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Recropping intervals for sulfonylurea herbicides are short in the semi-arid subtropics of Australia

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Summary. Chlorsulfuron, triasulfuron and metsulfuron methyl were applied at recommended and double recommended rates in 5 trials (1990–96) in winter (May–July) or late spring (October) to a heavy textured soil in the Central Highlands of the north-east grain region of Australia. Treated areas were sown back to sorghum in the following spring, to sorghum and sunflower in summer, and to chickpea in the following autumn. Shoot dry matter at 3 weeks after emergence and grain yields were measured. Soil residue levels of chlorsulfuron were measured by bioassay following herbicide application and at sowing of sorghum and chickpea. Rainfall and temperature were recorded for each fallow period. The recropping intervals ranged from 2.5 to 4.1 months for spring sorghum, 2.5 to 9.3 months for summer sorghum and sunflower, and 5.7 to 11.7 months for chickpea. The shorter intervals were a consequence of the late spring applications. The spring sorghum crops were significantly injured by all herbicides, when chlorsulfuron residues at sowing ranged from 1.67 to 2.1 ng/g in the surface 15 cm. Summer sorghum, sunflower and chickpea were unaffected by any herbicide treatment, except the covered (rainfall excluded) metsulfuron methyl treatment. Despite the differences in recropping intervals and fallow rain, all summer sorghum crops were sown into low chlorsulfuron residues (ranged from non-detectable to 0.2 ng/g). Similarly, residues measured at chickpea sowing ranged from non-detectable to 0.1 ng/g. The lack of crop response and the low levels of detected herbicide residue indicate that in this environment these herbicides dissipate rapidly, and the safe recropping intervals are much shorter than currently recommended on herbicide labels.

Introduction

The Central Highlands of Queensland, which comprises about 5×10^5 ha of cultivated land, is the most northern part of the north-east grain region of Australia. The main cropping soils are dark cracking clays (Spackman and Garside 1995), and the climate is semi-arid and subtropical, with summer-dominant but highly variable rainfall. Summer temperatures are consistently high, and prolonged heat waves frequently occur during December with maximum temperatures consistently above 35°C (Bourne *et al.* 1994). The median annual rainfall for the region is 610 mm (Willcocks and Young 1991). The main crops are sorghum [*Sorghum bicolor* (L.) Moench s. lat.], sunflower (*Helianthus annuus* L.) and wheat (*Triticum aestivum* L.), and minor crops include chickpea (*Cicer arietinum* L.), mungbean [*Vigna radiata* (L.) Wilczek] and cotton (*Gossypium hirsutum* L.). However, due to the unreliability of rainfall, cropping is opportunistic and fallow lengths are variable. Sorghum may be planted in spring (August–September) or summer (December–February); sunflowers are planted in summer (January–March). Wheat and chickpea are planted in autumn (April–May). Double cropping from winter to summer crops is possible with these optimum sowing times in some seasons.

The sulfonylurea herbicides, chlorsulfuron, triasulfuron and metsulfuron methyl, are widely used in the Australian winter cereal regions. These herbicides have residual activity with the current label recommended recropping intervals of 9–>24 months (Parsons 1995). These intervals, which vary for differences in soil pH and crop sensitivity, were determined in the cooler southern grain regions of Australia. However, research has shown that persistence of these sulfonylurea herbicides decreased with increased temperature (Walker and Brown 1983; Oppong and Sagar 1992). Therefore, the persistence of these herbicides may be considerably shorter in the hotter subtropical environment of Queensland.

Due to the opportunistic nature of the farming systems of Central Queensland, very little sulfonylurea herbicide is used, apart from some use of the short residual herbicide metsulfuron methyl in wheat and the preceding fallow. The aim of this research was to define the recropping intervals for the Central Highlands

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Table 1. Details of herbicide application dates, recropping intervals (months), and rainfall (mm) and temperatures (ºC) from spraying to sowing

Trial:	1	2	3	4	5
Herbicide app. date	31.x.90	29.x.91	28.x.92	4.vii.94	18.v.95
Spring sorghum					
Recropping interval				2.5	4.1
Rainfall				100	109
Mean air temperature					
Maximum				25.9	26.0
Minimum				9.8	11.2
Summer crops (sorghum and sunflower)					
Recropping interval	2.5	3.3	2.7	6.7	9.3
Rainfal	313	433	180	386	560
Mean air temperature					
Maximum	34.3	35.2	33.9	30.7	30.3
Minimum	21.0	20.8	20.1	15.2	15.7
Chickpea					
Recropping interval	6.0	6.0	5.7		11.7
Rainfall	557	605	308		785
Mean air temperature					
Maximum	33.1	33.9	33.6		30.6
Minimum	19.9	20.4	19.8		16.2

environment in order to determine whether these herbicides can be safely used in opportunistic cropping rotations. This was undertaken by measuring the responses of different crops to sulfonylurea residues in the field for recropping intervals of 2–12 months. For the chlorsulfuron treatments, crop responses were compared with the measured residue levels in the root zone at sowing.

Materials and methods

Site

Five trials were conducted from 1990 to 1996 at the Emerald Research Station (altitude 190 m, 23º29'S, 148º09'E). The soil was an Open Downs, Ug5.1 classification (Northcote *et al*. 1975), with pH (1 : 5 soil : water) 7.8, clay content 69% (mostly montmorillonite) and 0.6% organic carbon content. The mean temperatures and rainfall between spraying and sowing are presented in Table 1.

Herbicide treatments

All herbicides were applied to bare fallows using a boom, mounted on a 4-wheel drive motorbike, with 110º flat fan nozzles delivering the solutions at 62 L/ha and 200 kPa. Herbicides were applied in late October for trials 1–3, early July for trial 4, and mid May for trial 5 (Table 1). Chlorsulfuron (as Glean 750 g a.i./kg, Du Pont), triasulfuron (as Logran 714 g a.i./kg, Novatis) and metsulfuron methyl (as Ally 600 g a.i/kg, Du Pont) were applied at the recommended rate in all trials and at the double recommended rate in most trials (see Tables 2, 3 and 4). The exception was triasulfuron in trial 4, which was applied at slightly higher rates (see Table 2). In trial 3, additional metsulfuron methyl (4.2 g/ha) treatments had rain-out shelters erected immediately

Table 2. Sorghum shoot dry matter (SDM; g/m^2) and grain yield (t/ha) responses when sown in soils previously treated with sulfonylurea herbicides

Seedling response (SDM) was measured 3 weeks after emergence

Treatment	Trial 1		Trial 2		Trial 3		Trial 4			Trial 5		
	Summer		Summer		Summer		Spring	Summer		Spring	Summer	
	SDM	Yield	SDM	Yield	SDM	Yield	SDM	SDM	Yield	SDM	SDM	Yield
Metsulfuron methyl												
4.2 g/ha	76	3.79	64	3.36	57	1.63	2.2*	48	2.84	5.5*	34	3.68
4.2 g/ha covered					55	0.57*						
8.4 g/ha			54	2.91	69	1.79	1.8*	49	2.80	3.0*	35	3.41
Chlorsulfuron												
15 g/ha	77	3.62	65	3.40	49	1.40	2.8*	44	2.78	2.9*	34	4.05
30 g/ha			63	3.34	54	1.64	0.9*	35	2.78	1.2*	34	3.91
Triasulfuron												
25 g/ha										4.4*	42	3.84
50 g/ha										1.5*	34	3.59
32 g/ha							1.1*	29*	2.09*			
64 g/ha							0.6*	13*	1.80*			
Untreated	74	3.91	59	3.05	90	1.71	16	44	3.28	10.5	35	3.63
s.e.m.	4.5	0.24	4.9	0.22	19.7	0.14	0.49	5.5	0.15	0.96	5.8	0.38
Chlorsulfuron residue (ng/g)[A]												
Soil depth 0–5 cm	0.1 (0.08)		0.2 (0.11)		0.1 (0.07)		4.4 (0.71)	<0.05		3.2 (0.49)	<0.1	
Soil depth 5–15 cm	0.1 (0.04)		0.1(0.10)		0.2 (0.02)		0.3 (0.24)	<0.05		1.5 (0.09)	<0.1	

[A] Measured in the 15 g/ha treatment at 2 soil depths with s.e.m. in parentheses. * Significantly less (P = 0.05) than the untreated control.

Table 3. **Sunflower shoot dry matter (SDM; g/m²) and yield (t/ha) response when sown in soils previously treated with sulfonylurea herbicides**

Seedling response (SDM) was measured 3 weeks after emergence

Treatment	Trial 1 SDM	Trial 2 SDM	Trial 2 Yield	Trial 3 SDM	Trial 3 Yield	Trial 5 SDM
Metsulfuron methyl						
4.2 g/ha	41	75	1.22	37	0.58	40
4.2 g/ha covered				0*	0*	
8.4 g/ha		76	1.24	28	0.57	39
Chlorsulfuron						
15 g/ha	43	74	1.21	38	0.47	32
30 g/ha		70	1.31	47	0.37	26
Triasulfuron						
25 g/ha						42
50 g/ha						37
Untreated	39	73	1.21	36	0.38	33
s.e.m.	6.9	2.7	0.09	2.9	0.06	3.5

* Significantly less (P = 0.05) than the untreated control.

after spraying, which were removed for the sowing irrigation. Split applications of metsulfuron methyl (4.2 + 4.2 g/ha) were also included in trials 1, 2 and 3. The initial application coincided with the other herbicide treatments, followed by an additional application about 3 months later in mid January. These split application treatments were sown to chickpea only.

Crop details

The sprayed and unsprayed plots were sown to either spring sorghum (cv. MR 31) in September; sorghum [cv. Goldmine (trials 1, 2, 3, 4) or cv. Tulloch (trial 5)] and sunflower (cv. Hysun 33) in January–February; and chickpea (cv. Amethyst) in April–May. Recropping intervals varied from 2.5 to 11.7 months depending on time of spraying and crop sown (Table 1). The spring sorghum in trials 4 and 5 and sunflower in trial 5 were sprayed out with glyphosate shortly after early growth data were collected, allowing the sowing of subsequent crops into the same plots.

Design

Experimental design was a randomised complete block with 3 replicates for herbicide treatments, all of which were duplicated for sowing of different crops. Plots were 10 by 1.8 m for chickpea, and 10 by 3.6 m for sorghum and sunflower.

Measurements and analysis

Seedling shoots were removed from a 2 m row in each plot at 3 weeks after crop emergence, dried at 80ºC and weighed (SDM). These were converted to the equivalent g/m² based on the row spacing used for each crop. Grain yield (t/ha) was recorded using small plot header, except for spring sorghum and sunflower in trials 1 (due to extensive bird damage) and 5. Data were subjected to analysis of variance, and the least significant difference was used as the test statistic

Table 4. **Chickpea shoot dry matter (SDM; g/m²) and yield (t/ha) response when sown in soils previously treated with sulfonylurea herbicides**

Seedling response (SDM) was measured 3 weeks after emergence

Treatment	Trial 1 SDM	Trial 1 Yield	Trial 2 SDM	Trial 2 Yield	Trial 3 SDM	Trial 3 Yield	Trial 5 SDM	Trial 5 Yield
Metsulfuron methyl								
4.2 g/ha	24.6	2.72	7.0	1.94	22.8	1.96	10.8	1.26
4.2 g/ha covered					23.8	1.84		
8.4 g/ha			6.6	2.04	25.0	2.01	14.6	1.07
4.2 + 4.2 g/ha	34.4	2.82	5.8	2.20	25.0	1.93		
Chlorsulfuron								
15 g/ha	27.8	3.07	6.6	1.89	24.2	2.00	16.2	1.28
30 g/ha			6.2	2.02	24.0	2.05	13.2	1.37
Triasulfuron								
25 g/ha							9.2	1.41
50 g/ha							12.2	1.29
Untreated	23.2	2.70	7.2	2.05	29.6	2.04	11.6	1.38
s.e.m.	3.16	0.16	0.65	0.11	2.66	0.07	2.26	0.11
Chlorsulfuron residue (ng/g)[A]								
Soil depth 0–5 cm	0.1 (0.08)		0.1 (0.14)		<0.1		<0.1	
Soil depth 5–15 cm	0.1 (0.13)		0.1 (0.12)		<0.1		<0.1	

[A] Measured in the 15 g treatment at 2 soil depths with s.e.m. in parentheses.

between untreated and treated means when the *F*-value was significant.

Soil samples were collected from the chlorsulfuron (15 g/ha) treatments immediately after herbicide application (0–10 cm), as well as at sowing of sorghum and chickpea (0–5 cm and 5–15 cm). Chlorsulfuron concentrations in these samples were determined using a bioassay based on maize root growth suppression, as described by Walker and Robinson (1996). Bioassays for the other herbicides were not used, as they had not been evaluated for this soil. The logistic equation was fitted to the bioassay data by non-linear regression (Streibig 1988) using GRAPHPAD statistical package (Version 3.1)

$$Y = A + [(B - A)/(1 + (10^C/10^X)^D)]$$

where Y is root length (cm), X is logarithm of chlorsulfuron concentration (ng/g), A and B are the upper and lower asymptotes, C is $\log_{10}(ID_{50})$, and D is slope at ID_{50}, the dose for 50% response. Root lengths of each unknown were substituted into this equation, from which the chlorsulfuron concentration was estimated.

Results

Chlorsulfuron persistence

The logistic model gave good agreement with the data (R^2 = 0.98 or 0.99), and the estimated parameters were consistent between the 4 bioassays. The estimated chlorsulfuron concentrations following application were 9.2, 7.4, 9.2 and 9.0 ng/g in the surface 10 cm in trials 2, 3, 4 and 5 respectively (not measured in trial 1). A mean of 0.1 ng/g remained in the surface 15 cm in trials 1, 2 and 3 at 3 months after October applications, whereas a mean of 1.9 ng/g remained in trials 4 and 5 at 3 months after May–July applications (Table 2). Mean air temperatures for these 2 periods were 27.6 and 18.2°C respectively (Table 1). At sowing of chickpea, chlorsulfuron concentrations were either 0.1 ng/g or not detectable (Table 4).

Spring sorghum

These crops were substantially affected by winter applications of all herbicides in trials 4 and 5 (Table 2). Seedling biomass reduction, while significant (P = 0.05) in both trials, was greater in trial 4 (86–98%) with a recropping interval of 2.5 months than in trial 5 (48–89%) with a recropping interval of 4.1 months. Both trials had similar rainfall and temperatures during the fallow (Table 1).

Summer sorghum and sunflower

Sorghum seedling biomass and grain yield were not affected by any herbicide treatment, except for the covered metsulfuron methyl and the higher triasulfuron rates in trial 4 (Table 2). Similarly, sunflower was unaffected except for the covered metsulfuron methyl treatment, which resulted in complete crop death (Table 3). Recropping intervals varied from 2.5 to 9.3 months, and rainfall during the fallow varied from 180 to 560 mm (Table 1).

Chickpea

Seedling biomass and grain yield were not affected by any herbicide treatment (Table 4), and recropping interval ranged from 5.7 to 11.7 months (Table 1).

Discussion

Sorghum, sunflower and chickpea can be safely sown at much shorter recropping intervals on the heavy dark cracking clays of Central Queensland than currently recommended on the labels of chlorsulfuron, triasulfuron and metsulfuron methyl. For the summer crops this interval reduces to 6 months after a winter application, and to 3 months after a late spring application. Recropping to chickpea in the subsequent winter is safe irrespective of the herbicide application time. A similar field study in Greece showed that sunflower could be safely planted 7 months after applications of chlorsulfuron at rates up to 40 g/ha (Eleftherohorinos and Kotoula-Syka 1989). Blair and Martin (1988) have also indicated that in most European countries, triasulfuron can be applied to cereals without restricting rotational cropping. In contrast, significant crop injury in sorghum and sunflower has been reported 12 months after spring applications of 17 g/ha chlorsulfuron under cooler conditions in northern America (Peterson and Arnold 1986).

These sulfonylurea herbicides can be confidently used in certain opportunistic rotations of Central Queensland. Double or opportunity cropping from wheat, in which these sulfonylurea herbicides can be used, to summer crops in the following December–February period is not restricted. The use of all 3 herbicides in wheat will, however, restrict spring sorghum cropping but these opportunities will only arise if the wheat crop fails. In the past, the use of chlorsulfuron and triasulfuron has been negligible in these farming systems for fear of herbicide residues denying any summer crop options. Since neither of these herbicides are registered for use in fallow, late spring applications are unlikely to be made. However, metsulfuron methyl is registered for fallow use (in mix with glyphosate) before winter cereal cropping, but is not currently recommended before sorghum, sunflower and chickpea (Parsons 1995). The results from this study indicate that spring and early summer fallow applications of metsulfuron methyl to sorghum and sunflower planted 3 months later and to chickpea planted 6 months later are quite safe. Metsulfuron methyl can now be added to the herbicide options for spring–summer fallow weed control in this environment.

The short recropping intervals on the Central Highlands can be attributed to the rapid degradation of these herbicides under the very warm temperatures experienced in late spring and summer. Our data have shown that 96% of the applied chlorsulfuron dose had disappeared after 3 months with mean daily air temperature of 28°C. Chlorsulfuron, triasulfuron and metsulfuron methyl degrade by both chemical hydrolysis and microbial activity (Joshi *et al.* 1985; Thirunarayan *et al.* 1985; Brown 1990). These degradation mechanisms are dependent on the specific compound, the soil pH and temperature (Brown 1990). Walker and Brown (1983) and Thirunarayanan *et al.* (1985) have shown that half-lives for chlorsulfuron and metsulfuron methyl are shortened at high temperatures. Incubation studies at 30°C showed chlorsulfuron had a half-life of only 9 days (Walker and Brown 1983) and triasulfuron had a half-life of only 11–13 days (Oppong and Sagar 1992). Oppong and Sagar (1992) have also shown that 98% of the initial triasulfuron concentration had disappeared within 30 days in a soil held at 75% field capacity and 30°C.

While temperature appears to be the most influencing factor on sulfonylurea degradation in our environment, the effects of soil water have some importance. In the covered metsulfuron methyl treatments, where all rain except the sowing rain was excluded, yields were reduced by 66% for sorghum, 100% for sunflower but only 10% for chickpea. The excluded rain was about 80 mm before the summer crops, indicating that only a small amount of non-sowing rain is required to degrade the herbicides to non-injurious levels. In chickpea, more than 60% of the total fallow rain (308 mm) was excluded and crop injury was minimal. Similar chlorsulfuron residues were measured at sowing times of sorghum when fallow rainfall varied from 180 to 560 mm in different years. Variations in fallow rainfall were large across the trials before sowing of chickpea (ranging from 308 to 785 mm), but variations in the levels of chlorsulfuron residue were very small. This agrees with Oppong and Sagar (1992) who concluded that variations in temperature were far more influential on dissipation rates of triasulfuron than variations in soil water.

The crop responses measured were consistent with the chlorsulfuron residues measured in the root zone at sowing. It was safe to plant sorghum when residues in the surface 15 cm were <0.2 ng/g but not when residues were >1.5 ng/g. This is also consistent with the crop sensitivity data that has been determined in a soil-free system by Churchett *et al.* (1996). They have determined the ID_{10} value range (concentration at which seedling growth is inhibited by 10%) for the 3 crops to be 0.10–0.25 ng/mL chlorsulfuron when fully available, with sunflower being the most sensitive. The residues measured in the soil at time of sowing are 'total' residue where we estimated that about only 10–20% of this is available for plant uptake (Walker *et al*. 1997).

Conclusion

The recropping intervals for chlorsulfuron, triasulfuron and metsulfuron methyl are short in this semi-arid subtropical environment of Central Queensland. Our study suggests that the recropping interval for sorghum and sunflower be changed to 6 months after an early winter application, or 3 months after a late spring application, provided both periods receive a minimum 100 mm rainfall before a sowing rain event. Similarly, they are 12 and 6 months for chickpea. The recropping interval following spring applications is particularly important for the fallow use of metsulfuron methyl.

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