THE BELOW-GROUND FOOD-WEB AS AN INDICATOR OF DISTURBANCES RESULTING FROM WEED MANAGEMENT PRACTICES IN TWO CONTRASTING AGRO-ECOSYSTEMS

D.A. WARDLE, G.W. YEATES[1], R.N. WATSON,
K.S. NICHOLSON and M. AHMED

Ruakura Agricultural Centre, Private Bag 3123, Hamilton
[1]Landcare Research, Private Bag 31902, Lower Hutt

SUMMARY

A study was set up in an annual (maize : *Zea mays*) and perennial (asparagus : *Asparagus officinale*) cropping system in 1990 to determine the effects of weed management (sawdust mulching, cultivation, herbicides) on the detritus food-web and the below-ground ecosystem. Biota in the perennial system was more responsive to disturbance. Microflora was often strongly stimulated by mulching, and through tritrophic effects, caused large increases in top predatory, but not most microbe-feeding, nematodes. Micro- and meso- arthropod populations were generally most influenced by differences between treatments in plant residue and weed levels. Tillage and herbicide use did not exert consistent direct effects on any of the organisms considered. Where soil organisms are used as indicators of soil ecosystem disturbance, a food-web centred approach appears necessary to detect effects which have multi-trophic consequences.

Keywords: agro-ecosystem, food-web, ecological indicator, soil biota, weed management.

INTRODUCTION

In understanding the comparative benefits of different cropping systems it is becoming increasingly evident that those systems which most closely resemble natural ecosystems may require fewer inputs because greater reliance can be placed on ecosystem self-regulation (House *et al.* 1984). In particular, there has been an increasing emphasis on reducing both tillage (Hendrix *et al.* 1986) and herbicide use (Morgan 1989), resulting in a greater requirement for alternative weed management strategies. Although the detritus food-web is the biotic component responsible for ecosystem-level processes surprisingly little is known about its response to agricultural management and most studies have considered only the responses of isolated components of this web. This paper gives an overview of the results of the first $2^1/_2$ years of an ongoing study designed to assess the comparative ecosystem-level effects of a range of weed management practices in annual and perennial cropping systems, by using the detritus food-web as an indicator of ecosystem disturbance.

METHODS

The study was established in the spring of 1990 at the Rukuhia Horticultural Research Station, approx. 5 km south of Hamilton. Full site, soil, plot and treatment details are given in detail elsewhere (Wardle *et al.* 1993a). Briefly, two sites were selected and are hereafter referred to as the "maize" (=annual crop) and "asparagus" (=perennial crop) sites. Five treatments (each with five replicates in a randomised block design) were established at each site, i.e.

(i) Sawdust mulching. This involved a single placement of 10 cm thick sawdust on 17 September 1990 (asparagus) or 10 December 1990 (maize).
(ii) Cultivation of interrows. Conducted each spring between October and December, approximately every 3 weeks, to 10 cm depth, using a rotary hoe.

Proc. 46th N.Z. Plant Protection Conf. 1993: 338-343

(iii) Hand-hoeing each spring between October and December. This treatment is presumed to induce the least below-ground disturbance.

(iv) and (v) Two herbicide treatments applied once each spring. In the asparagus study the herbicides were either terbumeton/terbuthylazine (Caragard) at 5 kg/ha or bromacil (Hyvar X) at 1.6 kg/ha; and in the maize trial either pre-emergence atrazine (Gesaprim) at 1.5 kg/ha or a post-emergence sulfonylurea herbicide: rimsulfuron (Fortress (USA)) at 40 g/ha in 1990 and 1991; primisulfuron (Beacon) at 30 g/ha in 1992.

All management procedures (except the one-off application of sawdust) have been re-applied to the same plot each year. Additional management procedures (described in detail by Wardle *et al.* 1993a) involve planting maize each October, harvesting of maize grain each June, daily picking of asparagus spears each September-December, cutting and removal of asparagus ferns each June, and N and P fertilisation of all plots each spring.

Since initiation of this experiment, several measurements (Wardle *et al.* 1993a,c; Yeates *et al.* 1993) have been made on samples of fifteen 5 cm diam. cores at each of two soil depths (0-5 cm and 5-10 cm) bulked for each plot, as well as the sawdust mulch itself, i.e.

(i) Soil chemical factors (%N,%P, %C, NH_4^+, NO_3^-), determined at the end of each growing cycle, i.e. August (asparagus) or October (maize).

(ii) Soil microbial variables, i.e. basal respiration, substrate-induced respiration (S.I.R.) (proportionally related to active microbial biomass), bacterial and fungal S.I.R. (related to active bacterial and fungal biomass), basal respiration : S.I.R. ratio (inversely related to ecological efficiency of the below-ground ecosystem) and fumigation flush (proportionally related to the total microbial biomass). These were determined for samples collected every 3 months from each site, from August 1990 until present.

(iii) Total populations of microarthropods, i.e. Collembola, saprophagous mites and predatory mites, on the same samples as (ii) above.

(iv) Total populations of nematodes, identified for each sample to genus level and assigned into functional feeding groups, i.e. bacterial feeding, fungal-feeding, top predatory, plant-pathogenic, plant-associated and omnivorous. These have been determined at this stage for all the first-year samplings and the final sampling at year 2 for (ii) above.

Pitfall traps (three per plot) were situated at each site and assessments have been made of the soil-associated macroarthropods in each trap every 2 weeks since August 1990 (Wardle *et al.* 1993a). In addition to the above, crop yield and biomass, weed biomass, and rates of plant litter return and decomposition have been monitored throughout the course of the study.

RESULTS AND DISCUSSION

The asparagus crop was more responsive than the maize crop to the various disturbance treatments imposed (data not presented), indicating that perennial systems are more developed and less resilient than annual systems. In the first 2 years of the study the only treatment to exert consistent effects on the soil microfloral (bacterial and fungal) variables was the placement of sawdust mulch on the soil surface, which caused considerable effects in the asparagus site (Table 1) and mild, but statistically significant, effects in the maize site (data not presented). We believe this was due to higher moisture under the mulch, and the mulch buffering the microbial biomass against the effects of environmental extremes (Wardle 1992). No consistent effects of any treatment on any of the soil chemical characteristics have been observed. Initially the basal respiration : S.I.R. ratio (inversely related to ecosystem efficiency : Odum 1969; Insam and Domsch 1988) was greater in the cultivated and hand-hoed plots than in the sawdust-mulched plots. Odum's theory of ecosystem succession predicts that disturbed systems should respire a disproportionately high amount of available carbon reserves, but in our study the (disturbed) mulched plots had a lower respiration : S.I.R.

ratio than (relatively undisturbed) hand-hoed plots. Possibly this ratio is reduced by "non-stressful disturbance" (Wardle 1993), (as illustrated by the consistently higher soil moisture contents), with mulch stabilising the system and inducing ecological efficiency (Wardle *et al.* 1993c). In the third year the microbial biomass is beginning to rapidly increase in the cultivated plots relative to the hand-hoed and herbicide treated plots (data not presented). This appears to be due to high winter weed growth in these plots, combined with weeds being mixed into the soil over the spring and summer months, and suggests that the soil microflora are acting as an early indicator of improved quality of soil organic matter in these plots (Powlson *et al.* 1987). No negative impacts of tillage have emerged in this study, in contrast to other studies (e.g. Hendrix *et al.* 1986), which may reflect differences in soil type and possibly the ability of our soil ecosystem to rapidly adapt to cultivation.

TABLE 1: Response of various biotic and abiotic components of the detritus food-web in mineral soil to sawdust mulching, repeated interrow cultivation, and hand-hoeing of weeds in an asparagus cropping system (0-5 cm soil depth only).

Variables	End of first year (Aug. 1991)			End of second year (Aug. 1992)		
	mulch	cultivated	hand-hoed	mulch	cultivated	hand-hoed
Resource-base						
% soil C	9.8a	9.5a	10.3a	10.0a	9.9a	10.4a
% soil N	0.50b	0.54ab	0.55a	0.53a	0.51a	0.54a
% soil P	0.34a	0.33a	0.35a	0.45ab	0.36b	0.48a
% soil H_2O[a]	57.8a	53.2b	50.4c	66.4a	55.0b	53.2b
weed mass ($x10^{-2}gm^{-2}$)[a]	0.1c	13.1a	6.4b	1.1b	5.1ab	7.5a
asparagus fern mass ($x10^{-2}gm^{-2}$)[a]	6.0a	4.2b	3.9b	4.3a	3.9a	3.9a
Microbial variables						
fumigation flush ($x10^{-2}\mu g/g/10d$)	3.76a	3.58a	3.84a	4.60a	4.36a	3.70b
SIR[b] (µg/g/h)	6.4a	3.5b	4.1b	8.0a	4.8b	4.3b
BR[c] (µg/g/h)	1.8a	1.2b	1.5b	2.0a	1.0b	1.1b
BR/SIR	0.28a	0.35b	0.37b	0.25a	0.21b	0.23b
bacterial SIR (µg/g/h)	0.42a	0.29b	0.28b	0.74a	0.53b	0.52b
fungal SIR (µg/g/h)	1.44a	0.86b	0.97b	2.05a	1.40b	1.42b
Nematode populations (thousands/m^2)						
bacterial feeders	153a	110a	169a	192a	195a	204a
fungal feeders	19.8a	26.2a	27.2a	5.4a	10.6a	7.4a
top predators	7.0a	1.2b	0.4b	40.5a	0.0b	0.2b
Shannon-Weiner diversity index	2.2a	2.5a	2.5a	2.0a	2.0a	2.1a
Microarthropods populations (thousands/m^2)						
Collembola	5.0a	5.0a	6.6a	0.7b	1.7b	5.0a
Oribatid mites	1.3a	1.3a	0.3a	0.3a	0.0a	0.0a
Predatory mites	1.0a	1.7a	0.7a	0.0a	0.0a	0.0a

[a] dry weight basis [b] substrate-induced respiration [c] basal respiration
Within each year, numbers in each row followed by different letters are significantly different at P = 0.05 (LSD test).

The nematode populations (Table 1) revealed strong trophic linkages with the soil microflora. Stimulation of the microbial biomass by mulching did not cause an increase in the standing crop of microbial-feeding components (i.e. bacterial- and fungal-feeding nematodes) but caused a consistent enhancement of top predatory nematodes (which feed largely on other nematodes). This suggests that the intermediate (microbial-feeding nematode) trophic level is simply a transient conduit, which is kept in check by predation and through which resources pass from microbes to the top predators (Wardle and Yeates 1993). This indicates that agricultural management can induce trophic effects in the soil which can manifest themselves over several trophic levels. Furthermore, strong and consistent correlations between microbes and predators, but not microbial-feeders, have been detected throughout the course of the experiment (both spatially and temporally), both at the individual species/genus level (Yeates *et al.* 1993) and functional group level (Wardle and Yeates 1993). Strong positive relationships between bacterial-feeder numbers and fungal biomass indicates that competitive impacts of bacteria on fungi may be reduced by increased predation-pressure by bacterial feeders, and provides field confirmation for previous laboratory incubation studies (Wardle *et al.* 1993b). This suggests that many fungal species rapidly compensate for reductions in other components of the below-ground system.

Saprophagous microarthropod populations behaved rather unpredictably, although they sometimes demonstrated positive correlations with either weed biomass or surface plant residue levels. Little direct correlation was observed with the microbial biomass, suggesting that like microbe-feeding nematodes, microarthropod populations are influenced by "predation" rather than "resource-limitation".

TABLE 2: Relative abundance of various taxa of macrofauna in pitfall traps captured between 30 December 1992 and 27 January 1993.

Taxa	Asparagus				Maize			
	mulch	cultivated	hand-hoed	terb[a]	mulch	cultivated	hand hoed	atrazine
Amphipoda	8.8ab	11.6a	5.2ab	0.4b	12.2a	15.8a	12.6a	15.2a
wolf-spiders	5.0a	4.2a	2.4ab	0.6b	8.6a	6.4a	8.2a	10.2a
millipedes	3.4a	2.4a	1.2ab	0.6b	2.6b	0.8a	3.2a	1.2a
harvestmen	3.8a	2.6a	2.4a	0.0b	8.2a	5.2a	5.2a	1.4b
predatory/omnivorous beetles:								
Tiger beetles[b]	1.6ab	2.6ab	4.4a	3.8ab	0.0a	0.0a	0.0a	0.0a
Mecyclothorax rotundicollis[c]	0.0a	0.0a	0.0a	0.0a	2.6a	1.0b	1.4b	0.4b
Rhytisternus miser[c]	0.0a	0.0a	0.0a	0.0a	3.4a	1.6a	2.2a	2.4a
Threocephalus sp.[d]	2.2a	2.0a	3.0a	0.0b	5.6a	4.8a	2.2b	4.0ab
Elateridae	2.4a	0.4b	1.0b	0.2b	0.6a	0.0b	0.0b	0.0b
Shannon-Weiner diversity index	1.3a	1.2a	1.1a	0.1b	1.6a	1.1b	1.1b	1.1b

[a] Terbumeton/terbuthylazine [b] Cicindelidae [c] Carabidae [d] Staphylinidae

Within each cropping system numbers in each row followed by different letters are significantly different at P = 0.05 (LSD test).

The soil-associated macrofauna provides the linkage between the above-ground and below-ground food-webs and are thus critical in linking the two main compartments of terrestrial food-webs. Generally these organisms were more numerous in the annual cropping system and in treatments which increased surface residues (i.e.

sawdust mulching) or winter weed levels (i.e. summer cultivation and hand-hoeing treatments) (Table 2). These trends appear to have strengthened over time, since in the first year the only treatment to exert significant effects on any group was sawdust mulching (Wardle *et al.* 1993a). The results indicate that the importance of predation on the detritus food-web is likely to be enhanced mainly by treatments which increase levels of above-ground live or dead plant material.

In comparing the various treatment effects on below-ground food-webs in this soil, it appears disturbance caused by conventional agricultural management did not exert consistently negative impacts, and that treatments which increased surface organic matter (i.e. mulching), or weed density in the winter, may simultaneously benefit several groups of organisms. No negative impacts of cultivation or herbicides have been detected, and herbicide applications appear to only influence macrofaunal groups, probably indirectly through reducing weed density. Species diversity of nematodes (Table 1) was unaffected by any treatment at any time, while that of soil-associated beetles was generally enhanced by high weed levels, mulching, and possibly "intermediate disturbance" (Connell 1978) (Table 2). There is therefore little evidence from our study to suggest that certain conventional agricultural practices exert predictable harmful effects on the soil ecosystem within a 2-3 year period.

ACKNOWLEDGEMENTS

We thank T.K. James and P. Sanders for advice on the culture of maize and asparagus respectively, and F.J. Neville and N.L. Bell for nematode extraction and counting.

REFERENCES

Connell, J.H., 1978. Diversity in tropical rain forests and coral reefs. *Science 199*: 1302-1310.

Hendrix, P.F., Parmelee, R.W., Crossley, D.A., Coleman, D.C., Odum, E.P. and Groffman, P.M., 1986. Detritus food-webs in conventional and no-tillage agroecosystems. *Biosci. 36*: 374-380.

House, G.J., Stinner, B.R., Crossley, D.A., Odum, E.P. and Langdale, G.W., 1984. Nitrogen cycling in conventional and no-tillage agroecosystems in the southern piedmont. *J. Soil Water Conserv. 39*: 194-200.

Insam, H. and Domsch, K.H., 1988. Relationship between soil organic carbon and microbial biomass on chronosequences of reclamation sites. *Microb. Ecol. 15*: 177-188.

Morgan, W.C., 1989. Alternatives to herbicides. *Plant Prot. Quart. 4*: 33-37.

Odum, E.P., 1969. The strategy of ecosystem development. *Science 164*: 262-270.

Powlson, D.S., Brookes, P.C. and Jenkinson, D.S., 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. *Soil Biol. Biochem. 19*: 159-164.

Wardle, D.A., 1992. A comparative assessment of factors which influence microbial biomass carbon and nitrogen levels in soil. *Biol. Rev. 67*: 321-358.

Wardle, D.A., 1993. Changes in the microbial biomass and metabolic quotient during leaf litter succession in some New Zealand forest and scrubland ecosystems. *Funct. Ecol.*: in press.

Wardle, D.A. and Yeates, G.W., 1993. The dual importance of competition and predation as regulatory forces in terrestrial ecosystems: evidence from decomposer food-webs. *Oecologia 93*: 303-306.

Wardle, D.A., Nicholson, K.S. and Yeates, G.W., 1993a. Effects of weed management strategies on some soil-associated arthropods in maize and asparagus ecosystems. *Pedobiologia*: in press.

Wardle, D.A., Parkinson, D. and Waller, J.E., 1993b. Interspecific competitive interactions between pairs of fungal species in natural substrates. *Oecologia*: in press.

Wardle, D.A., Yeates, G.W., Watson, R.N. and Nicholson, K.S., 1993c. Response of soil microbial biomass and plant litter decomposition to weed management strategies in maize and asparagus ecosystems. *Soil Biol. Biochem.*: in press.

Yeates, G.W., Wardle, D.A. and Watson, R.N., 1993. Relationships between soil nematodes, soil microbial biomass and weed management strategies in maize and asparagus ecosystems. *Soil Biol. Biochem.*: in press.