ESTIMATING DOSE RESPONSE CURVES FOR PREDICTING GLYPHOSATE USE RATES IN AUSTRALIA

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Summary Parallel dose response curves were used to analyse the performance of glyphosate under a range of field conditions in 1995. The average slope of these curves was stable over a range of plant species, moisture and relative humidity conditions. The ED50, which indicates the position of the dose response curve, was sensitive to these conditions. Moisture stress, and low humidity increased the ED50. In general the ED50 for annual ryegrass>capeweed>volunteer canola>volunteer wheat in any given situation.

Over the range of conditions encountered, the glyphosate rate required for 90% control varied from 70 g a.i. ha^{-1} to 1350 a.i. ha^{-1}. Therefore the ability to predict an effective herbicide dose based on conditions should lead to reduced failures and less wastage of herbicide. A model to predict glyphosate use rates in the Australian environment to improve herbicide efficiency using parallel dose response curves is discussed.

INTRODUCTION

There is mounting pressure from farmer and community groups to decrease herbicide use in Australia. This is due to the costs of herbicides, risk of developing herbicide resistant weed populations, personal safety and residual effects of herbicides in the soil and environment.

We are investigating ways of optimizing the timing and rate of application of herbicides with respect to environmental interactions. This will lead to a reduction in herbicide use by firstly identifying those conditions where reduced herbicide rates can be used, without a reduction in performance, and secondly by applying the appropriate rate of herbicide to suit adverse conditions, thereby avoiding repeat applications after failures.

The optimal herbicide dose is influenced by how much needs to be applied to gain an acceptable level of control. Therefore in order to optimize herbicide usage a knowledge of efficacy is essential (Pannell 1990). Glyphosate efficacy has been reported to be affected by; plant species, plant development, light, temperature, humidity, soil moisture and precipitation (as reviewed by Caseley and Coupland 1985). There have been no studies on the influence of these factors in combination in the Australian environment on glyphosate performance. The problem is not just to test whether moisture stress adversely affects glyphosate performance, but to find a method that can quantitatively assess the range of factors that affect glyphosate performance under field conditions. The method needs to be able to predict the effective dose (ED) at various control levels, i.e. the ED50 (the dose that gives 50% control) or ED90 (the dose that gives 90% control), be biologically meaningful in that it predicts an upper and lower limit of the data set, and be able to compare results between experiments.

Dose response curves using non linear regression analysis have widely been used to assess herbicide efficacy under different environmental conditions (Lemerle and Verbeek 1995), weed density/development trials (Ascard 1994), to assess adjuvants (Streibig and Kudsk 1993) and to determine herbicide resistance (Seefeldt *et al.* 1994). For assessing dose response curves of the same chemical under different conditions a parallel line technique can be used. The technique assumes that the slopes of the dose response curves for a herbicide are the same and its value is determined by its mode of action. Thus under different conditions the mode of action remains the same but the amount of chemical reaching its site of action changes (Streibig and Kudsk 1993). The parallel dose response model has the potential advantage of being able to deal easily with several variables or factors affecting performance.

For a more complete review of the concept of parallel dose response curves see Seefeldt *et al.* (1995) and Streibig and Kudsk (1993).

The aim of this paper is to test whether the parallel dose response model fits the data for glyphosate and to see if it can be used to predict use rates in Australia.

MATERIALS AND METHODS

The dose response curve is typically sigmoidal in shape and can be fitted using a logistic non linear model (Streibig and Kudsk 1993).

$$U = (D-C)/(1 + EXP(-2*(a + b*\ln(z)))) + C. \quad b > 0 \qquad \text{Eqn 1}$$

Where U denotes plant response, D denotes the upper limit (zero dose), C denotes the lower limit (complete control dose), ‘a’ is the horizontal displacement of the curve at ED50 and ‘b’ is the slope of the curve at ‘a’.

The ‘b’ value can be fixed for all curves forcing the slopes to become parallel. A lack of fit F-test can then be made to see if the fixed slope curve (model i) is significantly different from the original curve (model ii) as described by Seefeldt *et al.* (1995).

$$F = \frac{(SS^{ii}_{e} - SS^{i}_{e})/(DF^{ii}_{e} - DF^{i}_{e})}{SS^{i}_{e}/ DF^{i}_{e}} \sim F\,(DF^{ii}_{e} - DF^{i}_{e},\, DF^{i}_{e}) \qquad \text{Eqn 2}$$

Where SS_e is error sum of squares, DF_e is error degrees of freedom and F is approximately F-distributed if model i can be reduced to model ii.

Efficacy results were analysed by fitting equation 1 into a non-linear regression program, using Genstat 5 release 3.1 (Rothamsted Experimental Station). The resulting 'b' values were averaged over all experiments to give us our fixed slope. The programme was then run again using the fixed 'b' value to obtain the 'a' values for each experiment. An F test using Eqn 2 was used to test whether the parallel dose response model holds for glyphosate.

During the 1995 growing season, 48 glyphosate dose response trials were carried out under varying conditions in the Western Australian wheat belt. Experiments 1 and 3 were taken from these trials while Experiment 2 was part of a pot trial carried out in Albany in April 1995.

Experiment 1. Moisture stress Wheat was sown at 80 kg ha^{-1} over site using a twelve run drill. 150 kg ha^{-1} of super Cu, Zn Mo fertilizer and 100 kg ha^{-1} of Agran was topdressed over site immediately before sowing. Three moisture treatments were generated by erecting a 50% rain shelter over an area 4 × 12 m. Rainfall was caught off the rain shelters and used to water another area 4 × 12 m using Turbo Tape. The remaining 4 × 12 m was left as a natural rainfall treatment. This created 50, 100 and 150% rainfall treatments. Plots were sprayed with glyphosate (Roundup CT® formulation) from 900 g a.i. ha^{-1} to 68 g a.i. ha^{-1} using a log sprayer (11003 VP XR TEEJET nozzle) along the 12 m of each treatment six weeks after seeding (early tillering). There were two replications. At the time of spraying, relative water contents (RWC) of wheat leaves were taken. Dry matter cuts and survival counts were taken six weeks after spraying.

Experiment 2. Plant species Four weed species, capeweed (*Arctotheca calendula*), annual ryegrass (*Lolium rigidum*), wheat (*Triticum aestivum*) and canola (*Brassica napus*), were sown in 1.6 kg pots filled with a siliceous sand, Northcotte classification of Uc 2.21., with the following nutrients mixed through (g pot^{-1}): KH_2PO_4 (0.114), K_2SO_4 (0.257), $CaCl_2.2H_2O$ (0.285), NH_4NO_3 (0.229), $MgSO_4.7H_2O$ (0.071), $ZNSO_4.7H_2O$ (0.009), $CuSO_4.5H_2O$ (0.009), $CoSO_4$ (0.0003), $MnSO_4.5H_2O$ (0.156), H_3BO_3 (0.0013) and $NaMoO_4.2H_2O$ (0.0003). Six weeks after seeding, plants were sprayed with 16 rates of glyphosate (Roundup CT® formulation, 80015 TEEJET nozzles) with rates ranging from 900 g a.i. ha^{-1} to 45 g a.i. ha^{-1}. Dry matter and survival counts were taken six weeks after spraying.

Experiment 3. Humidity Two field sites (Newdegate and Katanning) were sown to wheat at 80 kg ha^{-1} using a tyned cone seeder on a similar soil type. They received similar climatic conditions during their life and on the day of spraying had identical RWC (95%), shoot to root ratio (1.2), relative regrowth rate (0.4), and temperature (14°C). The only measurable difference was relative humidity (30% at Katanning and 80% at Newdegate). They were sprayed using a log sprayer (11003 VP XR TEEJET nozzles) from 450 g a.i. ha^{-1} glyphosate (Roundup CT® formulation) to 45 g a.i. ha^{-1} over 20 m, with two replications, five weeks after seeding (early tillering stage).

RESULTS

During the 1995 season the range in ED90s experienced were from 70 to 1350 g a.i. ha^{-1} (Table 1). Annual ryegrass showed the largest range in responses and also had the largest average ED90 of 201.7 (Table 1). Despite the large range in ED90s, the average ED90 values for all species were below the recommended label rate (360–540 g a.i. ha^{-1}, for Roundup CT®).

Table 1. Trial summary for glyphosate trials in 1995. Figures expressed as g a.i. ha^{-1} (Roundup CT® formulation). Where SE is the standard error of the average ED90 value.

Weed	Range ED90	Average ED90	SE
Wheat	70–1292	172	16.23
Annual ryegrass	87–1350	201.7	40.41
Capeweed	75–520	91.5	31.16

Table 2. Summary of the fixed slope parameters generated from equation 1 for the three experiments. Where SE is the standard error of a, and CL is the upper and lower 95% confidence limits for the ED50.

Treatment	a	SE	ED90	ED50	CL
65% RWC	6.07	0.13	1292.4	431.1	(558–332)
74% RWC	4.50	0.08	270.3	90.2	(106–77)
85% RWC	3.64	0.05	113.8	37.9	(42–35)
Wheat	4.59	0.08	294.2	98.2	(115–84)
Canola	4.78	0.09	358.3	119.5	(143–100)
Capeweed	5.01	0.11	447.4	149.2	(185–120)
Annual ryegrass	5.33	0.05	618.5	206.3	(228–186)
80% RH	4.80	0.04	364.1	121.4	(132–111)
30% RH	5.29	0.04	593.8	198.1	(214–183)

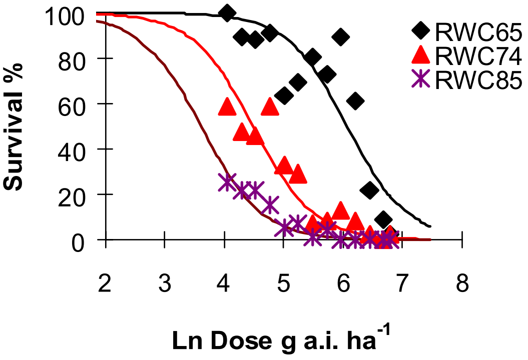

Figure 1. Response (survival %) of wheat to glyphosate herbicide under three plant water status treatments. i) RWC of 65%, ii) RWC of 74% and iii) RWC of 85%.

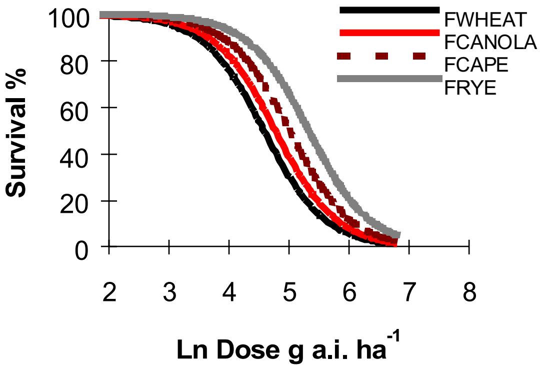

Figure 2. Response (survival %) of four weed species to glyphosate herbicide. i) wheat, ii) canola, iii) capeweed and iv) annual ryegrass. Graph shows fitted line only.

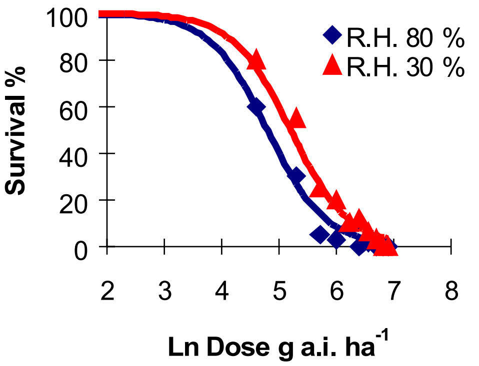

Figure 3. Response (survival %) of wheat to glyphosate herbicide under 2 RH treatments. i) RH of 80% and ii) RH of 30%.

For the three experiments the fixed slope parameters of the dose response curves are shown in Table 2. For all cases there was no significant difference between the empirical curve fit (slope not fixed) and the fixed curve fit (b = -1.0) using the F test (Eqn 2). This indicates that the slopes at 'a' are parallel and a fixed slope can be used to fit the data sets presented (Figures 1, 2 and 3).

Experiment 1 Using a 50% rain shelter reduced the RWC of wheat from 74% (100% rainfall) to 65%, while watering the third moisture treatment (150% rainfall) increased the RWC to 85% (Table 2). Results show that the greater the moisture stress (lower the RWC) the less effective glyphosate becomes (Figure 1 and Table 2). The 50% rainfall treatment had an ED50 of 431 g a.i. ha^{-1}, compared to the 100% rainfall treatment, 90 g a.i. ha^{-1}, and 150% rainfall treatment, 38 g a.i. ha^{-1} (Table 2). Figure 1 shows that the lower the RWC the further the dose response curve was displaced along the dose axis.

Experiment 2 Table two shows that the ED50 increased in order of wheat (98), canola (120), capeweed (149) and annual ryegrass (206). This caused the dose response curves to be displaced along the dose axis (Figure 2).

Experiment 3 A relative humidity of 80% at time of spraying resulted in an ED50 of 220 for wheat, compared to 330 when sprayed under conditions of 30% relative humidity (Table 2). Figure three shows the parallel displacement along the dose axis for the effect of relative humidity on glyphosate efficacy.

DISCUSSION

This work shows that under naturally occurring conditions the amount of glyphosate required for weed control varies by over an order of magnitude (Table 1). Therefore the ability to predict an effective dose rate should lead to reduced failures and more efficient use of the herbicide.

Glyphosate performance was affected by RWC, RH and weed species present in the three cases presented. A low RWC (65%) reduced glyphosate efficacy to a point where label rates would not have achieved a satisfactory control level. With this information a farmer can decide when to stop spraying if a dry spell occurred after rain. He will have to trade off the cost of delays to planting, against the cost of applying more herbicide. Similarly a low RH reduces glyphosate efficacy. A reduction in the RH from 80 to 30% increased the ED90 by 63% for volunteer wheat (Table 2). A farmer using reduced herbicide rates will have to monitor RH during the spray period to ensure conditions of high RH. Annual ryegrass was the hardest weed to control, followed by capeweed, volunteer canola and volunteer wheat (Table 2). If only volunteer wheat and canola were present (and assuming there are no other stresses) low rates could be used, but these rates need to be increased by 50% if capeweed is present or doubled if annual ryegrass is present (Table 2). Therefore when predicting an appropriate herbicide rate, the hardest weed species to control or the potentially more damaging weed species should be targeted.

Using parallel dose response curves to fit the data we were able to explain the differences between treatments as confidently as using more empirical methods. The average slope was determined to be -1.0 (on a ln scale) and this was stable over a range of soil moistures, relative humidity levels and weed species. The advantage of using the parallel dose response model is that once you have determined the ‘a’ value under various conditions the same formula can be applied to calculate the various ED values, i.e. the slope would not have to be determined for each set of circumstances. This would be particularly important for the flexibility of our model in that optimizing herbicide use may not necessarily mean achieving a set control level. For example it may be more profitable to use half the normal rate to achieve 70% control of weeds, rather than achieving 90% control using higher rates.

Where does this leave the farmers? It is hoped that farmers will be able to measure the relevant factors that affect glyphosate performance and by either using a computer driven model, or by a series of steps, to determine the optimal herbicide rate. One of the problems with determining these measures is that they can be either time consuming, such as RWC, or involve the use of very expensive, highly technical pieces of equipment. Both of which are of little practical use. Developing measures that are quick and practical under field conditions is an area that needs further investigation.

Future research is required to determine the additivity of factors determining the position of the dose response curve. For example if you need 10 times more herbicide under conditions of moisture stress and twice as much under conditions of low relative humidity, does this mean that you need 20 times more herbicide under conditions of moisture stress and low relative humidity?

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