# Impacts of pesticides and fertilisers on soil biota.

Nicole Seymour
Department of Primary Industries and Fisheries
PO Box 2282, Toowoomba, Qld, 4350

## Introduction

The effects of inorganic amendments (fertilisers and pesticides) on soil biota that are reported in the scientific literature are, to say the least, variable. Though there is clear evidence that certain products can have significant impacts, the effects can be positive or negative. This is not surprising when you consider the number of organisms and amount of different functional groups, the number of products and various rates at which they could be applied, the methods of application and the environmental differences that occur in soil at a micro scale (within centimetres) in a paddock, let alone between paddocks, farms, catchments, regions etc. It therefore becomes extremely difficult to draw definitive conclusions from the reported results in order to summarise the impacts of these inputs. Several research trials and review papers have been published on this subject and most similarly conclude that the implications of many of the effects are still uncertain.

## Types of effects

Effects of fertilisers and pesticides can be either direct (immediate or short-term impacts) due to harm to the organisms that come in contact with the chemical, or indirect due to changes caused by the chemical to the environment and/or food source of the organisms being studied. Time of sampling (in relation to last rainfall event, soil temperature, prevalence of food source, background nutrient levels in soil, soil pH), can be pivotal in the outcome of results as soil environmental conditions impinge greatly on microbial activity. Other factors include time between fertiliser/pesticide application and sampling, formulation and rate of fertilisers, depth of soil sampled, effects on food sources i.e. impacts on predator-prey interactions.

In some cases there maybe a short-term but no long-term effect due to resilience of soil biological populations (ability to come back with time) (Angus *et al.* 1999). Altering the detritus food web through the use of broad-spectrum pesticides reduces biological diversity and therefore alters the balance or equilibrium of the ecosystem. This could lead to pest resurgence through the absence of natural predators (Wildermuth *et al.* 1997).

## Fertilisers

The direct effects of fertilisers on soil biota can be short- (obvious in the first season after application of the fertiliser) or long-term (if repeated additions are required to see the effect). Indirect effects are usually long-term (take more than one season to develop) and are due to changes in pH or changes in productivity, residue inputs and soil organic matter levels (Bunemann and McNeill 2004). These effects become important in agriculture when nutrient availability to plants and hence crop productivity are changed due to the effect.

One issue generally of concern to growers has been the potential damage to soil microorganisms from high concentrations of ammonia fertiliser applied in bands. Toxic effects of ammonia on soil organisms are known but injection of anhydrous ammonia into soils has impacts only in the zone/band of application and the effects are usually short-term. A project conducted in the mid 1990s in southern NSW showed that the injection of ammonia and urea in bands reduced total microbial activity in the narrow band of application for a period of 5 weeks, after which levels returned to normal. Recovery was however a little slower for some groups of organisms. There was an 80% reduction in the number of protozoa and their numbers did not return to normal after 5 weeks. Also, there was a large increase in the number of nitrifying bacteria in the soil five weeks after application (Angus *et al.* 1999). The researchers concluded that most groups of soil microorganisms were not adversely affected by banded ammonia or urea with a single year of applications however they could not draw any conclusions about long-term effects on soil microorganisms.

Work by Biederbeck *et al.* (1996) in Canada showed minimal impact on soil microbial populations and soil quality after ten years of fertilisation with urea and anhydrous ammonia. However, Stirling (pers. comm.) found that long-term use (9 years) of urea or ammonium fertilisers in a trial near Tulloona, NSW, had impacts on the longer lifecycle omnivorous nematodes. Numbers were lower in plots fertilised at 90 kg N/ha than in those not fertilised in soil from 5-15 and 15-30 cm depth intervals. These effects were still evident after the growing of a wheat crop. Other shorter life-cycle nematodes were not affected. Measurements of microbial biomass and activity on the same soil taken down to 30 cm in soil in the same trial were similarly not significantly different due to different fertiliser treatments (Van Zwieten pers. comm.).

In a review on the effects of management practices on soil mesofauna (protozoa, amoeba and nematodes), Gupta (1994) compares reported effects of N fertiliser on protozoa. The diverse range of responses illustrates dangers in extrapolating from one data set in one environment. Effects reported covered significant increases; initial decreases that then became increases in a short period of time; and stabilisation of numbers when lime was added with fertiliser. Similarly, effects of fertiliser applications on nematode populations were diverse and changes in both abundance and trophic diversity have been reported (see Gupta 1994).

Mycorrhizal fungi have been consistently reported as being decreased by P fertiliser but the extent to which this occurs may be dependent on species of fungus involved and level of plant available P in the soil. Phosphorus applications of 50 $mg.kg^{-1}$ and above were significantly correlated with decreases in the mycorrhizal colonisation of linseed (Seymour 2002) and wheat (Thompson 1990) in Vertosols from the Darling Downs.

## Herbicides

Much of the research on herbicide effects on soil biota has been done overseas but our increase in reliance on herbicides in zero-till systems in Australia has no doubt had impacts on soil biota. Glyphosate has stimulated populations of fungi and actinomycetes with general increases in overall microbial activity even though bacterial populations were reduced (Araujo *et al.* 2003). Glyphosate and chlorosulfuron have each been associated with increased levels of Pythium root rot in barley seedlings (Blowes 1987), and take-all fungus (Mekwatanakarn and Sivasithamparam 1987). The application of chlorsulfuron increased root disease by *Rhizoctonia solani* but had no effect on take-all levels (Rovira and McDonald 1986).

Some other herbicide effects are listed below in Table 1. Generally, herbicides don't appear to cause major changes on populations of earthworms while smaller organisms can be adversely affected.

## Fungicides

If a fungicide improves crop growth though eliminating foliar or soil-borne diseases, then increased organic matter in the system will generally boost microbial activity. Fungicides may however have direct effects on the non-target organisms particularly the saprobic and symbiotic soil-borne fungi. Benomyl for instance is particularly toxic to mycorrhizal fungi (Smith *et al.* 2000) which could have implications for the nutrition of the plants. Foliar-applied sprays that miss the target leaves and spray drift could also cause undesired/unintentional impacts on soil biota.

## Conclusions

There is clear evidence that non-target soil biota are influenced by pesticides and fertilisers but the impacts are wide ranging – some are stimulatory, others highly inhibitory. Effects may be direct or indirect and are dependent upon several interacting factors that relate to the mode of application, the soil environment and the availability of food sources at the time of sampling. The dynamic nature of soil biology, and the effects of environment on the fate of chemical or fertiliser added and on the populations of different functional groups of biota, makes it very difficult to draw conclusions about the impacts of various inputs in our agricultural systems.

Fertilisers generally increase plant production and hence organic matter levels in soil are increased. This is generally beneficial for soil biota as food sources are increased. Some direct toxic effects of fertilisers on microorganisms have been reported but generally effects are only in the band of application and very high levels of the chemical are required to cause damage.

Pesticides depending on their purpose may have a positive (insecticide or fungicide allow increased plant production) or negative (herbicide will decrease organic matter inputs from weeds) but may also have direct impact on non-target soil biota. In broad-acre agriculture, soil-applied pesticides (eg broad-spectrum fumigants, nematicides, fungicidal drenches) are generally uneconomic and therefore not often used. Particular pesticides may affect short-life cycle organisms such as bacteria, but recover in relatively short time frames and so the productivity of the cropping system may not have been influenced at all. However, populations of longer-lived organisms such as omnivorous nematodes and earthworms take longer to recover from damage and therefore effects are more likely to be seen in the longer term.

In a review of the impacts of pesticides on soil biota by Van Zwieten (2004), it is noted that the long-term effects or significance for future health of agroecosysytems in Australia are still unknown as few studies have been conducted over several cropping seasons. Research on the implications of agricultural management on soil biology needs to continue in order to better understand the interactions between crop management and soil biology.

**Table 1. Some other examples of impacts of pesticides and fertilisers reported in scientific literature.**

| Chemical or product | Organism/s | Effect or impact on non-target microorganisms | Reference |
|---|---|---|---|
| **Pesticides** | | | |
| Herbicides | Nitrifying and denitrifying bacteria | Prosulfuron inhibited $N_2O$ and NO production by the bacteria | (Kinney *et al.* 2005) |
| | Mycorrhizal fungi | Decreased in some situations | (Dodd and Jeffries 1989) |
| | Protozoa | Reductions due to recommended rates of 2,4-D, simazine, diuron, monuron, cotoran.<br>Increases in protozoa attributed to stimulation of bacteria and fungal populations as herbicide is decomposed | See (Gupta 1994) |
| | Earthworms | No effect in top 10cm | (Mele and Carter 1999) |
| | Microarthropods and microflora | Paraquat and glyphosate altered activities and reduced decomposition of crop residues. | (Hendrix and Parmelee 1985) |
| | Collembola and mites | Adverse effects of atrazine and simizine for up to four weeks | See (Gupta 1994) |
| Insecticides | Bacteria | Chlorpyrifos reduced numbers | (Pandey and Singh 2004) |
| | Fungi | Chlorpyrifos significantly increased numbers | (Pandey and Singh 2004) |
| | Protozoa | Diazinon decreased protozoan populations | (Ingham and Coleman 1984) |
| | Earthworms | Extremely sensitive to organophosphates and carbamates, less sensitive to organochlorines although can be affected over time due to persistent nature of these chemicals | See (Fraser 1994) |
| Fungicides | Nitrifying and denitrifying bacteria | Mancozeb and chlorothalonil inhibited $N_2O$ and NO production | (Kinney *et al.* 2005) |
| | Earthworms | Copper oxychloride used in orchards is very toxic | (Lee 1985) |
| **Fertilisers** | | | |
| Phosphorus | Mycorrhizal fungi | Several reports that increasing P concentration to very high levels decreases colonisation of roots and/or spore numbers in soil | (Jensen and Jakobsen 1980)<br>(Seymour 2002)<br>(Hayman *et al*. 1975) |
| | Earthworms | Increased numbers with increasing P applications to pasture probably due to increased plant productivity | Fraser et al. 1993 |

| Chemical or product | Organism/s | Effect or impact on non-target microorganisms | Reference |
|---|---|---|---|
| Nitrogen | Mycorrhizal fungi | Spore number and root colonisation decreased | (Hayman 1970) |
| | | Effect varied with site | (Jensen and Jakobsen 1980) |
| | Protozoa | Significant increases, stabilisation and decreases all reported depending on situation | See (Gupta 1994) |
| | Actinomycetes | No effect on total counts | (Zaitlin *et al.* 2004) |
| | Earthworms | Increases due to long-term applications to wheat at Rothamstead (130 yrs), barley (5yrs) | See (Fraser 1994) |
| | Root-lesion nematodes | *Pratylenchus thornei* increased with long-term use of N fertiliser of wheat crops. | (Thompson 1992) |
| Lime | Mycorrhizal fungi | Little effect on colonisation; change in fungi present | (Wang *et al.* 1985) |
| | Earthworms | Often increases populations – response due to pH change rather than increased calcium supply | See (Fraser 1994) |
| Sulfur | Bacterial-feeding protozoa | 30-71% decline in populations | (Gupta and Germida 1988) |
| | Fungal-feeding amoebe | >84% decline in fungal-feeding amoebe | (Gupta and Germida 1988) |
| | Fungi | reduced biomass | |

## References

Angus, J. J., Gupta, V. V. S. R., Good, A. J. and Pitson, G. D. (1999). Wheat yield and protein responses to anhydrous ammonia (Coldflo) and urea, and their effects on soil. Final Report of Project CSP169 for the Grains Research and Development Corporation. CSIRO 17pp.

Araujo, A. S. F., Monteiro, R. T. R. and Abarkeli, R. B. (2003). Effect of glyphospate on the microbial activity of two Brazilian soils. Chemosphere **52**: 799-804.

Biederbeck, V. O., Campbell, C. A., Ukrainetz , H., Curtin, D. and Bouman, O. T. (1996). Soil microbial and biochemical properties after ten years of fetilisation with urea and anhydrous ammonia. Canadian Journal of Soil Science **76**: 7-14.

Blowes, W. M. (1987). Effect of ryegrass root residues, knock-down herbicides, and fungicides on the emergence of barley in sandy soils. Australian Journal of Experimental Agriculture **27**: 785-790.

Bunemann, E. K. and McNeill, A. (2004). Impact of fertilisers on soil biota. In “Soil Biology in Agriculture”. Proceedings of a workshop on current research into soil biology in agriculture. Ed. R. Lines-Kelly. Tamworth, NSW Department of Primary Industries.pp.64-71

Dodd, J.C. and Jeffries, P. (1989). Effects of herbicides on three vesicular-arbuscular fungi associated with winter wheat (*Triticum aestivum* L.). Biology and Fertility of Soils **7**: 113-119.

Fraser, P. M. (1994). The impact of soil and crop management practices on soil macrofauna. In “Soil Biota: Management in Sustainable Farming Systems”. Eds. C. E. Pankhurst, B. M. Doube, V. V. S. R. Gupta and P. R. Grace. pp. 125-132. CSIRO Australia, Melbourne.

Gupta, V. V. S. R. (1994). The impact of soil and crop management practices on the dynamics of soil microfauna and mesofauna. In “Soil Biota: Management in Sustainable Farming Systems”. Eds. C. E. Pankhurst, B. M. Doube, V. V. S. R. Gupta and P. R. Grace. pp. 107-124. CSIRO Australia, Melbourne.

Gupta, V. V. S. R. and Germida, J. J. (1988). Populations of predatory protozoa in field soils after 5 years of elemental S fertiliser application. Soil Biology and Biochemistry **20**: 787-791.

Hayman, D.S. (1970). *Endogone* spore number sin soil and vesicular-arbuscular mycorrhiza in wheat as influenced by season and soil treatment. Transactions of the British Mycological Society **54**: 53-63.

Hayman, D.S., Johnson, A.M. and Ruddlesdin, I. (1975). The influence of phosphate and crop species on endogone spores and vesicular-arbuscular mycorrhiza under field conditions. Plant and Soil **43**: 489-495.

Hendrix, P.F. and Parmalee, R.W. (1985). Decomposition, nutrient loss and microarthropod densities in herbicide-treated grass litter in a Georgia piedmont agroecosystem. Soil Biology and Biochemistry **17**: 421-428.

Ingham, E.R. and Coleman, D.C. (1984). Effects of streptomycin, cycloheximide, fungizone, Captan, Carbofuron, Cygon and PCNB on soil microorganisms. Microbial Ecology **10**: 345-358.

Jensen, A. and Jakobsen, I. (1980). The occurrence of vesicular-arbuscular mycorrhiza in barley and wheat grown in some Danish soils with different fertiliser treatments. Plant and Soil **55**: 403-414.

Kinney, C.A., Mandernack, K.W. and Mosier, A.R. (2005). Laboratory investigations into the effects of the pesticides mancozeb, chlorothalonil, and prosulfuron on nitrous oxide and nitric oxide production in fertilised soil. Soil Biology and Biochemistry **37**: 837-850.

Lee, K.E. (1985). "Earthworms: their ecology and relationships to soils and land use". Academic Press, New York.

Mele, P. M. and Carter, M. R. (1999). Impact of crop management factors in conservation tillage farming on earthworm density, age structure and species abundance in south-eastern Australia. Soil and Tillage Research **50**: 1-10.

Mekwatanakarn, P. and Sivasithamparam, K. (1987). Effect of certain herbicides on saprophytic survival and biological suppression of the take-all fungus. New Phytology **106**: 153-159.

Pankhurst, C. E. and Lynch, J. M. (1994). The role of soil biota in sustainable agriculture. In "Soil Biota: Management in Sustainable Farming Systems". Eds. C. E. Pankhurst, B. M. Doube, V. V. S. R. Gupta and P. R. Grace. pp. 3-9. CSIRO Australia, Melbourne.

Rovira, A. D. and McDonald, H. (1986). Effects of herbicide chlorsulfuron on *Rhizoctonia* bare patch and take-all of barley and wheat. Plant Disease **70**: 879-882.

Seymour, N. P. (2002). Responses of linseed to vesicular-arbuscular mycorrhizae, phosphorus and zinc in a vertisol. Doctor of Philosophy, University of Queensland. 263 pp.

Smith, M. D., Hartnett, D. C. and Rice, C. W. (2000). Effects of long-term fungicide applications on microbial properties in tallgrass prairie soil. Soil Biology and Biochemistry **32**: 935-946.

Thompson, J. P. (1990). Soil sterilization methods to show VA-mycorrhizae aid P and Zn nutrition of wheat in vertisols. Soil Biology and Biochemistry **22**: 229-240.

Thompson, J. P. (1992). Soil biotic and biochemical factors in a long-term tillage and stubble management experiment on a vertisol. 2. Nitrogen deficiency with zero tillage and stubble retention. Soil and Tillage Research **22**: 339-361.

Van Zwieten, L. (2004). Impacts of pesticides on soil biota. In "Soil Biology in Agriculture". Proceedings of a workshop on current research into soil biology in agriculture. Ed. R. Lines-Kelly. pp.72-79. Tamworth, NSW Department of Primary Industries.

Wang, G., Stribley, D.P., Tinker, P.B. and Walker, C. (1985). Soil pH and vesicular-arbuscular mycorrhizas. In "Ecological interactions in soil". Ed. A.H. Fitter. pp.219-224. Blackwell Scientific Publications, Oxford, U.K.

Wildermuth, G. B., Thompson, J. P. and Robertson, L. N. (1997). Biological change: diseases, insects and beneficial organisms. In "Sustainable crop production in the sub-tropics. An Australian perspective". Ed. A. L. Clarke and P. B. Wylie. pp. 112-130. Brisbane, Department of Primary Industries, Queensland.

Zaitlin, B., Turkington, K., Parkinson, D. and Clayton, G. (2004). Effects of tillage and inorganic fertilisers on culturable soil actinomycete communities and inhibition of fungi by specific actinomycetes. Applied Soil Ecology **26**: 53-62.