

## DO INCREMENTAL INCREASES OF THE HERBICIDE GLYPHOSATE HAVE INDIRECT CONSEQUENCES FOR SPIDER COMMUNITIES?

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**ABSTRACT.** We examined the indirect effect of the herbicide glyphosate on field margin spider communities. Glyphosate was applied to two replicated ( $n = 8$  per treatment) randomized field experiments over two years in 1997–1998. Spiders were sampled using a modified garden vac monthly from May–October in the following treatments: 1997 comprised 90g, 180g, & 360g active ingredient (a.i.) glyphosate  $\text{ha}^{-1}$  treatments and an unsprayed control; 1998 comprised 360g, 720g and 1440g a.i. glyphosate  $\text{ha}^{-1}$  treatments and an unsprayed control. We examined the indirect effect of glyphosate on the spider community using DECORANA (DCA), an indirect form of gradient analysis. We subjected DCA-derived Euclidean distances (one a measure of beta diversity and the other a measure of variability), to the scrutiny of a repeated measures ANOVA design. We found that species turnover and cluster variation did not differ significantly between treatments. We attribute the lack of any effect to a large number of common agricultural species which are never eliminated from a habitat, but are instead significantly reduced. Reduction rather than elimination does not cause the spider communities within these plots to turn over any faster than the control. However, like most other animal communities, the spider community did turn over and change in structure and composition through the season, regardless of treatment. Using Spearman rank correlations, we found that this within-season species turnover is related to the decline in vegetation height and the increase in percentage dead vegetation cover in the field margin.

**Keywords:** Glyphosate, herbicide, spiders, species turnover, DECORANA, field margins

Field margins play an important agricultural role in providing a refuge for beneficial invertebrate predators (e.g., Araneae, some Carabidae; Staphylinidae; Heteroptera) facilitating movements of invertebrates into the crop (e.g., Duelli et al. 1990). Data from herbicide-treated and untreated cereal headlands suggest that butterflies, carabid beetles, Auchenorrhyncha and Heteroptera (Hemiptera) are detrimentally affected by spray applications, but to differing degrees (e.g., Chiverton & Sotherton

1991; Feber et al. 1996; Houghton et al. 1999a,b). This detrimental effect on non-target invertebrates following an experimental spray application of herbicide simulates what may happen when spray is allowed to drift onto non-target areas. Drift may be a product of operator error or a sudden increase in wind speed and in either of these situations, the spray is likely to become misplaced and affect field margins and adjacent semi-natural habitats.

Recent evidence suggests that spider numbers are likely to be significantly affected even by a relatively low rate of herbicide application (Baines et al. 1998; Houghton et al. 1999c). This effect, even at low rates, may

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have detrimental implications for both field margin biodiversity and bio-control programs which use beneficial spiders to control pests. In the context of a rapid increase in worldwide demand for glyphosate when, for example, 70 million hectares of land worldwide were sprayed in 1997 (Woodburn 2000), it is easy to demonstrate a need for a clearer understanding of the potential effect on spiders and other non-target invertebrates.

The properties of glyphosate (*N*-(phosphonomethyl)glycine), an exceedingly effective but slow-acting broad spectrum herbicide, are well known. The herbicide acts by inhibiting the biochemical pathway in plants (i.e., 5-enolpyruvylshikimate 3-phosphate synthase) by blocking the production of aromatic amino acids thus restricting protein synthesis and photosynthetic activity (Bayliss 2000). It is used in a range of agricultural (particularly cereals), industrial and domestic situations to control grasses and other weeds (Woodburn 2000). However, the toxicological effect on invertebrates is little understood except to state that the herbicide is classified as 'harmless' to spiders and a range of other common non-target invertebrates by The Society of Environmental Toxicology and Chemistry (Europe) (Bartlett et al. 1994)

In this paper we investigated the within-season effect of incremental levels of glyphosate application (six levels from 90–1440 g active ingredient (a.i) glyphosate ha<sup>-1</sup> with a control) on field margin spiders from a community perspective.

## METHODS

**Study sites.**—The field research was based at the Allerton Research and Educational Trust Estate, Loddington, Leicestershire, UK (grid reference: SK 789015). We spread the effort of conducting such a large experiment over two years between 1997–1998. Two field margin study sites were used which were separated by a minor road but were no more than 20 m apart. Both sites had an adjacent dense uncut Hawthorn (*Crataegus monogyna* Jacq.) and Blackthorn (*Prunus spinosa* L.) hedge running along their length. The experimental plot size was the same in both years: field margins were divided into 32 contiguous plots, each measuring 12 m long × 2 m wide.

The 1997 margin was dominated by False Oat-grass (*Arrhenatherum elatius* (L.) and

Couch-grass (*Elymus repens* (L.)). Eight replicates of four treatments, 90 g, 180 g and 360 g a.i. glyphosate ha<sup>-1</sup> (Roundup Biactive, Monsanto, High Wycombe, Berkshire) and an unsprayed control, were randomly assigned along the field margin. Glyphosate was applied to these plots at a volume rate of 200 litres ha<sup>-1</sup> and a pressure of 2.5 bar using an Oxford Precision Sprayer fitted with flat fan nozzles on 30.v.1997, during dry and calm conditions (24 °C, RH 55%, wind speed <1 m s<sup>-1</sup>).

The 1998 margin was dominated by False Oat-grass (*A. elatius* (L.)) and Yorkshire Fog (*Holcus lanatus* (L.)). Eight replicates of four treatments were assigned in a randomized block design: 360 g, 720 g and 1440 g a.i. glyphosate ha<sup>-1</sup> (Roundup Biactive, Monsanto, High Wycombe, Berkshire) suspended in water and an unsprayed control. Glyphosate was applied to the plots on the 4.vi.1998 during dry, calm conditions (17.5 °C, RH 84.5%, wind speed <2 m s<sup>-1</sup>) with the same equipment, volume rate and pressure as that described in 1997.

**Data collection.**—Spiders were sampled using a modified garden-vac (g-vac) (Ryobi RSV3100E: engine capacity 31 cm<sup>3</sup> with a nozzle size 13 cm). The spider samples from each experimental plot comprised 10 sub-samples of 30 second sucks at 1 m intervals along each experimental plot. Sampling was done on the central 10 m of each plot to avoid edge effects from neighboring treatments: the total sampling area per plot approximated to 0.13 m<sup>2</sup>. Each sample of spiders was emptied from the g-vac into a plastic bag, extracted with an aspirator into 70% alcohol and then identified to species level.

Two measures of vegetation structure were taken. Percentage ground cover of dead vegetation in the experimental plots was recorded using permanent 0.25 m<sup>2</sup> quadrats and, average vegetation height at five positions (as in a domino-5) within the quadrats was recorded to the nearest cm. Three quadrats were positioned at 3 m, 6 m and 9 m within each of the 32 plots and mean percentage dead vegetation cover and mean vegetation height. Spider and vegetation sampling was done monthly between May–October inclusive, to monitor any changes over the season.

**Data analyses.**—There are many ways of calculating species turnover, but most index-

type methods which have traditionally been used do not take account of the community dynamics as they fail to retain all the information from the species matrix. However, multivariate statistics have been suggested as an inclusive technique which does not oversimplify the dynamic nature of the community (Williamson 1987). We introduce a simple method of calculating species turnover while retaining most of the ecological information from the data matrix. Using DECORANA (DEtrended CORrespondence ANALysis or DCA for short), a widely available package designed specifically for ecological studies to avoid distortions caused by either the arch or horseshoe effects (Hill 1994), *P* values are attached to the turnover rates in DCA-Euclidean space using ANOVAs. This is an extension of Hill's (1994) approximation of the standard deviation of species turnover along the x-axis. Species turnover, which is sometimes referred to as beta ( $\beta$ ) diversity, is used here as meaning "the change in the composition of a biological community as a result of either or both the immigration and local extinction of species" (Russell et al. 1995).

First, two binary matrices were created (1997:  $58 \times 192$ ; 1998:  $59 \times 192$ ) which represented the presence/absence of species within each year. These were analyzed separately using DCA (default settings with 26 segments used to remove the arch effect), which arranges points along the axes on the basis of species composition data. Thus, the further two points are from one another in the DCA ordination space, the more dissimilar the spider communities. Once the DCA had produced two biplots (1997 & 1998), the axes 1 and 2 scores were separated into herbicide treatment (i.e., control, 90 g, 180 g etc.). Using the DCA axis 1 and 2 scores, the Euclidean distance for each replicate within each treatment was calculated for consecutive between-month shifts to establish the rate of species turnover. For example, in 1997 for the first replicate in the 90 g a.i. glyphosate  $\text{ha}^{-1}$  treatment, the following Euclidean distances were calculated from axis 1 and 2 scores: May→June; June→July; July→August; August→September; September→October. Thus, there were five measurements for each of the eight replicates in each of the four treatments ( $n = 160$ ) for both years. These distances indicate the seasonal species turnover in  $n$  dimensional space. Ul-

timately, these Euclidean distances indicate the level of species stability (i.e., high or low rates of turnover) between treatments.

We then calculated the average Euclidean distance between all points within the same treatment for each of the months from May–October inclusive ( $n = 672$ ) using the DCA axis 1 and 2 scores for each year (i.e., we generated a distance matrix for each treatment for each month). This approach would indicate whether the size of the cluster varied between treatment. The size of the cluster equates to a measure of community variation; large clusters have more variation in the species complex than small ones.

Univariate repeated measures, with date as the within-subject factor and treatment as the main effect, were used to analyze differences in species turnover (i.e., distance moved in DCA-Euclidean space) and cluster distance throughout the season in each year. As a prerequisite to using a repeated measures ANOVA, we logged ( $x + 1$ ) the data and tested it for sphericity using Mauchly's *W* test. Where significant differences were found between treatments, a Tukey *post hoc* test was used to establish the location of the difference. We also used Monte Carlo randomization tests to establish whether the null hypothesis, that a pattern is present as purely a chance effect of observations in a random order, should be rejected (Manley 1991). Monte Carlo randomizations are useful for verifying the significance level in an ANOVA design when some of the statistical assumptions (i.e., independence) may be in question. The level of significance in a Monte Carlo test is expressed as the percentage of values which are equal to, or higher than can be found in a randomized distribution. If the percentage of values that exceed the observed mean square is less than 5%, then this suggests that the null hypothesis should be rejected. We used 30,000 Monte Carlo randomizations to test this null hypothesis on significant ANOVA test results to check for their validity.

In order to interpret the importance to the arthropod community of the changes in the vegetation caused by the rate of glyphosate, Spearman's rank correlation was used to test for the strength of association between the axis scores and vegetation height and percentage dead vegetation cover.

Table 1.—Araneae species recorded from the field margins at Loddington.

Oonopidae	Araneidae
<i>Oonops domesticus</i> de Dalmas 1916	<i>Lariniodes cornutus</i> (Clerck 1757)
Gnaphosidae	<i>Araniella opistographa</i> (Kulczynski 19505)
<i>Micaria pulicaria</i> (Sundevall 1832)	Linyphiidae
Clubionidae	<i>Ceratinella brevipes</i> (Westring 1851)
<i>Clubiona reclusa</i> Cambridge 1863	<i>Ceratinella scabrosa</i> (Cambridge 1871)
<i>Clubiona lutescens</i> Westring 1851	<i>Walckenaeria acuminata</i> Blackwall 1833
<i>Clubiona compta</i> Koch 1839	<i>Walckenaeria nudipalpis</i> (Westring 1851)
Zoridae	<i>Walckenaeria unicornis</i> Cambridge 1861
<i>Zora spinimana</i> (Sundevall 1833)	<i>Walckenaeria cuspidata</i> (Blackwall 1833)
Thomisidae	<i>Dicymbium nigrum</i> (Blackwall 1834)
<i>Xysticus cristatus</i> (Clerck 1757)	<i>Entelecara erythropus</i> (Westring 1851)
<i>Ozyptila praticola</i> (Koch 1837)	<i>Dismodicus bifrons</i> (Blackwall 1841)
Philodromidae	<i>Gonatium rubens</i> (Blackwall 1833)
<i>Philodromus dispar</i> Walckenaer 1826	<i>Maso sundevalli</i> (Westring 1851)
<i>Philodromus cespitum</i> Walckenaer 1802	<i>Pocadicnemis juncea</i> Locket & Millidge 1953
<i>Philodromus collinus</i> Koch 1835	<i>Oedothorax fuscus</i> (Blackwall 1834)
<i>Tibellus oblongus</i> Walckenaer 1802	<i>Oedothorax retusus</i> (Westring 1851)
Salticidae	<i>Cnephalocotes obscurus</i> (Blackwall 1834)
<i>Euophrys frontalis</i> (Walckenaer 1802)	<i>Monocephalus fuscipes</i> (Blackwall 1836)
Lycosidae	<i>Gongylidiellum vivum</i> (Cambridge 1875)
<i>Pardosa palustris</i> (L. 1758)	<i>Micrargus herbigradus</i> (Blackwall 1854)
<i>Pardosa pullata</i> (Clerck 1757)	<i>Micrargus subaequalis</i> (Westring 1851)
<i>Pardosa prativaga</i> (Koch 1870)	<i>Erigonella hiemalis</i> (Blackwall 1841)
<i>Pardosa amentata</i> (Clerck 1757)	<i>Savignya frontata</i> (Blackwall 1833)
<i>Pardosa nigriceps</i> (Thorell 1856)	<i>Diplocephalus latiformis</i> (Cambridge 1863)
<i>Alopecosa pulverulenta</i> (Clerck 1757)	<i>Diplocephalus connatus</i> Bertkau 1889
<i>Trochosa ruricola</i> (Degeer 1778)	<i>Araeoncus humilis</i> (Blackwall 1841)
<i>Trochosa terricola</i> Thorell 1856	<i>Panamomops sulciformis</i> (Wider 1834)
Pisauridae	<i>Erigone dentipalpis</i> (Wider 1834)
<i>Pisaura mirabilis</i> (Clerck 1757)	<i>Erigone atra</i> (Blackwall 1833)
Mimetidae	<i>Porrhomma microphthalmum</i> (Cambridge 1871)
<i>Ero cambridgei</i> Kulczynski 1911	<i>Meioneta rurestris</i> (Koch 1836)
<i>Ero furcata</i> (Villers 1789)	<i>Meioneta saxatilis</i> (Blackwall 1844)
Theridiidae	<i>Syedra gracilis</i> (Menge 1869)
<i>Episinus angulatus</i> (Blackwall 1836)	<i>Centromerus sylvaticus</i> (Blackwall 1841)
<i>Theridion bimaculatum</i> (L. 1767)	<i>Centromerita bicolor</i> (Blackwall 1833)
<i>Enoplognatha ovata</i> (Clerck 1757)	<i>Bathyphantes gracilis</i> (Blackwall 1841)
<i>Robertus lividus</i> (Blackwall 1836)	<i>Bathyphantes parvulus</i> (Westring 1851)
<i>Pholcomma gibbum</i> (Westring 1851)	<i>Diplostyla concolor</i> (Wider 1834)
Tetragnathidae	<i>Poeciloneta globosa</i> (Wider 1841)
<i>Tetragnatha extensa</i> (L. 1758)	<i>Stemonyphantes lineatus</i> (L. 1758)
<i>Tetragnatha montana</i> Simon 1874	<i>Lepthyphantes tenuis</i> (Blackwall 1852)
<i>Pachygnatha clercki</i> Sundevall 1823	<i>Lepthyphantes mengei</i> Kulczynski 1887
<i>Pachygnatha degeeri</i> Sundevall 1830	<i>Lepthyphantes ericaeus</i> (Blackwall 1853)
<i>Meta segmentata</i> (Clerck 1757)	<i>Lepthyphantes pallidus</i> (Cambridge 1871)
<i>Meta mengei</i> (Blackwall 1869)	<i>Lepthyphantes insignis</i> Cambridge 1913
	<i>Neriene clathrata</i> (Sundevall 1830)
	<i>Microlinyphia pusilla</i> (Sundevall 1830)

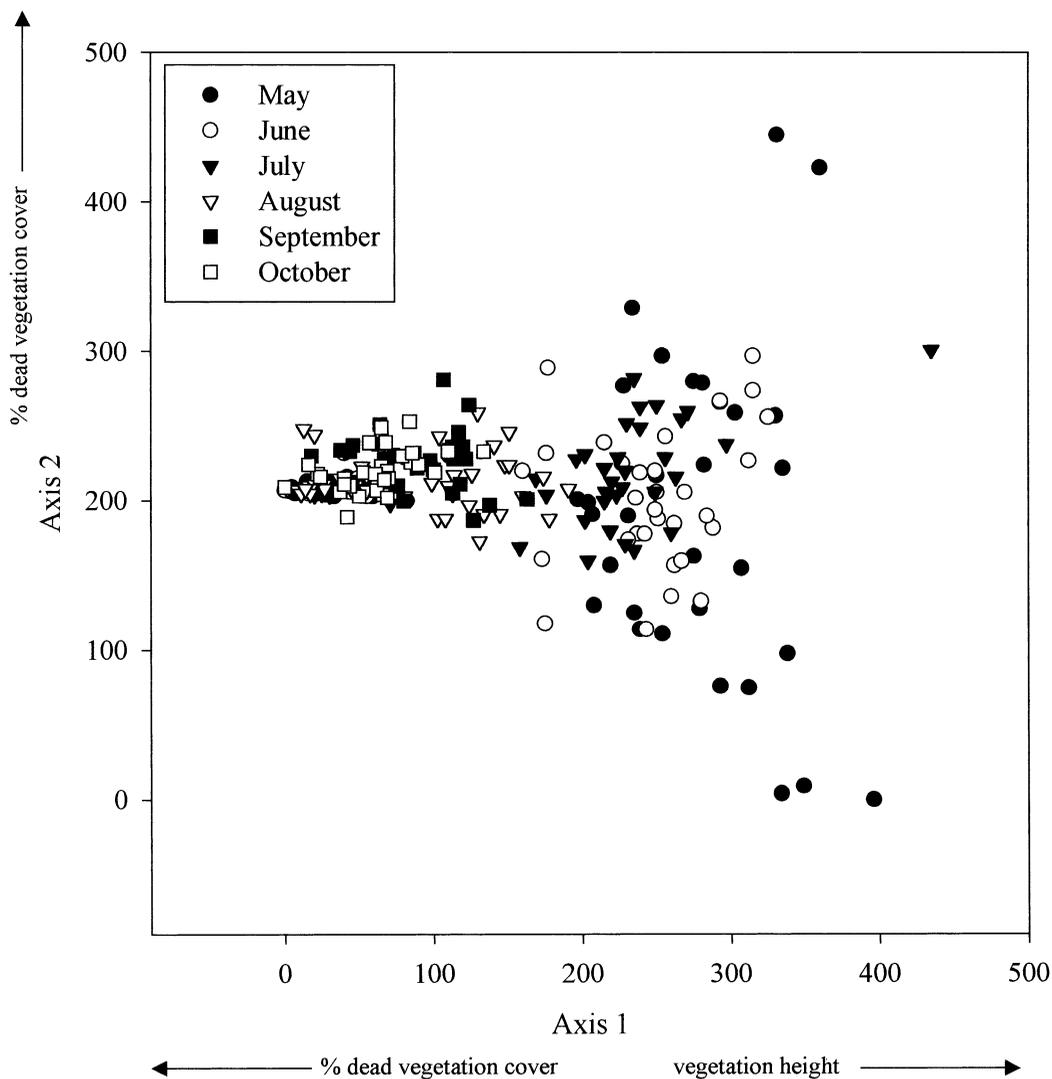


Figure 1.—DCA biplot of 1997 field margin spider samples. (Note: plots indicating symbols as treatments rather than months are not shown because no clear separation can be made between different herbicide rates).

## RESULTS

**The spider community.**—In both 1997 and 1998, the adult spider community was dominated by linyphiids (Table 1). The three species that occurred most frequently (percentage of all the samples in 1997 and 1998 respectively) were *Lepthyphantes ericaeus* (Blackwall 1853) (77.1%; 73.9%), *Lepthyphantes tenuis* (Blackwall 1852) (69.3%; 84.3%) and *Bathyphantes gracilis* (Blackwall 1841) (49.5%; 43.2%), all of which are considered common field margin spiders in Brit-

ain. Between 58 and 59 species were recorded in total in 1997 and 1998 respectively, 44 of which were recorded in less than 10% of the total number of samples for both years, 28 of which were singletons. The total number of spiders recorded in the study was 46,393. Voucher specimens were deposited with Leicester Museum through John Crocker, the county recorder for Leicestershire.

**DCA biplots.**—No separation along axis 1 or 2 is apparent on either of the 1997 or 1998 biplots (Figs. 1, 2). Instead, all samples form

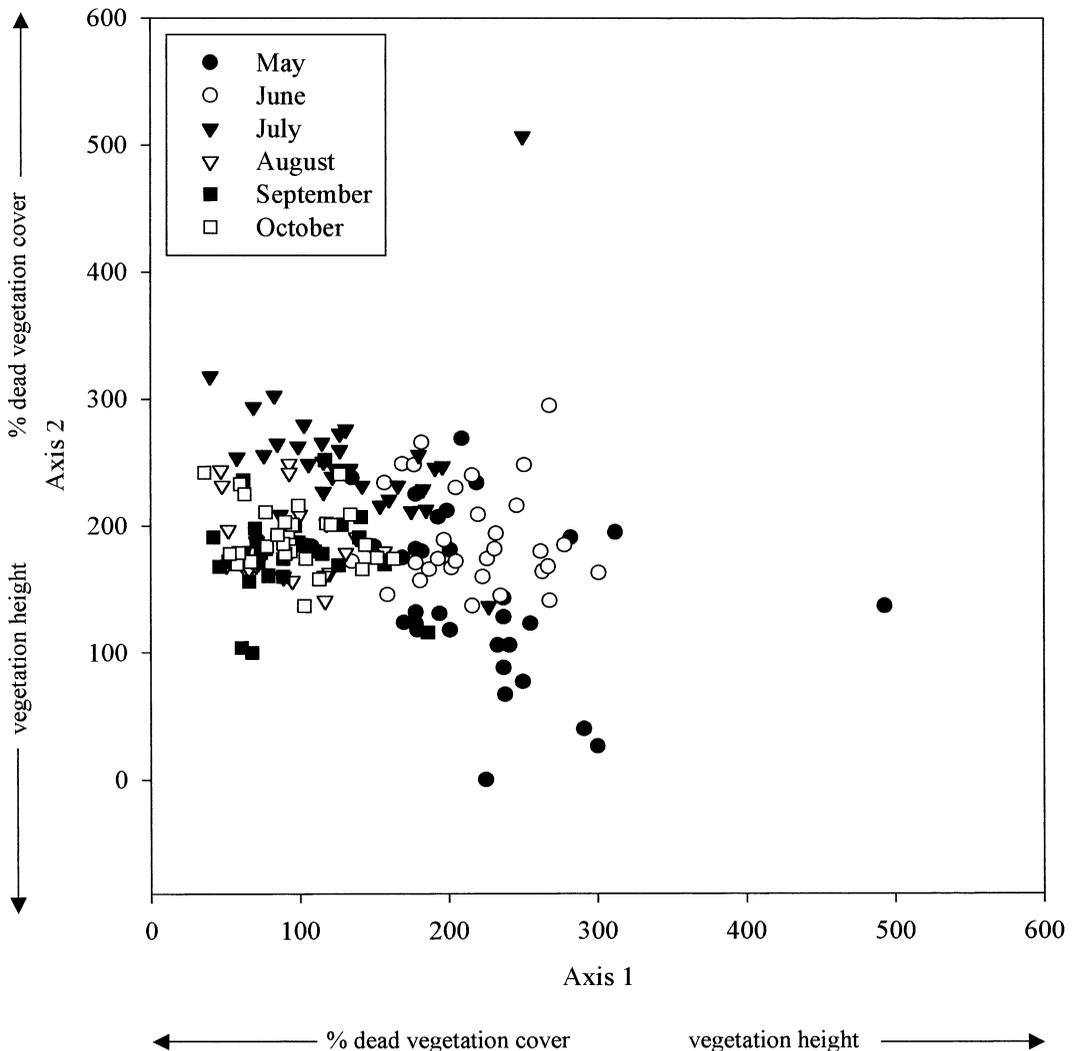


Figure 2.—DCA biplot of 1998 field margin spider samples. (Note: plots indicating symbols as treatments rather than months are not shown because no clear separation can be made between different herbicide rates).

a homogenous cluster, with a tendency for samples within the same month to be aligned. In the 1997 biplot (Fig. 1), axis 1 scores decline as samples move in ordination space through the season. This effect is less discernable in the 1998 biplot (Fig. 2), although samples within each month do aggregate to some extent. The relationship between axis 1 scores and vegetation height and percentage dead vegetation cover indicates significant correlations (Table 2); axis 1 is positively correlated with vegetation height, but negatively correlated with percentage dead vegetation cover in both years. These relationships are reversed

on axis 2 where, apart from a lack of a significant result in 1997 with vegetation height, axis 2 is negatively correlated with vegetation height, but positively correlated with percentage dead vegetation cover in both years.

**DCA-Euclidean species turnover.**—Species turnover analysis revealed a significant treatment effect in 1997 ( $F_{3,28} 3.63 P = 0.024$ ) but no such effect in 1998 ( $F_{3,28} 0.24 P = 0.867$ ). Significant test results were compared with 30,000 Monte Carlo randomizations and their respective observed mean squares. For the 1997 ANOVA result (i.e.,  $F_{3,28} 3.63 P = 0.024$ ), only 0.060% of the randomizations ex-

Table 2.—Spearman rank correlations between vegetation characteristics and DCA axis scores for field margin spiders.

Year	Axis	Vegetation height		Percentage dead vegetation cover	
		$r_s$	$P$	$r_s$	$P$
1997	1	0.434	<0.001	-0.452	<0.001
	2	-0.753	0.299	0.185	0.010
1998	1	0.477	<0.001	-0.314	<0.001
	2	-0.183	0.011	0.218	0.002

ceeded the observed mean square—strong evidence that observed test results could not be generated randomly.

The differences between treatments in 1997 were due to significantly higher rates of turnover in the 90 g a.i. glyphosate treatments when compared all others (Table 3). Overall, the general trend was for species turnover to decline slightly over the season in 1997 (Fig. 3). The trend in 1998 was much more variable with treatments apparently acting independently of one another (Fig. 4).

**DCA-Euclidean cluster size.**—Cluster size did not differ significantly over the season between treatment for 1997 ( $F_{3,108}$  1.17  $P$  = 0.327) or 1998 ( $F_{3,108}$  1.45  $P$  = 0.233). The general trend was that cluster size did get smaller over the season in 1997 (Fig. 5) but in 1998, it was more variable with size declining towards the middle of the summer and increasing approaching the end (Fig. 6).

#### DISCUSSION

**DCA biplots and related tests.**—Considering all the repeated measures ANOVAs, no consistent monotonic relationship between glyphosate application rate and species turnover or cluster size could be found. The only significant result that was detected in the 90 g a.i. glyphosate  $ha^{-1}$  treatment, but this does not compare with the effects measured at higher treatments and thus must be considered a rogue effect. Spider communities did change in many ways over the season (Figs. 1–6), but

this was not related to an incremental increase in the rate of glyphosate application. One major factor which influenced the spider community composition over the season was the profound effect of differences in spider phenology. There is often a marked difference between the composition of the spider community in the spring compared to autumn. July and August are the transition months when spring species disappear (e.g., *Pardosa* species) and autumn species emerge (e.g., *Goniatium rubens* (Blackwall 1833)). However, most of the abundant spiders occurred throughout the whole sampling period; either low in number in spring and more abundant in autumn (e.g., *Bathyphantes gracilis* (Blackwall 1841)) or the reverse (e.g., *Pocadicnemis juncea* Locket & Millidge 1953).

Overall, the response of the spider community was, on first inspection, very different from that of various single species responses observed in other Loddington research. At relatively low rates of glyphosate application (360 g a.i.  $ha^{-1}$ ), a significant decline in numbers of *L. tenuis* was detected (Haughton et al. 2001a; Haughton et al. 1999c). Similarly, another linyphiid, *G. rubens* was reduced by even lower rates of glyphosate application (180 g a.i.  $ha^{-1}$ ) and evidence from the same experiment suggests that total spider abundance, and the number of web-spinners are also detrimentally affected (Haughton et al. 1999c).

Table 3.—Tukey  $P$  values for differences between mean DCA-Euclidean distances for field margin spiders in the 90 g a.i. glyphosate  $ha^{-1}$  treatment when compared with all other individual treatments.

	Control	90 g a.i. glyphosate $ha^{-1}$	180 g a.i. glyphosate $ha^{-1}$	360 g a.i. glyphosate $ha^{-1}$
Mean	73.32	141.10	92.80	93.62
$P$	0.002	—	0.037	0.040

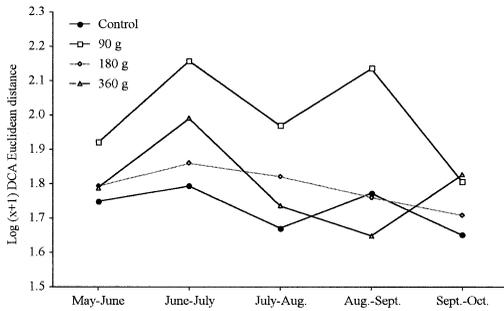


Figure 3.—The mean ( $n = 160$ ) seasonal spider species turnover between glyphosate treatments in 1997 showing moderate variability within the season and the lack of a single trend. (Note: this graph should not be used to located differences between treatments, please refer to statistics in Table 2).

The question arises then, why are the measures of species turnover and cluster size not showing a similar trend? The answer lies with the way in which spiders respond, even to the highest rate of glyphosate application. As detailed earlier from previous experiments at Loddington, although spiders were shown to be significantly reduced, they were never completely eliminated (see Houghton et al. 1999c; Houghton et al. 2001a). This constant species presence was apparent in the lack of any significant differences in either the species turnover or cluster size results, suggesting that there was little variation in the composition of the spider community, whatever the herbicide treatment. This lack of variation may indicate that an active aerial spider community is “blanketing out” any treatment ef-

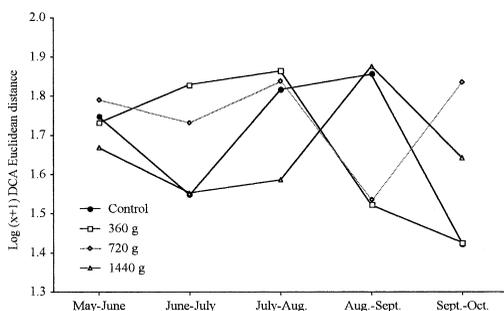


Figure 4.—The mean ( $n = 160$ ) seasonal spider species turnover between glyphosate treatments in 1998 showing the large variability within the season and the lack of a single trend. (Note: this graph should not be used to located differences between treatments, please refer to statistics in the text).

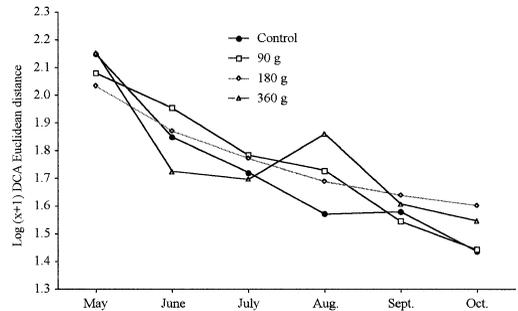


Figure 5.—The mean ( $n = 672$ ) seasonal decline in spider community DCA-Euclidean cluster size between glyphosate treatments in 1997 showing the trend of variable decline in cluster size through the season. (Note: this graph should not be used to located differences between treatments, please refer to statistics in the text).

fects. The great majority of spiders from the Loddington species list (78%) have a propensity to balloon, either in their immature phase (e.g., *Pardosa* species) or throughout their lives (i.e., most Linyphiidae and some Theridiidae and Tetragnathidae) (e.g., Duffey, 1956; Meijer, 1977). The ability to balloon will undoubtedly have affected the rate at which the different spider communities turn over, causing the differences between treatments to be blurred by a constant aerial fallout or emmigration.

Exposure to herbicides reduces weed cover and diversity (e.g., de Snoo & van der Poll 1999), which in turn reduces the habitat qual-

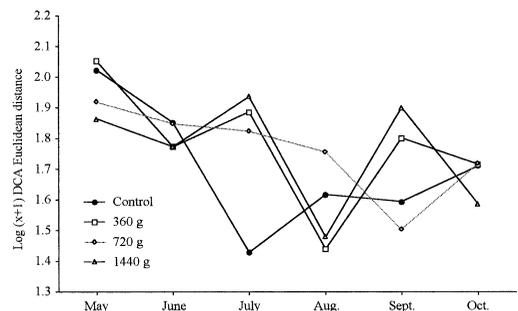


Figure 6.—The mean ( $n = 672$ ) seasonal decline in spider community DCA-Euclidean cluster size between glyphosate treatments in 1998 showing the trend of variable decline in cluster size through the season until August–October when clusters become larger. (Note: this graph should not be used to located differences between treatments, please refer to statistics in the text).

ity for the spiders, and consequently their numbers decline. Recently, using the spider *L. tenuis*, we demonstrated that at relatively low rates of glyphosate application in the field (360 g a.i. ha<sup>-1</sup>), a significant decline in numbers of *L. tenuis* was detected (Haughton et al. 2001a). The herbicide was not shown to act as an insecticide in direct toxicity tests, even at very high rates of glyphosate application (2160 g a.i. ha<sup>-1</sup>), but indirectly through habitat degradation: poisson regression showed that numbers of *L. tenuis* were related (non-linear) to vegetation height and percentage dead vegetation cover (Haughton et al. 2001a,b). The same two variables, vegetation height and percentage dead vegetation cover, were also found to be significantly related to the spider community along axes 1 and 2 in this experiment (Table 2). It is undeniable that vegetation structure has a profound effect on spiders (Uetz 1991). Various studies have demonstrated a relationship between spiders and vegetation height (e.g., Döbel et al., 1990; Rushton & Eyre 1992) and selection of dead vegetation by spiders has also been noted (e.g., Duffey 1962; Gibson et al. 1992). However, vegetation height and percentage dead vegetation cover were only correlated with the change in the spider community over the season, not with the difference between treatments as there were no cluster divisions by treatment in either of the DCA ordinations.

**Implications of incremental increases of glyphosate.**—Based on our previous research, incremental increases of glyphosate have caused a significant reduction in numbers at the species level, between guilds and for total numbers. From this perspective, the spider community is detrimentally affected by applications of this herbicide. However, in terms of effect on the composition of the spider community, the answer is less clear; species were not eliminated from herbicide treated margins and thus there would seem less cause for concern. However, perpetual use of glyphosate at high rates during the growing season may contribute to a sustained reduction in species, particularly for those species which are not *r*-strategists.

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