Residual activity of three herbicides following exposure to summer-autumn conditions on the surface of three Western Australian wheatbelt soils

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Summary

The naturally infertile sandy soils of the Western Australian (WA) wheatbelt are likely to prolong the duration of effective residual activity of residual herbicides following a pre-season application. This study aimed to determine the loss of residual activity of three herbicides following exposure to extended periods of hot, dry and intense sunlight conditions after application to the surface of three typical WA wheatbelt soils. Plant bioassays were used to determine the residual activity of pendimethalin, s-metolachlor and diuron following exposure to these conditions over an 84 day period. Pendimethalin was found to have a high level of residual activity through these conditions on all three soil types indicating that this herbicide could provide effective weed control following a pre-season application. More importantly, there was a uniform rate of loss of pendimethalin activity that allowed the accurate prediction of efficacy of this herbicide over time. This uniform loss of residual activity under these conditions provides the potential for determining an expected period of effective ryegrass control following application. Similarly high levels of residual activity were not observed for s-metolachlor and diuron.

Keywords: Pendimethalin, diuron, s-metolachlor, residual herbicide, pre-season herbicide application.

Introduction

The Western Australian (WA) dryland cropping zone (wheatbelt) has a Mediterranean-type climate characterized by a short, cool and moist growing season from May to October alternating with extended periods of hot and dry conditions. To maximize crop yield potential from this short growing season (4–5 months) it is essential to plant as early as possible. The growing season commences following significant rainfall event/s over the April-June period. In WA this rainfall also stimulates the emergence of the most problematic annual weed species, annual ryegrass (*Lolium rigidum* Gaudin) (Alemseged *et al*. 2001). It is essential to control this initial annual ryegrass emergence to prevent a substantial impact on subsequent crop establishment, growth and consequently grain yield (Gill and Davidson 2000). Commonly seeding is delayed to allow effective control of early emerging ryegrass seedlings, however, any delay after the optimum seeding date can significantly reduce crop yields (Anderson *et al*. 2004). Therefore, the objective is to seed a crop as soon as possible after the season-opening rains whilst effectively controlling any emerging weed populations.

Across the WA wheatbelt resistance to selective herbicides in annual ryegrass populations is present at very high frequencies (Llewellyn and Powles 2001, Owen *et al*. 2005). This places even greater emphasis on the need for effective pre-seeding weed control using non-selective herbicides such as glyphosate. However, the reliance on glyphosate for weed control at pre-seeding is also leading to the evolution of resistance to this herbicide in annual ryegrass populations (Powles *et al.* 1998, Pratley *et al.* 1999, Neve *et al.* 2004). The number of glyphosate resistant populations of annual ryegrass is increasing and there is a real concern that widespread development of resistance will occur with the continued reliance on this herbicide for pre-seeding weed control. Therefore, there is a need to develop alternate and complementary pre-seeding weed control strategies.

The application of a residual herbicide in anticipation of the season opening rains (pre-season) allows for the control of the initial ryegrass cohort and thus permits the earliest possible seeding time for wheat. However, the timing of the season commencing rainfall events is highly variable occurring anytime between mid-April and late June and lacks a consistent pattern (Chapman and Asseng 2001). Therefore, residual herbicides must be capable of persisting through an extended period of hot and dry conditions, exposed to sunlight as they will not be incorporated by tillage until seeding or from rainfall at the break of the season. Additionally, a suitable herbicide must persist past the start of the growing season to control the subsequently emerging annual ryegrass seedlings. Preliminary studies have determined that some residual herbicides have the ability to effectively persist through these harsh conditions (Walsh *et al*. 2004, 2005). These studies determined that residual activity was enhanced by the greater adsorption of herbicides to dry soils, particularly at soil moisture levels below the wilting point, −1.5 MPa (Bailey and White. 1964, Green and Obien 1969). The very low soil moisture levels occurring in soils across the WA wheatbelt prior to the commencement of the growing season may enhance the residual activity of residual herbicides following a pre-season application.

The objectives of this study were firstly to examine the residual activity of three herbicides, pendimethalin, s-metolachlor and diuron over an extended period of hot, dry and intense sunlight conditions following their application to the surface of three typical WA wheatbelt soils. A second objective was to determine the influence of soil type on the residual activity of these herbicides under these conditions. A final objective was to assess if there is predictability of the loss of residual activity of these herbicides over time enabling the accurate prediction of application rates required for specific periods of effective control of annual ryegrass.

Materials and methods

Soil collection and analysis

Topsoils (0–5 cm) were collected from wheat cropping fields on two farms, Penny (PH and PL) and Keeble (KL) located within a 20 km radius of Greenhills (Lat. 31.98°S, Long. 118.08°E.), 160 km east south-east of Perth, WA. Soils were collected on 2 January 2003, approximately one month past the end of the 2002 cropping season, from fields that had been under wheat production during this season. The soil types selected had a range of chemical and physical properties representative of those occurring in soils used for crop production across the WA wheatbelt. Collected soils were air dried for seven days in a non-air conditioned glasshouse before passing through a 4 mm sieve to remove rocks and stubble material. Samples were forwarded to CSBP®[A] soil testing laboratories for the determination of relevant physical and chemical properties (Table 1). The field capacity of each soil was determined to allow the calculation of the amount of water to be added to each soil in the bioassay procedures. To determine the gravimetric soil moisture content at field capacity of each soil three 250 mL measuring cylinders were each filled with 200 mL of soil which were then saturated

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Footnote

[A] CSBP Soil and Plant Analysis Service, 2 Altona Street, Bibra Lake, Western Australia 6163.

with 50 mL of water. After two hours, a soil sample was taken from the saturated soil at the top of each measuring cylinder. The soil samples were weighed (wet weight) and then oven dried for 24 hours at 105°C, reweighed (dry weight) and the percent gravimetric moisture content was calculated (Equation 1) for the three soils (Table 1).

Gravimetric water content (%) =

$$\left(\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}}\right) \times 100 \tag{1}$$

Table 1. Physical and chemical properties of the three soils collected from wheatbelt fields near Northam, WA.

Property	Soil type		
	PH	PL	KL
Colour	brown/red	brown/red	grey
Textural class	loamy sand	loamy sand	sand
Sand (%)	83	83	93
Silt (%)	9	5.5	3
Clay (%)	7.9	11.8	3.9
Water content at FC (%)	13.4	16.9	12.1
pH (H_2O)	5.2	5.8	5.5
N (mg kg^{-1})	18	12	18
P (mg kg^{-1})	63.0	41	29
K (mg kg^{-1})	179	236	12
S (mg kg^{-1})	7.8	13.4	8.2
Organic carbon (%)	1.3	1.4	1.1
Reactive Iron (mg kg^{-1})	971	740	318
Conductivity (dS m^{-1})	0.06	0.09	0.04

Plant bioassay procedure

Bioassays were used to determine the residual activity of three residual herbicides, diuron, pendimethalin and s-metolachlor in the three soils. As diuron is a photosystem II inhibitor, shoot biomass was used to indicate diuron activity. As pendimethalin and s-metolachlor both affect root growth, root length measurements were used to determine the activity of these herbicides (Zimdahl and Clark 1982, Zimdahl *et al*. 1984). A screening process was undertaken to select the appropriate plant species that were suitable for use at both high and low soil herbicide concentrations for each of the herbicide bioassays. Wheat (*Triticum aestivum* cv. Spear) was selected as the most appropriate plant species for use in the s-metolachlor and diuron bioassays while oats (*Avena sativa* cv. Coomallow) were used in the pendimethalin bioassay.

Herbicide application Herbicides were applied to the surface of 500 g of soil contained in one litre rectangular plastic containers (165 mm L × 110 mm W × 70 mm H) using a cabinet sprayer, equipped with two flat fan nozzles that provided a delivery rate of 98 L ha^{-1} at 210 Kpa and 3.6 km h^{-1}.

Diuron bioassay Ten wheat seeds were planted 1 cm deep into the treated soils. These soils were then watered to 90% field capacity and placed in the glasshouse where moisture content was maintained at or near field capacity by daily watering. Approximately 12–15 days after planting wheat seedling survival was recorded. The living above ground shoot biomass was harvested and dried at 70°C for 48 hours to determine the average shoot dry weights for each container.

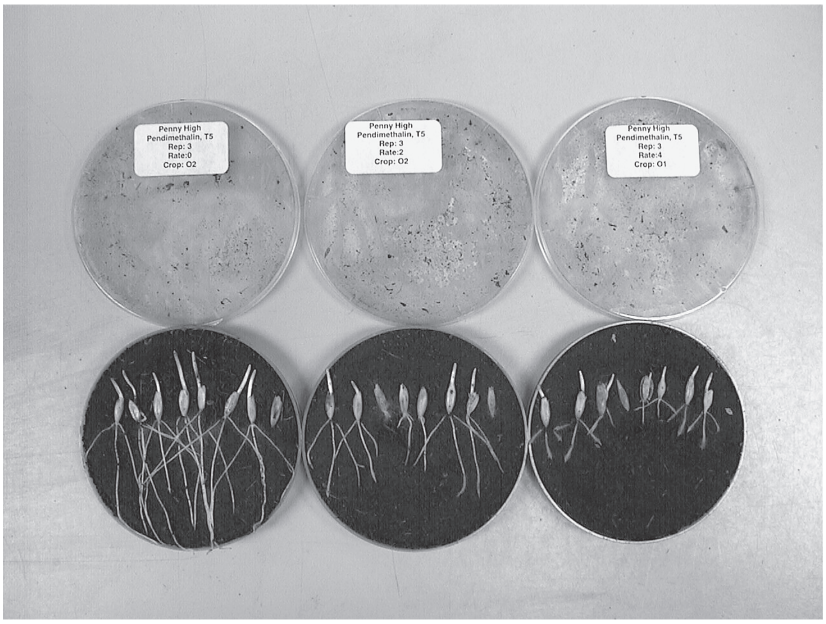

Plate 1. Placement and alignment of seeds on soils in Petri-dishes for the pendimethalin and s-metolachlor bioassays.

Pendimethalin and s-metolachlor bioassays From each container of herbicide treated soil, 95 g soil samples were weighed into four Petri dishes. The soils were moistened to 90% field capacity and depending on the herbicide eight oat or wheat seeds were placed on the soil surface, germ end facing down, in a line above the centre of each Petri dish (Plate 1). Petri dishes were sealed with masking tape and placed at an approximately 60° angle to the vertical and incubated at 12-hourly alternating 25/15°C temperatures with light provided during the warm phase by fluorescent lights (c. 50 µmol $m^{-2}s$). After four days of in these conditions the root length of each seedling was measured and the average root length per container was calculated.

Determination of calibration curves Bioassays for the development of calibration curves for diuron, s-metolachlor and pendimethalin were conducted using the procedures described above. The rates of diuron applied to each of four replicate soil samples were 0, 0.05, 0.1, 0.15, 0.2, 0.25, 0.5, 0.75, 1.0, 1.5 and 2.0 kg ha^{-1}. S-metolachlor at 0, 0.48, 0.96, 1.44, 1.92, 2.88 and 3.84 kg a.i. ha^{-1} and pendimethalin at 0, 0.16, 0.33, 0.5, 0.66, 0.99 and 1.32 kg a.i. ha^{-1} were each applied to three replicated soil samples. Treated soils used for the determination of calibration curves were allowed to dry for 30 minutes before lids were placed on the containers and the soils were mixed for 200 revolutions in an end over end mixer. The bioassay procedures described above were then used to establish the effects of increasing application rates of diuron on the shoot biomass of wheat and of s-metolachlor and pendimethalin on oat and wheat root growth respectively. The shoot biomass and root length data were expressed as a percentage reduction of the untreated control. These results were then used to establish a relationship between herbicide rate and herbicide efficacy for each of the three soil types.

Herbicide residual activity

An experiment to determine the residual activity of diuron, s-metolachlor and pendimethalin after exposure to conditions of high temperatures, low soil moisture and prolonged sunlight was conducted. At the commencement of the study the following rates of pendimethalin 0, 0.33, 0.66, 0.99 and 1.32 kg ha^{-1}, s-metolachlor 0, 0.96, 1.92, 2.88 and 3.84 kg ha^{-1} and diuron 0, 0.5, 1.0, 1.5 and 2.0 kg ha^{-1} were applied to the surface of 500 g samples of the three wheatbelt soils PH, PL and KL in plastic containers as described earlier. Diuron, s-metolachlor and pendimethalin treatments were applied on 19, 20 and 21 February respectively. Following the application of herbicide treatments soils were transferred immediately to a 20 m × 20 m field plot area on the Nedlands campus at UWA (31.59°S, 115.09°E). Trays were placed on the soil surface approximately 10 cm apart in an area protected from wind but exposed to summer-autumn (February-May) temperature and sunlight conditions for the duration of the experiment. Soils were collected on seven occasions commencing with time 0 (immediately after treatment application) and then at 14 day intervals for 84 days. Collected soils were used for the determination of herbicide residual activity using the bioassay procedures described earlier. Average shoot biomass for diuron and average root lengths for pendimethalin and s-metolachlor were converted to a percentage reduction in shoot biomass or root length when compared with the untreated control for each soil type. This allowed the comparison of herbicide efficacy across application rates and soil types over time. All treatments for each of the seven times of collection and assessment were replicated four times for diuron and three times for s-metolachlor and pendimethalin. The residual activity of the three herbicides, based on the reductions in root length or shoot biomass, was plotted for each application rate on each soil type over time.

A data logger was used to record daily soil temperatures throughout the herbicide residual activity study where temperatures were recorded from probes placed at a depth of 2 cm in trays containing the KL and PL soil types (Figure 1). Photosynthetically available radiation data was recorded at a nearby weather station (10 km) in Shenton Park. Daily maximum and minimum temperatures were identical for both soil types, therefore, the data for the KL soil only is presented. To ensure that the herbicide treated soils remained dry and herbicide degradation was not influenced by rainfall, plastic sheeting was used to cover the soils when rain was imminent. However, on 21 March, 29 days after the commencement of the study, soils received 2 mm of rain following an unexpected rainfall event.

Development of residual activity curves

The calibration curves developed earlier were used to convert root length/shoot biomass data from the herbicide residual activity study to equivalent application rates. The calibration equations derived from the bioassay experiments to determine herbicidal activity on root length/shoot biomass immediately after application to the soil surface. These calibration equations were then used to determine the residual activity of each of the herbicides as a residual activity for period of exposure.

Statistical analysis

For each herbicide, regression analyses (Sigmaplot ver. 9.0) were conducted using a three parameter sigmoidal logistic function (Equation 2) on data from the calibration experiment.

$$Y = ((a/x-1) \times x_{50}{}^{b})^{1/b} \qquad (2)$$

Where **x** represents application rate, **Y** represents percentage reduction in root length or shoot biomass compared with the untreated control, **a** represents the maximum value of **y** (100%), $\mathbf{x_{50}}$ is the application rate required to produce a 50% reduction in root length or shoot biomass and **b** is the slope at $\mathbf{x_{50}}$.

An ANOVA was performed on percentage root length and biomass reduction data derived from the herbicide residual activity study for each herbicide (SAS ver. 9.1). There were significant two way interactions for all three herbicides and, therefore, herbicide rate effects were compared at each period of exposure for each soil type. Treatment means were compared using Tukey's honest significant difference test at $\alpha = 0.05$ (SAS ver. 9.1).

The three parameter sigmoidal logistic function (Equation 2) was used to describe the relationship between residual activity and exposure period. Where **Y** represents residual activity, **x** represents exposure period, **a** represents the maximum value of **Y** (initial application rate), $\mathbf{x_{50}}$ is days taken for residual activity to reach zero, **b** is the slope at $\mathbf{x_{50}}$ where $\mathbf{x_{50}}$ is the time in days to 50% residual activity of the herbicide. Regression analysis (Genstat ver 6.1.0) and R^2 values were used to assess the suitability of the fitted curves in describing the relationship.

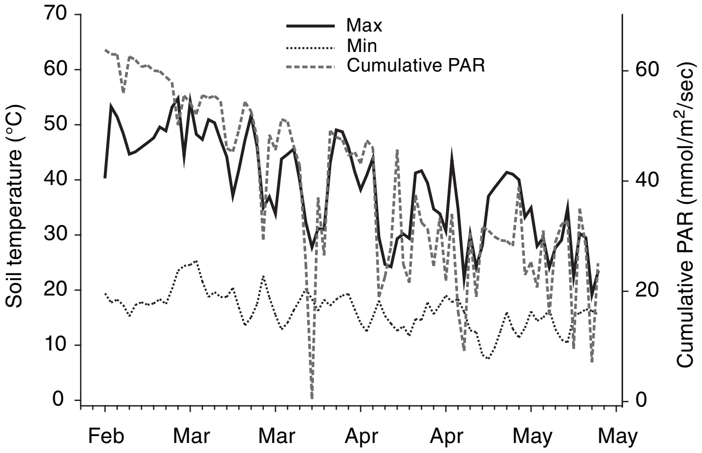

Figure 1. Maximum and minimum soil temperatures and cumulative photosynthetically available radiation (PAR) recorded over the late summer/early autumn period of 2003 at the University of Western Australia.

Table 2. Analysis of variance of seedling root length (pendimethalin, s-metolachlor) or seedling biomass (diuron) as affected by exposure time (E), soil type (S) and application rate (R) of three herbicides.

Source	df	pendimethalin	s-metolachlor	diuron
Exposure time (E)	6	*** A	***	**
Soil type (S)	2	***	***	**
Application rate (R)	4	***	***	**
E × S	12	***	***	*
S × R	8	***	**	**
E × R	24	***	***	**
E × S × R	48	NS	NS	*

[A] Abbreviations: NS, not significant at the 0.05 probability level; *, **, *** significant at the 0.05, 0.01 and 0.001 probability levels, respectively.

Results and discussion

The residual activity of three herbicides, pendimethalin, s-metolachlor and diuron, was significantly influenced by application rate, exposure time, and soil type (Table 2). As indicated by the reductions in oat and wheat seedling root lengths, the residual activity of pendimethalin (Figure 2) and s-metolachlor (Figure 3) respectively, was affected ($P < 0.05$) by application rate, soil type and exposure period. Similarly, diuron residual activity, assessed by the change in wheat seedling biomass levels (Figure 4), was also affected by application rate, soil type and exposure period. There were two way interactions between these three factors for all three herbicides and a significant three way interaction effect for diuron. Therefore, effects of herbicide rate, exposure period and soil type on the residual activity patterns were examined separately for each herbicide.

Pendimethalin residual activity

Pendimethalin retained a high degree of efficacy throughout the 84 day period of exposure and significant levels of pendimethalin remained in all three soils at the end of the period (Figure 2). Pendimethalin is tightly bound in soils with soil adsorption increasing with increasing levels of organic matter and clay content (Weber 1990). Residual activity is also likely to be greater in dry soils with less competition with water for binding sites (Fryer and Makepeace 1977). The primary dissipative processes of pendimethalin are microbial degradation and volatilization (Walker and Bond 1977, Parochetti and Dec 1978, Zimdahl *et al*. 1984). These processes are dependant on soil moisture and their impact on pendimethalin in dry soils will be reduced. As herbicides were applied to the surface of these very dry soils the enhanced residual activity of pendimethalin indicates that this herbicide is not readily photodegraded. This confirms results from previous studies that have also determined only low levels of photodegradation of pendimethalin (Parochetti and Dec 1978, Weber 1990).

Higher pendimethalin application rates consistently prolonged the residual activity of this herbicide throughout the duration of this study. In almost all instances a 0.33 kg ha^{-1} increase in the application rate of pendimethalin resulted in a significant increase ($P < 0.05$) in residual activity following each period of exposure (Figure 2). However, the level of these increases varied between exposure periods and pendimethalin rates.

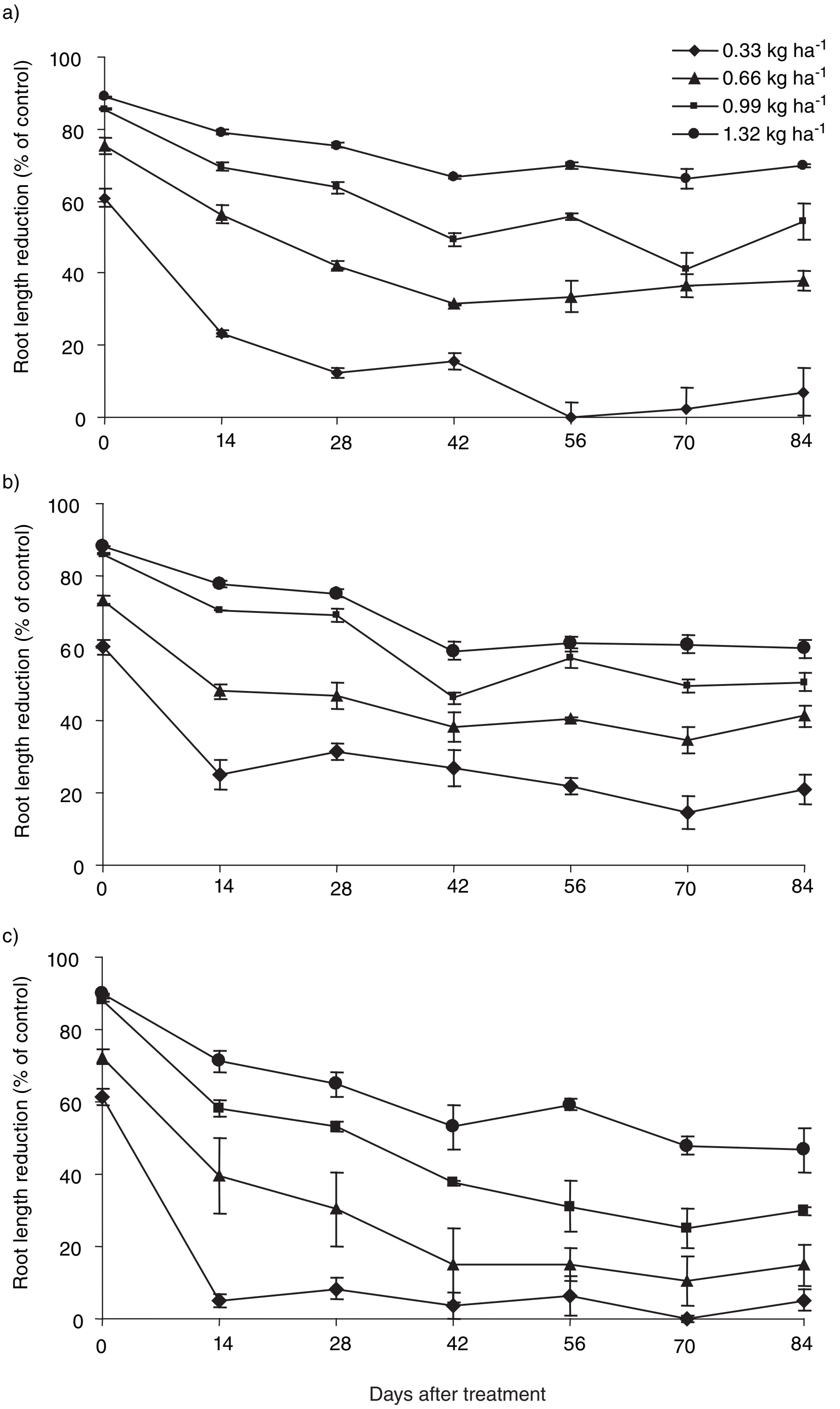

Figure 2. Efficacy of pendimethalin applied at four rates on oat seedling root length following increasing periods of exposure on the surface of three soil types PH (a), PL (b) and KL (c) soils. Bars indicate standard errors.

Pendimethalin residual activity was higher in soil types with higher clay and organic matter contents. Losses in the residual activity of pendimethalin averaged over four application rates for the 84 day exposure period were larger for the KL (54%) soil than for the PH (35%) and PL (34%) soils. The lower clay and organic matter content (Table 1) in the KL soil would have reduced the binding of pendimethalin in this soil (Walker and Bond 1977, Parochetti and Dec 1978, Zimdahl *et al*. 1984, Weber 1990) leading to larger reductions in residual activity observed in this soil (Figure 2).

Differences in pendimethalin residual activity between the soil types at the end of the study period were primarily due to the large losses in residual activity that occurred during the first period of exposure (Figure 2). Averaged across all rates, the KL soil lost 34% of residual activity compared with losses of 21 and 22% respectively for the PH and PL soils during the

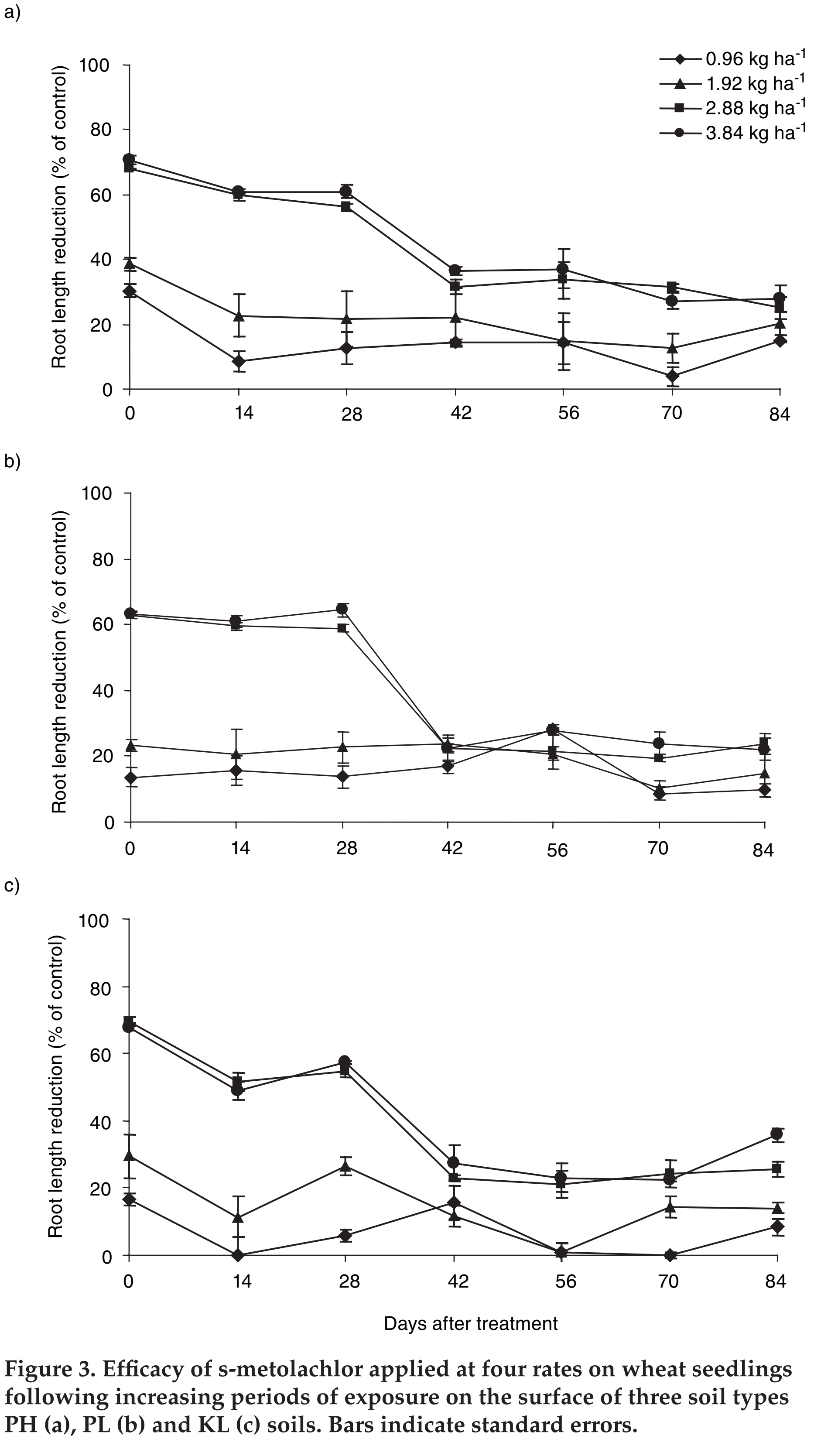

Figure 3. Efficacy of s-metolachlor applied at four rates on wheat seedlings following increasing periods of exposure on the surface of three soil types PH (a), PL (b) and KL (c) soils. Bars indicate standard errors.

initial exposure period. After this period herbicide residual activity losses were uniformly lower in the order of 5-10% per 14 day period for each soil type.

S-metolachlor residual activity

There was a similar pattern of residual s-metolachlor activity over the 84 day exposure period for all four application rates in all three soils. The residual activity of s-metolachlor remained high for the two highest application rates for the initial 28 day exposure period only, after this time activity was similarly low across all application rates (Figure 3). The two highest application rates (2.88 and 3.84 kg ha^{-1}) produced very similar levels of residual activity across the three soil types where wheat root lengths were reduced by between 50 to 60% over the initial 28 days of exposure and by 20 to 30% for the remaining period. The residual activity for the lower application rates of s-metolachlor (0.96 and 1.92 kg ha^{-1}) was low throughout the experiment.

It is likely that a minor rainfall event caused a substantial reduction in the residual activity of the high application rates of s-metolachlor. The large and significant ($P < 0.05$) decrease in the activity of the 2.88 and 3.84 kg ha^{-1} treatment rates of s-metolachlor that occurred during the period between days 28 and 42 after application coincided with a single 2 mm rainfall event occurring on 21 Mar, 29 days after the commencement of the study (Figure 3). Dissipation of metolachlor is more rapid from warm moist soils and it is likely that this minor rainfall event was responsible for the subsequent 30 to 40% drop in residual activity of this herbicide. After this period the activity of s-metolachlor was more uniform where reductions in efficacy for subsequent exposure periods were consistently smaller (<10%). This large reduction in efficacy of s-metolachlor from such a small rainfall event indicates that this herbicide is not suitable for use in pre-season applications where these types of rainfall events are a common occurrence.

Diuron residual activity

Although the residual activity of diuron appeared to be elevated, particularly at the highest application rates, the variation in the effects of diuron treated soils on wheat seedling biomass prevented any clear pattern of herbicidal activity from developing over time. Inconsistencies in biomass reductions and the large LSD values indicate that the bioassay technique used in this study to determine diuron levels was ineffective (Figure 4). It is likely that the loss in soil structure as a result of soil sieving was responsible for an uneven germination and establishment of wheat seedlings observed in this study. Despite this there is a trend for high levels of residual activity following high application rates over the 84 day period in all three soil types. At the 1.5 and 2.0 kg ha^{-1} application rates the residual activity of diuron on wheat shoot biomass remained relatively high. This was particularly evident in the KL soil indicating the potential for high efficacy over extended periods in sandier soils. This trend should be further explored using intact soil cores or in field studies.

Calibration curves

Curves were derived that provided an accurate fit of the data from the bioassays examining the effects of pendimethalin and s-metolachlor residues on oat and wheat root lengths respectively (Figure 5). Therefore, these curves (Table 3) were subsequently used in the calculation of

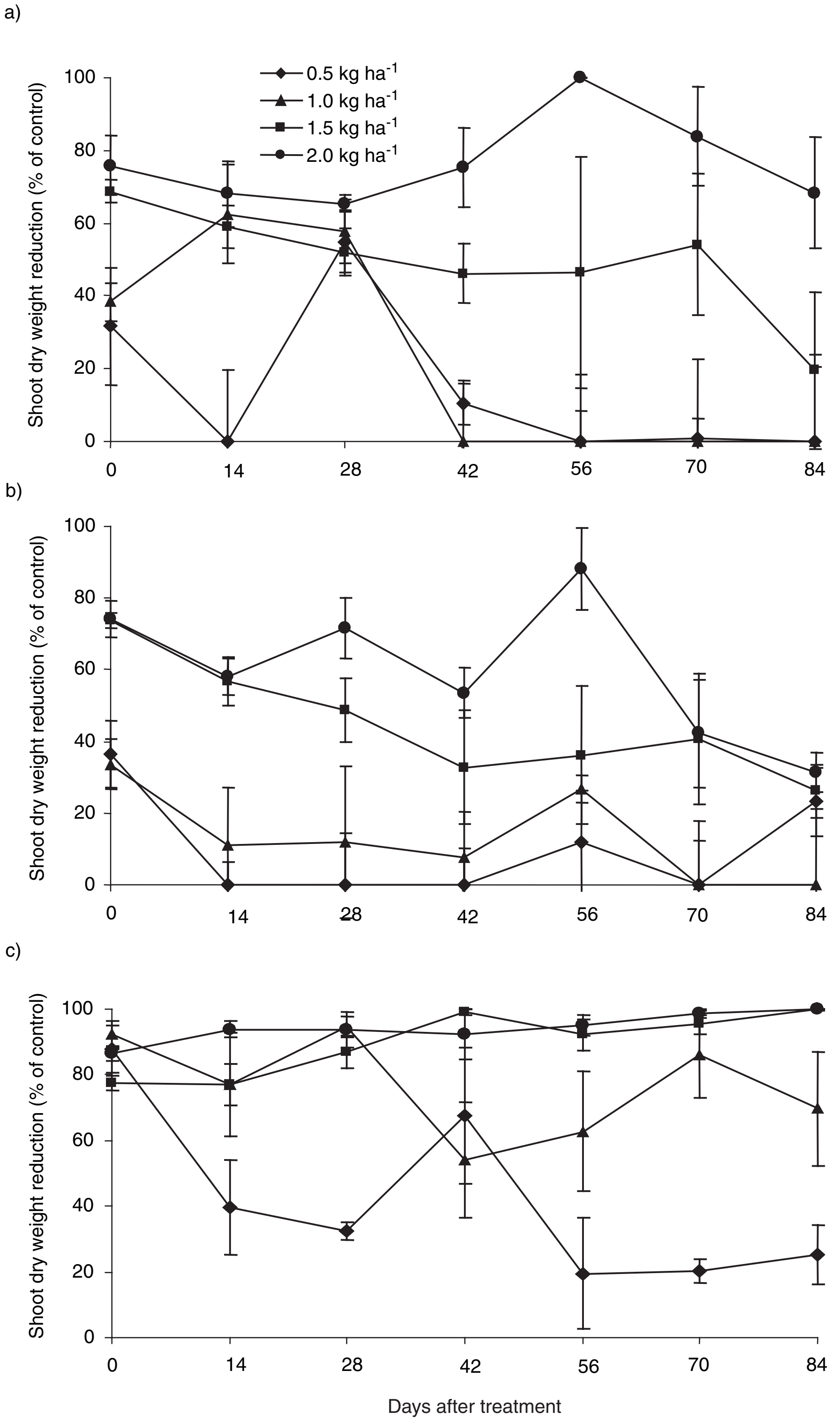

Figure 4. Efficacy of diuron applied at four rates on wheat seedling biomass following increasing periods of exposure on the surface of three soil types PH (a), PL (b) and KL (c) soils. Bars indicate standard errors.

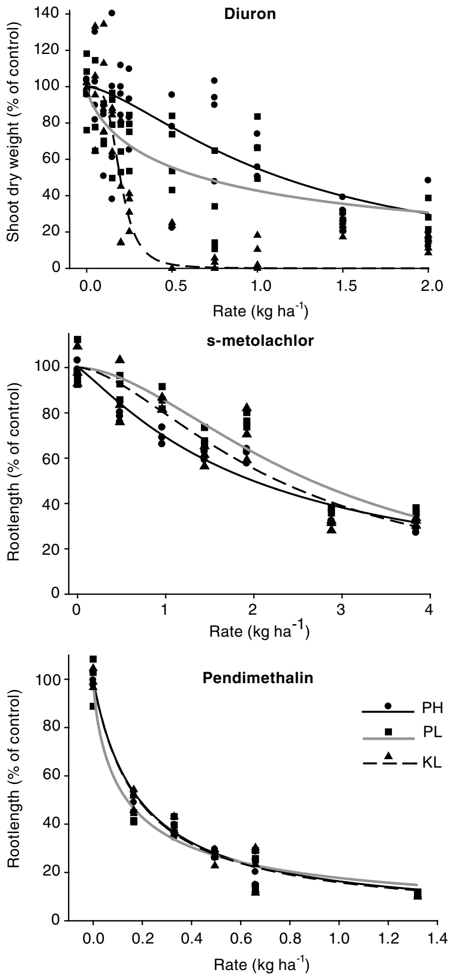

Figure 5. Calibration curves fitted to shoot biomass reductions due to the presence of diuron and root length reductions due to the presence of s-metolachlor and pendimethalin in three WA wheatbelt soils.

residual activity of pendimethalin and s-metolachlor as an application rate in kg ha^{-1} based on root length measurements in the persistence study. Because of variable data suitable curves could not be developed to fit the relationship between wheat shoot biomass and diuron residual activity (Figure 5).

The uniform loss in residual activity of pendimethalin made it possible to predict with some accuracy the application rate at any time over the 84 day period that corresponded to the observed residual activity in the persistence study (Figure 6). The residual activity of pendimethalin can then be compared with the recommended rate for the control of annual ryegrass following a pre-seeding application. This comparison can be made at any stage during the residual activity study to determine the likely period of effective control resulting from each of the application rates on each of the soil types. The recommended rate of pendimethalin for annual ryegrass control in wheat following pre-seeding application is 0.59 kg ha^{-1}. By solving Equation 2 using this rate the period of effective residual activity (PERA) is determined. This is the period over which the residual activity is equal to or greater than that recorded in the bioassay study immediately after the application of the recommended rate of this herbicide.

Period of effective activity

The Period of Effective Activity (PERA) indicates the number of days following application when effective control of annual ryegrass could be expected for each herbicide treatment and soil type

Table 3. Calibration curve parameters for pendimethalin, s-metolachlor and diuron following pre-season application to three different soil types.

Herbicide	Soil	Parameters a	b	x_{50}	R^2	Regression analysis F-test
Pendimethalin	PH	100	1.04	0.19	0.98	***
	PL	100	0.81	0.14	0.96	***
	KL	100	1.04	0.18	0.97	***
s-metolachlor	PH	100	1.18	1.99	0.94	***
	PL	100	1.79	2.66	0.89	***
	KL	100	1.64	1.99	0.86	***
Diuron	PH	100	1.51	1.41	0.53	***
	PL	100	0.75	0.68	0.60	***
	KL	100	4.14	0.20	0.82	***

Table 4. Residual activity curve parameters and the period of effective residual activity (PERA) for pendimethalin in three WA wheatbelt soils.

Soil	Rate (kg ha^{-1})	Parameters a^A	b	x_{50}	R^2	PERA d
PH	0.33	0.33	0.98	0.3918	0.99	0
	0.66	0.66	0.75	0.8491	0.97	0.3
	0.99	0.99	0.75	1.4370	0.96	10
	1.32	1.32	0.61	2.5828	0.96	26
PL	0.33	0.33	0.32	0.0058	0.99	0
	0.66	0.66	0.37	0.0456	0.99	0
	0.99	0.99	0.96	1.6364	0.95	12
	1.32	1.32	1.09	2.3618	0.95	20
KL	0.33	0.33	0.25	0.00	0.99	0
	0.66	0.66	1.08	0.61	0.96	0.6
	0.99	0.99	0.90	0.69	0.97	4
	1.32	1.32	0.76	0.97	0.97	9

[A] a = initial application rate, b = slope of the curve at x_{50} which is days to 50% initial residual activity.

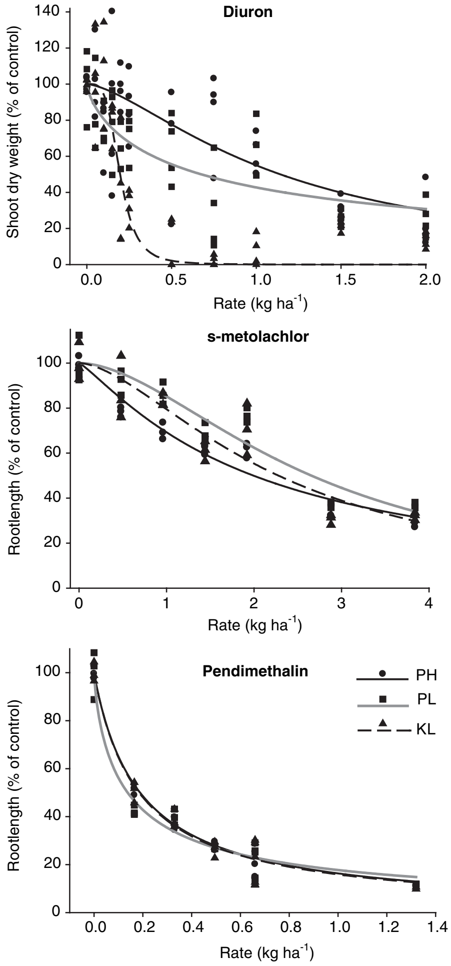

Figure 6. The residual activity of pendimethalin in three wheatbelt soils as indicated by residual activity over an 84 day period following initial application rates of 0.33 (a), 0.66 (b), 0.99 (c) and 1.32 (d) kg ha^{-1}.

combination (Table 4). These results indicate that following the highest application rates of pendimethalin effective ryegrass control could be expected for 26, 20 and 9 days on the PH, PL and KL soils respectively Therefore, despite applying almost 2.5 times the recommended rate of pendimethalin, effective ryegrass control would only be possible for up to 26 days on a WA wheatbelt soil following a pre-season application.

The predictability of the residual activity of pendimethalin when exposed to pre-break of season conditions could provide farmers with confidence in using this herbicide at the pre-season application timing. Knowing the likely PERA values for particular soil types provides farmers with the ability to make informed decisions on the application times and rates according to the time to crop seeding and weather forecast. For instance the application rate of pendimethalin would be reduced when it is likely that the break of the season is imminent (within 14 days) and also if the soil type contained higher levels of clay and OM. Alternatively, rates would be increased for sandier soils, low in OM and where the forecast was for a reduced chance of a season opening rain fall event in the near future. This ability to accurately predict the required application rates will be essential for the practical adoption of this novel approach to weed control.

Inconsistencies in the patterns of s-metolachlor loss prevented the development of predictive curves for the residual activity of this herbicide. The root length data derived from the s-metolachlor residual activity experiment did not allow for the development of functions that accurately predicted the residual activity levels of this herbicide (Figure 7). Despite the development of appropriate calibration curves that aptly fit the relationships between root length reduction and s-metolachlor application rate, suitable relationships could not be derived for residual activity and exposure periods.

Conclusion

The loss of residual activity of pendimethalin follows a uniform and predictable pattern when this herbicide is exposed to pre-break of season conditions on the surface of three wheatbelt soils. This pattern subsequently allowed the determination of periods of effective control of annual ryegrass following pendimethalin application to each soil type. An accurate estimation of PERA values is considered to be essential for the determination of the correct pre-season application timing of a residual herbicide. The bioassay techniques used here were found to be suitable for determining the patterns of residual activity of herbicides affecting root growth. These techniques could be used to evaluate these types of residual herbicides under pre-break of season conditions in controlled situations as used here or in the field to evaluate their patterns of residual activity to potentially develop predictions of periods of effective control.

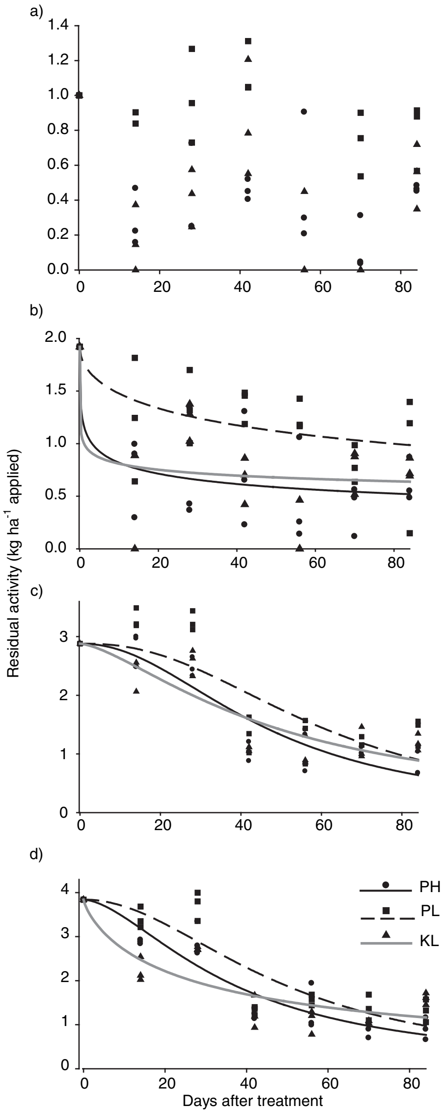

Figure 7. The residual activity of s-metolachlor in three wheatbelt soils as indicated by residual activity over an 84 day period following initial application rates of 0.96 (a), 1.92 (b), 2.88 (c) and 3.84 (d) kg ha^{-1}.

Acknowledgments

The authors wish to thank the staff and students of the Western Australian Herbicide Resistance Initiative for their support and assistance in the preparation of this manuscript. We also thank the Grains Research and Development Corporation of Australia for providing financial support for this research.

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