Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Short Communication

Herbicides have negligible effects on ants and springtails in an Australian wheat field

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ARTICLE INFO

Article history:

Received 8 December 2009

Received in revised form

14 March 2010

Accepted 16 March 2010

Available online xxx

Keywords:

Conservation farming

Conventional tillage

Bromoxynil

Hoegrass

*Jeannenotia stachi**Hemisotoma thermophila**Brachystomella platensis*

Collembola

Formicidae

ABSTRACT

The effects of herbicides applied to a direct drilled and traditionally tilled wheat field on trap catches of the abundant Collembola and Formicidae were examined. Significantly higher abundances of Collembola and species richness of ants were found on the direct-drilled plots. A significant effect of the herbicides, bromoxynil ($C_7H_3Br_2NO$) and hoegrass (diclofop-methyl), on the activity of two of the fourteen species of surface-dwelling Collembola was detected but no effect was observed on surface-active Formicidae. *Jeannenotia stachi* numbers were significantly more reduced on the direct-drilled compared to the traditionally tilled plot after herbicide treatment possibly because of higher predator abundance on the latter. In the short term, herbicides have a minimal effect on most species of surface-active arthropods although Collembola were more adversely affected than Formicidae.

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Australian cropping practices have traditionally involved cultivation and long periods of fallow resulting in soil degradation. Conservation farming such as direct drilling leaves soils less susceptible to degradation. Using minimum cultivation requires herbicides to control weeds. Soil organisms are important in no-tillage farming regimes because of their contribution to soil fertility and nutrient cycling (Longstaff et al., 1997) but herbicides can adversely affect these beneficials (Eijsackers and van de Bund, 1980).

Field data on the effects of herbicides on soil fauna in the Northern Hemisphere have indicated that herbicides have little effect in the short term on the activity and abundance of soil fauna (Eijsackers and van de Bund, 1980; Kulshrestha and Singh, 1994). However, laboratory studies show that some species are adversely affected by contact with these chemicals (Mola et al., 1987; Sabatini et al., 1998). Herbicide application has been reported to alter rates

of organic matter decomposition and lead to nutrient loss in the long term (Hendrix and Parmelee, 1985) but short term effects on these processes may differ. Overseas literature on this topic is extensive (Eijsackers and van de Drift, 1976), but there is apparently no extant published data relating to Australia.

We investigated the short-term effect of two herbicides, commonly used by wheat farmers in central New South Wales, on surface-active arthropod fauna of broad-acre arable land in southeastern Australia. Collembola are appropriate for study because of their sensitivity to chemical impacts, high activity and abundance, ubiquity and are considered functionally important in soils (Eijsackers and van de Bund, 1980; Greenslade and Greenslade, 1983). Laboratory studies have shown some species of Collembola are susceptible to herbicides via direct effects on activity, reproduction, and development (Eijsackers, 1978a, 1978b; Fratello et al., 1986; Badejo and van Straalen, 1992). As surface-active Collembola are most likely to come in contact with chemical sprays, we used pitfall trapping for sampling and ants (Formicidae) were also recorded as dominant predators.

A tillage trial planted with winter wheat and established since 1980 at the New South Wales Department of Conservation and

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Table 1

Numbers of individuals of Collembola species caught in pitfall traps on each treatment subplot and on each sampling occasion expressed as means per trap per 5 days.

Tillage treatment	DD	DD	DD	DD	DD	DD	DD	DD
Sampling period	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Treatment time	Prespray	Postspray	Prespray	Postspray	Prespray	Postspray	Prespray	Postspray
Herbicide treatment	+ herbicide	+ herbicide	- herbicide	- herbicide	+ herbicide	+ herbicide	- herbicide	- herbicide
Replicate	Rep 1	Rep 1	Rep 1	Rep 1	Rep 2	Rep 2	Rep 2	Rep 2
<i>Brachystomella platensis</i> Najt and Massoud	173	84	153	175	114	75	162	121
<i>Ceratophysella gibbosa</i> (Bagnall)	57	38	77	52	410	164	940	454
<i>Hemisotoma thermophila</i> (Axelson)	131	28	173	44	194	17	120	27
<i>Lepidocyrtus kuakea</i> Christiansen and Bellinger	0	0	0	1	1	0	1	0
<i>Drepanura</i> spp.	4	2	2	4	2	2	0	3
<i>Entomobrya multifasciata</i> (Tullberg)	0	1	0	1	1	1	2	2
<i>Entomobrya unostrigata</i> Stach	2	3	2	5	1	2	2	2
<i>Lepidosira nigrocephala</i> Womersley	0	1	1	2	4	1	1	1
Indet. imm. Entomobryidae	4	2	4	9	31	6	3	4
<i>Jeannenotia stachi</i> (Jeannenot)	105	24	33	13	89	8	69	36
<i>Katianna australis</i> Womersley	166	95	55	73	10	42	103	84
<i>Sminthurinus elegans</i> Fitch	15	8	6	6	2	5	10	8
<i>Sminthurinus</i> sp.	2	2	1	2	0	1	2	1
Indet. imm. Sminthuridae	1	1	0	0	0	1	0	1
Tillage treatment	TT	TT	TT	TT	TT	TT	TT	TT
Treatment time	Prespray	Postspray	Prespray	Postspray	Prespray	Postspray	Prespray	Postspray
Sampling period	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Herbicide treatment	+ herbicide	+ herbicide	- herbicide	- herbicide	+ herbicide	+ herbicide	- herbicide	- herbicide
Replicate	Rep 1	Rep 1	Rep 1	Rep 1	Rep 2	Rep 2	Rep 2	Rep 2
<i>B. platensis</i>	93	21	59	23	25	6	36	3
<i>C. gibbosa</i>	191	79	63	62	33	6	51	39
<i>H. thermophila</i>	212	43	195	43	60	33	136	56
<i>Lepidocyrtus kukua</i>	0	0	0	0	0	0	0	0
<i>Drepanura</i> spp.	0	0	0	0	0	0	0	0
<i>Entomobrya multifasciata</i>	0	0	0	0	0	0	0	0
<i>Entomobrya unostrigata</i>	0	0	0	0	0	0	0	0
<i>Lepidosira nigrocephala</i>	0	0	0	0	0	0	0	0
Indet. imm. Entomobryidae	6	4	7	11	2	2	5	2
<i>J. stachi</i>	19	14	10	17	11	4	13	10
<i>K. australis</i>	96	69	92	80	72	63	116	108
<i>Sminthurinus elegans</i>	11	2	7	7	7	3	9	5
<i>Sminthurinus</i> sp.	1	1	1	2	1	1	1	0
Indet. imm. Sminthuridae	0	0	0	0	0	0	0	0

Fig. 1. Comparison of mean abundance in traps per day of five collembolan species collected on DD and TT plots in Sample 1 (first period 13–17 August 1993) and Sample 2 (second period 18–23 August 1993) combined. Paler columns represent DD plots and darker columns TT plots. Error bars denote standard deviation.

Table 2
Results of the analysis of variance.

Factor 1	Factor 2	F value	P value
a) Data from first sampling period, i. e. preherbicide sample, using square-root transformed data. Significant probabilities to three decimal places are given in bold.			
<i>B. platensis</i>	Tillage	46.83	<0.001
<i>B. platensis</i>	Herbicide	1.233	0.688
<i>C. gibbosa</i>	Tillage	16.730	<0.001
<i>C. gibbosa</i>	Herbicide	0.800	0.375
<i>H. thermophila</i>	Tillage	0.012	0.912
<i>H. thermophila</i>	Herbicide	0.087	0.769
<i>J. stachi</i>	Tillage	39.954	<0.001
<i>J. stachi</i>	Herbicide	0.006	0.937
<i>K. australis</i>	Tillage	0.014	0.906
<i>K. australis</i>	Herbicide	0.014	0.906
b) Data from second sampling period, ie post-herbicide sample, using square-root transformed data. Significant probabilities given in bold.			
<i>B. platensis</i>	Tillage	<0.001	<0.001
<i>B. platensis</i>	Herbicide	6.550	<0.05
<i>C. gibbosa</i>	Tillage	8.627	<0.05
<i>C. gibbosa</i>	Herbicide	3.743	0.058
<i>H. thermophila</i>	Tillage	11.976	<0.001
<i>H. thermophila</i>	Herbicide	6.013	<0.05
<i>J. stachi</i>	Tillage	4.448	<0.05
<i>J. stachi</i>	Herbicide	2.510	0.118
<i>K. australis</i>	Tillage	0.224	0.638
<i>K. australis</i>	Herbicide	1.976	0.165
c) Results of ANOVA analysis for interactions between tillage, time and herbicide treatment.			
<i>B. platensis</i>	Herbicide × date × tillage	0.000	0.984
<i>C. gibbosa</i>	Herbicide × date × tillage	0.803	0.372
<i>H. thermophila</i>	Herbicide × date × tillage	0.237	0.627
<i>J. stachi</i>	Herbicide × date × tillage	1.715	0.193
<i>K. australis</i>	Herbicide × date × tillage	0.550	0.460

Land Management Research Centre at Cowra, (143°42' S 33°51' E, elevation 384 m) was sampled. It consisted of two plots of approximately 200 m × 45 m (0.9 ha) each within a larger field, running along a contour line with an 8% slope in a southeasterly direction. One plot was direct-drilled (DD) and the other traditionally tilled (TT) (Packer et al., 1992). The soil is a red duplex (Rd 3.22/Dr 3.23) with a hard setting sandy loam surface texture (Northcote, 1979) or a Xeralfic Alfisol (Soil Survey Staff, 1975). Mean annual rainfall is 645 mm fairly evenly distributed throughout the year. Mean daily maximum temperatures are 30.8 °C in summer and 12.8 °C in winter with the respective minima being 16.3 °C and 3.6 °C. Management consists of sowing from May to July after sufficient autumn rain has fallen, and harvesting is from December to January.

Fig. 2. Comparison of abundance of native (*K. australis*, *B. platensis*) and introduced (*C. gibbosa*, *H. thermophila*, *J. stachi*) Collembola in traps in both tillage treatments from Sample 1 (13–17 August 1993) as mean numbers per trap per day. Paler columns represent DD plots and darker columns TT plots.

Fig. 3. Log abundance of ant morphospecies trapped in the two tillage treatments. Paler columns represent DD plots and darker columns TT plots.

A representative area (subplot) of 20 × 20 m was selected in the treatment plots and divided into four 10 × 10 m square block. Sampling was in late winter after moist weather when wheat was well grown being 30 cm high. Ten pitfall traps, 1.8 cm diameter, three quarters filled with 95% ethanol (Greenslade and Greenslade, 1971), were placed randomly within each block on 13 August 1993 (Sample 1). After collection on 18 August 1993 two of the four blocks in each subplot were selected at random and sprayed with 2 L of Hoegrass and 1.4 L of Bromoxynil/MCPA plus surfactant, while the remaining two blocks in each field were unsprayed. New traps were placed from 19 to 24 August (Sample 2). Six mm of rain fell during Sample 1 and the average sunshine was 5.22 h d⁻¹. No rain fell during Sample 2 and average sunshine was 9.09 h d⁻¹. Both ants and Collembola were sorted into species or morphospecies and counted.

Analysis of variance was carried out on the Collembola using SYSTAT 6.0 for Windows and a square-root transformation. Simpson's diversity index (Southwood, 1964) was calculated for ants.

The 160 pitfall traps collected 64,536 Collembola, comprising 13 species (Table 1). Five species: *Jeannenotia stachi* (Jeannenot) (5%), *Katianna australis* Womersley (17%), *Brachystomella platensis* Najt & Massoud (17%), *Ceratophysella gibbosa* (Bagnall) (40%) and *Hemisotoma thermophila* (Axelson) (18%), represented 97% of the Collembola trapped.

Fewer Collembola were trapped in Sample 2 than Sample 1 but both samples trapped more Collembola on DD than on TT subplots (Fig. 1). In Sample 1, significantly ($p < 0.05$) higher numbers of three species, *B. platensis*, *C. gibbosa* and *J. stachi*, while in Sample 2 significantly higher numbers of four species, *B. platensis*, *C. gibbosa*, *J. stachi* and *H. thermophila* were trapped in DD compared to TT subplots (Table 2a and b).

Numbers of each collembolan species in each of the eight blocks did not vary significantly from each other in pre-treatment samples. After the application of herbicide, significantly fewer individuals of *B. platensis* and *H. thermophila* were trapped on the

Table 3
Simpson's index of diversity for Formicidae genera.

Tillage treatment	First sample, treatment plot	Second sample, treatment plot	First sample, control plot	Second sample, control plot
DD	1.717	2.188	1.750	3.036
TT	1.234	1.223	2.537	1.181

treatment than control blocks (Table 2b). The limited replication did not enable interactions between tillage and herbicide to be tested (Table 2c). There was no difference in relative numbers of native versus introduced species between the DD and TT subplots and both groups were more abundant on the DD than the TT subplots (Fig. 2). The opposite trend was found for *J. stachi* which were significantly more reduced on the DD compared to the TT blocks after herbicide treatment (Fig. 1).

Twelve morphospecies of ants were distinguished in the trap catches (Fig. 3). Simpson's index of diversity showed that the DD blocks had a higher diversity than the TT blocks for three of the four treatments/samples (Table 3). The data were strongly influenced by catches from two traps that caught excessively high numbers of ants (Fig. 3). If these two traps were excluded from the ANOVA calculation, the abundance in traps of *Pheidole* spp., a seed-harvesting genus, was significantly different between tillage treatments ($p < 0.05$) and total predatory ants and *Rhytidoponera* spp. differed between Samples 1 and 2 ($p < 0.005$, $p < 0.05$ respectively).

Proportions of native versus introduced species were similar on all plots. *J. stachi* numbers were significantly more reduced on the herbicide treated DD compared to the herbicide treated TT subplots might be the result of higher numbers of ant predators on the DD subplots (Fig. 1d). Higher numbers of ants active on the ground surface in Sample 2 compared to Sample 1 were probably because of higher temperatures.

Greater differences were found between tillage treatment and between sampling periods than between herbicide application indicating the greater influence of weather and long term management than herbicides on fauna. Three of the species examined, *J. stachi*, *B. platensis* and *C. gibbosa*, showed significantly higher activity in the DD than the TT subplots as shown for Collembola generally overseas (Edwards and Loft, 1977; Wardle et al., 1993a, b). In Australia, Malinda et al. (1982) reported on soil faunal responses to hoegrass and butyl with tillage over a longer term, identified the fauna to family only, sampled the soil and were confounded by seasonal effects.

The only sensitive species, *H. thermophila* and *B. platensis*, are diurnally surface-active so were directly exposed to herbicides. The culture of both species has a more simplified structure than the other three species so would be less hydrophobic (P. Greenslade, unpublished observations).

A beneficial effect of DD management was in increasing predatory ant species richness on the DD plot compared to TT so exerting better control of herbivorous pests. Herbicides did not affect diversity or abundance of ants trapped probably because soil nesting colonies are protected against surface impacts.

This study is the first in Australia at species-level for effects of herbicides on surface-active Collembola and ants of tilled and direct-drilled soils on broad-acre arable land (Malinda et al., 1982; Park and Lees, 2004; Lindsay, 2004). Our results indicate that in late winter, herbicides have a minimal effect in the short term on the most surface-active fauna in wheat fields and conservation farming results in a more abundant and diverse soil fauna compared to traditionally tilled fields.

Acknowledgements

The authors are grateful to staff of the Soil Conservation Laboratory at Cowra Research Station who took the samples for us and

managed the plots and to the Rural Industries Research and Development Corporation for funding the project. B. Longstaff, M. Hodda and J. Lytton-Hitchins made useful suggestions to improve the manuscript.

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