# Rate, Timing and Split Application of Glyphosate to Control Plants of *Poa pratensis* L. and *Festuca rubra* L. after Seed Harvest

Peter Kryger Jensen[1]

## ABSTRACT

The control of regrowth of *Poa pratensis* L. and *Festuca rubra* L. ssp. *rubra* after the last seed harvest by single and split applications of glyphosate was investigated. Glyphosate application rates ranged from 720 to 2160 g. a.i. ha$^{-1}$ for *Poa pratensis* and from 432 to 2160 g. a.i. ha$^{-1}$ for *Festuca rubra*. Control of regrowth of both species was dependent on application timing. For a single glyphosate application, control was greater for the lowest application rate at an optimal time than for the highest application rate at an unfavourable time. Poor control of regrowth was primarily seen when treatments were applied in a dry period with a high soil moisture deficit. High efficcacy on the other hand was obtained from applications where growth was not limited by moisture deficit. Split applications did not generally increase control efficacy over that of a single application at the optimal time, provided the same total amount of active ingredient was used. This result occurred for different time intervals between applications, for two or three application splits, and for equal and unequal splits between two application dates. However split application increased the control stability, as split application efficacy was greater than the mean for single applications on the same dates.

*Additional index words*: *Poa pratensis* L., *Festuca rubra* L. ssp. *rubra*, control, split application, regrowth control.

## INTRODUCTION

For grass seed production, it is important to avoid crop contamination by plants from a cultivar previously grown in the same field. Contamination arises if the soil still contains volunteer seeds from a previous grass seed crop at the time when the next grass seed crop of another cultivar is established after the required time interval of three to five years between consecutive crops. Such contamination can arise from different sources during the period between the two grass seed crops. One such source of contamination comes from old grass plants that are not properly destroyed after the final seed harvest and are allowed to re-establish in the following crop. This will inevitably allow grass seed production in this crop and thereby a maintenance of the soil seed bank. Stubble cultivation and ploughing are not effective tools for controlling the old grass plants and glyphosate treatment is often used in order to provide more effective control. However treatments with glyphosate are not always effective, and this is especially so when the interval between the grass seed harvest and the following crop is short. A dry period, which allows only limited regrowth before treatment also reduces efficacy.

One possibility for increasing glyphosate efficacy is the use of split applications. This strategy has improved the control of annual dicot weeds and in sugar beet, increased efficacy of weed control compared to a single treatment, while using the same total amount of herbicide (Pallutt and Hoffman, 1980; Dexter, 1987; Norris, 1991). Similar results have been obtained in soybeans (Defelice, Brown, Aldrich, Sims, Judy, and Guethle, 1989), in potatoes (Speller and Dover, 1989), in peas (Jensen, 1992) and in oilseed rape (Jensen, 1994). These reports all describe results with newly emerged weeds. Single applications with foliar herbicides must be delayed until almost all weeds have emerged, and at that time the weed population consists of larger weeds requiring a higher total application rate. The improved efficacy under these circumstances is obtained because small weeds can be controlled with a very low herbicide rate (Kudsk, 1989). The principle with split application is in fact to obtain control of all emerged weeds at both application dates.

The use of single versus split applications to control older plants of *Avena fatua* L. (Gummeson, 1975) and *Sorghum halepense* L. (Banks and Tripp, 1983) did not show any advantage for split application. Similar investigations with *Elytrigia repens* L. (Trimmer and Linscott, 1988; Harker, 1995) showed more variable results, with improved efficacy for split application in some cases.

The idea in using a split application on established plants is to weaken the plants with the first application, and then after an interval control the damaged plants with the second application. In species with buds the objective is to kill actively growing shoots with the first application. Resting buds do not act as sinks and herbicides therefore are not transported into these in lethal concentrations. Killing of shoots with the first application however often results in termination of the condition of apical dominance enforced by these shoots, and resting shoots will start sprouting. With split application the second application is used to kill these shoots.

The objective of this investigation was therefore to test these hypotheses when controlling the regrowth of *Poa pratensis* and *Festuca rubra* ssp. *rubra*.

## MATERIALS AND METHODS

Three field experiments were conducted at the Danish Institute of Agricultural Sciences in Flakkebjerg during the period 1995-1998. Experiments were carried out in grass seed fields which had grown grass seed crops according to normal agricultural practice. The experimental treatments were applied to regrowth of stubble fields of *Poa pratensis* L. cv. Balin (1995 and 1996) and *Festuca rubra* L. ssp. *rubra* cv. Pernille (1997). After seed harvest in July, the straw was removed, and the fields were left undisturbed until the

[1] *Danish Institute of Agricultural Sciences, Department of Crop Protection, Research Centre, Flakkebjerg, DK-4200 Slagelse, Denmark.* *Accepted for publication 4 December 1998.*

experimental glyphosate treatments were applied using a self-propelled plot sprayer equipped with Hardi S4110-14 flat fan nozzles delivering a volume of 165 l $ha^{-1}$ at 6 km $h^{-1}$. Plot size used in all years was 2.5 x 3.0 m. The randomized complete block design included six replicates per treatment in *Poa pratensis* and five replicates per treatment in 1997 in *Festuca rubra*. The high number of replicates were chosen because the regrowth from stubble fields normally is relatively heterogeneous.

Effect of treatments on regrowth was monitored with a non-destructive measurement of plant canopy reflectance in the red and the near-infrared spectrum. The reflectance measurements were converted to vegetation indices that measure the photosynthetic size of plant canopies. A close correlation between plant biomass and vegetation index was found by Jensen and Christensen (1993) and the use of vegetation indices therefore offers an alternative method of evaluating herbicide performance in pure stands. The measurements, presented as a vegetation index (RVI), range from approximately 1.3 on bare soil and increase linearly with biomass within the range recorded in these experiments. The RVI is converted to relative figures, with biomass in the control equal to 100 in Tables 2-4. The experiments were left undisturbed until the following spring in order to evaluate long-term glyphosate activity. The results from the experiments are presented for two reflectance measurements. The first measurement was taken around December 1, 1-2 months after the last treatment. The second reflectance measurement was taken the following spring (early May) when growth had resumed after the winter.

moisture deficit in the period after seed harvest. An interval of 3-4 weeks between subsequent application times was used.

Due to the extreme differences in efficacy between treatments, it was not possible to fit dose response curves to the data from all treatments. The statistical evaluation is therefore based on an LSD test ($P<0.05$).

## RESULTS

In *Poa pratensis* the early single application (treatment 2) in 1995 performed very poorly compared to the two later single applications (Table 2). The efficacy of the 2160 g. a.i.$ha^{-1}$ application rate in the early spraying was less than that for the 970 g. a.i. $ha^{-1}$ application rate used in the later single application. Efficacy with 2160 g. a.i. $ha^{-1}$ in treatment 2 was also less than from any of the split application treatments which received a total dosage of 970 g. a.i. $ha^{-1}$, although some of these included the early application date. Complete control had not been obtained in any of the treaments at the autumn evaluation, despite the fact that the autumn measurement was carried out 1.5 months after the last application. For the spring evaluation, treatments 3 and 4 changed order compared to the autumn assessment. Generally no advantage of split application was found compared to single application of the same total rate when the timing was optimal.

Results from the 1996-97 experiment (Table 3) follow the same trends as the preceding year with little if any benefit

**Table 1. Experimental treatments: the plan shows the percentage of the total rate of glyphosate applied at each application time**

| | | Application time | | |
|---|---|---|---|---|
| | Treatment | 1st spray | 2nd spray | 3rd spray |
| 1. | Untreated | | | |
| 2. | 1st date | 100 | | |
| 3. | 2nd date | | 100 | |
| 4. | 3rd date | | | 100 |
| 5. | 1st & 2nd date | 50 | 50 | |
| 6. | 1st & 3rd date | 50 | | 50 |
| 7. | 2nd & 3rd date | | 50 | 50 |
| 8. | 1st, 2nd & 3rd date | 33 | 33 | 33 |
| 9. | 1st & 3rd date | 66 | | 33 |
| 10. | 1st & 3rd date | 33 | | 66 |

Treatments in all years followed the protocol in Table 1, except treatments 8-10 which were included only in the last two years. The experiments included four glyphosate application rates in 1995 and 1996, and 5 rates in 1997. The first application date was when the regrowth in the stubble fields had reached a height of approximately 10 cm. This stage occurred at the end of August, 4-6 weeks after seed harvest. It was very difficult to define the growth stage as the stubble fields typically consisted of a few green tillers with a couple of leaves and a lot of shoots which had not started growth after the seed harvest. The limited regrowth seen in all three years at the first application was primarily due to a high

obtained from split application. The only exception was when the early or late single application (treatments 2 and 4) was compared with the split application at these same timings (treatment 6). This was the only instance where a split application gave an efficacy greater than both of the corresponding single applications. Large differences in efficacy of single applications between the three application dates were also recorded in this year.

The experiment in *Festuca rubra* in 1997-98 followed the same trend as the two preceding years with *Poa pratensis*, with little benefit obtained using split application. In the spring an increasing RVI with increasing glyphosate rate was found

Table 2. Effect of single and split applications of glyphosate (Roundup) on regrowth of *Poa pratensis* in 1995/1996. The effect is evaluated as a vegetation index and converted to relative figures with biomass in the control = 100.

| Treatment | Application timing in 1995 | | | Rate of glyphosate (g. a.i. ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30/8 | 20/9 | 16/10 | 720 | 970 | 1440 | 2160 | 720 | 970 | 1440 | 2160 |
| | Percentage of the total rate applied | | | Assessment 1/12/1995 | | | | Assessment 6/5/1996 | | | |
| 1. | | | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. | 100 | | | 55 | 52 | 42 | 47 | 38 | 35 | 25 | 24 |
| 3. | | 100 | | 22 | 21 | 16 | 17 | 3 | 2 | 2 | 2 |
| 4. | | | 100 | 32 | 28 | 23 | 24 | 1 | 1 | 1 | 1 |
| 5. | 50 | 50 | | 27 | 24 | 20 | 17 | 12 | 5 | 4 | 3 |
| 6. | 50 | | 50 | 46 | 43 | 22 | 20 | 4 | 4 | 3 | 3 |
| 7. | | 50 | 50 | 25 | 25 | 18 | 16 | 2 | 2 | 2 | 2 |
| 8. | 33 | 33 | 33 | 27 | 24 | 22 | 20 | 7 | 4 | 3 | 3 |
| LSD P<0.05 | | | | 11 | 6 | 4 | 9 | 9 | 6 | 9 | 6 |

Table 3. Effect of single and split applications of glyphosate (Roundup) on regrowth of *Poa pratensis* in 1996/97. The effect is evaluated as a vegetation index and converted to relative figures with biomass in the control = 100.

| Treatment | Application timing in 1996 | | | Rate of glyphosate (g. a.i. ha$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 27/8 | 19/9 | 21/10 | 720 | 970 | 1440 | 2160 | 720 | 970 | 1440 | 2160 |
| | Percentage of the total rate applied | | | Assessment 3/12/1995 | | | | Assessment 5/5/1996 | | | |
| 1. | | | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. | 100 | | | 47 | 44 | 38 | 34 | 84 | 72 | 36 | 28 |
| 3. | | 100 | | 37 | 33 | 29 | 26 | 19 | 15 | 13 | 13 |
| 4. | | | 100 | 88 | 77 | 71 | 53 | 74 | 48 | 34 | 26 |
| 5. | 50 | 50 | | 43 | 38 | 35 | 31 | 62 | 38 | 22 | 21 |
| 6. | 50 | | 50 | 58 | 49 | 40 | 33 | 79 | 61 | 25 | 17 |
| 7. | | 50 | 50 | 49 | 42 | 31 | 31 | 25 | 15 | 12 | 12 |
| 8. | 33 | 33 | 33 | 46 | 43 | 36 | 34 | 54 | 33 | 17 | 16 |
| 9. | 67 | | 33 | 52 | 46 | 38 | 35 | 96 | 59 | 27 | 18 |
| 10. | 33 | | 67 | 72 | 58 | 41 | 34 | 80 | 59 | 25 | 18 |
| LSD P<0.05 | | | | 9 | 8 | 9 | 9 | 18 | 12 | 8 | 16 |

(Table 4) after the early treatment 2. This was due to the fact that the growth started earlier in the spring in these plots, probably because light and temperature were more favourable as a consequence of a reduced amount of dead leaves in the spring.

## DISCUSSION

In Denmark the preferred crop after a grass seed crop is winter wheat. In order to avoid re-establishment of old grass plants in the following crop it is important to control them effectively for two reasons. One is that regrowth of grass plants can cause yield depression in the following crop, and they cannot be controlled in winter wheat and other cereals. Second, plants that re-establish are able to produce seeds and thereby maintain a seedbank. If a grass seed crop is established on the same area a few years later there will be an increased risk of contamination from the previous grass seed crop.

Glyphosate products are often used on grass regrowth after the last seed harvest, in order to control the plants before the next crop is established. The treatments are however not always effective. Split application has been used to improve efficacy of herbicides against newly emerged seed propagated weeds. It was therefore important to investigate the use of this method to improve the control of grasses with glyphosate. *Poa pratensis* and *Festuca rubra* were chosen because control of these plants is difficult, especially for *Festuca rubra* ssp. *rubra* with its stoloniferous habit. These species were supposed to behave like *Elytrigia repens*, where apical dominance exerted by shoots results in resting buds with little or no assimilate sink. Many of these buds are relatively inaccessible to herbicide action (Claus and Behrens, 1976; Stoltenberg and

**Table 4. Effect of single and split applications of glyphosate (Roundup) on regrowth of *Festuca rubra* ssp. *rubra* in 1997/98. The effect is evaluated as a vegetation index and converted to relative figures with biomass in the control = 100.**

| Treatment | Application timing in 1997 | | | Rate of glyphosate (g. a.i. ha$^{-1}$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25/8 | 19/9 | 14/10 | 432 | 720 | 970 | 1440 | 2160 | 432 | 720 | 970 | 1440 | 2160 |
| | Percentage of the total rate applied | | | Assessment 25/11/1997 | | | | | Assessment 22/4/1998 | | | | |
| 1. | | | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 2. | 100 | | | 83 | 81 | 70 | 58 | 53 | 82 | 107 | 101 | 109 | 120 |
| 3. | | 100 | | 56 | 39 | 25 | 19 | 16 | 75 | 48 | 23 | 15 | 11 |
| 4. | | | 100 | 79 | 72 | 66 | 52 | 50 | 70 | 60 | 49 | 39 | 26 |
| 5. | 50 | 50 | | 78 | 61 | 41 | 34 | 25 | 94 | 71 | 54 | 44 | 29 |
| 6. | 50 | | 50 | 86 | 83 | 70 | 63 | 54 | 84 | 85 | 74 | 57 | 52 |
| 7. | | 50 | 50 | 72 | 57 | 45 | 36 | 21 | 69 | 48 | 32 | 27 | 14 |
| 8. | 33 | 33 | 33 | 75 | 69 | 58 | 41 | 32 | 70 | 64 | 56 | 44 | 24 |
| 9. | 67 | | 33 | 88 | 82 | 69 | 59 | 52 | 89 | 80 | 73 | 68 | 65 |
| 10. | 33 | | 67 | 88 | 84 | 73 | 70 | 49 | 67 | 72 | 64 | 54 | 38 |
| LSD $P<0.05$ | | | | 9 | 13 | 11 | 13 | 9 | 21 | 24 | 20 | 24 | 26 |

**Table 5. July to October rainfall, potential evaporation (1995-97) and 30 year rainfall mean (mm).**

| | 1995 | | 1996 | | 1997 | | |
|---|---|---|---|---|---|---|---|
| Month | Rainfall | Potential evaporation | Rainfall | Potential evaporation | Rainfall | Potential evaporation | Rainfall 30 year mean |
| July | 13 | 121 | 27 | 105 | 51 | 109 | 59 |
| August | 13 | 114 | 33 | 105 | 80 | 107 | 55 |
| September | 80 | 41 | 54 | 50 | 16 | 62 | 59 |
| October | 13 | 17 | 56 | 15 | 75 | 24 | 53 |

Wyse, 1986; Harker and Dekker, 1988). With one exception split application of glyphosate did not improve the control obtained compared with the best single application on any of the two grasses tested. The only argument for using split application is that the control obtained was less variable than the control obtained with single application, where a high application rate at an unfavourable time was more or less wasted.

The three experiments have shown that application timing is very important. Generally only poor control was obtained with an early single application when regrowth was approximately 10 cm high at the end of August. Better control was achieved with the two later single applications in September or October in the experiments with *Poa pratensis*. In the third experiment in *Festuca rubra* however, it was surprising that the efficacy obtained from the single applications on the third application date was much poorer than from the second application. Both the weather conditions and the plant conditions were evaluated as nearly optimal for good control. This variable effect could be an argument for using split application, as a more stable efficacy level was obtained no matter which application dates were involved.

The reasons for the low efficacy at the early application were not clarified in this investigation. One reason could be that regrowth was minimal at the early timing. Another reason could be the high moisture deficit which was found in all three years in the last part of August. This is illustrated in Table 5 which shows the monthly rainfall and potential evaporation in the three years. The two first years had a rainfall below the normal in July and August. In 1997 rainfall was above the normal, but this was due to 60 mm in the last days of August after the first application. The decision as to whether the application should be carried out or should await further regrowth is difficult. The investigations will therefore continue in order to isolate factors which can be used to describe the regrowth in situations where good control can be obtained. The soil moisture regime will be followed closely as drought stress has been shown to have a major influence on the activity of systemic herbicides against different weeds (Boydston, 1992; Rossi, di Tomaso and Neal, 1993), and probably had a significant influence here. For the time being the advice is to control the regrowth when it has developed a height of 10-15 cm, and in a period where growth is not limited by drought stress.

## ACKNOWLEDGEMENTS

The investigation was financed by the Research Programme "Seed Production".

## REFERENCES

1. Banks, P. A. and Tripp, T. N. 1983. Control of Johnsongrass (*Sorghum halepense*) in soybeans (*Glycine max*) with foliar applied herbicides. *Weed Science* 31:628-633.

2. Boydston, R. A. 1992. Drought stress reduces fluazifop-P activity on green foxtail *(Setaria viridis). Weed Science* 40:20-24.

3. Claus, J. S. and Behrens, R. 1976. Glyphosate translocation and quackgrass rhizome bud kill. *Weed Science* 24:149-152.

4. Defelice, M. S., Brown, W. B., Aldrich, R. J., Sims, B. D., Judy, D. T., and Guethle, D. R. 1989. Weed control in soybeans (*Glycine max*) with reduced rates of postemergence herbicides. *Weed Science* 37:365-374.

5. Dexter, A. G. 1987. Influence of additives on sugarbeet injury and weed control from postemergence herbicides. *1987 Sugarbeet research and extension reports, North Dakota State University of Agriculture and Applied Science* 18:57-63.

6. Gummeson, G. 1975. Bekämpning av flyghavre. *6e Swedish Weed Control Conference*: G10-G11.

7. Harker, K. N. 1995. Short-term split application effects of grass-specific herbicides on quackgrass (*Elytrigia repens*) under field conditions. *Weed Technology* 9:710- 715.

8. Harker, K. N. and Dekker, J. 1988. Effects of phenology on translocation patterns of several herbicides in quackgrass, *Agropyron repens. Weed Science* 36:463-472.

9. Jensen, P. K. 1992 Split application of herbicides in peas. *Weed Research* 32:295-302.

10. Jensen, P. K. 1994 Split application of herbicides in winter oilseed rape. *Proceedings of the Rapssymposium zu fragen der phytopathologie und des pflanzenschutzes*:125- 135.

11. Jensen, P. K. and Christensen, S. 1993 Reflectance measurements as a tool for monitoring herbicide efficacy and herbicide tolerance. *Proceedings of the EWRS Symposium - Quantitative approaches in weed and herbicide research and their practical application*:235-241.

12. Kudsk, P. 1989 Experiences with reduced herbicide doses in Denmark and the development of the concept of factor-adjusted doses. *Proceedings of the Brighton Crop Protection Conference – Weeds*:545-554.

13. Norris, R. F. 1991. Sugarbeet tolerance and weed control efficacy with split applications of phenmedipham plus desmedipham. *Weed Research* 31: 317-331.

14. Pallutt, B. and Hoffman, B. 1980. Untersuchungen zum Einfluss ökologischer Bedingungen auf die Wirkung Herbiziden in Zuckerrüben und zur Optimierung des Einsatzes von Phenmedipham. *Tagungsbericht, Akademische und Landwirtschaftliche Wissenschaft. DDR, Berlin* 182: 113122.

15. Rossi, F. S., Di Tomaso, J. M. and Neal, J. C. 1993. Fate of fenoxaprop-ethyl applied to moisture-stressed smooth crabgrass (*Digitaria ischaemum). Weed Science* 41:335- 340.

16. Speller, C. S. and Dover, P. A. 1989. Use of sequences for the control of broad leaved weeds in maincrop potatoes. *Proceedings of the 1989 Brighton Crop Protection Conference – Weeds*: 213-218.

17. Stoltenberg, D. E. and Wyse, D. L. 1986. Quackgrass (*Agropyron repens*) control in soybeans (*Glycine max*) with BAS 9052 OH, KK-80, and Ro-138895. *Weed Science* 34:664-668.

18. Trimmer, M. C. and Linscott, D. L. 1988. Water relations in quackgrass (*Agropyron repens*) following postemergence herbicides. *Weed Science* 36:273-278.