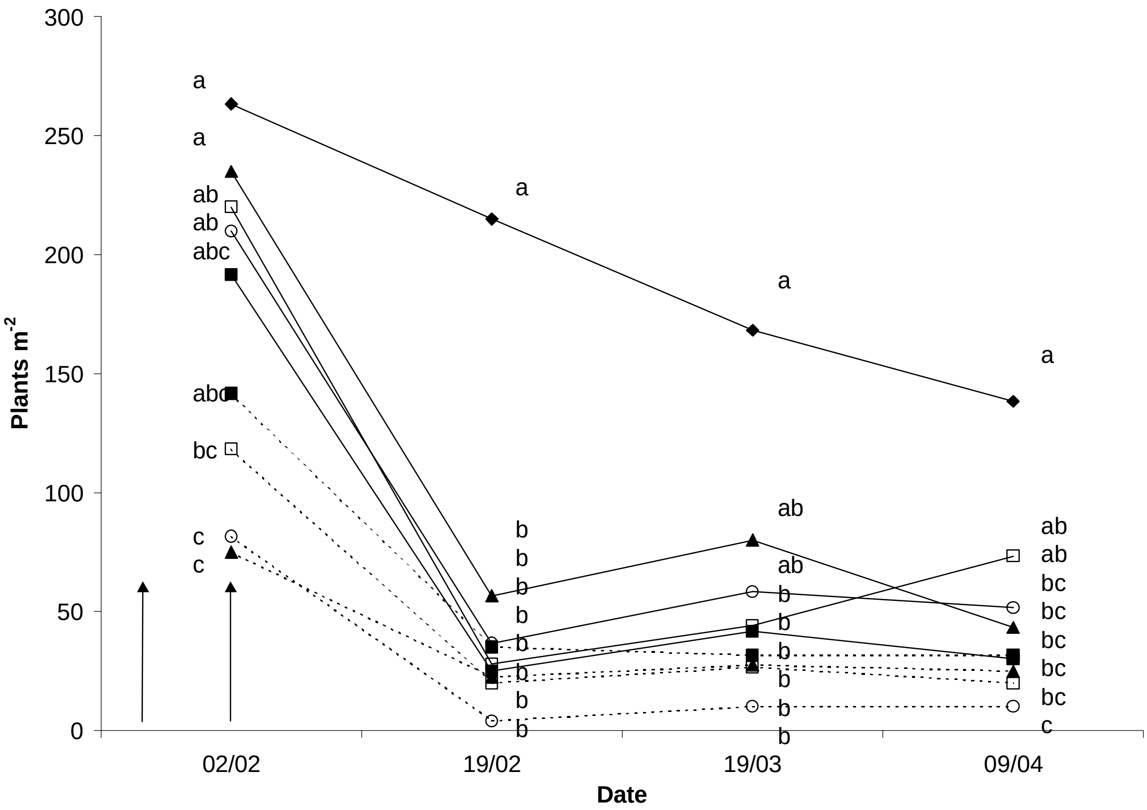

Figure 7.18. c. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Nalec in 2000-01. The arrows indicate the harrowing moments. ? Untreated, --¦ -- pre- and post-emergence at 2 km h^{-1}, --? -- pre- and post-emergence at 4 km h^{-1}, --? -- pre- and post-emergence at 6 km h^{-1}, --? --pre- and post-emergence at 8 km h^{-1} ¦ post-emergence at 2 km h^{-1}, ? post-emergence at 4 km h^{-1}, ? post-emergence at 6 km h^{-1}, ? post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.05.

Different initial plant density was found between plots harrowed **in pre-emergence and in post-emergence** with plots harrowed in post-emergence alone (Figure 7.18. c) (P<0.05). A slight control effect seemed, thus, to be achieved with pre-emergence harrowing in this location. Plant density evolution in time was non-significant for the plot harrowed two times in contrast with the clear decline in the plots harrowed in post-emergence only. In the plots harrowed two times, 6 and 8 km h^{-1} were the most effective treatments soon after harrowing and also at the end of the cycle (Table 7.6.). As in most of the cases observed in this work, also in this treatments efficacy decreased in time, probably mainly due to plant recovery and mortality in the untreated plots.

Table 7.6.: Evolution of control efficacy (%) of *Papaver rhoeas* in the trial conducted in Nalec in 2000-01. Efficacy was calculated taking into account the evolution of plant number in the untreated control plots. Own control plots were maintained for the rolled plots. DAT = days after treatment.

Treatment	Speed ($km\ h^{-1}$)	Efficacy		
		17 DAT	**45 DAT**	**66 DAT**
Pre- and post-emergence	2	69.7	65.0	57.4
	4	63.3	42.6	36.5
	6	79.3	64.7	67.8
	8	94.0	80.8	76.7
Roll, pre- and post-emergence	2	85.0	82.0	85.8
	4	67.6	67.9	80.6
	6	80.4	78.9	77.2
	8	79.6	61.9	79.7
Post-emergence	2	84.0	66.0	70.2
	4	70.5	46.7	64.9
	6	84.4	68.7	36.5
	8	78.6	56.5	53.2

Similar results were obtained in the rolled plots harrowed in post-emergence (Figure 7.18. d). The initial plant density was quite inhomogeneous also even if no statistically significant differences occurred. The post-emergence treatment was effective and *P. rhoeas* plant density was smaller compared to the untreated plots and to the plots harrowed in pre-emergence, only ($P<0.05$). These decreases, however, were only significant in time for the plots harrowed at 6 $km\ h^{-1}$, as observed also for the non-rolled plots.

Thus, probably a slight reduction in *P. rhoeas* density was achieved with pre-emergence harrowing. Compared to plant evolution in the untreated non-rolled plots, plant number was more stable and no clear plant mortality occurred. A non-significant increase was observed at the end of March. Due to this, efficacy was more stable in time (Table 7.6.).

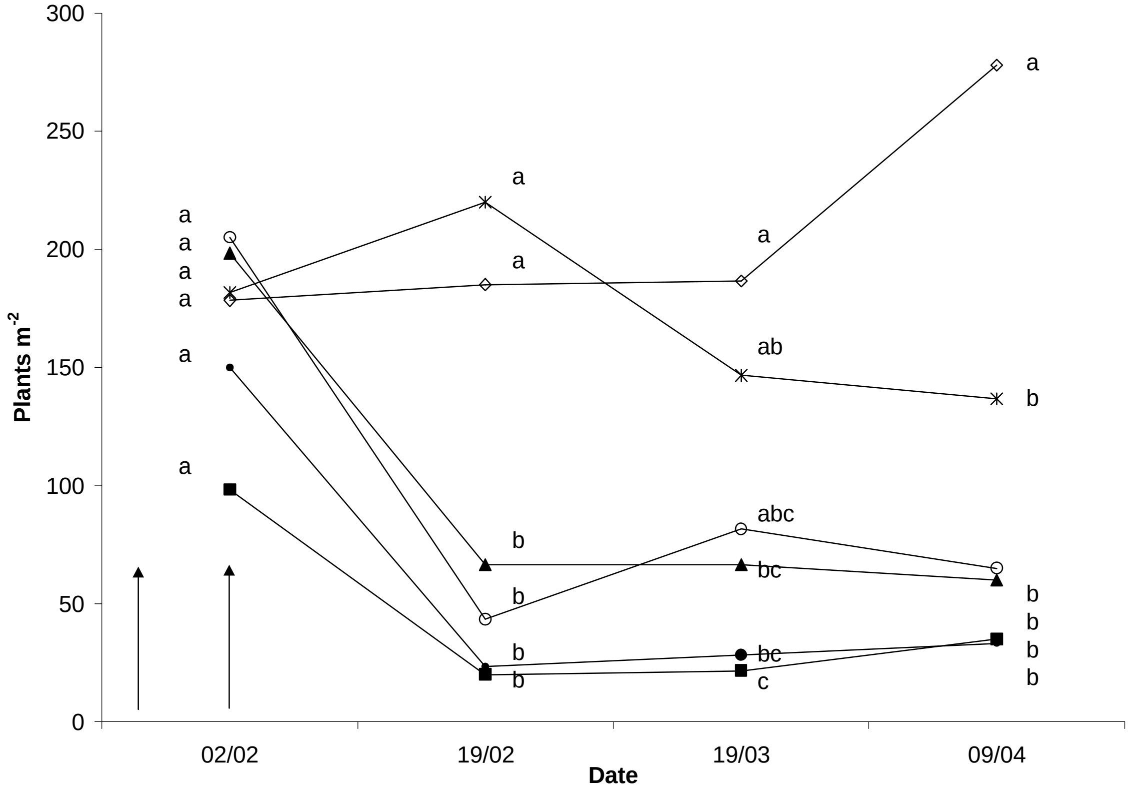

Figure 7.18. d. *Papaver rhoeas* plant number evolution in time in the field trial conducted in Nalec in 2000-01. The arrows indicate the harrowing moments. ? Roll and untreated, * roll and pre-emergence, ? roll and pre- and post-emergence at 2 km h^{-1}, ? roll and pre- and post-emergence at 4 km h^{-1}, ? roll and pre- and post-emergence at 6 km h^{-1}, ? roll and pre- and post-emergence at 8 km h^{-1}. Different letters correspond to statistically significant differences at P<0.05.

Baldomar field 1 in 1998-99, 1999-00 and 2000-01

A single post-emergence harrowing was conducted in this case. Weed density prior to harrowing was low in 1998-99 compared to 1999-00 and 2000-01. The average density was 28 ± 12.5, 170 ± 38.5 and 158 ± 54.0 plants m^{-2} in the respective cropping seasons.

Results on the harrowing control efficacy as well as of the natural plant mortality in the control plots are shown in Table 7.7.

Table 7.7.: Evolution of *Papaver rhoeas* efficacy in field Baldomar 1 after a single post-emergence harrowing during the cropping seasons 1998-99, 1999-00 and 2000-01.

Cropping season	Days after harrowing	Natural mortality (control plots)	Efficacy (%)
1998-99	36	16.6	43.7
1999-00	12	8.7	91.3
	51	72.0	57.1
2000-01	23	-17.0	62.8
	45	40.0	12.3

As observed in several other experiments, initial high efficacy decreased in time. Despite the high initial density in 1999-00 still 57% reduction was observed. These results suggest that initial plant density was not the key factor for control as in 2000-01 much lower efficacy was obtained with a similar initial density. Probably the climatic conditions affected the control much more. In 1999-00 climatic conditions were very dry increasing the harrowing control effect. In 2000-01 the very moist conditions obliged to conduct the harrowing later than convenient and big plants were not well controlled, re-growing after treatment.

A single harrowing treatment in a same field and on the same weed species can, thus, lead to different situations. The most important factors are probably the moisture conditions of the soil, allowing a better or worse plant recovery, the weed emergence timing as well as the plant size at the harrowing time.

General discussion

Even if not reflected in high efficacy values, *P. rhoeas* populations were reduced down to acceptable levels in several trials by post-emergence harrowing. In the following field trials, the *P. rhoeas* densities were below 50 plants m^{-2}: go-and-back pass in Nalec 1998-99, early post-emergence and early + late post-emergence in Nalec 1999-00, early, late and early + late post-emergence harrowing in Torrelameu 1999-00, several post-emergence treatments in Baldomar 2000-01 and some post-emergence treatments in Nalec 2000-01. 50 plants m^{-2} represent an important achievement compared to the lack of control obtained with the herbicides, the populations were resistant to.

Thus, a single post-emergence treatment was enough in some cases, as found also by Pardo *et al.* (2001) in a cropping season with low rainfall in a field containing a mixture of dicotyledoneous weeds in Zaragoza (North-eastern Spain). The same authors observed less damage and higher yield for a single harrowing compared to repeated treatments. Opposite, no crop damage was observed in the present experiments when harrowing was conducted two times over the cropping season.

The high variability of *P. rhoeas* density was an additional difficulty for assessment. This problem was also high because big plots are needed in order to have a regular harrowing effect. Solutions to this problem are keeping fixed counting places and doing several measures in each plot.

The sufficient control observed in the present experiments and in the trials described by Pardo *et al.* (2001) are consistent with the observations of Rasmussen & Svenningson (1995). These authors stated that post-emergence harrowing could lead to high degrees of weed control by post-emergence harrowing alone repeated as often as necessary without including pre-emergence nor selective harrowing. These authors found that the first pass was more effective than the second and the third was more effective than the third, etc. thus, the **number of treatments** has to be decided in each case by finding a balance between weed control and yield decrease.

The needed **intensity** of the treatment will also depend on the field. In the present experiments, two-times harrowing increased the plant density in one occasion out of three (Nalec 1998-99). Additionally, no crop damage was observed.

The climatic conditions after the harrowing should be taken into account for discussion. Opposite to the results of Jones & Blair (1996) in greenhouse trials it was observed in the present experiments that the moisture content of the soil after harrowing was important for *P. rhoeas* efficacy. In the present experiments it was observed that in a **dry** year, the new anchorage of the moved weed plants was impeded and efficacy on *P. rhoeas* could increase as it clearly occurred in the experiment conducted in Torrelameu 1999-00. In these cases of lack of rainfall a herbicide application could be non-economic and a sufficient weed control might be achieved by harrowing alone.

Jones & Blair (1996) simulated harrowing effects in pots and left some of them unwatered after treatment observing no important differences towards the watered pots. These different results compared to the present experiments can be due to the lack of competition and to the shorter duration of the pot experiments. In another simulation carried out by Kurstjens & Kropff (2001) on other weed species more mortality was obtained in pots kept in dry conditions compared to pots with moist soil in *Lolium perenne* out of three tested species. The consequence of the climatic conditions after harrowing seems to be, thus, dependent on the weed species.

A very dry soil surface can be very hard demanding a strong harrow position. As pointed out earlier, especially in these situations, nevertheless, efficacy can be very high due to the susceptibility of *P. rhoeas*.

If **rainfall or humid conditions** followed the harrowing, efficacy could be very low at the beginning (as in Baldomar and in Sanaüja 2000-01) and low since the end. In the experiments conducted in Sanaüja 2000-01, bigger crop competition caused by the moisture increased this initially low efficacy at the end of the cropping cycle. In other cases, moisture could also stimulate new germination. This was clearly observed in the experiment conducted in Torrelameu in 1998-99 and in Baldomar 2 in 2000-01. In other trials, in which no new germination was observed, efficacy also often decreased some weeks after the treatment probably due to recovery of half-buried plants. This was observed in several field trials: single pass in Nalec 1998-99, early post-emergence in Nalec 1999-00, early post-emergence in Torrelameu 1999-00 and to a smaller extent in several post-emergence treatments in Nalec 2000-01.

Additionally, soil should not be too moist in order to avoid wheel tracks and damaging the crop.

Plant **density** was not observed to be an important factor on weed harrowing effect. High efficacy was achieved with low or with high densities and low effect was also observed in both situations. Natural weed mortality was very high in some cases, so that at the end of the cropping cycle the *P. rhoeas* density was very similar to the one resulting from a harrowing treatment considered effective. The difference is that when the natural mortality was the cause of plant number decrease, these lower densities were achieved at the end of the cycle, whilst the crop suffered less weed competition during a longer period of time if harrowing was the responsible of the plant number decrease.
Due to this mortality, which affected also the untreated plots, efficacy decreased in time in most of the trials.

There is an additional unpredictable difficulty linked to the biology of *P. rhoeas*. In the present area, germination normally starts in September, reaching its maximum in November but can continue until March and even until April in some cases. Early harrowing can, thus, in occasions promote germination forcing to conduct a second pass. These differences can occur even in the same location between years, so that different strategies might be necessary in different years. In a dry year (as in the Torrelameu 1998-99 experiment) even a late post-emergence harrowing can be sufficient. In a moist year it would be probably better to harrow as soon as possible in order to allow a later second harrowing in case plants recover or new plants emerge. In addition, by eliminating the first emerging weeds, plant development would be delayed and competition reduced.

The **pre-emergence** harrowing effect was difficult to evaluate due to lack of *P. rhoeas* emergence homogeneity. In both fields only slight differences were found. Results of experiments conducted in Germany by Koch (1964b), however, describe reductions of 30% for *P. rhoeas*, showing that reductions in this species can at least be expected. Probably the efficacy is strongly related to climatic factors, which were different in Germany than in Spain. In fact, the same author states that probably this "blind" harrowing is the harrowing process, which is most dependent on climatic factors, soil type, timing and type of weeds (Koch, 1964a).

Pre-emergence harrowing is a risky decision to take as it is difficult to predict its effect. Probably it is necessary that warm and moist weather follows sowing previous to harrowing, in order to stimulate *P. rhoeas* germination.

P. rhoeas **plant size** had an important relationship to the harrowing effect. This could be observed in the Nalec 1999-00 and in the Torrelameu 1999-00 experiments. As commented by Welsh *et al.* (1997) as soon as the tap root started to grow in thickness, harrowing was not aggressive enough any more and *P. rhoeas* plants survived easier. So, the correct timing from the weed point of view is to wait that most of the *P. rhoeas* plants had germinated (between January and February) but without allowing a big weed plant growth, which means in the local conditions since February. It is, thus, difficult to predict when maximum population establishment has occurred. When the root was still small, *P. rhoeas* plants died as soon as this root was pulled off the soil. Harrowing should thus be conducted later in winter than in Britain (Welsh *et al.*, 1997) and harrowing is not worth to be repeated in spring as recommended for Britain due to bigger plant development in Spanish conditions.

Increasing **speed** caused an increase in efficacy in one location out of three, only. In this case (Sanaüja 2000-01) the increases in efficacy were not significant for speed higher than 4 km h^{-1}. This result is consistent with the data of Rydberg (1994) who found only slight increases in efficacy with speed higher than 5 km h^{-1}. In the other two locations, no clear relationship between speed and efficacy was found. This irregularity in the results is consistent with other experiments, as described previously. Also Rasmussen (1990) found it difficult to establish a relationship between forward speed and weed control.

No important **crop soil cover** was visually found in any of the field trials even if the soil was dry in many cases, so that plants could easily be covered by loose soil. Probably, the main reason is that the cereal was in most of the cases in tillering stage, coincident with the correct stadium for mechanical weed control regarding *P. rhoeas* germination periods and plant size. In this stage, crop plants are not any more so susceptible to soil cover. Rasmussen (1990) stated that serious crop cover accompanies early harrowing, while in late selective harrowing crop cover is not significant (Rasmussen & Svenningson, 1995). The present experiments were conducted between these two moments. Another reason might be that sunshine is normally not a limiting factor in the present conditions so that plants, which are covered by soil, might recover quite fast due to new growth.

No **crop damage** was observed in the fields, where final crop biomass was assessed. As analyses were conducted at the end of the cropping cycle, plant could have recovered from a possible damage, although no visible important damage was observed at the harrowing either. No biomass evaluations were conducted in the Nalec 2000-01 field due to a very irregular crop establishment throughout the field. In Baldomar 2000-01 and in Sanaüja 2000-01 a late frost at the end of April damaged crop and *P. rhoeas* plants in a very severe way killing even several *P. rhoeas* plants. The influence of these factors on the biomass was not possible to be separated from the harrowing effect. Moreover, these variability factors can not be controlled neither sampling with many repetitions, so that biomass assessment were rejected.

Conclusions

After discussing the results of the present experiments in the described conditions of North-eastern Spain it can be concluded that:

The effect of pre-emergence harrowing on *P. rhoeas* was very low or inappreciable.

Post-emergence harrowing of *P. rhoeas* populations led to important plant density reductions so that harrowing was in some cases a sufficient control method.

Efficacy was found to be mainly dependent on the weed size and on the weather conditions around the treatment dates.

Better effects were observed in early weed growth stages. On the other hand, early harrowing stimulated new germination, forcing to repeat the treatment. The decision on the exact timing and intensity of the treatment as well as the possible need of repetition should thus be taken separately in each case.

The harrowing effect was generally higher when conducted in dry conditions. In one occasion, however, moist conditions stimulated crop growth enhancing competition against the weeds increasing the initial very low efficacy.

Increasing speed tended to reduce weed density in one experiment out of three. Speed over 4 km h^{-1}, however, did not result in significant differences.

Further work could focus on conducting post-emergence harrowing earlier (November or December) when *P. rhoeas* was in cotyledon stage or 4-5 leaves, only. The aim would be to find out how early the treatments could be conducted harming the crop as little as possible. Biomass assessments soon after harrowing and crop yield could be a measure for this damage. There is also a need in repeating pre-emergence harrowing experiments in order to observe if a *P. rhoeas* density reduction effect can be expected in the present conditions.

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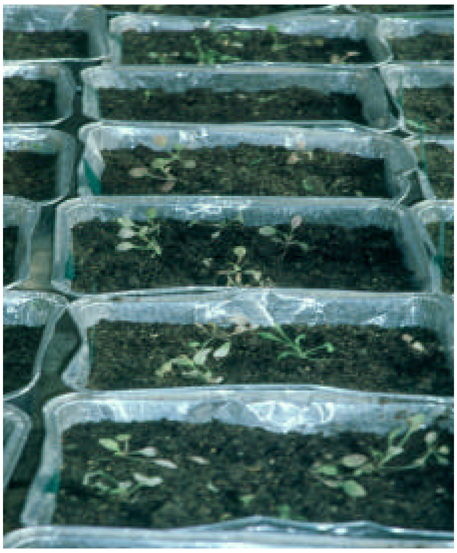




Chapter 8

Chemical control of herbicide resistant *Papaver rhoeas* L. to tribenuron-methyl and to 2.4-D in North-eastern Spain (Catalonia)

Summary

Facing the herbicide resistance, fourteen field trials were established in North-eastern Spain during the cropping seasons 1997-98 until 2000-01 in order to test the efficacy of some herbicides on herbicide resistant *Papaver rhoeas* L. populations.

The chemical solution was considered to be a first step in the integrated weed management, though other techniques should be included to control and to prevent herbicide resistance. Populations resistant to 2.4-D or resistant to 2.4-D and tribenuron-methyl were chosen.

Within the group of pre-emergence herbicides high and regular efficacy was obtained within the trials using pendimethaline, trifluraline + chlortoluron or trifluraline + linuron.

In early post-emergence no product had a very constant activity throughout the years and in the tested fields. The mixtures including diflufenican as well as the mixture tribenuron-methyl + metribuzine were effective in some cases, only.

In late post-emergence mixtures containing ioxinil and especially bromoxinil were generally very effective. Better results, however, would be expected if these products were sprayed earlier. The mixture florasulam + 2.4-D was effective in most of the cases, even if its actuation was slow. Dicamba was not effective in any field, suggesting cross-resistance to 2.4-D. Further research including greenhouse trials are needed to confirm the results and to adjust the correct doses to the optimal application moment. In some fields slight up to moderate phytotoxicity was observed, which disappeared afterwards.

In one field only, some crop plant death was observed using trifluraline + chlortoluron in two cropping seasons and for terbutrine + chlortoluron + triasulfuron in the same location in one season, only.

Keywords: herbicide resistance, *Papaver rhoeas* L., tribenuron-methyl, 2.4-D, chemical weed control, integrated weed control.

Introduction

Referring to the correct weed management strategies, it is commonly accepted that integrated weed management is the only way to overcome the problems, which have evolved lately, as the environmental damage, herbicide resistance, the abundance of new weed species difficult to control, etc. Nevertheless, different opinions towards how to conduct integrated weed management are found in the literature. Liebmann & Gallandt, (1997), for example, think that weed plants should be imposed to multiple and temporary variable stresses, mainly based on biological knowledge of the species to be controlled. These authors do not exclude a direct control including the use of herbicides, but they state that a shift from chemical technologies towards ecologically based strategies is now desirable.

Also Regehr (1993) describes that in creative, well-designed weed management systems herbicides should not play a dominating but a complementary role. The problem is, thus, that the systems often relies completely on herbicides, so that including other techniques conduces to important changes in the conventional farming systems. In the region, where the present study has been conducted, barley is grown as a monocrop in a semi-arid climate without irrigation. The main limiting factor is the rainfall, which is irregular in time and in quantity and leads to yields around 3000 to 4000 kg ha^{-1}. Due to the low grain prices farmers invest as little as possible. Normal practices are minimum tillage after harvest (not always) and prior to sowing, fertilisation at sowing and a second time after winter and one or two herbicide applications during the cropping cycle depending on the weed infestation.

Problems in controlling *Papaver rhoeas* L. in winter cereal towards 2.4-D have been quoted since 1992 in Spain (Taberner *et al.*, 1992). In 1998 the first case of herbicide resistant *P. rhoeas* towards 2.4-D and tribenuron-methyl was quoted (Claude *et al.*, 1998) and the affected surface is growing since then. The farming systems, however, have not evolved and most of the farmer's age is, moreover, high. It is, thus, difficult to aim introducing other cropping practices as ploughing or to introduce alternative weed control practices, as it is weed harrowing. Anyway, once the farmers face the resistance problem, following the Herbicide Resistance Action Committee (HRAC) simply changing herbicides is not enough to overcome resistance in the mid to long term and that a integrated system needs to be developed (HRAC, 2001). The smallest changes would be use of herbicides from different chemical families. Crop rotation and cultural techniques including occasional deep ploughing, delaying sowing date, etc. would be other recommended control measures (HRAC, 2001).

The present study is part of a broader project, which evaluates the efficacy of other control strategies such as ploughing and mechanical control with a tine harrow. The first step to control and to prevent herbicide resistance in *P. rhoeas* was considered to be finding other herbicides to be introduced in the weed control programs. These effective herbicides should be used in an alternated way in order to slow down possible new herbicide resistance appearances. Herbicides belonging to different groups of mode of action, following the HRAC herbicide classification (HRAC, 2001) should be used, if possible.

The aim of this study was to find herbicides controlling tribenuron-methyl and 2.4-D resistant *P. rhoeas* populations in winter cereal. Trials conducted in different cropping seasons and in several fields were supposed to give a broad spectrum on the efficacy of these products.

Material and Methods

A total amount of fourteen field trials were conducted during the cropping seasons 1997-98, 1998-99, 1999-00 and 2000-01 in winter cereal crops. The field selection was based on a high and uniform *P. rhoeas* infestation in different areas of Catalonia. Most of the fields had control problems with one or both herbicides within 2.4-D and tribenuron-methyl. In some of the fields, herbicide resistance was already confirmed before conducting the trials following the two seed quick-tests described by Cirujeda *et al.*, (in press) as it occurred in the Baldomar site since 1998-99, in Torrelameu 1999-00 and in Sanahüja 2000-01. The spraying history of the fields was similar: 2.4-D had been used for decades and was in many cases no more active at the low doses used before. Tribenuron-methyl appeared in the Spanish market in 1986, replacing 2.4-D being used in many cases without interruption during several years. The location characteristics of the field trials are described in Table 8.1.

Table 8.1.: Description of the location characteristics of the field trials of chemical control of herbicide resistant *Papaver rhoeas*. Locations with different number refer to different fields in the same village. W b = Winter barley; W w = Winter wheat.

Cropping season	Location	Region	Soil type	Crop	Resistance to the herbicide(s)
1997-98	Baldomar 1	Noguera	Loamy sand	W b	Tribenuron-methyl, 2.4-D
1997-98	Savallà del Comptat	Conca de Barberà	Silt loam	W w	Tribenuron-methyl, 2.4-D
1998-99	Torrelameu	Segrià	Loam	W b	Tribenuron-methyl, 2.4-D
1998-99	Baldomar 2	Noguera	Loamy sand	W b	Tribenuron-methyl, 2.4-D
1998-99	Nalec 1	Urgell	Silt loam	W w	Tribenuron-methyl, 2.4-D
1999-00	Baldomar 2	Noguera	Loamy sand	W b	Tribenuron-methyl, 2.4-D
1999-00	Torrelameu	Segrià	Loam	W b	Tribenuron-methyl, 2.4-D
1999-00	Nalec 2	Urgell	Silt loam	W w	2.4-D
1999-00	Bellprat	Anoia	Loam	W b	2.4-D
2000-01	Baldomar 2	Noguera	Loamy sand	W b	Tribenuron-methyl, 2.4-D
2000-01	Nalec 2	Urgell	Silt loam	W b	2.4-D
2000-01	Sta. Coloma de Queralt	Conca de Barberà	Loam	W b	Tribenuron-methyl, 2.4-D
2000-01	Sanaüja	Segarra	Silt loam	W b	Tribenuron-methyl, 2.4-D
2000-01	Algerri	Noguera	Silt loam	W b	Tribenuron-methyl, 2.4-D

A randomised block design with three replicates was used in all the trials. Each plot measured 2 m x 5 m. Herbicide application was made with a constant pressure sprayer at 2.5 atm pressure using a total liquid amount of 300 L ha^{-1}. Different pre-emergence, early post-emergence and late post-emergence herbicides were tested. All the products were commercial herbicides authorised for broadleaf control in winter cereal in Spain and were applied in the recommended doses following the recommendations of the Plant Protection Service of Catalunya (Taberner *et al.*, 2000). Some of the pre-emergence herbicides were not commonly used in the study area due to their high costs and fear towards phytotoxicity (e.g.trifluraline + linuron, pendimethaline). Also the use of some of the late post-emergence products was not wildly spread because of possible phytotoxicity on the crops (e.g. ioxinil + bromoxinil + MCPP).

Table 8.2. lists the tested herbicides and the used doses. In other cases, herbicides, which are not very active on susceptible *P. rhoeas*, were tested on the resistant populations, as some farmers, applicators and distributors commented that certain increase in efficacy had been observed in some resistant fields.

Some other additional products were applied in the field trials conducted in 1997-98. In early post-emergence Tordon 101 (24% 2.4-D + 6% picloram) was sprayed at 0.072 + 0.018 L a.i. ha^{-1}, Duplosan super (31% diclorprop, 13% mecoprop and 16% MCPA) was sprayed at 0.775 + 0.325 + 1.075 L a.i. ha^{-1}, Dicuran extra (7% terbutrine + 43% chlortoluron) was sprayed at 0.175 + 1.075 L a.i. ha^{-1}; the mixture Yard + Granstar was applied at 0.500 + 0.050 L a.i. ha^{-1} MCPA + diflufenican and 0.0113 kg a.i. ha^{-1}; Procer M 40 contains 40% MCPA and was sprayed mixed with Certrol H at 0.2 L a.i. ha^{-1}.

Higher 2.4-D rates were tested in late post-emergence in Savallà del Comptat in 1997-98 (1.8 L a.i. ha^{-1}) and in Nalec (2) in 2000-01 (0.9 L a.i. ha^{-1}). The efficacy of these other herbicides are shown in the Annexes.

Table 8.2.: Sprayed herbicides in the field trials of resistant *Papaver rhoeas* expressed in g ha^{-1} or L ha^{-1}. Obe: octanic and butilglicolic ester. Be: butilic ester. Ie: isooctilic ester. Oe: octanic ester. The HRAC classification group is based on the different modes of action of the herbicides.

Commercial Product	Composition	a.i. in kg ha^{-1} or L ha^{-1}	HRAC classification group
Pre-emergence			
Araflurex + Oracle	48% trifluraline + 50% chlortoluron	0.720 + 2.500	K1 + C2
Gadisan	24% trifluraline + 12% linuron	0.720 + 0.360	K1 + C2
Glean	75% chlorsulfuron	0.015	B
Rokenil 50	50% isoxaben	0.125	L
Stomp	33% pendimethaline	1.650	K1
Tricuran 64	10.75% terbutrine + 53% chlortoluron + 0.25% triasulfuron	0.188 + 0.928 + 0.004	C1 + C2 + B
Early post-emergence			
Clorturex Ter	43% chlortoluron + 7% terbutrine	1.075 + 0.175	C2 + C1
Garlon + Oracle	48% triclopir + 50% chlortoluron	0.480 + 1.250	O + C2
Granstar + surfactant	75% tribenuron-methyl	0.015	B
Granstar + Lexone	75% tribenuron-methyl + 70% metribuzine	0.015 + 0.070	B + C1
IP 50 + Bladex	50% isoproturon + 50 % cianazine	1.250 + 0.250	C2 + C1
Javelo	45% isoproturon + 4.2 % diflufenican	1.350 + 0.126	C2 + F1
Logran Extra 60	59.4% terbutrine + 0.6% triasulfuron	0.300 + 0.003	C1 + B
Sencor IP	50% isoproturon + 2.8 % metribuzine	1.375 + 0.077	C2 + C1
Yard	25% MCPA ie + 2.5% diflufenican	0.500 + 0.050 (0.375 + 0.038 in 1998-99)	O + F1
Late post-emergence			
Asitel	12% bromoxinil oe + 36% 2.4-D obe	0.180 + 0.540	C3 + O
Banvel D	48% dicamba	0.192	O
CertrolH	36% MCPP be + 12% ioxinil	0.900 + 0.300	O + C3
Esteron	60% 2.4-D ie	0.600	O
Image	12% ioxinil + 12% bromoxinil + 36% MCPP (p)	0.120 + 0.120 + 0.360	C3 + C3 + O
Mustang + surfactant	0.625% florasulam + 30% 2.4-D ie	0.006 + 0.300	B + O
Oxytril	7.5% ioxinil + 7.5% bromoxinil + 37.5% MCPP ie	0.190 + 0.190 + 0.940	C3 + C3 + O
Tralla	12% bromoxinil + 36% MCPP	0.300 + 0.900	O + O

Short practical description of the tested herbicides and herbicide mixtures

Pre-emergence herbicides

Trifluraline + chlortoluron is a not very used mixture in the area but is offered at low prices. Its main defect is the risk of phyotoxicity on the cereals. It contains a member of the chemical family of the triazines and a compound of the urea family.

Trifluraline + linuron is an old and very common mixture in the area useful for grass- and broad-leaved weed control including some species difficult to control as e.g. *Phalaris minor*. Nevertheless, this mixture is not very used in winter cereals in the study area due to its risk of phytotoxicity. This risk is especially high in shallow soils if rainfall and low temperatures occur after treatment. It contains a triazine and a herbicide of the urea family.

The effect of the sulfonylurea **chlorsulfuron** on susceptible *P. rhoeas* is not very high. Its efficacy on resistant *P. rhoeas,* however, is unknown. The product is cheap, has a broad weed control spectrum but shows carry-over risk. It is used in the area to keep the stubble clean from weeds like *Salsola kali*, in order to obtain similar effects as chemical fallow. Sprayed in pre-emergence this product is selective in wheat, only.

Isoxaben is a pre-emergence herbicide of the chemical family of the benzamides authorised but not used in cereals because its activity on some important broad-leaved weeds is very low.

Pendimethaline is a pre-emergence herbicide from the dinitroaniline family positioned mainly for weed control in fruit orchards and in vegetable fields. It is not commonly used in cereals due to its high cost and possible phytotoxicity in shallow soils.

Terbutrine + chlortoluron + triasulfuron substituted the mixture terbutrine + chlortoluron with the aim of improving the broad-leaved weed control. Terbutrine + chlortoluron + triasulfuron is active on grass weeds (*L. rigidum* with a secondary effect on *Avena sp.*) and on some broad-leaved weeds difficult to control (*Veronica sp.* and *Galium aparine*). It contains a triazine, a member of the urea family and a sulfonylurea.

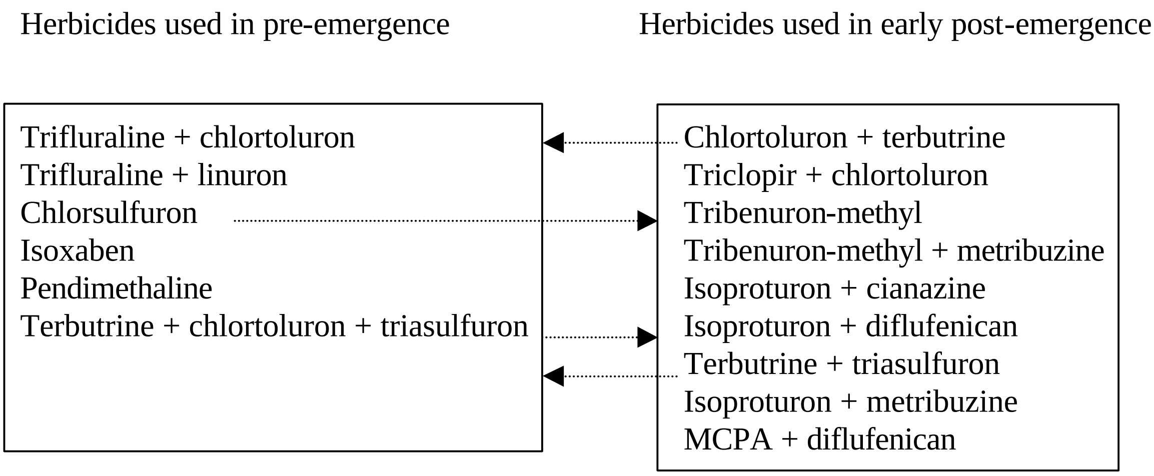


Figure 8.1. Herbicides used for weed control in winter cereals mainly sprayed in pre-emergence or in early post-emergence. The arrows indicate those products, which can also be sprayed in the other shown moment.

Early post-emergence herbicides

Chlortoluron + terbutrine is an interesting mixture of an urea and a triazine for *L. rigidum* control and for a wide range of broad-leaved weeds as *P. rhoeas* and *Veronica sp.*. It is possibly one of the most widespread mixtures in the area. It shows a clear synergism as *P. rhoeas* and *Veronica hederifolia* and *V. persica* are not controlled by any of the two compounds by separate.

Triclopir + chlortoluron is a mixture, which is very useful in the control of bushes and other perennial weeds. Therefor, a high activity on *P. rhoeas* could also be expected. Triclopir belongs to the pyridine carboxylic-acids group (synthetic auxin).

The sulfonylurea **tribenuron-methyl** has been sold in Spain since 1986. The high efficacy, regular effect, low cost (comparable to 2.4-D), low necessary doses, high control on difficult weed species as *G. aparine, Scandix pecten-veneris* and *Hypecoum procumbens*, lack of carry-over problems, lack of volatility and low toxicity risk for the applicator caused the great acceptance of this herbicide. Tribenuron-methyl substituted the use of 2.4-D in many cases, which main disadvantages were volatility and need to spray with higher rates due to the occurrence of herbicide resistance. It is not active against *Veronica hederifolia*.

Tribenuron-methyl + metribuzine is a mixture designed after resistance appearance after observing in some cases that the resistant populations were susceptible to this mixture (sulfonylurea + triazine).

Isoproturon + cianazine is a very known, old and cheap mixture, combining an urea and a triazine. The same synergetic effect is observed than with the mixture chlortoluron + terbutrine. This mixture is also very active on *V. hederifolia* and *V. persica*.

Isoproturon + diflufenican also aims to control both grass and broad-leaved weeds in cereals. It combines an urea with a nicotinalide. It is a new mixture with a similar efficacy profile than chlortoluron + terbutrine, even if the symptoms are different to the ones caused by this other mixture. It should be used in pre-emergence (selective of wheat, only) or in early-post-emergence.

Terbutrine + triasulfuron is a quite new mixture moderately used (triazine + sulfonylurea). Its aim is to control broad-leaved weeds, showing an additional efficacy on *Lolium rigidum.* The sulfonylurea triasulfuron is added to the triazine at low rates in order to avoid carry-over.

Isoproturon + metribuzine is a not very widespread mixture of an urea with a triazine, possible due to a low control of *G. aparine* and to a low selectivity in cereals.

MCPA + diflufenican is a new and not very used mixture in the area designed with the aim of controlling broad-leaved weeds. It combines a phenoxy-carboxylic-acid (synthetic auxin) with a nicotinalide.

Herbicides used in early post-emergence		Herbicides used in late post-emergence
Chlortoluron + terbutrine	◄	Bromoxinil + 2.4-D
Triclopir + chlortoluron		Dicamba
Tribenuron-methyl	◄	MCPP + ioxinil
Tribenuron-methyl + metribuzine		2.4-D
Isoproturon + cianazine	◄	Ioxinil + bromoxinil + MCPP
Isoproturon + diflufenican	◄	Florasulam + 2.4-D
Isoproturon + metribuzine	◄	Bromoxinil + MCPP
MCPA + diflufenican		

Figure 8.2. Herbicides used for weed control in winter cereals mainly sprayed in early or in late post-emergence. The arrows indicate those products, which can also be sprayed in the other shown moment.

Late post-emergence herbicides

As shown in Figure 8.2., many of the herbicides listed in this group could also be sprayed in early post-emergence. In the experiments conducted in 1997-98 and 1998-99 some of them were sprayed in early post-emergence (Annexes). In the experiments conducted in 1999-00 and 2000-01, however, it was aimed to test their efficacy in late post-emergence testing them as a possible chemical solution of failed herbicide treatments in early post-emergence.

Bromoxinil + 2.4-D is a mixture aiming to improve the efficacy of the phenoxy-carboxylic-acid (synthetic auxin) herbicide 2.4-D by adding control speed with the nitrile bromoxinil, especially in cases of weeds difficult to be controlled as it is e.g. *G. aparine* but is not active on *Veronica* sp.. This mixture is not very widespread because the addition of bromoxinil to 2.4-D supposes a notable price increase.

Dicamba is a very old synthetic auxin herbicide (from the benzoic acid chemical family) often mixed with 2.4-D or MCPA (synthetic auxins from the phenoxy-carboxylic acid chemical family) and selective for cereal. It is always been considered one of the herbicides, which can be sprayed very late in the cereal cycle (until late tillering). Its inconvenient is that weed control is not spectacular and the product needs to be sprayed with big water volumes.

MCPP + ioxinil is a mixture devoted to fill the control gaps leaved out by 2.4-D. An important contact action of ioxinil is combined with the intensity of MCPP. (Phenoxy-carboxylic-acid + nitrile). It is also interesting to test this mixture because they are recommended to be mixed with herbicides of the aryloxyphenoxypropanoates family ("fops") and cyclohexanediones family ("dims"). Sulfonylureas and fops and dims have often antagonistic effects.

2.4-D appeared in the 50's and was the first herbicide commonly used. Broad-leaved weeds were very well controlled and low cost made the herbicide widespread. Its wide use caused flora inversion so that new mixtures and herbicides were necessary. This herbicide needs temperature exceeding 15ºC so that this herbicide is normally sprayed in spring, coincident with the tillering stage of the cereal. It belongs to the chemical family of the phenoxy-carboxylic-acids (synthetic acids).

Ioxinil + bromoxinil + MCPP is a very widespread mixture in the area, often mixed with isoproturon. The activity of MCPP + ioxinil is improved by the addition of bromoxinil. (Two compounds of the nitrile chemical family and one of the phenoxy-carboxylic-acids).

The mixture **florasulam + 2.4-D** contains the new ALS-inhibitor florasulam out of the triazolopyrimidine chemical family. In winter cereals this herbicide is especially active on *G. aparine*, *Matricaria* spp., *S. media*, *Polygonum convolvulus* and *P. rhoeas* (Thompson *et al*., 1999).

Bromoxinil + MCPP is another of the mixtures combining a nitrile and a phenoxy-carboxylic-acid, in which the addition of bromoxinil aims to improve the efficacy of MCPP, even if this is related to a cost increase. Due to this price increase it is not often used.

The growth stage of *P. rhoeas* at the application was 3-4 real leaves for the early pre-emergence treatments and complete rosette stadium in active growth conditions for the late post-emergence herbicides. The detailed size is indicated in Table 8.3.. Not all the tested products were applied in all the trials. The pre-emergence products could only be sprayed in fields chosen early enough. The late post-emergence products could not be sprayed in Torrelameu 1999-00 nor in Sanaüja 2000-01. In the first case, drought was so extreme that plants were considered to be unable to absorb the herbicides. In the second case, a very mild and moist winter enhanced growth so much that the crop was too developed when the climatic conditions were appropriate for the application making the placement of the herbicide on the weeds impossible. Weed plant emergence was very mince in Algerri in 2000-01 so that only pre-emergence products were applied. Results of this field trial were not included due to the sparse *P. rhoeas* infestation.

Alive plants were counted in all the plots every fortnight after treatment in order to observe the evolution of the weed plant number. A 0.10 m^2 frame was used three times per plot. At the end of the crop season (flowering stage of *P. rhoeas*) one visual assessment on percentage of weed cover were performed. The aim of this second assessment was to follow the development of the weed infestation until the end of the cropping season especially for the slow-acting herbicides as florasulam + 2.4-D.

Efficacy was calculated following Abbott's formula, so that each plot was referred to the untreated plot of the same block (Ciba-Geigy, 1992).

[% efficacy = (1-*Ta* / *Ca*) 100]
Ta is the infestation in the treated plot after application
Ca is the infestation in the control plot after application

Efficacy was considered to be acceptable if more than 95% of the weeds were controlled. Values of 90-95% were accounted separately. If an important change was observed from the last evaluation based on plant number with the visual assessment conducted at the end of the cropping season, this second value was taken into account (Annexes).

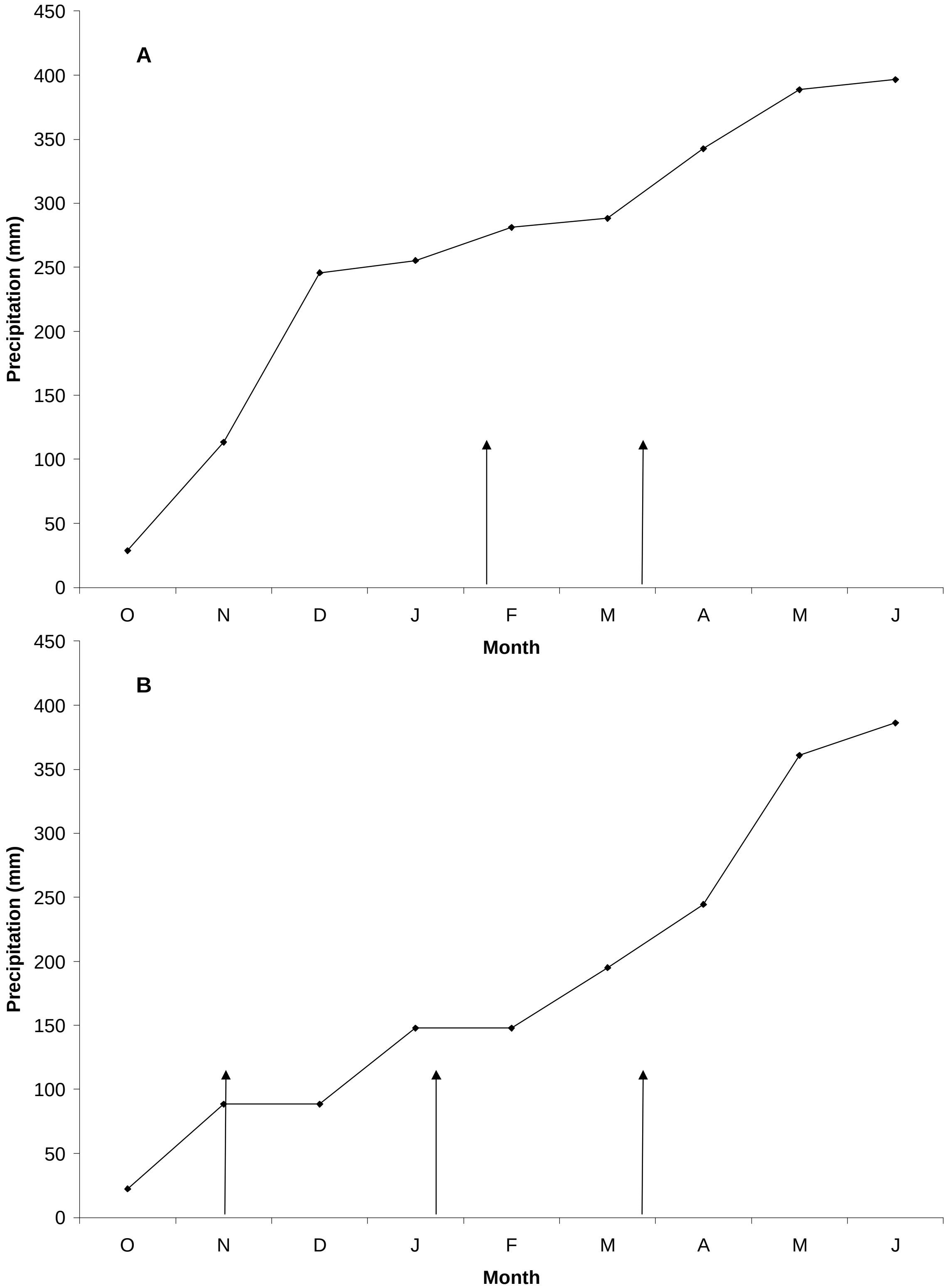
Table 8.3.: Spraying dates of the different herbicide treatments conducted on *Papaver rhoeas* in the tested locations, crop growth stage (CGS) following BBCH scale, weed size, temperature (T) and soil conditions at treatment. PE = Pre-emergence; EPE = Early post-emergence; LPE = Late post-emergence.

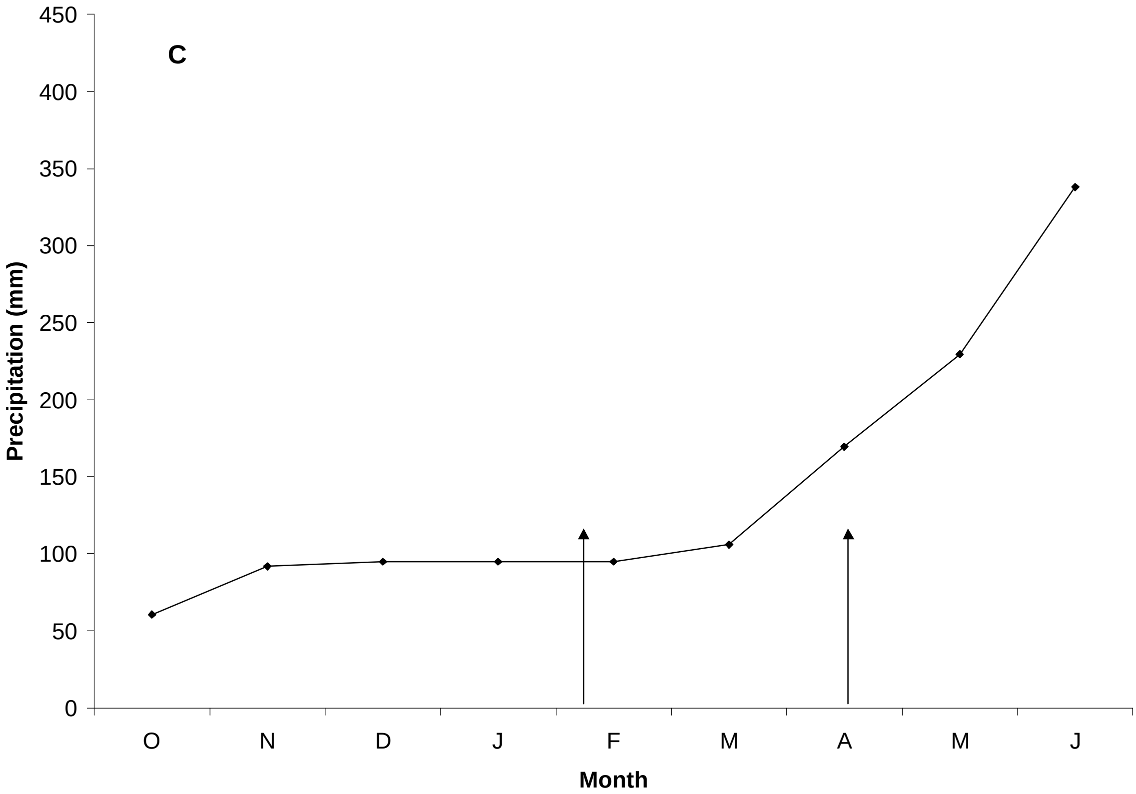
Season	Location	Treatment	Date	CGS	Weed size (cm)	T (ºC)	Soil
1997-98	Baldomar 1	EPE	06/02/98	14-21	2-3	15	Moist
		LPE	24/03/98	24-30	5-10	10	Very dry
1997-98	Savallà del Comptat	EPE	02/04/98	31	5-10	14	Dry
		LPE	02/04/98	31	5-10	14	Dry
1998-99	Torrelameu	PE	16 + 23/11/98	03-05	-	11.3 / 10	Dry
		EPE	19/02/99	22	2-5	12	Good conditions
		LPE	29/03/99	24-30	5-10	15	Drier than before
1998-99	Baldomar 2	PE	16/11/98	03-05	-	13	Good conditions
		EPE	20/01/99	14-21	2-3	10	Good conditions
		LPE	23/03/99	24-30	5-10	14	Good conditions
1998-99	Nalec 1	EPE	25/02/99	23-24	3-5	12	Very dry
		LPE	29/03/99	24-30	5-10	11	Good conditions
1999-00	Baldomar 2	EPE	08/02/00	13-14	0.5-1	14	Very dry
		LPE	17/04/00	23-24	5-10	20	Moist
1999-00	Torrelameu	PE	10 + 23/11/99	03-05	-	15	Good conditions
		EPE	25/01/00	23-30	0.5-1.5	5	Good conditions
1999-00	Bellprat	EPE	24/02/00	23	3.5-6	17	Very dry
		LPE	16/03/00	30	4-10	12.6	A bit less dry
1999-00	Nalec 1	PE	04 + 23/11/99	03-05	-	13	Dry on top, moist underneath
		EPE	29/02/00	14-22	0.7-3	12	Dry
		LPE	19/04/00	24-30	5-10	15	Dry
2000-01	Baldomar 2	PE	15/11/00	03-05	-	11	Moist
		EPE	22/01/00	14-23	1-2.5	14	Good conditions
		LPE	12/03/00	23-24	5-15	16	Good conditions
2000-01	Nalec 2	EPE	19/02/01	13-14	1.5-5	8	Dry
		LPE	19/03/01	23-24	6-10	?	A bit less dry
2000-01	Sta. Coloma de Q.	EPE	26/03/01	22-24	2.5-7	12	Good conditions
		LPE	26/03/01	22-24	2.5-7	12	Good conditions
2000-01	Sanaüja	EPE	23/01/01	21-24	1-5	11	Moist
2000-01	Algerri	PE	12/11/00	03-05	-	15	Dry

Climatic data

The seasons 1997-98 and 2000-01 had a more wet autumn and winter so that some treatments had even to be delayed due to excess of moisture (Figures 8.3. - 8.8.).

In general, the cropping seasons 1998-99 and 1999-00 had a very dry autumn and winter. This is reflected in Figures 8.3. - 8.8., where the accumulated precipitation is shown.





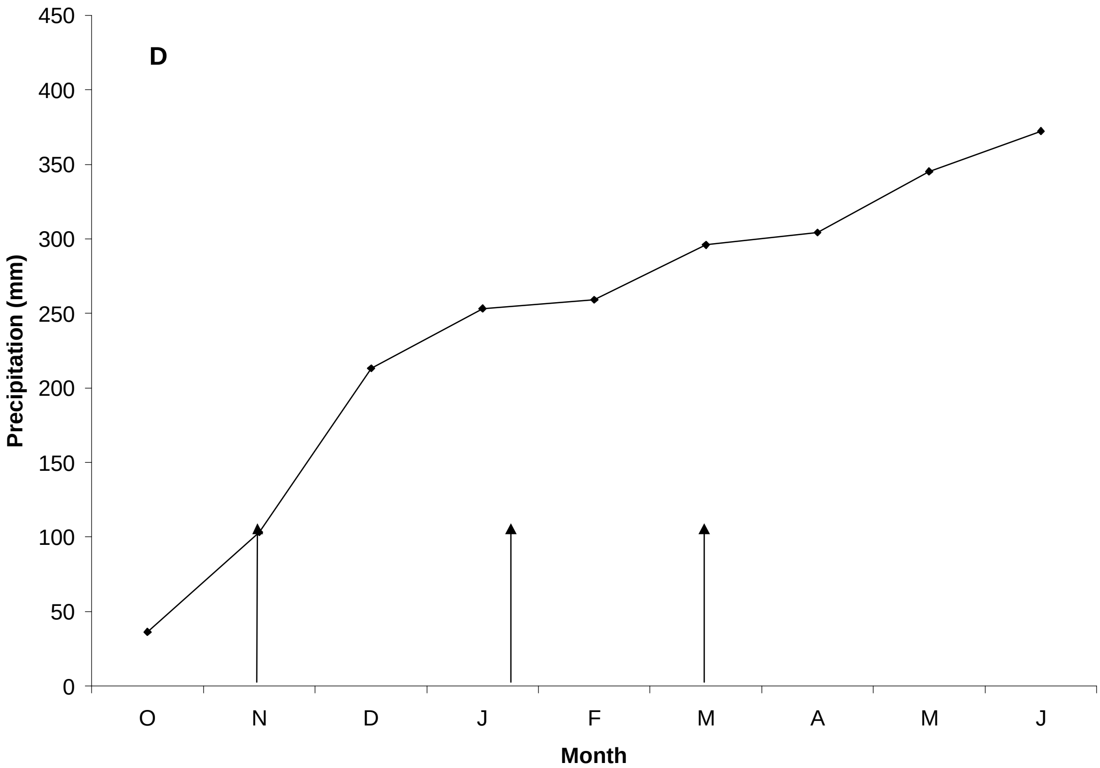
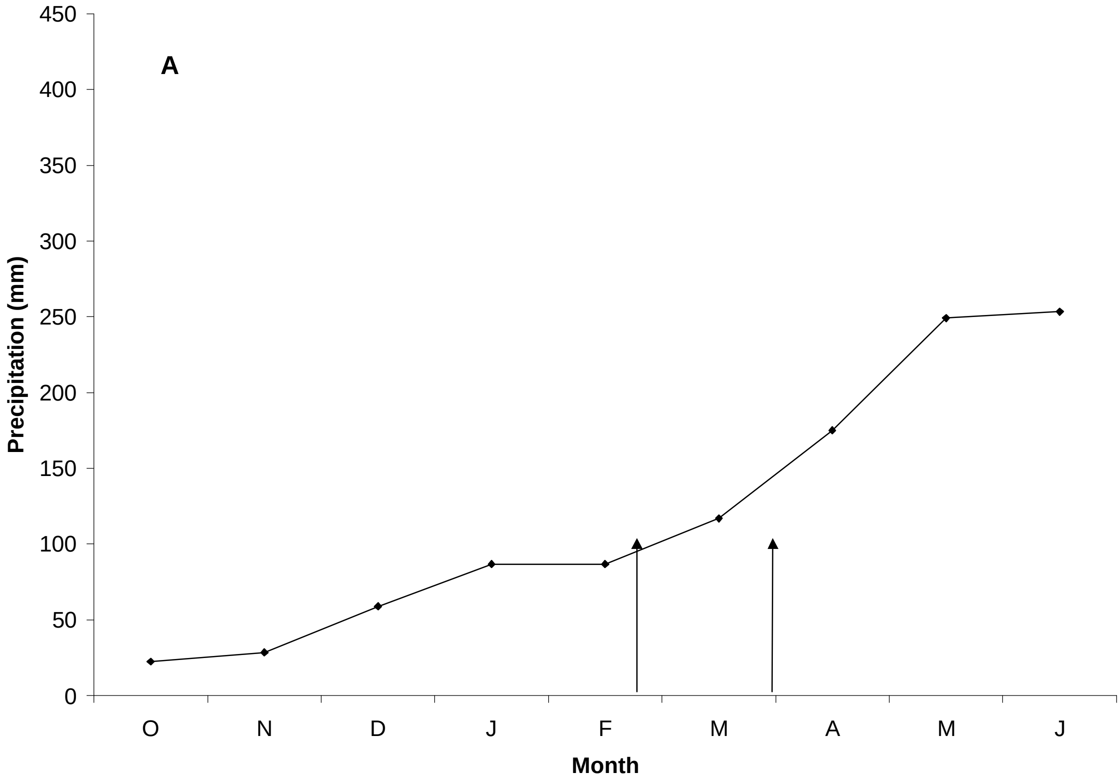


Figure 8.3. a, b, c, d. Accumulated precipitation in Baldomar (La Noguera, Catalonia) during the cropping seasons 1997-98, 1998-99, 1999-00 and 2000-01. Data from the nearby observatory in Vilanova de Meià located at 41.991º latitude, 1.022º longitude and 590 m altitude. The arrows refer to the treatment timings.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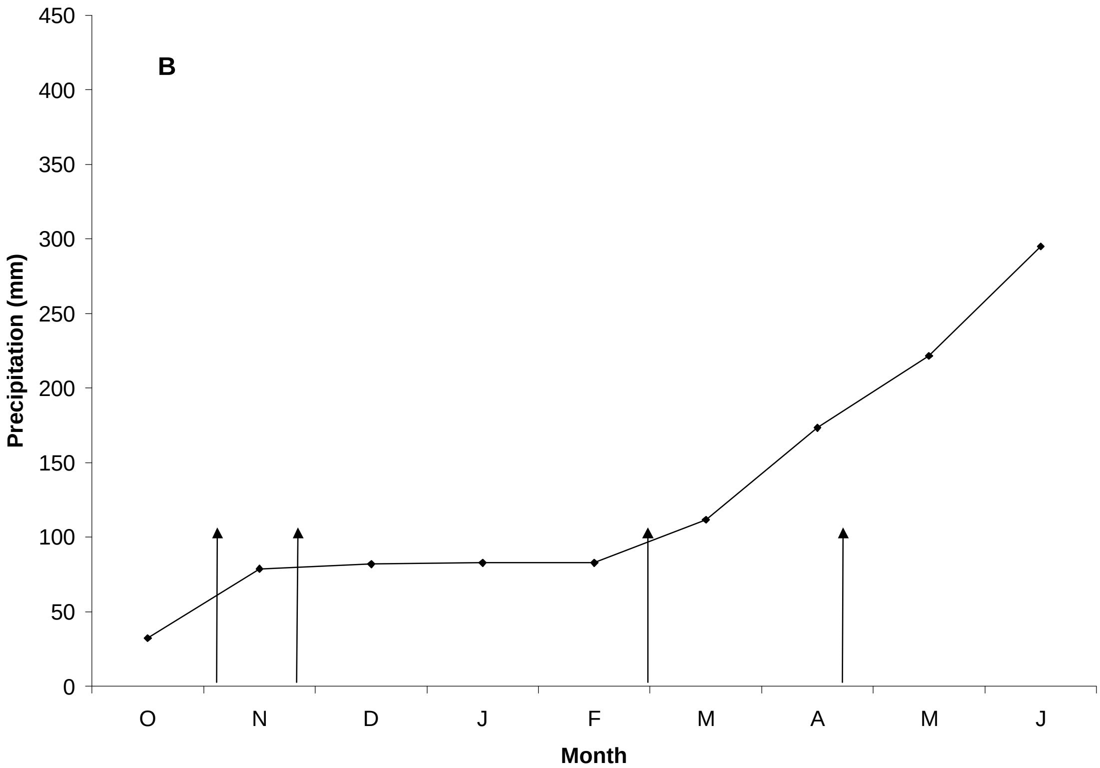
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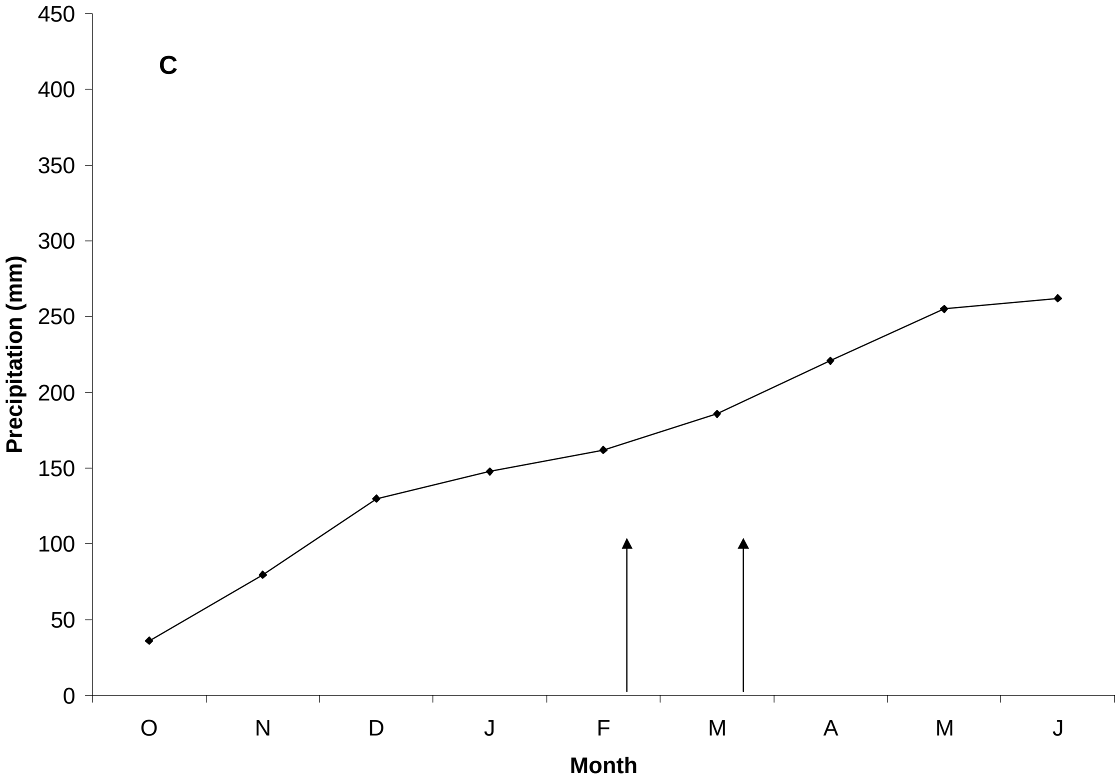


Figure 8.4. a, b, c. Accumulated precipitation in Nalec (Urgell, Catalonia) during the cropping seasons 1998-99, 1999-00 and 2000-01. Data from the nearby observatory in Tàrrega located at 41.668º latitude, 1.164º longitude and 420 m altitude. The arrows refer to the treatment timings.

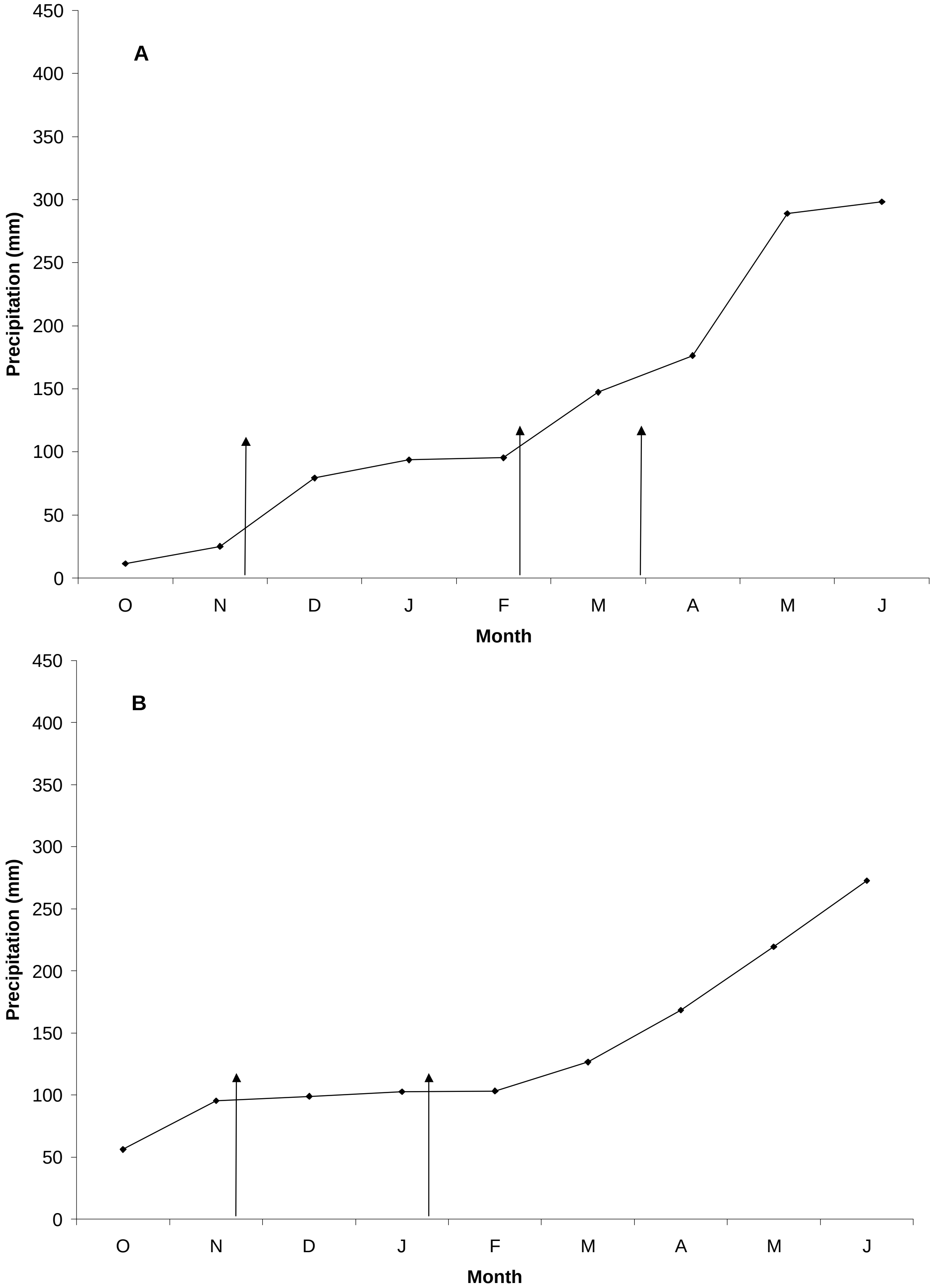


Figure 8.5. a, b. Accumulated precipitation in Torrelameu (Segrià, Catalonia) during the cropping seasons 1998-99 and 1999-00. Data from the nearby observatory in Vilanova de Segrià located at 41.715º latitude, 0.629º longitude and 218 m altitude. The arrows refer to the treatment timings.

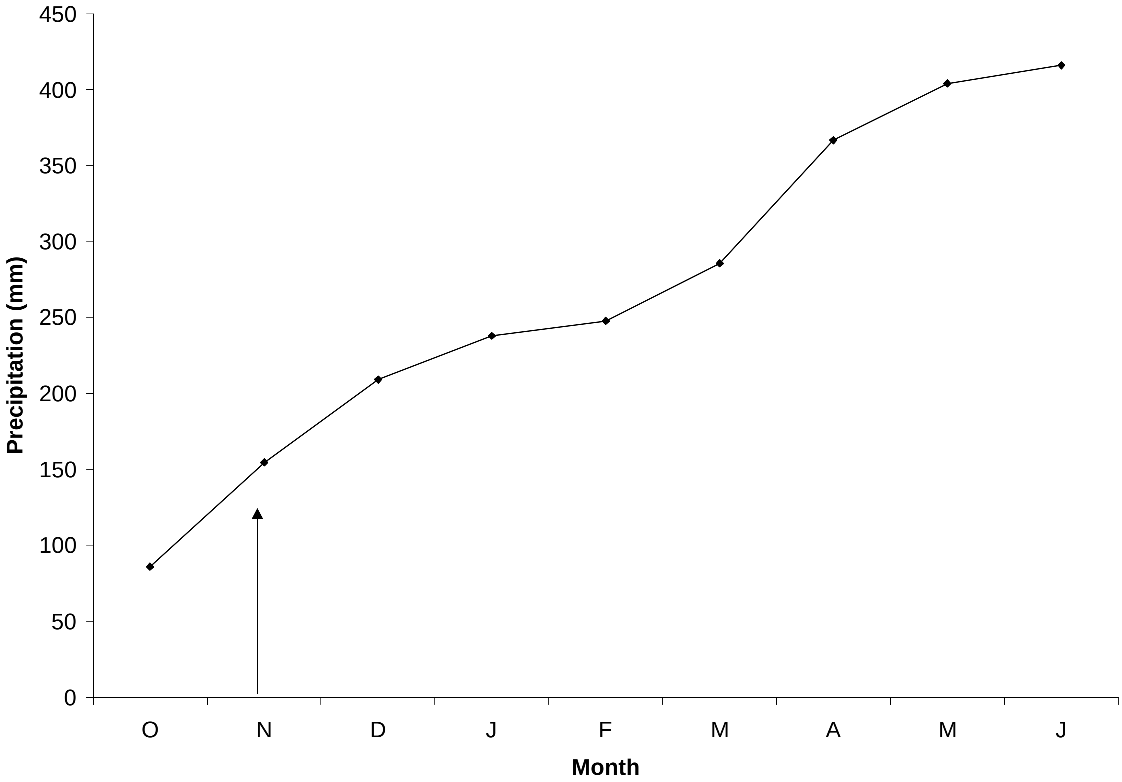


Figure 8.6. Accumulated precipitation in Algerri (La Noguera, Catalonia) during the cropping season 2000-01. Data from the nearby observatory in Albesa located at 41.760º latitude, 0.629º longitude and 262 m altitude. The arrows refer to the treatment timings.

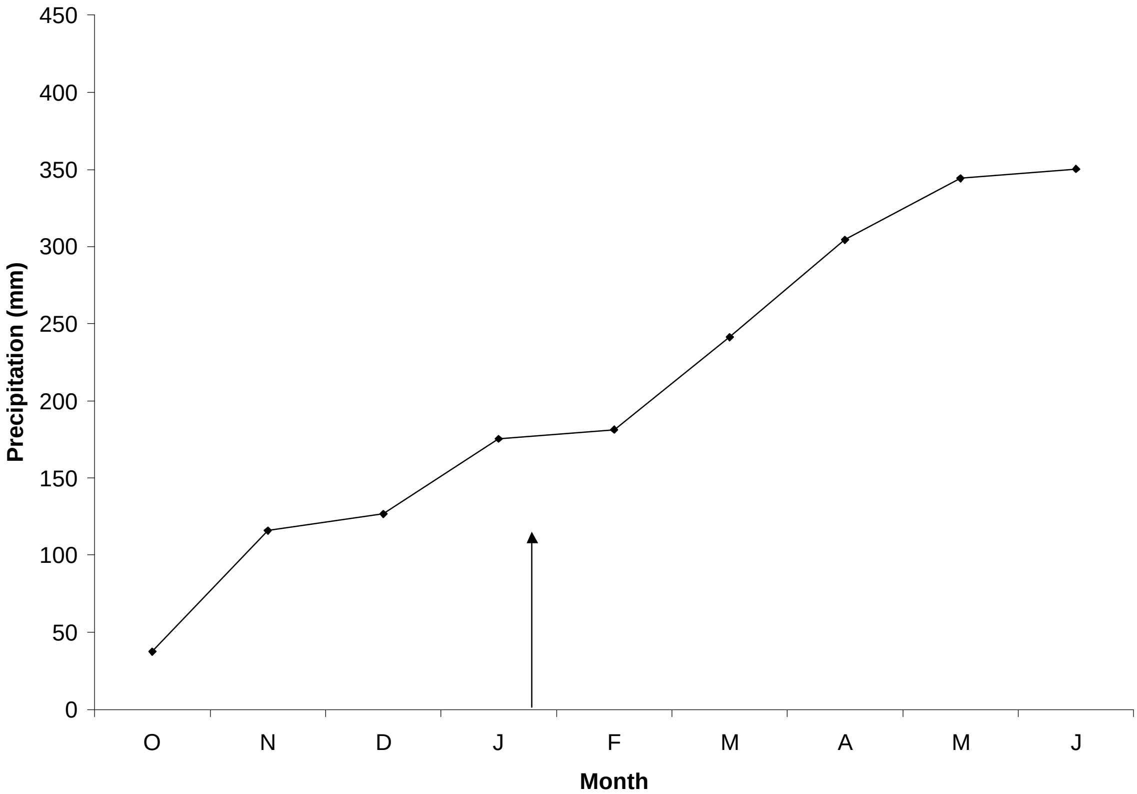
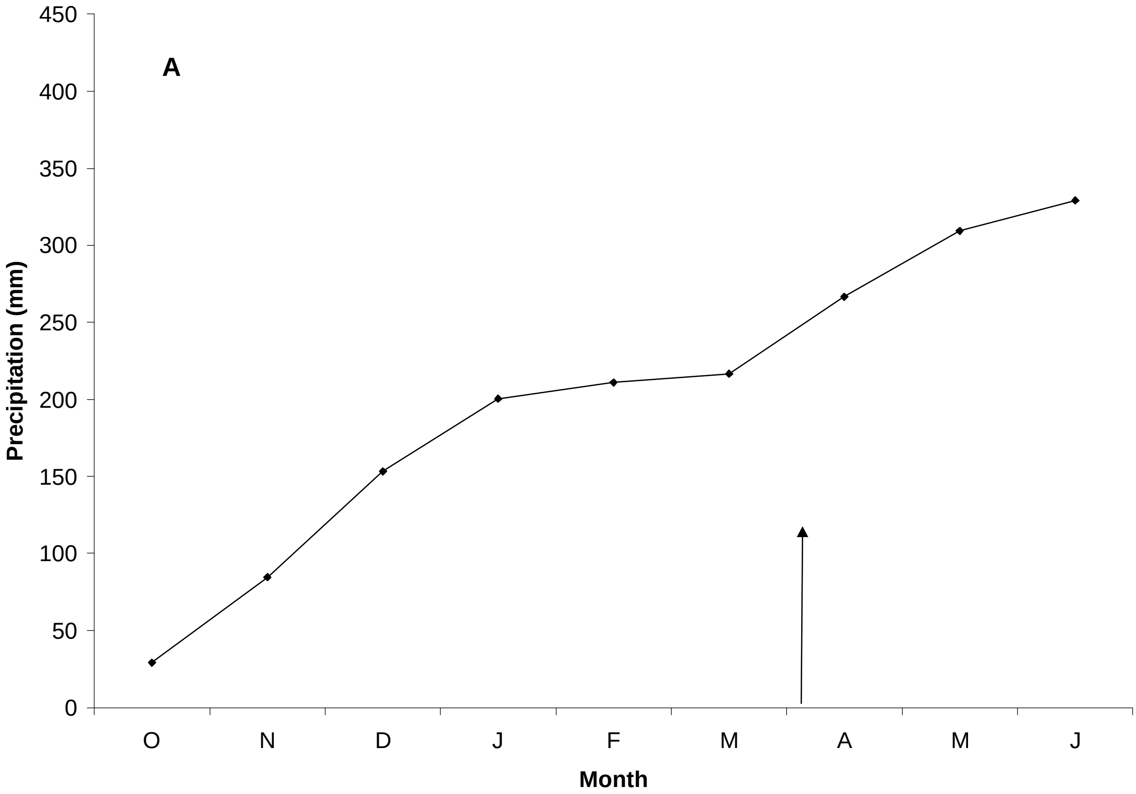


Figure 8.7. Accumulated precipitation in Sanaüja (La Segarra, Catalonia) during the cropping season 2000-01. Data from the nearby observatory in Artesa de Segre located at 41.896º latitude, 1.047º longitude and 315 m altitude. The arrows refer to the treatment timings.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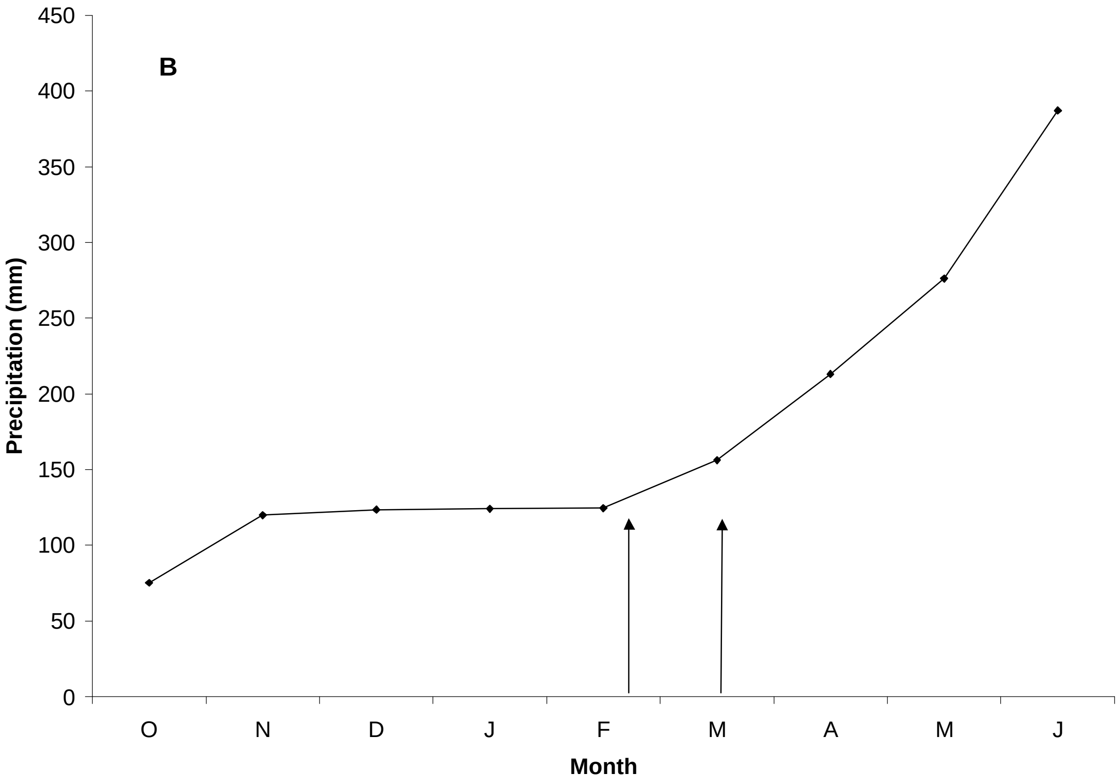
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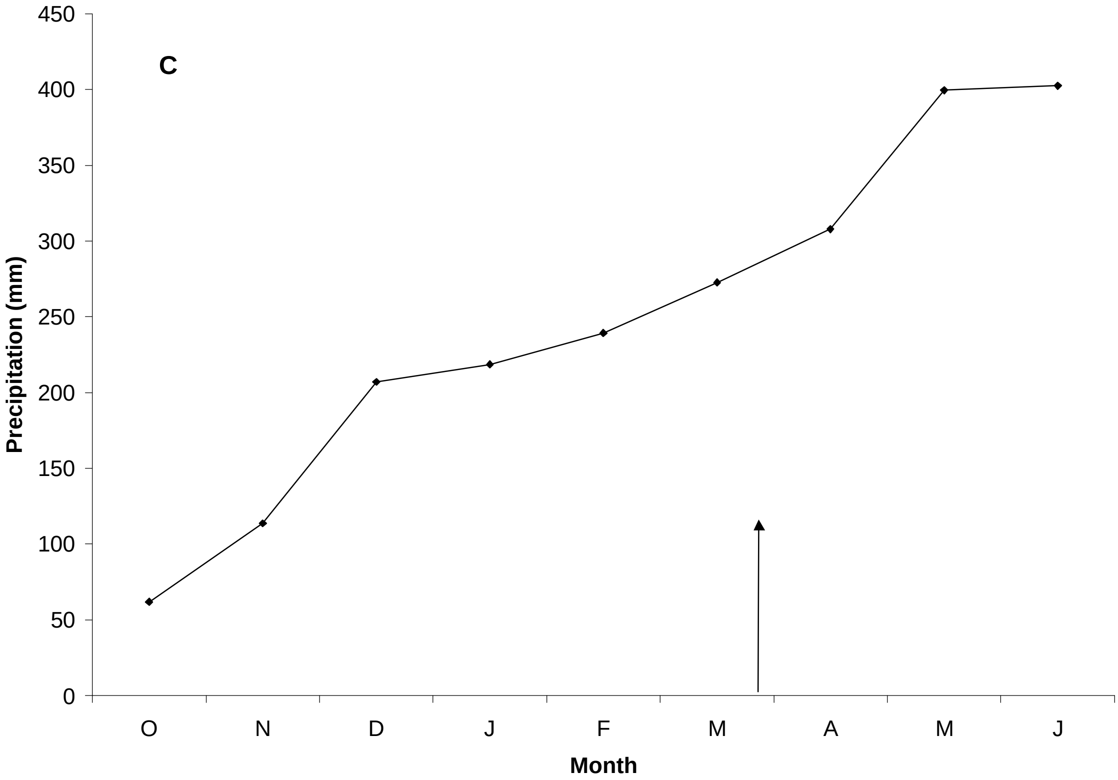

Figure 8.8. a, b, c. Accumulated precipitation in Savallà del Comptat (1997-98), Bellprat (1999-00) and Santa Coloma de Queralt (2000-01) (La Conca de Barberà, Catalonia). Data from the observatory in Santa Coloma de Queralt at 41.530º latitude, 1.368º longitude and 718 m altitude. The arrows refer to the treatment timings.

In Figure 8.9. the amount of precipitation collected during the cropping cycle is shown considering the period from October to June. The locations of Nalec and Torrelameu recorded the least precipitation values. Most overall rainfall was recorded in Algerri 2000-01 and in Baldomar.

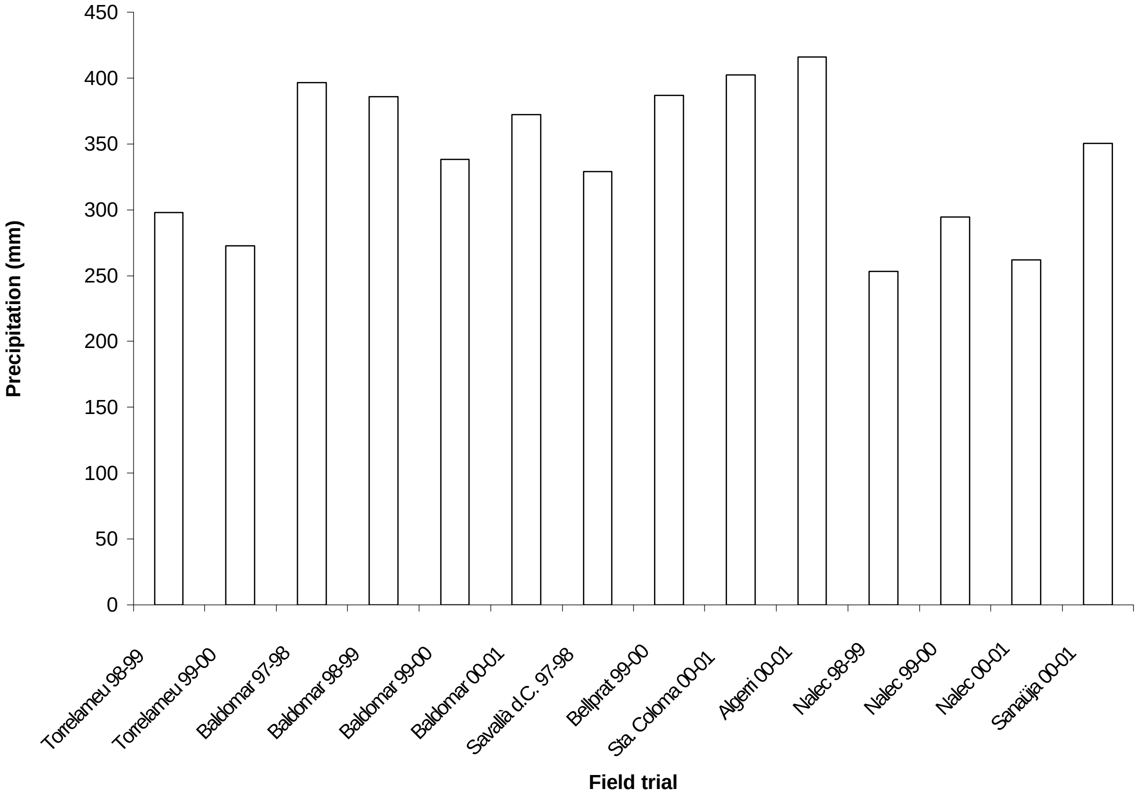

Figure 8.9. Amount of rainfall collected between October and June in the different field experiments.

The ombrothermic diagrams of the locations during the experiments are shown in Figures 8.10 – 8. 15.

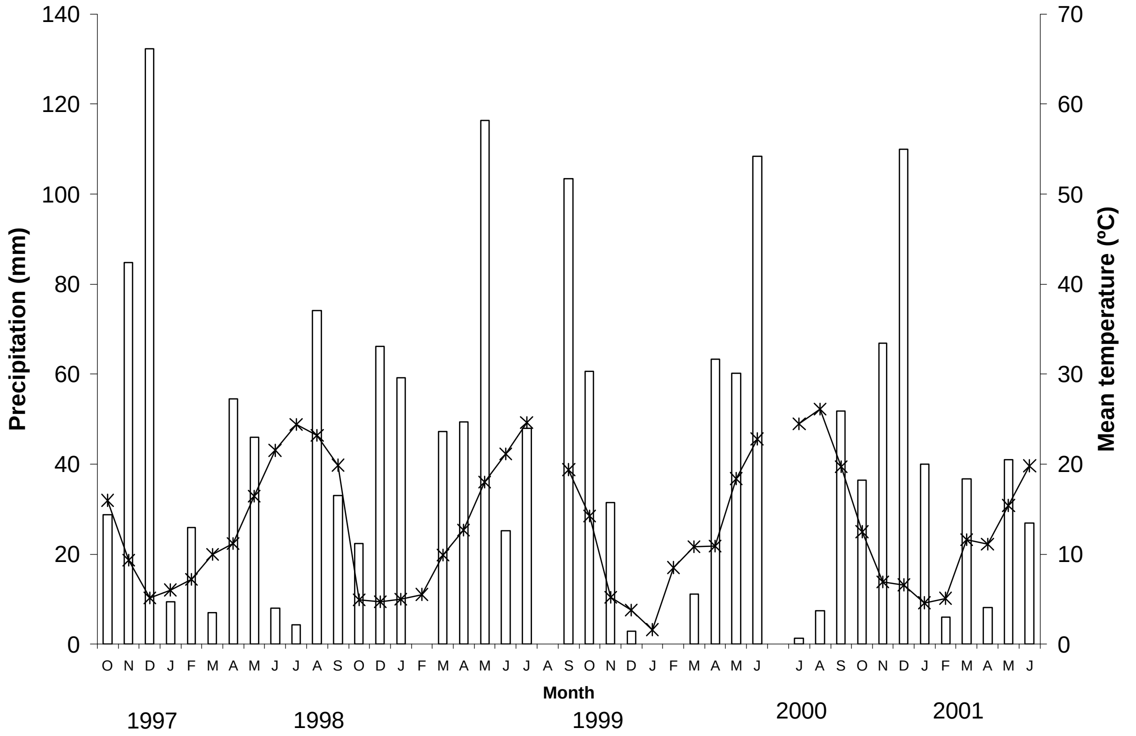

Figure 8.10. Ombrothermic diagram of Baldomar (La Noguera, Catalonia). Data from the nearby observatory in Vilanova de Meià located at 41.199º latitude, 1.022º longitude and 590 m altitude.

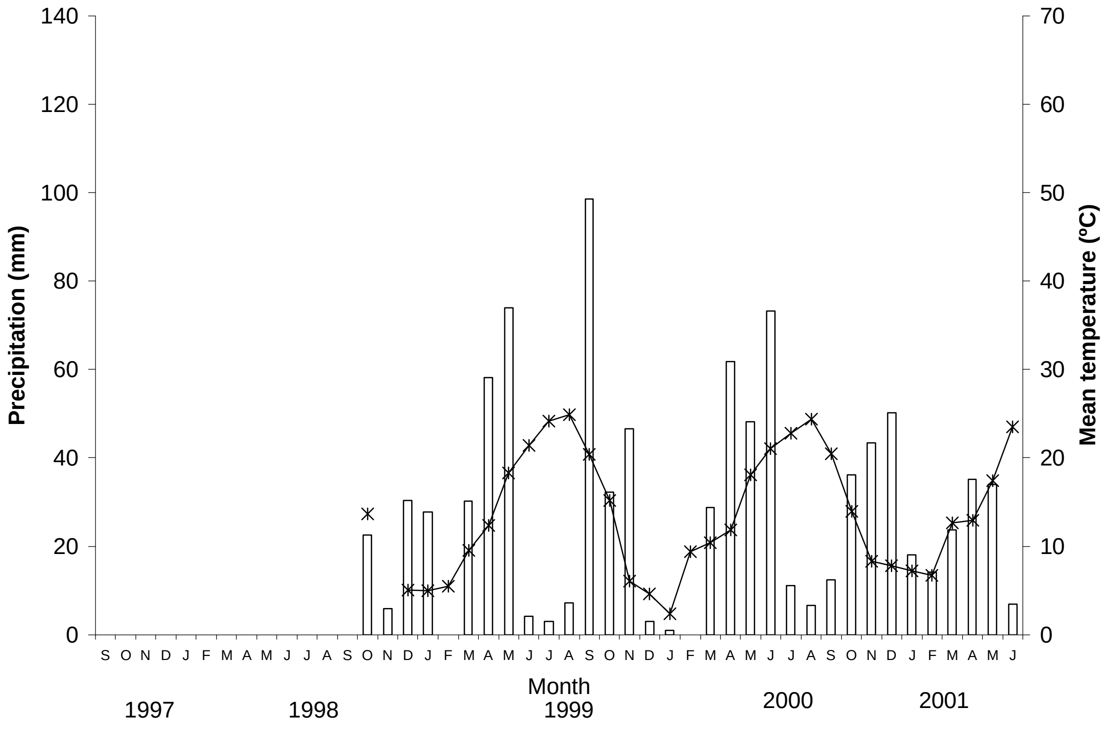

Figure 8.11. Ombrothermic diagram of Nalec (Urgell, Catalonia). Data from the nearby observatory in Tàrrega located at 41.668º latitude, 1.164º longitude and 420 m altitude.

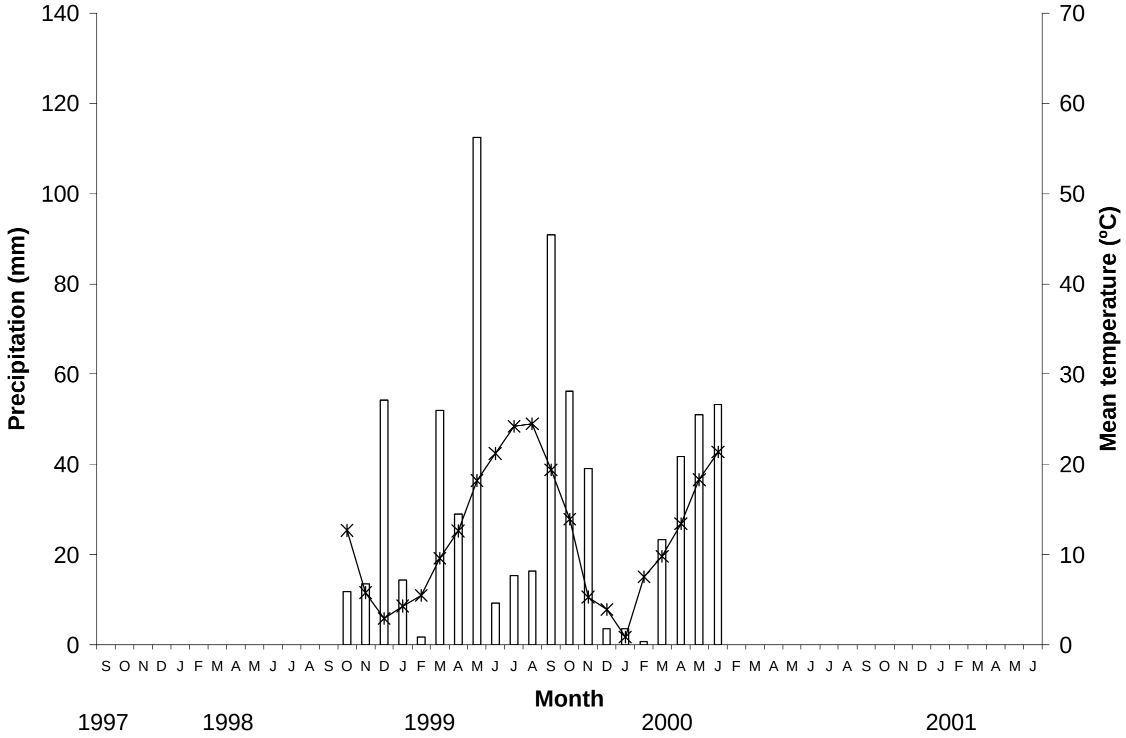

Figure 8.12.. Ombrothermic diagram of Torrelameu (Segrià, Catalonia). Data from the nearby observatory in Vilanova de Segrià located at 41.715º latitude, 0.629º longitude and 218 m altitude.

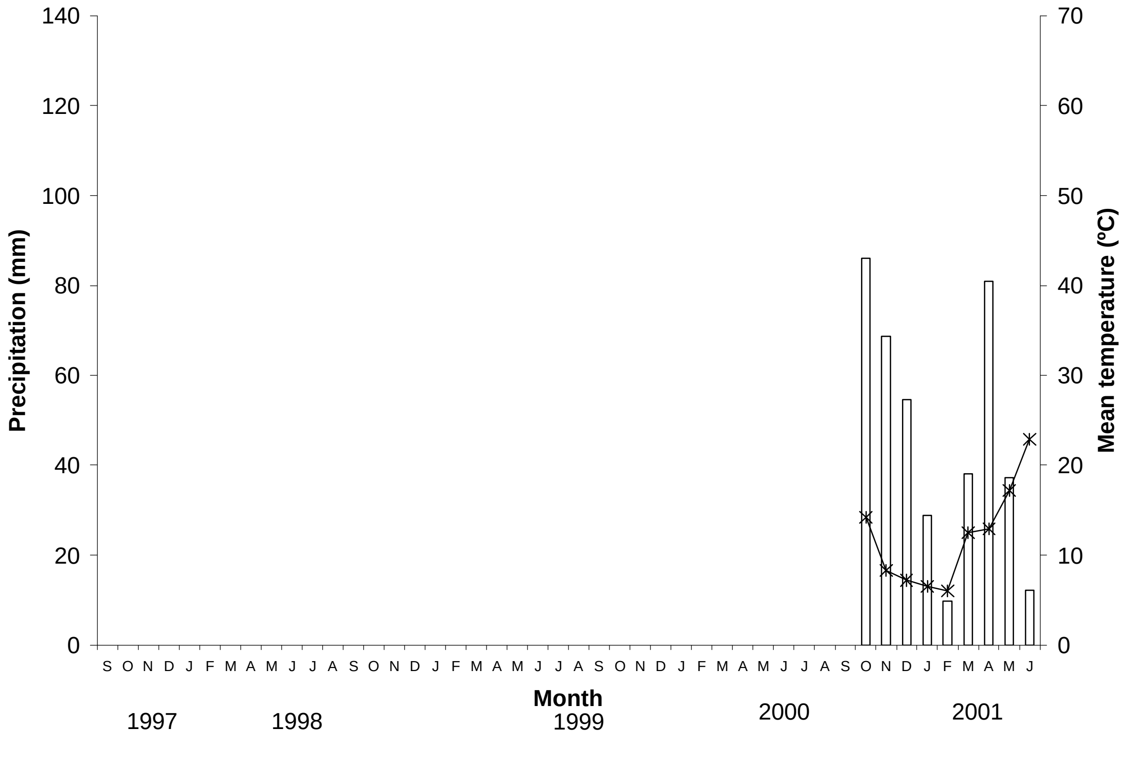

Figure 8.13. Ombrothermic diagram of Algerri (La Noguera, Catalonia). Data from the nearby observatory in Albesa located at 41.760 latitude, 0.672º longitude and 262 m altitude.

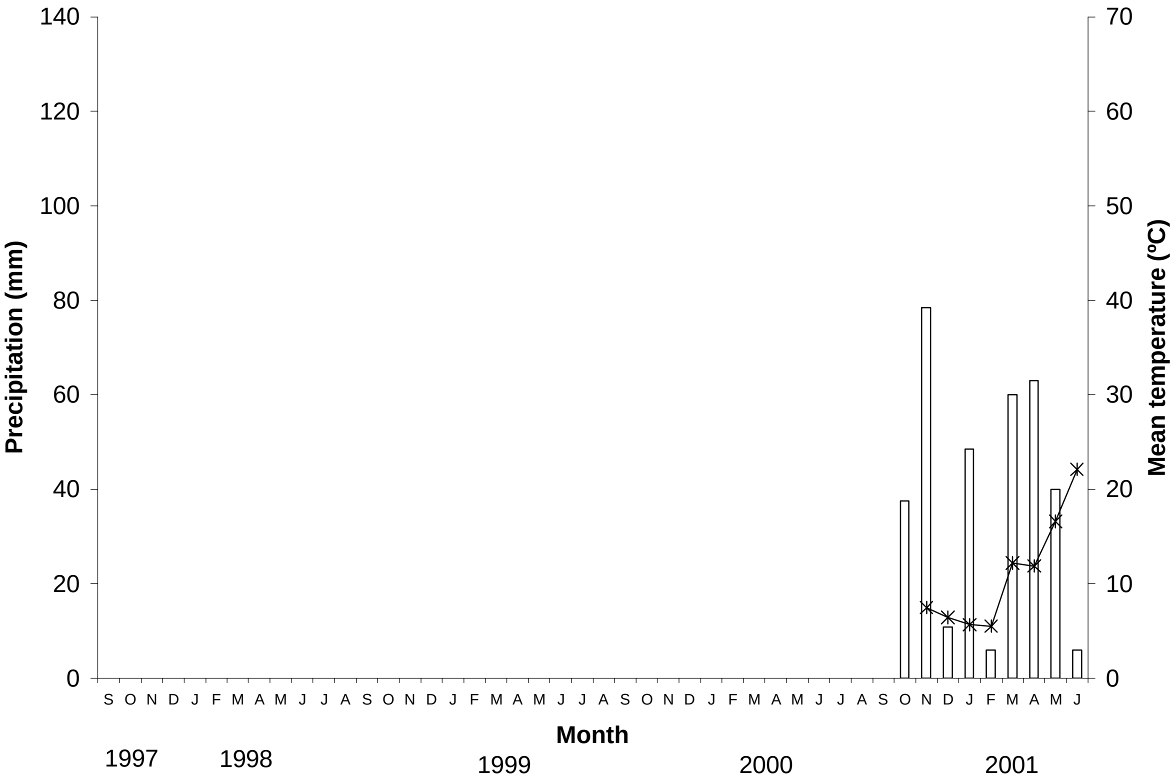

Figure 8.14. Ombrothermic diagram of Sanaüja (La Segarra, Catalonia). Data from the nearby observatory in Artesa de Segre located at 41.896º latitude, 1.047º longitude and 315 m altitude.

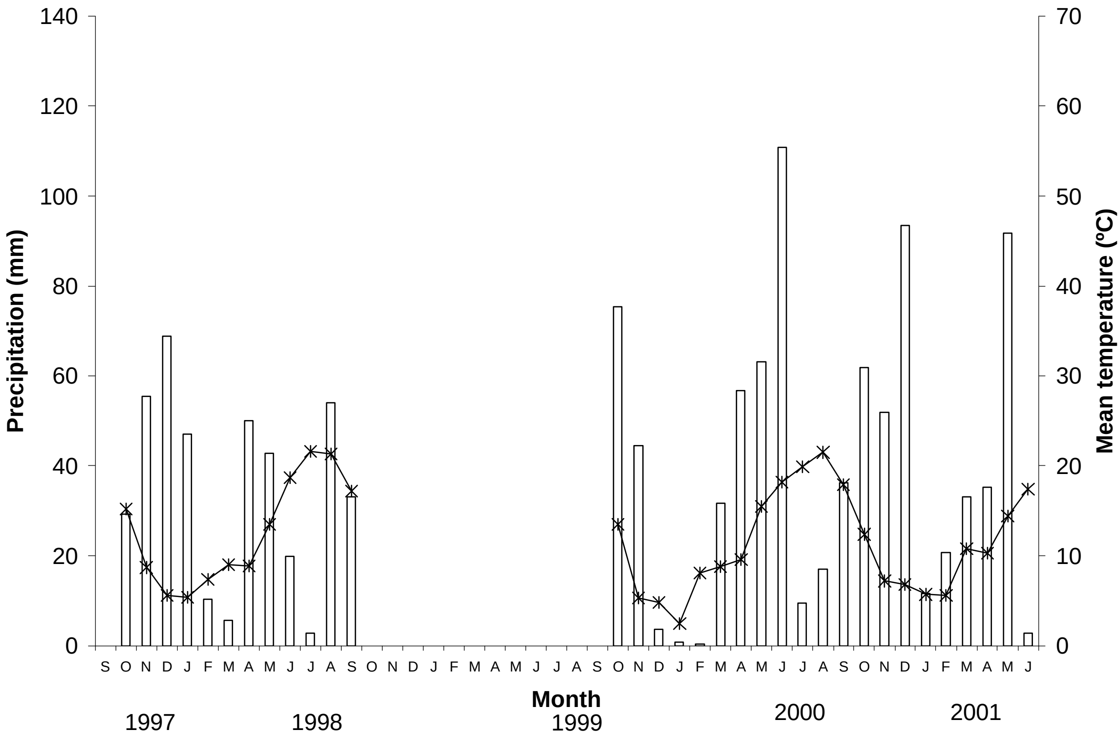

Figure 8.15. Ombrothermic diagram of Savallà del Comptat in 1997-98, of Bellprat in 1999-00 and of Santa Coloma de Queralt In 2000-01 (La Conca de Barberà, Catalonia). Data from the nearby observatory in the same location located at 41.53 latitude, 1.368º longitude and 718 m altitude.

Results and Discussion

Natural mortality even in the untreated plots was observed in all the years and in all the fields (Table 8.4.). This was probably due to the intraspecific competition resulting from the high initial plant number and was enhanced by the dry and hot climatic conditions. The initial and final plant number of *P. rhoeas* per square meter in the untreated plots are presented in Table 8.4. Initial plant number was very low in the trial conducted in Algerri in 2000-01and natural mortality due probably mainly to crop-weed competition reduced the population to non-observable levels.

Table 8.4.: *Papaver rhoeas* plant number per square meter in the different locations and years in the untreated plots before treatment and at the end of the field trial. Three counts per plot were realised.

Cropping season	Location	Date of initial count	Date of final count	Initial plant number	Final plant number
1997-98	Baldomar 1	23/02/98	13/05/98	752±96.7	523±59.3
1997-98	Savallà del Comptat	No data	No data	No data	No data
1998-99	Torrelameu	9/03/99	23/04/99	553±185.0	192±20.4
1998-99	Baldomar 2	4/02/99	14/04/99	220±37.6	92±43.0
1998-99	Nalec 1	19/03/99	7/04/99	407±51.7	378±82.8
1999-00	Baldomar 2	2/02/00	5/05/00	313±85.4	49±16.8
1999-00	Torrelameu	25/01/00	16/03/00	243±13.8	188±113.0
1999-00	Nalec 2	29/02/00	4/05/00	117±81.6	71±26.7
1999-00	Bellprat	24/02/00	4/05/00	156±61.7	86±59.7
2000-01	Baldomar 2	22/01/01	26/04/01	161±33.4	38±45.3
2000-01	Nalec 2	19/02/01	26/04/01	268±67.4	190±37.7
2000-01	Sta. Coloma de Queralt	23/01/01	18/04/01	1743±257.1	446±5.0
2000-01	Sanaüja	23/01/01	26/04/01	178±132.4	28±13.9
2000-01	Algerri	26/01/01	29/03/01	10±5.0	0±0.0

Efficacy on plant number

The results of the herbicide efficacy are summarised in Table 8.5. Control superior to 95% was considered as good, efficacy between 90 and 95% was considered acceptable.

Table 8.5. a: Efficacy of the herbicides sprayed in pre-emergence on herbicide resistant *Papaver rhoeas*.

Herbicide	Number of fields with efficacy >95% out of the total tested number of fields	Number of fields with 90 = efficacy < 95% out of the total tested number of fields
trifluraline + chlortoluron	3 out of 4	0
trifluraline + linuron	4 out of 5	0
chlorsulfuron	0 out of 3	0
isoxaben	0 out of 2	0
pendimethaline	5 out of 5	0
terbutrine + chlortoluron + triasulfuron	1 out of 3	1 out of 3

Some of the **pre-emergence** products used had very uniform high control rates throughout the years and the different locations namely pendimethaline, trifluraline + linuron and trifluraline + chlortoluron. Terbutrine + chlorsulfuron + triasulfuron gave also quite good results. Although the soil conditions were very dry in 1999-00, these herbicides were very active. Chlorsulfuron and isoxaben did not control *P. rhoeas* in any case. Chlorsulfuron was tested on fields resistant to tribenuron-methyl and 2.4-D and on fields resistant to 2.4-D, only. Lack of efficacy was observed for both cases, so that the control problem was not due to cross-resistance toward tribenuron-methyl. Even if controlling well other broad-leaved weeds, chlorsulfuron is not commonly used in the study area for *P. rhoeas* control due to its low action on this weed species.

Some degree of phytotoxicity was only observed for isoxaben (Torrelameu 1999-00), trifluraline + chlortoluron (Torrelameu 1998-99, Torrelameu 1999-00 and Algerri 2000-01), for terbutrine + chlortoluron + triasulfuron (Torrelameu 1999-00) and for chlorsulfuron (Algerri 2000-01). Only in Torrelameu phytotoxicity was strong enough to kill some cereal plants with trifluraline + chlortoluron (in both cropping seasons 1998-99 and 1999-00) and with terbutrine + chlortoluron + triasulfuron (1999-00). In all the other cases, plants recovered colour and vigour.

Table 8.5. b summarises the efficacy results of the early post-emergence herbicides.

Table 8.5. b: Efficacy of the herbicides sprayed in early post-emergence on herbicide resistant *Papaver rhoeas*.

Herbicide	Number of fields with efficacy >95% out of the total tested number of fields	Number of fields with 90 = efficacy < 95% out of the total tested number of fields
triclopir + chlortoluron	0 out of 3	0
chlortoluron + terbutrine	1 out of 3	1 out of 3
tribenuron-methyl	2 out of 13	1 out of 13
tribenuron-methyl + metribuzine	3 out of 11	2 out of 11
isoproturon + cianazine	1 out of 5	0
isoproturon + diflufenican	5 out of 10	0
terbutrine + triasulfuron	0	1 out of 3
isoproturon + metribuzine	1 out of 5	0
MCPA + diflufenican	3 out of 12	2 out of 12

Out of the **early post-emergence herbicides** tested none had a very constant activity throughout the years and in the tested fields. Tribenuron-methyl was active in 3 fields only, confirming herbicide resistance towards this herbicide in most of the selected fields. The mixtures including diflufenican as well as the mixture tribenuron-methyl + metribuzine were the most effective ones out of the tested early post-emergence herbicides. The reason for the irregular behaviour is unclear, also taking into account that these products were applied in early growth stages. These results also reflect the opinion of farmers who state that high efficacy in the mixtures containing metribuzine is obtained in some cases and much less efficacy in others.

MCPA + diflufenican showed an initial high activity in most of the fields and on most of the weed plants. In several cases re-growth of *P. rhoeas* plants was observed reducing the initially high efficacy. In four cases, efficacy >95% reduced down to 72-93%, depending on the case (Annexes). Also in the mixtures triclopir + chlortoluron and tribenuron-methyl + metribuzine initially high efficacy in two fields decreased down to unacceptable levels. As the last evaluations were based on visual observations, possibly plant number did not increase at the end in many cases, but the surviving plants were able to produce many flowers so that the percentage of weed cover was high, reducing visual efficacy.

Moreover, quite severe phytotoxicity was observed for MCPA + diflufenican during the years 1999-00 and 2000-01 (Baldomar 1999-00, Bellprat 1999-00, Sanaüja 2000-01 and Sta. Coloma 2000-01). No death of cereal plants was detected but decrease of growth and plant decoloration, which disappeared during the plant cycle. The mixture of chlortoluron + terbutrine caused also a slight degree of phytotoxicity in Sanaüja 2000-01.

Table 8.5. c: Efficacy of the herbicides sprayed in late post-emergence on herbicide resistant *Papaver rhoeas*.

Herbicide	Number of fields with efficacy >95% out of the total tested number of fields	Number of fields with 90 = efficacy < 95% out of the total tested number of fields
bromoxinil + 2.4-D	2 out of 6	2 out of 6
dicamba	0 out of 9	0
MCPP + ioxinil	3 out of 9	0
2.4-D	0 out of 11	1 out of 11
ioxinil + bromoxinil + MCPP (1)	3 out of 9	2 out of 9
florasulam + 2.4-D	5 out of 9	0
ioxinil + bromoxinil + MCPP (2)	0	1 out of 3
bromoxinil + MCPP	4 out of 6	0

Out of the herbicides tested in **late post-emergence**, the mixtures containing ioxinil and especially those containing bromoxinil gave generally good results, although some herbicides were irregular depending on the location and on the year. It was observed that in other commercial fields these products were in some occasions very active when sprayed in early stages even at lower rates, so that this could be the reason of the reduced activity in some cases. The most regular herbicide mixture was bromoxinil + MCPP followed by ioxinil + bromoxinil + MCPP and florasulam + 2.4-D. The inconvenient of the mixture florasulam + 2.4-D was its very slow actuation rate, suggesting that earlier application could be advantageous.

Dicamba and 2.4-D gave very bad control results. In the second case this was a consequence of confirmed herbicide resistance after numerous decades of spraying history with this product. In all cases, *P. rhoeas* seeds were tested in laboratory following the quick-test described by Cirujeda *et al.* (in press) and resistance confirmed (data not shown). The lack of activity towards dicamba could be caused by cross-resistance. As in all the tested fields herbicide resistance towards 2.4-D was detected, this cross-resistance could not be confirmed. This hypothesis is, however, supported by the fact that the lack of efficacy is not normal as dicamba is a herbicide used for broad-leaf annual and perennial weed and brush species in numerous crops including cereals (Tomlin, 1994). In order to clarify this aspect it could be interesting to conduct field trials on susceptible *P. rhoeas* populations and on populations resistant to tribenuron-methyl, only. This way, possible cross-resistance between 2.4-D or tribenuron-methyl towards other herbicides could be detected. Also other unknown interactions might appear.

No clear differences were found in the activity of the herbicides taking into account if the fields were resistant to 2.4-D and tribenuron-methyl or to 2.4-D alone. Irregular behaviour occurred even in the same fields treated in different years, so that climatic conditions and weed plant size are probably very important factors influencing the treatment’s efficacy.

In the tested area, many years the climatic conditions impeded to do a correct application of late post-emergence products due to drought, which makes absorption very difficult. This occurred in Savallà del Comptat 1997-98 and in Torrelameu 1999-00. In this last case, these products were even not sprayed due to the severe drought. Even when sprayed, non-optimal conditions were normal. Irregular results between locations could also reflect this problem, which is worth to be analysed in **further work**. Irregular results between years and locations, however, were also found towards the mixtures containing herbicides from the triazine group and containing diflufenican sprayed in early post-emergence. It is thus necessary to deepen in the study of these herbicides on different *P. rhoeas* populations in order to find an answer to the irregular behaviour. Greenhouse trials could help finding an answer to these questions.

Other arising aspects worth to be studied are:

To adjust the right weed growth stage for treatment with the mixtures containing ioxinil and bromoxinil. Also the possible dose reduction for the pre-emergence herbicides as pendimethaline, trifluraline + chlortoluron and trifluraline + linuron and the mixtures containing ioxinil and bromoxinil is worth to be tested.

The effect of increasing 2.4-D doses in field trials and observing the evolution of resistance on the populations by using this control method could also help defining the appropriate chemical control strategy.

Another interesting aspect is to prevent the appearance of herbicide resistance of *P. rhoeas* to other herbicides. Some of the tested populations in this work showed already less susceptibility against ioxinil than other populations (data not shown). Before ioxinil and bromoxinil are used without preventing herbicide appearance it could be useful to study the appropriate use of these products and to assess the possible risk of herbicide resistance appearance towards them.

Conclusions

The results of the trials confirmed herbicide resistance towards tribenuron-methyl and/or 2.4-D in the selected sites. Chemical control of *P. rhoeas* resistant to tribenuron-methyl and to 2.4-D has been found to be possible. Within the tested products in pre-emergence, pendimethaline, trifluraline + chlortoluron and trifluraline + linuron showed the highest and most regular efficacy. In early post-emergence, isoproturon + diflufenican, MCPA + isoproturon and tribenuron-methyl + metribuzine were the most regular products, even if in several trials efficacy was not high enough. Irregular results are consistent with the observations of farmers.

More field experiments combined with studies in greenhouse would help detecting the most indicated moments and conditions for spraying aiming to find a more homogeneous efficacy pattern. Sprayed in late post-emergence, the mixtures ioxinil + bromoxinil + MCPP and florasulam + 2.4-D achieved high efficacy in most of the tested cases. Anyway, more constant high efficacy should be possible spraying these herbicides at earlier weed growth stages.

Further research could also focus on the timing and on the use of lower doses, especially in the pre-emergence herbicides but also in the mixtures used in late post-emergence.

It was possible to overcome herbicide resistance by combining herbicides from different groups following the HRAC classification. In this case, resistance to group B and O (where tribenuron-methyl and 2.4-D respectively belong to) could be overcome by herbicides and mixtures of herbicides of the classes K1, K1 + C2, C2 + F1, O + F1, C3 + C3 + O. The classification system of the HRAC showed, thus, its utility.

Other aspects to be studied are testing different herbicides and mixtures on fields with susceptible populations and on populations resistant to tribenuron-methyl, only. Many other aspects are worth to be studied, concluding that the results found in the present study are only a start in designing a possible chemical control program of herbicide resistant *P. rhoeas* populations.

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ANNEXES

Table A.1.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Baldomar (1) in 1997-98. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**17**	**35**	**60**	**75**	**96**
Tordon 101	31±8.2	28±8.2	53±11.9	52±11.8	66±20.5
Sencor + Granstar	82±4.2	84±12.4	90±6.1	93±4.9	86±5.1
Sencor IP	100±0.6	100	100±0.3	100±0.2	100±0.7
Duplosan super	32±6.9	46±25.2	75±11.3	81±5.7	76±17.6
IP + Bladex	100±0.3	100	99±1.2	100	100±0.4
Dicuran extra	100	100	100	100±0.2	100
Certrol H + Procer	92±7.0	98±2.4	96±3.0	97±2.7	97±2.3
Yard	65±20.6	82±5.2	83±12.6	92±4.1	80±16.8
Yard + Granstar	45±12.5	75±13.0	78±14.6	90±1.9	91±2.2
Esteron (early application)	20±16.4	30±14.6	52±13.7	59±16.8	56±12.0
DAT			**14**	**29**	**50**
Granstar (0.015 kg a.i. ha^{-1})			18±18.8	37±23.4	32±15.4
Granstar (0.045 kg a.i. ha^{-1})			38	31±22.0	30±21.3
Esteron			29±19.0	55±30.4	63±13.9
Sencor (late application)			43	41±5.8	24±13.0
Tordon 101 (late application)			84±26.4	82±29.5	51±28.5

Table A.2.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Savallà del Comptat in 1997-98. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**Visual assessment** **55**
Tordon 101	69±21.2
Certrol H + Procer M 40	90±10.8
Granstar (0.015 kg a.i. ha^{-1})	19±33.7
Granstar (0.045 kg a.i. ha^{-1})	76±16.8
Esteron (0.6 L a.i. ha^{-1})	58±30.0
Esteron (1.8 L a.i. ha^{-1})	46±5.1

Table A.3.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Torrelameu in 1998-99. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment. Logran Extra was applied in pre-emergence at the same dose as applied in pre-emergence in other trials.

Herbicide				**Visual assessment**
DAT	**113**	**128**	**142**	**172**
Gadisan	100	100±0.5	100	92±10.4
Stomp	100	100	100	100±0.6
	106	**121**	**135**	**165**
Araflurex + Oracle	92±13.8	94±9.3	100±0.5	96±15.0
Logran Extra	91±12.5	74±28.5	90±13.5	85±20.8
DAT	**18**	**33**	**47**	**77**
Asitel	100±0.5	95±8.3	100±0.5	93±7.2
Certrol H	97±2.2	98±1.8	97±2.7	98±2.3
Tralla	98±0.4	97±3.7	99±1.3	96±2.3
Oxytril	99±0.3	98±2.3	100±0.5	100±0.6
Garlon + Oracle	43±52.2	29±8.0	39±35.5	40±45.8
Granstar	0.3±0.5	7±12.5	0±0.0	7±5.6
Granstar + Lexone	44±30.8	68±23.2	56±29.8	57±25.2
Logran Extra	22±34.9	25±21.3	14±5.5	17±15.3
Yard	77±6.2	82±11.8	96±2.2	72±18.9
Javelo	6±5.1	85±1.4	83±3.7	53±25.2
DAT			**24**	**38**
Esteron			94±0.5	65±4.5
Banvel D			95±3.1	73±5.5
Mustang			95±6.9	95±13.2

Table A.4.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Baldomar (2) in 1998-99. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide					**Visual assessment**
DAT	**59**	**77**	**94**	**106**	**134**
Gadisan	100	100	100	100	100
Stomp	100	100	100	100	100
DAT	**16**	**34**	**51**	**63**	**91**
Asitel	98±3.2	100	100±0.0	99±1.9	93±5.2
Certrol H	98±2.9	100	98±3.2	99±1.1	100±0.6
Tralla	100	100	100	100	98±2.9
Oxytril	100	100	100	100	95±4.5
Garlon + Oracle	100	100	99±2.3	96±4.9	77±15.3
Granstar	57±36.2	80±21.3	91±7.3	75±10.7	37±20.8
Granstar + Lexone	98±2.1	100	100	100	96±5.5
Logran Extra	100100	100	100	100±0.8	92±5.8
Yard	87±5.3	100	100±0.9	97±4.4	87±7.6
Javelo	100±0.8	100	100	100	98±2.7
DAT				**22**	**50**
Esteron				33±17.8	12±10.4
Banvel D				47±61.1	23±25.2
Mustang				61±19.0	80±10.0

Table A.5.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Nalec (1) in 1998-99. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide			**Visual assessment**
DAT	**22**	**41**	**83**
Asitel	95±3.8	96±5.4	97±2.9
Certrol H	90±8.1	92±2.8	77±15.3
Tralla	100	100	98±3.5
Oxytril	96±3.4	99±0.9	92±10.4
Garlon + Oracle	62±32.2	84±6.7	47±23.1
Granstar	6±9.5	11±18.5	3±5.8
Granstar + Lexone	56±50.9	44±48.9	43±3.5
Logran Extra	36±35.6	28±29.0	30±26.5
Yard	80±12.4	88±16.7	93±11.0
Javelo	37±49.3	87±7.2	83±17.6
DAT			**50**
Esteron			91±10.0
Banvel D			78±7.6
Mustang			96±2.3

Table A.6.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Nalec (2) in 1999-00. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide				**Visual assessment**
DAT	**117**	**167**	**182**	**201**
Gadisan	97±3.0	97±4.9	97±2.7	84±0.0
Stomp	100	96±4.3	100	100
Araflurex + Oracle	83±11.4	91±4.3	84±9.8	74±18.2
DAT	**98**	**148**	**163**	**182**
Tricuran	89±13.0	95±1.6	89±9.8	84±0.0
Glean	11.5±20.0	43±30.3	47±31.9	42±18.2
Rokenyl	6.8±11.8	33±40.0	48±20.4	15±13.2
DAT		**50**	**65**	**84**
Granstar		86±13.0	97±5.4	84±0.0
Granstar + Sencor		95±3.3	97±5.4	90±9.1
Sencor IP		18±12.4	45±25.7	46±42.5
IP + Bladex		31±14.3	29±25.7	53±15.8
Yard		100	100	100
Javelo		82±14.3	97±5.4	95±9.1
DAT			**15**	**34**
Certrol H			91±8.1	100
Oxytril			52±11.8	58±32.9
Esteron			36±9.8	53±15.8
Banvel D			47±28.3	53±15.8
Mustang			41±10.8	100

Table A.7.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Bellprat in 1999-00. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide			**Visual assessment**
DAT	**41**	**70**	**81**
Granstar	24±28.7	92±6.8	90±11.8
Granstar + Sencor	33±21.6	97±4.5	92±0.0
Logran Extra	9±4.2	26±31.3	31±53.3
IP + Bladex	2±4.1	1±1.5	3±4.4
Yard	83±11.2	84±3.9	67±22.2
Javelo	9±14.8	18±30.7	8±13.3
DAT	**20**	**49**	**60**
Certrol H	56±10.4	49±35.7	26±22.2
Oxytril	60±11.2	22±37.6	13±22.2
Esteron	54±32.1	71±17.6	51±8.9
Banvel D	10±11.1	10±17.3	8±13.3
Mustang	52±50.1	100	97±4.4

Table A.8.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Torrelameu in 1999-00. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide					**Visual assessment**
DAT	**76**	**97**	**113**	**127**	**188**
Gadisan	100	100	100	98±3.1	100
Stomp	100	100	100	100	100
Araflurex + Oracle	100	100	100	100	100
DAT	**63**	**84**	**100**	**114**	**175**
Tricuran	99±2.4	100±0.5	100±0.8	100	90±13.8
Glean	0.1±9.6	27±5.8	30±19.4	64±6.3	48±47.0
Rokenyl	44±26.7	11±9.8	5±9.4	4±6.3	0±0.0
		21	**37**	**51**	**112**
Granstar		12±10.1	6±10.2	10±16.7	0
Granstar + Sencor		91±5.7	95±8.1	91±9.4	74±13.0
Sencor + IP		96±3.6	97±1.6	97±3.3	68±24.2
IP + Bladex		29±28.6	78±10.5	77±29.5	77±25.2
Yard		100	100	100	94±6.6
Javelo		41±29.6	66±22.4	90±14.5	96±7.5

Table A.9.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Baldomar (2) in 1999-00. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide					**Visual assessment**
DAT	**20**	**48**	**68**	**86**	**106**
Granstar	22±31.8	28±9.1	22±37.2	22±38.1	25±42.9
Granstar + Sencor	25±42.5	32±37.3	3±4.9	33±33.0	54±26.2
Sencor + IP	53±48.4	50±48.9	61±28.0	64±40.0	69±32.5
IP + Bladex	32±27.90	28±27.5	24±31.1	20±34.1	41±41.4
Yard	68±25.0	100	93±7.8	96±7.9	93±3.0
Javelo	39±34.0	31±29.0	31±38.8	42±37.5	60±21.6
DAT				**18**	**38**
Certrol H				64±31.5	82±12.9
Oxytril				91±3.9	87±7.9
2.4-D				46±27.3	46±30.1
Banvel D				17±30.2	22±37.9
Mustang				35±33.1	97±4.9

Table A.10.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Baldomar (2) in 2000-01. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**68**	**89**	**113**
Gadisan	98±3.6	100	100
Stomp	93±4.3	98±3.2	100
Araflurex + Oracle	100	100	100
Tricuran	97±4.3	83±5.6	86±14.5
Glean	20±20.1	0	0
DAT		**21**	**45**
Granstar		0	12.4±21.4
Granstar + Lexone		82±11.6	86±9.7
Yard		63±54.8	73±43.4
Javelo		89±19.3	97±2.8
Clorturex Ter		70±14.0	71±41.9
DAT			**21**
Mustang			40±32.2
Certrol H			69±15.6
Oxytril			98±2.8
Banvel D			30±48.5
Esteron			37±26.9
Tralla			97±2.8
Asitel			87±10.1
Image			94±11.2

Table A.11.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Nalec (2) in 2000-01. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**23**	**49**	**66**
Granstar	78±7.8	98±1.7	96±7.1
Granstar + Lexone	82±5.5	99±2.5	100
Yard	76±7.1	50±11.4	52±17.6
Javelo	91±6.5	92±11.7	87±9.0
Clorturex Ter	87±2.3	82±10.8	90±11.5
DAT		**21**	**38**
Mustang		40±19.9	88±15.9
Certrol H		73±24.5	74±23.4
Oxytril		91±15.0	87±22.3
Banvel D		19±5.8	39±24.6
Esteron (0.6 L a.i. ha^{-1})		53±49.2	30±0.0
Esteron (0.9 L a.i. ha^{-1})		81±24.4	61±28.5
Tralla		76±12.2	68±27.6
Asitel		98±0.8	100
Image		89±17.0	87±23.3

Table A.12.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Sanaüja in 2000-01. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**50**	**67**
Granstar	22±37.7	70±25.3
Granstar + Lexone	65±49.2	95±2.5
Yard	100	100
Javelo	94±7.0	97±4.0
Clorturex Ter	80±30.6	98±1.7

Table A.13.: Evolution of *Papaver rhoeas* efficacy during the cropping season in the field trial conducted in Santa Coloma de Queralt in 2000-01. Commercial names of herbicides are used. Herbicides are grouped following the application moment. DAT = days after treatment.

Herbicide **DAT**	**24**
Untreated	26±10.5
Granstar	48±23.9
Yard	48±5.8
Mustang	68±9.8
Certrol H	68±9.8
Oxytril	91±5.7
Banvel D	3±5.5
Esteron	38±33.0
Tralla	62±27.0
Asitel	45±46.8
Image	72±14.5

Table A 14. a.: Efficacy of the herbicides sprayed in the different locations on *Papaver rhoeas* in the cropping seasons 1997-98, 1998-99 and 1999-00.Efficacy calculated on the last counts. PE = Pre-emergence, EPE = Early post-emergence, LPE = Late post-emergence. Red numbers: 95 < efficacy ≤ 100; blue numbers: 90 ≤ efficacy < 95. Yellow ground: considerable changes were observed compared with later visual evaluation.

	1997-98		1998-99			1999-00				2000-01			
	Savallà del Comptat	Baldomar 1	Baldomar 2	Torrelameu	Nalec 1	Baldomar 2	Torrelameu	Nalec 2	Bellprat	Baldomar 2	Nalec 2	Sanaüja	Sta. Coloma de Queralt
PE			T + 106	T + 142	-	-	T +127 / 114	T+182	-	T + 113			
trifluraline + chlortoluron	-	-	-	100±0.5	-	-	100	84±9.8	-	100	-	-	-
trifluraline + linuron	-	-	100	100	-	-	98±3.1	97±2.7	-	100	-	-	-
chlorsulfuron	-	-	-	-	-	-	64±6.3	47±31.9	-	0	-	-	-
isoxaben	-	-	-	-	-	-	4±6.3	48±20.4	-	-	-	-	-
pendimethaline	-	-	100	100	-	-	100	100	-	100	-	-	-
terbutrine + chlorsulfuron + triasulfuron	-	-	-	-	-	-	100	89±9.8	-	86±14.5	-	-	-
EPE		T+ 50 / 96	T + 63	T + 47	T + 41	T + 86	T + 51	T + 65	T + 70	T + 45	T + 66	T + 67	T + 24
chlortoluron + terbutrine	-	-	-	-	-	-	-	-	-	71±41.9	90±11.5	98±1.7	-
triclopir + chlortoluron	-	-	96±4.9	39±35.5	84±6.7	-	-	-	-	-	-	-	-
tribenuron-methyl	-	32±15.4	75±10.7	0	11±18.5	22±38.1	10±16.7	97±5.4	92±6.8	12.4±21.4	96±7.1	70±25.3	48±23.9
tribenuron-methyl + metribuzine	-	86±5.1	100	56±29.8	44±48.9	33±33.0	91±9.4	97±5.4	97±4.5	86±9.7	100	95±2.5	
isoproturon + cianacine	-	100±0.4	-	-	-	20±34.1	77±29.5	29±25.7	1±1.5	-	-	-	
isoproturon + diflufenican	-	-	100	83±3.7	87±7.2	42±37.5	90±14.5	97±5.4	18±30.7	97±2.8	87±9.0	97±4.0	
terbutrine + triasulfuron	-	-	100±0.8	14±5.5	28±29.0	-	-	-	26±31.3	-	-	-	
isoproturon + metribucine	-	100±0.7	-	-	-	64±40.0	97±3.3	45±25.7	-	-	-	-	
MCPA + diflufenican	-	80±16.8	97±4.4	96±2.2	88±16.7	96±7.9	100	100	84±3.9	73±43.4	52±17.6	100	48±5.8
LPE		T+96	T+ 22 / 63	T + 47 / 24	T + 41	T+18		T+15	T+49	T + 21	T + 38		T + 24
bromoxinil + 2.4-D	-	-	99±1.9	100±0.5	96±5.4	-	-	-	-	87±10.1	100	-	45±46.8
dicamba	-	-	47±61.1	95±3.1	-	17±30.2	-	47±28.3	10±17.3	30±48.5	39±24.6	-	3±5.5
MCPP + ioxinil	-	-	99±1.1	97±2.7	92±2.8	64±31.5	-	91±8.1	49±35.7	69±15.6	74±23.4	-	68±9.8
2.4-D	-	56±12.0	33±17.8	94±0.5	-	46±27.3	-	36±9.8	71±17.6	37±26.9	30±0.0	-	38±33.0
ioxinil + bromoxinil + MCPP (Oxytril)	-	-	100	100±0.5	99±0.9	91±3.9	-	52±11.8	22±37.6	98±2.8	87±22.3	-	91±5.7
ioxinil + bromoxinil + MCPP (Image)	-	-	-	-	-	-	-	-	-	94±11.2	87±23.3	-	72±14.5
florasulam + 2.4-D	-	-	61±19.0	95±6.9	-	35±33.1	-	41±10.8	100	40±32.2	88±15.9	-	68±9.8
bromoxinil + MCPP	-	-	100	99±1.3	100	-	-	-	-	97±2.8	68±27.6	-	62±27.0

Table A 14. b.: Visual efficacy of the herbicides sprayed in the different locations on *Papaver rhoeas* in the cropping seasons 1997-98, 1998-99 and 1999-00.Efficacy calculated on the visual evaluation done at the end of the cropping cycle. PE = Pre-emergence, EPE = Early post-emergence, LPE = Late post-emergence. Red numbers: 95 < efficacy ≤ 100; blue numbers: 90 ≤ efficacy < 95.

	1997-98		1998-99			1999-00				2000-01			
	Savallà del Comptat	**Baldomar 1**	**Baldomar 2**	**Torrelameu**	**Nalec 1**	**Baldomar 2**	**Torrelameu**	**Nalec 2**	**Bellprat**	**Baldomar 2**	**Nalec 2**	**Sanaüja**	**Sta. Coloma de Q.**
PE			**T+134**	**T+172**			**T + 188 / 175**	**T + 201 / 182**		**-**	**-**	**-**	**-**
trifluraline + chlortoluron	-	-	-	96±15.0	-	-	100	74±18.2	-	-	-	-	-
trifluraline + linuron	-	-	100	92±10.4	-	-	100	84±0.0	-	-	-	-	-
chlorsulfuron	-	-	-	-	-	-	48±47.0	42±18.2	-	-	-	-	-
isoxaben	-	-	-	-	-	-	0	15±13.2	-	-	-	-	-
pendimethaline	-	-	100	100±0.6	-	-	100	100	-	-	-	-	-
terbutrine + chlorsulfuron + triasulfuron	-	-	-	-	-	-	90±13.8	84±0.0	-	-	-	-	-
EPE	**T + 55**		**T + 91**	**T + 77**	**T + 83**	**T + 106**	**T + 112**	**T + 84**	**T + 81**				
chlortoluron + terbutrine	-	-	-	-	-	-	-	-	-	-	-	-	-
triclopir + chlortoluron	-	-	77±15.3	40±45.8	47±23.1	-	-	-	-	-	-	-	-
tribenuron-methyl	19±33.7	-	37±20.8	7±5.6	3±5.8	25±42.9	0	84±0.0	90±11.8	-	-	-	-
tribenuron-methyl + metribuzine	-	-	96±5.5	57±25.2	43±3.5	54±26.2	74±13.0	90±9.1	92±0.0	-	-	-	-
isoproturon + cianacine	-	-	-	-	-	41±41.4	77±25.2	53±15.8	3±4.4	-	-	-	-
isoproturon + diflufenican	-	-	98±2.7	53±25.2	83±17.6	60±21.6	96±7.5	95±9.1	8±13.3	-	-	-	-
terbutrine + triasulfuron	-	-	92±5.8	17±15.3	30±26.5	-	-	-	31±53.3	-	-	-	-
isoproturon + metribucine	-	-	-	-	-	69±32.5	68±24.2	46±42.5	-	-	-	-	-
MCPA + diflufenican	-	-	87±7.6	72±18.9	93±11.0	93±3.0	94±6.6	100	67±22.2	-	-	-	-
LPE	**T + 55**		**T + 51 / 91**	**T + 38 / 77**	**T + 50 / 83**	**T + 38**		**T + 34**	**T + 60**				
bromoxinil + 2.4-D	-	-	93±5.2	93±7.2	97±2.9	-	-	-	-	-	-	-	-
dicamba	-	-	23±25.2	73±5.5	78±7.6	22±37.9	-	53±15.8	8±13.3	-	-	-	-
MCPP + ioxinil	-	-	100±0.6	98±2.3	77±15.3	82±12.9	-	100	26±22.2	-	-	-	-
2.4-D	58.3±30.0	-	12±10.4	65±4.5	91±10.0	46±30.1	-	53±15.8	51±8.9	-	-	-	-
ioxinil + bromoxinil + MCPP (Oxytril)	-	-	95±4.5	100±0.6	92±10.4	87±7.9	-	58±32.9	13±22.2	-	-	-	-
ioxinil + bromoxinil + MCPP (Image)	-	-	-	-	-	-	-	-	-	-	-	-	-
florasulam + 2.4-D	-	-	80±10.0	95±13.2	96±2.3	97±4.9	-	100	97±4.4	-	-	-	-
bromoxinil + MCPP	-	-	98±2.9	96±2.3	98±3.5	-	-	-	-	-	-	-	-

III. General Discussion

The study of the different aspects of *Papaver rhoeas* L. biology and of the possible control methods will contribute designing an integrated weed control management strategy of herbicide resistant *P. rhoeas* in the study area of Catalonia (North-eastern Spain).

The study of the different surveyed populations contributes in standardising the weed populations. Some of the described populations can be proposed as reference populations for further work in and outside Spain.

Referring to the different tests used for herbicide resistance detection in the present work, advantages and disadvantages were found. The **whole plant tests** for herbicide resistance detection conducted in greenhouses were very difficult to be conducted with precision, as *P. rhoeas* is very sensitive towards manipulation. Even if handled very carefully, excess of moisture, of direct sun or dryness and also too cold temperatures conduced very easily to plant death. These method, however, were found necessary in order to find the dose-response curves of the different populations, as stated by Heap (1994). For routine tests and for analysing many populations, quick-tests are much more suitable.

The seed-based **quick-tests** were found to be useful for both tested herbicides namely 2.4-D and tribenuron-methyl.

In the case of tribenuron-methyl, susceptible plants could be distinguished from resistant plants considering the development stage of the plants, but no gradual sensitivity behaviour could be observed in the dishes. Thus, the test was qualitative, even if the proportion of susceptible and resistant plants inside the sample could be determined. Together with the lack of dose-response in the greenhouse trials on whole plants, this behaviour suggested that the resistance mechanism was target-site resistance. This is the most frequent mechanism observed in ALS-herbicide resistant weeds (reviewed by Saari *et al.*, 1994).

Nevertheless, a detailed study of the ALS-enzyme by the spectrophotometric method described by Singh *et al.* (1988) could be useful to confirm this hypothesis. Another interesting approach would be the study of the genes codifying for this enzyme of susceptible and resistant populations with the aim of detecting possible mutations.

In the case of 2.4-D, stem length was measured providing information on the resistance degree of the population. The method was quantitative and a ranking between populations could be established. These results together with the dose-response in the greenhouse trials on whole plants suggest that the resistance mechanism is metabolism-based. This is the most frequent herbicide resistance mechanism towards auxin herbicides, found also for other weed species as *Sisymbrium orientale* (reviewed by Holt *et al.*, 1993) and *Carduus nutans* (reviewed by Coupland, 1994).

Also for this herbicide further work is necessary to clarify the resistance mechanism, especially because several different mechanisms are suspected in other weed species resistant to 2.4-D (reviewed by Holt *et al.*, 1993 and by Coupland, 1994).

The **survey** results show that herbicide resistance towards tribenuron-methyl and 2.4-D is widespread. As the spraying history in the area suggested, most of the resistant samples were resistant to both 2.4-D and to tribenuron-methyl. A continuous use of 2.4-D lead to resistance but was substituted in the late 80's by the use of tribenuron-methyl since resistance appeared again. Much less 2.4-D is sprayed in the resistant areas at present, so that the selection pressure nowadays is mainly done by tribenuron-methyl or by other herbicides. This explains the fact that the resistance degree of 2.4-D populations was less than the ones found for tribenuron-methyl.

The percentage of susceptible samples out of the collected populations with known history was low, so that farmers' complains were, in most of the cases, justified.

Also quite a lot of resistant samples were found in the randomly collected populations, indicating that the resistance problem is common in the study area.

The **studies on *P. rhoeas* biology** in the present work have shown that the emergence patterns were independent on the populations' origin, on the resistance or susceptibility of the population and on the seed age. Germination occurred during autumn, the whole winter and in some cases until early spring. Maximum germination was recorded between September and December in both tested fields. The main influence was the location and the year. Direct weed control measures should, thus, be conducted in this period.

The burial experiments showed that the dormancy cycles were in accordance to the emergence periods recorded in the germination experiments in the fields. In the burial treatment, however, germination was possible between May and August, which was not observed in any field, probably due to too high temperatures and drought. If the seeds were placed in the appropriate climatic conditions, germination was possible also in these months.

Initial plant densities and final plant survival was found to be very irregular in the study area. Even if high mortality occurred in most of the times, final huge densities were also found in some cases. It is thus difficult to predict the possible plant density evolution, as it mainly depends on competition and on climatic conditions, which are variable.

The long survival capacity after 31 months even in 20 cm depth shows that once big *P. rhoeas* populations have been established in a field, control measures will have to be taken during a long time. Exhausting the seed-bank in big populations is probably not a realistic target.

An initial plant density reduction up to around 40% could be obtained by **ploughing** during the first cropping season and a reduction was visible still 2 years after. In case of high initial *P. rhoeas* populations additionally control methods were necessary. The same reduction was obtained regardless in which year ploughing was conducted, suggesting that this practice depends mainly on the burial of the seeds independently of the climatic conditions. Aiming to reduce the *P. rhoeas* weed density, ploughing should not be repeated after several years, as the buried weed seeds were still alive and non-dormant when brought up to surface again.

Harrowing was an effective control method when conducted in the right moment and when the climatic conditions favoured weed mortality. If only mechanical control is targeted, an accurate observation of weed plant number and weed size is necessary in order to conduct the harrowing treatments in time.

One of the principles guiding weed management is delaying weed emergence relative to crop emergence (Liebmann & Gallandt, 1997). Pre-emergence harrowing and early post-emergence treatments follow this objective, by reducing early weed competition. In the present work, different timing combinations were tested. Despite the gradual emergence of *P. rhoeas*, it would be interesting to see the effect of earlier harrowing treatments conducted in November or in December. Probably the emerged weeds would be well controlled due to their small size. New germination could be stimulated in these early treatments, forcing to a later control, which would included then small mainly easy to control weeds.

The **combination of herbicides and mechanical weed control** would as well be interesting to be studied on the herbicide resistant *P. rhoeas* populations. Caseley *et al.* (1993), Blair & Green (1993) and Cashmore & Caseley (1995) conducted experiments on mixed weed populations susceptible to herbicides combining sublethal herbicide doses. Also the use of a first mechanical and a second herbicide treatment (if necessary) could be investigated as tested by Ferrero & Vidotto (2000) on susceptible weeds. Any of these techniques would reduce the herbicide use leading to preventing new outcome of herbicide resistance among weeds.

The herbicide trials show that a **chemical control** of herbicide resistant *P. rhoeas* populations is possible. Nevertheless, in very few cases a constant efficacy throughout the different populations, fields and years was found. Also irregular phytotoxicity levels were detected depending on the year and on the field.

These results show again that a reliance on herbicides alone can be risky. Further work on chemical weed control could focus on:

- Testing the activity of the active ingredients or mixtures containing ioxinil, bromoxinil and florasulam on *P. rhoeas* plants in earlier growth stages.
- Adjusting dosage of the herbicides found effective (pendimethaline, trifluraline + linuron, some mixtures containing bromoxinil, etc.).
- Checking the activity of metribuzine, cianazine and diflufenican, which gave irregular control results in the field trials.
- Testing the risk of phytotoxicity of some of these herbicides in further experiments.

Some of these tests could be conducted in greenhouse trials, saving time and homogenising some environmental factors. Greenhouse trials allow also testing a higher number of populations.

Some of the populations resistant towards 2.4-D and tribenuron-methyl already showed less sensibility to ioxinil in greenhouse tests (data not shown). The most active herbicides found in the experiments as pendimethaline, trifluraline + chlortoluron, trifluraline + linuron, mixtures including ioxinil, bromoxinil or diflufenican, florasulam + 2.4-D and others are already being more used for *P. rhoeas* control than when this work started.

For many of these products, which were effective on herbicide resistant *P. rhoeas,* herbicide resistance is known on other weed species. For example, a resistant biotype of *Alopecurus myposuroides* towards pendimethaline has been found in United Kingdom. A population of *Fumaria densiflora* resistant to trifluraline is quoted from Australia. *Amaranthus powelii* and *Senecio vulgaris* are described as resistant to linuron in USA and Switzerland, respectively. A resistant *Senecio vulgaris* biotype towards bromoxinil has been found in USA. Herbicide resistant *Raphanus raphanistrum* to diflufenican is quoted from Australia (Heap, 2001). And despite being active on ALS-resistant *P. rhoeas*, florasulam is an ALS-inhibitor, which belongs to the chemical family of herbicides, in which most cases of resistant weeds have been found.

Thus, if these products are not used in rotation or combined with other methods including the ones described in this work, new cases of lack of control can occur again on *P. rhoeas*.

Taking into account that high populations of *P. rhoeas* are difficult to control with any of the described methods including herbicides and that the seed bank is very persistent, prevention of big populations would probably be an important target.

If the weed management relies completely on herbicides and there is an abuse, resistance can develop and probably high densities will be faced. Thus, prevention of herbicide resistance will also lead to lower weed densities.

Following the recommendations of the HRAC (2001), **Integrated Weed Management** should be targeted both for prevention and management of herbicide resistance. This would include crop rotation, cultural techniques and herbicide control.

Regarding *P. rhoeas* control in the study area, crop rotation shows certain limits. Possible alternative crops to cereals are mainly oil-seed rape (*Brassica napus*) and peas (*Pisum sativum*). In the study area both crops are sown earlier than the cereal, so that germination of *P. rhoeas* will occur after sowing. Moreover, the use of herbicides for broad-leaf weed control inside these crops is very limited. This problem is especially important for *P. rhoeas*.

An alternative to crop rotation could be a one-year fallow. The set-aside policy of the European Union reduces the cost of this practice, as a certain percentage of the total farm surface has to be either set-aside or cultivated with a non-food crop, anyway. This method would be a more drastic preventive or curative strategy, which would allow the elimination of any germinated *P. rhoeas* plant during one year.

Possible cultural techniques suggested by the HRAC (2001) would include in the present case ploughing, delaying sowing date and mechanical weed control. As discussed previously, these techniques could be very useful when conducted in the correct form.

Finally, herbicide control will probably continue the most wide spread weed control strategy in the study area. In order to prevent and to control herbicide resistant weed populations, chemical control should be conducted in all cases very carefully taking into account the discussed preventive measures.

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IV. Conclusions

Conclusions

The detailed conclusions of each chapter correspond basically to the following main conclusions:

1. The best medium composition for the seed-based quick-test for herbicide resistance detection towards tribenuron-methyl in *Papaver rhoeas* was based on a 1.3 % agar medium containing 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} and 7.68 μmol a.i. tribenuron-methyl and was useful to describe the frequency of herbicide resistant plants inside the seed sample.

2. The best medium composition for the seed-based quick-test for herbicide resistance detection towards 2.4-D was based on a 1.3 % agar medium containing 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} and 3.49 μmol a.i. 2.4-D and was useful to find a hipocotyl length ratio, which was bigger for high-degree resistant populations.

3. The mortality of the populations resistant to tribenuron-methyl did not increase with increasing herbicide rate. This behaviour corresponds to a target-site resistance due to a mutation of the point of action.

4. The mortality of the 2.4-D resistant populations increased with increasing herbicide rate. This behaviour corresponds to herbicide resistance based on an enhanced metabolism activity.

5. The most frequent cases found in the semi-directed survey on *P. rhoeas* was resistance towards both tribenuron-methyl and 2.4-D with a high proportion of resistant plants towards tribenuron-methyl and with low-degree resistance towards 2.4-D.

6. Germination of *P. rhoeas* was found to occur between September and April, but main germination was observed between October and December.

7. Shallow cultivation at around 5 cm depth conducted in September and/or October stimulated the germination of *P. rhoeas* in a field pot experiment. Cereal seed bed preparation can thus stimulate the germination of this weed.

8. No differences in the germination period, neither in the amount of germination nor in the longevity of the seed bank were observed between *P. rhoeas* populations susceptible or resistant to the herbicides.

9. High natural plant mortality of *P. rhoeas* mainly between February and April was found in most of the studied cases. Dry conditions often enhanced this mortality.

10. Buried *P. rhoeas* seeds showed a cyclic dormancy pattern, similar in 2, 8 and 20 cm depth. Once exhumed and placed in optimal germination conditions germination was high from September to January.

11. Seed viability ranged between 63 and 99% after 31 months of burial at 2, 8 and 20 cm depth depending also on the populations' origin. To avoid germination in field conditions, seeds placed in depth should not be moved upwards soon.

12. One-year ploughing reduced *P. rhoeas* emergence to around 40% and the effect was still visible two years later. When ploughing was conducted again two years later, more germination occurred than after one single ploughing.

13. Pre-emergence harrowing had a very low or inappreciable effect on *P. rhoeas*. Post-emergence harrowing should be conducted in early weed growth stages before development of the strong tap-root. A higher control effect was achieved when harrowing was conducted in dry conditions. Increasing speed tended only to result in higher weed control.

14. Chemical control of tribenuron-methyl and/or 2.4-D resistant *P. rhoeas* populations in cereal fields is possible with herbicides applied in pre-emergence, early and late post-emergence. The most regular effect in pre-emergence was achieved with pendimethaline, trifluraline + chlortoluron and trifluraline + linuron. In early post-emergence the efficacy of the herbicides was less regular. The best compounds found were: isoproturon + diflufenican, MCPA + isoproturon and tribenuron-methyl + metribuzine. In late post-emergence mixtures containing bromoxinil or ioxinil and the mixture florasulam + 2.4-D achieved high efficacy in many cases.

15. The detection of some *P. rhoeas* populations less susceptible to ioxinil + bromoxinil + 2.4-D as well as the growing cases of resistance towards tribenuron-methyl and 2.4-D forces to prevent and to manage herbicide resistance by conducting Integrated Weed Management. A combination of soil ploughing, shallow cultivation, weed harrowing and change of herbicides is proposed.

Conclusiones

Las conclusiones detalladas de cada capítulo corresponden básicamente a las siguientes conclusiones generales:

1. La mejor composición del medio para el test rápido basado en semillas para la detección de la resistencia al herbicida tribenurón-metil en *Papaver rhoeas* fue un medio de agar al 1.3% que contenía 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} y 7.68 μmol m. a. tribenurón-metil. El método fue usado para describir la frecuencia de las plantas resistentes dentro de la muestra de semillas.

2. La mejor composición del medio para el test rápido basado en semillas para la detección de la resistencia al herbicida 2.4-D fue un medio de agar al 1.3% que contenía 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} y 3.49 μmol m. a. 2.4-D. El método fue usado para encontrar un ratio de longitud del hipocótilo el cual era mayor para poblaciones de resistencia elevada.

3. La mortalidad de las poblaciones resistentes a tribenurón-metil no incrementó con un aumento de la dosis de herbicidas. Este comportamiento corresponde a un mecanismo de resistencia basado en la mutación del punto de acción del herbicida.

4. La mortalidad de las poblaciones resistentes a 2.4-D incrementó con un aumento de dosis de herbicida. Este comportamiento corresponde a una resistencia al herbicida basada en un aumento de la actividad metabólica.

5. Los casos más frecuentes encontrados en una prospección semi-dirigida de *P. rhoeas* fueron de resistencia a ambos tribenurón-metil y 2.4-D con una alta proporción de plantas resistentes a tribenurón-metil y con un grado de resistencia a 2.4-D bajo.

6. Se observó germinación de *P. rhoeas* entre septiembre y abril, aunque el período de máxima germinación fue entre octubre y diciembre.

7. El laboreo superficial en una profundidad de aproximadamente 5 cm realizado en septiembre y/o octubre estimuló la germinación de *P. rhoeas* en un ensayo en tiestos en campo. La preparación del lecho de siembra del cereal puede por tanto estimular la germinación de esta especie.

8. No se observaron diferencias en el período de germinación, la cantidad de germinación ni en la longevidad del banco de semillas entre poblaciones de *P. rhoeas* sensibles o resistentes a los herbicidas.

9. Se encontró una mortalidad natural elevada de *P. rhoeas* principalmente entre febrero y abril. En muchos casos, la sequía incrementó la mortalidad.

10. Semillas de *P. rhoeas* enterradas mostraron un patrón de dormición cíclico similar para profundidades de enterrado de 2, 8 o 20 cm de profundidad. Una vez desenterradas y mantenidas en condiciones de germinación óptimas se observó germinación elevada entre septiembre y enero.

11. La viabilidad de las semillas osciló entre 63 y 99% tras 31 meses de enterrado a 2, 8 o 20 cm de profundidad dependiendo también del origen de las poblaciones. Con el fin de evitar germinación en campo las semillas no deben ser subidas a capas superficiales del suelo poco tiempo después de ser enterradas.

12. Un laboreo en profundidad con arado de vertedera redujo la emergencia de *P. rhoeas* alrededor de 40% y el efecto fue todavía visible dos años más tarde. Cuando el laboreo se produjo de nuevo dos años más tarde se observó más germinación que después de un único laboreo.

13. El uso de la grada de púas flexibles en pre-emergencia tuvo un efecto pequeño o inapreciable sobre *P. rhoeas*. En post-emergencia la grada debe ser utilizada en estadíos precoces de la hierba, antes de que ésta desarrolle la fuerte raíz pivotante. Se obtuvo un mejor control cuando el suelo estaba en condiciones secas. Un aumento de la velocidad solamente tendió repercutir en un mayor control de *P. rhoeas*.

14. El control químico de poblaciones de *P. rhoeas* resistentes a tribenurón-metil y/o 2.4-D es posible mediante herbicidas utilizados en pre-emergencia y en post-emergencia precoz y tardía. El efecto más regular en pre-emergencia fue obtenido con pendimetalina, trifluralina + clortolurón y trifluralina + linurón. En post-emergencia precoz la eficacia de los herbicidas fue menos regular. Los mejores productos encontrados fueron: isoproturón + diflufenican, MCPA + isoproturón y tribenurón-metil + metribucina. En post-emergencia tardía, las mezclas conteniendo bromoxinil o ioxinil y las mezcla florasulam + 2.4-D alcanzaron eficacias elevadas en muchos casos.

15. La detección de algunas poblaciones de *P. rhoeas* menos sensibles a ioxinil + bromoxinil + 2.4-D así como el incremento de casos de resistencia frente a tribenurón-metil y a 2.4-D obliga a prevenir y a controlar la resistencia a los herbicidas mediante un Manejo Integrado de las Malas Hierbas. Se propone una combinación de las técnicas de laboreo del suelo, el uso de la grada de púas flexibles y un cambio en el uso de los herbicidas.

Conclusions

Les conclusions detallades de cada capítol corresponen bàsicament a les següents conclusions generals:

1. La millor composició del medi per al test ràpid basat en llavors per a la detecció de la resistència a l'herbicida tribenuró-metil a *Papaver rhoeas* va ser un medi d'agar al 1.3% que contenia 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} i 7.68 μmol m. a. tribenuró-metil. Aquest mètode va ser emprat per a descriure la freqüència de les plantes resistents dins de la mostra de llavors.

2. La millor composició del medi per al test ràpid basat en llavors per a la detecció de la resistència al herbicida 2.4-D a *P. rhoeas* va ser un medi d'agar al 1.3% que contenia 2 g KNO_3 L^{-1}, 0.2 g GA_3 L^{-1} i 3.49 μmol m. a. 2.4-D. Aquest mètode va ser emprat per a trobar un ratio de longitud de l'hipocòtil , el qual era més gran per a poblacions de resistència elevada.

3. La mortalitat de les poblacions resistents a tribenuró-metil no va incrementar amb un augment de la dosis de herbicides. Aquest comportament correspon a un mecanisme d'acció basat en la mutació d'un punt d'acció de l'herbicida.

4. La mortalitat de les poblacions resistents a 2.4-D va incrementar amb un augment de la dosis d'herbicida. Aquest comportament correspon a una resistència a l'herbicida basada en un augment de l'activitat metabòlica.

5. Els casos més freqüents trobats a una prospecció semi-dirigida de *P. rhoeas* van ser resistència a tribenuró-metil i a 2.4-D amb una alta proporció de plantes resistents a tribenuró-metil i amb un grau de resistència a 2.4-D baix.

6. La germinació de *P. rhoeas* es va observar entre setembre i abril, tot i que el període de màxima germinació va ser entre octubre i desembre.

7. El conreu del sòl a una fondària d'aproximadament 5 cm realitzat al setembre i/o octubre va estimular la germinació de *P. rhoeas* a un assaig en testos a camp. La preparació del llit de sembra del cereal pot, per tant, estimular la germinació d'aquesta espècie.

8. No es van observar diferències al període de germinació, a la quantitat de germinació ni a la longevitat del banc de llavors entre poblacions de *P. rhoeas* sensibles o resistents als herbicides.

9. Es va trobar una mortalitat natural elevada de *P. rhoeas* principalment entre febrer i abril. A molts casos, la sequera va incrementar la mortalitat.

10. Llavors de *P. rhoeas* enterrades van mostrar un patró de dormició cíclic simlar per a les fondàries d'enterrat a 2, 8 o 20 cm. Una vegada desenterrades i mantingudes a condicions de germinació òptimes, es va observar una germinació elevada entre setembre i gener.

11. La viabilitat de les llavors va oscil·lar entre 63 i 99% després de 31 mesos d'enterrat a 2, 8 o 20 cm de fondària depenent també de l'origen de les poblacions. Amb la finalitat d'evitar germinació a camp les llavors no han de ser pujades a capes superficials del sòl poc temps després de ser enterrades.

12. Un conreu del sòl en profunditat amb l'arreu de pales va reduir l'emergència de *P. rhoeas* al voltant de 40% i l'efecte va ser encara visible dos anys més tard. Quan el conreu del sòl es va repetir dos anys més tard, es va observar una germinació més alta que després d'un únic laboreig.

13. La utilització de la grada de pues flexible en pre-emergència va tenir un efecte petit o inapreciable sobre *P. rhoeas*. A post-emergència cal utilitzar la grada en estadis precoços de l'herba, abans de que aquesta desenvolupi la forta arrel pivotant. Es va obtenir un millor control quan el sòl estava en condicions seques. Un augment de la velocitat va tendir solament a un major control de *P. rhoeas*.

14. El control químic de poblacions de *P. rhoeas* resistents a tribenuró-metil i/o 2.4-D és possible mitjançant herbicides utilitzats en pre-emergència i en post-emergència tant precoç com tardana. L'efecte més regular en pre-emergència va ser obtingut amb pendimetalina, trifluralina + clortoluró i trifluralina + linuró. En post-emergència precoç l'eficàcia dels herbicides va ser menys regular. Els millors productes trobats van ser: isoproturó + diflufenican, MCPA + isoproturó i tribenurón-metil + metribucina. A post-emergència tardana, les barreges que contenen bromoxinil o ioxinil així com la barreja florasulam + 2.4-D van resultar en eficàcies elevades a molts casos.

15. La detecció d'algunes poblacions de *P. rhoeas* menys sensibles a ioxinil + bromoxinil + 2.4-D així com l'increment de casos de resistència a tribenuró-metil i a 2.4-D obliga a prevenir i a controlar la resistència als herbicides mitjançant un Maneig Integrat de Males Herbes. Es proposa una combinació de les tècniques del laboreig del sòl, la utilització de la grada de pues flexibles i un canvi en l'ús dels herbicides.