Biological Agriculture & Horticulture
An International Journal for Sustainable Production Systems

ISSN: 0144-8765 (Print) 2165-0616 (Online) Journal homepage: https://www.tandfonline.com/loi/tbah20

Is an Enhanced Soil Biological Community, Relative to Conventional Neighbours, a Consistent Feature of Alternative (Organic and Biodynamic) Agricultural Systems?

Megan Ryan

Biological Agriculture and Horticulture, 1999, Vol. 17, pp. 131–144
0144-8765/99 $10

Is an Enhanced Soil Biological Community, Relative to Conventional Neighbours, a Consistent Feature of Alternative (Organic and Biodynamic) Agricultural Systems?

Megan Ryan*

Division of Botany and Zoology, Australian National University, Canberra, ACT, 0200, Australia

ABSTRACT

A review was conducted of studies which compare the soil biological community on farms where plant nutrition is managed in a 'conventional' manner (addition of synthetic easily-soluble fertilizers) with farms which adopt 'alternative' fertilizer strategies (organic or biodynamic). Such alternative strategies include additions of natural minerals, composts or manures, and growth of green manure crops or inclusion of legumes in the rotation. Four groups of soil organisms are examined (soil micro-organisms, soil fauna, soil-borne plant pathogens and soil micro-organism/plant symbioses which enhance plant nutrient uptake) and a case study of biodynamic and conventional dairy farms in southern Australia is presented.

It is concluded that the total soil microbial biomass and the biomass of many specific groups of soil organisms will reflect the level of soil organic matter which will, in turn, be largely determined by the volume of recent organic matter inputs. Hence, when alternative farms include regular inputs of organic matter in their rotation, they will tend to have a larger soil community than conventional neighbours whilst these inputs are decomposed. Non-transient increases in the soil community may take many years to appear as relatively stable soil organic carbon tends to increase slowly. Conventional practices, such as addition of soluble fertilizers and pesticides, may affect some groups of soil organisms, but their overall effect on the soil community will generally be small.

However, if alternative farming systems do not include large inputs of organic matter, if their production is strongly limited by low levels of nutrients such as phosphorus, or if they are of a low intensity nature, the soil community may not differ from a conventional neighbour. This is often the case in Australia and may occur with increasing frequency in other regions if alternative farms have negative nutrient balances. Hence, an enhanced soil community relative to conventional neighbours should not be considered as a definitive feature of alternative agricultural systems.

*Present address: CSIRO, Plant Industry, GPO Box 1600, Canberra, ACT, 2601, Australia.

INTRODUCTION

Plant growth is central to most agricultural systems and is dependent on the availability of nutrients in the soil. Plant nutrient supply is manipulated by farmers in various ways and these may be broadly categorized as a 'conventional' approach, which utilizes synthetic easily-soluble fertilizers to address specific perceived deficiencies, and an 'alternative' (organic or biodynamic) approach which relies upon additions of relatively insoluble natural minerals and, often, more copious additions or greater retention of plant and animal residues. A diverse and carefully planned rotation including crops or pasture components which host nitrogen-fixing organisms is also usually a feature of alternative farms.

Thus the conventional approach aims to directly feed plant growth, with incidental direct impacts on soil organisms capable of utilizing inorganic substrates, while the alternative approach generally provides both an array of nutrients and also the organic matter which is the basis for saprophytic food chains. These food chains will consist of a diverse range of organisms which will affect nutrient release and cycling, supply of nutrients to plants, and soil structure.

These contrasting fertilizer strategies, along with the non-use of biocides on alternative farms, are fairly consistent differences across many regions and agricultural crops, although, as discussed later, the amount of organic matter inputs on alternative farms may vary greatly. Thus, it is not surprising that alternative farmers, and others, claim that alternative management practices enhance the soil biological community and its functioning and that this is a definitive feature of alternative systems (Lopez-Real, 1985; La Rooj, 1989; National Research Council, 1989; Wynen, 1992; Macgregor, 1994; Penfold *et al.*, 1995; Sinnamon, 1996; Ritz *et al.*, 1997). For instance, the Australian National Standard for Organic and Biodynamic Produce states that produce from alternative farms is defined by being "produced in soils of enhanced biological activity, ... , such that plants are fed through the soil ecosystem and not primarily through soluble fertilizers added to the soil" (AQIS, 1997).

In order to establish whether an enhanced soil community is a consistent feature of alternative systems and therefore can be used in the definition of such systems, this paper reviews studies which have compared the soil community between alternative and conventional farms.

SOIL MICRO-ORGANISMS

The total microbial biomass in agricultural systems, although fluctuating widely with environmental parameters such as water (Wander *et al.*, 1995), is generally positively correlated with soil organic matter levels (Schnürer *et al.*, 1985;

Anderson & Domsch, 1989; Witter *et al.*, 1993). Alternative farms often receive more organic matter inputs than conventional farms due to incorporation of compost and green manure crops, and this is often reported to be the major factor responsible for an enhanced soil community on the alternative farms relative to conventional neighbours (Foissner, 1987; Elmholt & Kjøller, 1989; Reganold, 1988).

For instance, in an Australian trial comparing growth of vegetables under organic and conventional management, the organic plots, where a high rate of compost (80–120 t ha^{-1}) had been added, supported greater populations of fungi, bacteria and actinomycetes than the conventional plots (Sivapalan *et al.*, 1993). A similar result was reported by Workneh & van Bruggen (1994a) who isolated actinomycetes, bacteria and fungi from the rhizosphere of tomato plants from three organic and three conventional farms in California. Compost had been applied on the organic farms 1–4 weeks prior to sampling. The largest difference between the farms was the greater number and diversity of actinomycetes in the organic soil, including a higher proportion of cellulolytic and hemicellulolytic actinomycetes.

Other management practices may indirectly influence soil micro-organisms through their effect on soil organic matter levels. For instance, inclusion of pasture phases in the rotation tends to increase microbial populations (Sivapalan *et al.*, 1993; Robertson & Morgan, 1996). This reflects soil organic matter increasing under pasture, due to the proliferation, death and rapid decomposition of roots, and increased water retention (Grace *et al.*, 1995). Tillage is likely to decrease the level of soil organic matter through increasing its oxidation (Grace *et al.*, 1995) and therefore may cause a decline in the soil microbial biomass (Karlen *et al.*, 1994). Alternative farmers may make greater use of tillage than conventional farmers, as the application of herbicides to control weeds is not an option (AQIS, 1997).

However, addition of organic matter on alternative farms does not guarantee an increase in soil microbial biomass. For instance, Robertson & Morgan (1996) reported that a two-four fold increase in annual organic matter inputs as compost (6–42 t ha^{-1}) did not increase microbial biomass. They attributed this to the quantity or quality of the compost, other factors limiting soil microbes such as water, or sudden bursts in activity which were not detected by their sampling. Indeed, it appears that while additions of organic matter cause short-term fluctuations in microbial biomass, the added organic matter is no longer available, or insignificant in amount relative to the older material, within one year (Anderson & Domsch, 1989; Witter *et al.*, 1993; Keeling *et al.*, 1995). Hence, many years of increased organic matter inputs may be necessary on alternative farms before soil organic matter levels and the equilibrium size of the microbial biomass are increased.

For instance, Penfold *et al.* (1995) conducted trials in South Australia comparing organic, biodynamic, integrated and conventional extensive farming systems in large replicated field plots. The alternative plots received composted animal manure and green manure crops, or cereal crops undersown with legumes were included in the rotation. After 6 years there were no significant differences in organic carbon levels, although there was an indication that the alternative plots had higher levels of microbial activity, as measured by loss of tensile strength by cotton. Wander *et al.* (1995) also reported that the microbial biomass and microbial community structure did not differ significantly between treatments in a 10-year-old field trial in Pennsylvania. The trial included two organic treatments, animal manure or cover crops, and a conventional treatment where soluble fertilizers were applied. The organic soils had slightly higher total soil carbon.

Hence, it seems that a long period of time, often greater than 10 years, may be required before alternative management has a large enough effect on soil organic matter levels to have a consistent influence on the soil community. Indeed, it may take even longer when agricultural systems are of low intensity, that is, have a relatively low level of production and few inputs, due to limiting factors such as low rainfall or extreme temperatures.

For instance, in a low rainfall area in Australia (average annual rainfall 430 mm), where crop stubble production is relatively low (15.5 t C ha^{-1}) and tillage rarely intensive, Fettell & Gill (1995) found the type of stubble management and tillage (burned/retained, conventional tillage/direct drilling) had not, after 14 years, resulted in significantly different levels of soil organic carbon. Similarly, Ryan (1992) examined cellulose decomposing fungi in soil from neighbouring organic and conventional wheat farms in southern Australia (average annual rainfall 490 mm); the organic farm had been retaining crop stubble for 30 years while on the conventional farm, stubble was generally burnt. Organic carbon levels were higher, but not significantly so, on the organic farm (Derrick, 1996). Fungi were distinguished by their colony morphology on cellophane. Species diversity was similar on the two farms and although there was an indication that cellulose decomposing ability was higher on the organic farm, the results were not significant (Ryan, 1992).

Other management practices which differ between alternative and conventional farms may also directly influence the soil microbial community. Although there are few reports of soluble fertilizers having direct effects on soil micro-organisms, Workneh & van Bruggen (1994a) did find significantly greater numbers of fluorescent *Pseudomonas* spp. in organic soil and suggested soluble fertilizer applications on the conventional farms were responsible. However, addition of soluble fertilizers may, overall, increase microbial populations through enhancing plant growth. For instance, Martyniuk & Wagner (1978) reported that microbial populations were low in unfertilized soils, intermediate in soil where soluble artificial fertilizers were applied and high in soils that received manure. The higher populations in the artificially fertilized soils relative to the unfertilized soils were ascribed to the fertilizers increasing plant growth and plant residues and thereby increasing the level of soil organic matter.

Studies that report enhanced biological activity in alternatively managed soils sometimes attribute this to the use of biocides in the conventional system (Sivapalan *et al.*, 1993), but usually this is not supported by quantitative evidence. While biocides may affect the functioning of various groups of soil organisms, the resilience of the soil ecosystem means that the effects of biocides may generally be short-lived (Elmholt & Kjøller, 1989; Schuster & Schroder, 1990; Vreeken-Buijs *et al.*, 1994). Tillage may have a direct negative effect on the soil community by causing erosion and structural degradation (Foissner, 1992).

Biodynamic farmers apply many preparations, including BD500, which are designed to supply the soil and plants with cosmic forces and thereby stimulate soil life (Kirchmann, 1994). However, there is no evidence for such an effect. For instance, Penfold *et al.* (1995) found BD500 to have no detectable impact on the microbial biomass over 2 years of measurement. It is possible, however, that the preparation affects the biomass and activity of particular organisms; an effect not detected by broad measures of biomass or activity.

SOIL FAUNA

Soil fauna will generally respond to differences in farm management in a similar manner to soil micro-organisms. For instance, in a Californian apple orchard, Werner (1997) reported that earthworm abundance and biomass increased under organic management and speculated that greater compost inputs and growth of weeds under trees in the organic orchard were responsible. Similarly, Werner & Dindal (1990) examined the soil fauna in year five of a trial in Pennsylvania where three treatments had been established: organic-manure, organic-legume and conventional. They found that nematodes, prostigmatid mites and collembola were all more abundant on the organic plots, apparently in response to the organic matter inputs. The predatory mesostigmatid mites were also most abundant in organic-manure plots and appeared to be positively affected by weed growth in the plots. Tillage exerted a strong negative effect on oribatid mites and earthworms. Earthworms and other soil fauna have often been reported to be significantly less abundant in conventional tillage systems than in no-tillage systems (House & Parmelee, 1985), with the negative effect of tillage on soil organic matter probably being largely responsible (Karlen *et al.*, 1994). Similarly, Griffiths *et al.* (1994) examined nematodes on a Scottish organic farm, finding the addition of poultry manure increased the numbers, and altered the types, of nematodes present.

In New Zealand, Springett (1994) examined two pairs of adjacent organic and conventional farms, one dairying and the other mixed cropping. Indices of species diversity, richness, and evenness for soil fauna were slightly higher for the organic farms. Oribatid mites and spiders were present only on the organic farms and earthworm biomass was greater on the organic farms, although species composition did not differ between farms. The length of earthworm burrows was significantly higher on the organic dairy farm (410 cm m^{-2}) than on the conventional dairy farm (154 cm m^{-2}) (Springett & Gray, 1994). It was not determined which management practices were responsible for these differences. However, Reganold & Palmer (1995) reported a similar trend when examining earthworms on New Zealand market garden farms and attributed it to use of biocides on the conventional farm.

In contrast to the above studies, Small *et al.* (1994) examined permanent perennial pastures on ten pairs of Australian biodynamic and conventional irrigated dairy farms and found a significantly higher biomass of worms on the conventional farms (87 g m^{-2} compared with 59 g m^{-2}). This probably reflects the lower organic matter inputs on the biodynamic farms (Small *et al.*, 1994) and is discussed further later.

Thus, the abundance of the two groups of soil organisms discussed so far is generally dependent on the availability of organic matter, as this is their primary energy source. Soil fauna populations may be more susceptible to pesticides and mechanical damage from tillage (Fraser, 1994), perhaps due to their larger size and slower growth rates. However, two agriculturally important groups of soil organisms, those interacting directly with plants either pathogenically or symbiotically, rely on plants for provision of the majority, or all, of their carbon requirements and therefore will not be as directly affected by soil organic carbon levels.

SOIL-BORNE PLANT PATHOGENS

Root diseases and pests have generally been reported to either occur at similar levels on alternative and conventional farms, or be less severe on alternative farms (see review by van Bruggen, 1995). The instances of lower disease levels on alternative farms are ascribed by van Bruggen (1995) to the regular application of organic matter and elimination of pesticides increasing the general level of soil microbial activity, and thereby increasing competition and/or antagonism in the soil, as well as longer rotations breaking the disease cycle.

A number of studies suggest that addition of organic matter may be particularly important in controlling disease through encouraging certain groups of soil organisms that are antagonistic to pathogens. For instance, Workneh & van Bruggen (1994a) examined rhizosphere soil of tomato plants grown on organic and conventional farms in California. The organic soils exhibited a greater degree of suppression of the disease corky root (*Pyrenochaeta lycopersici*), possibly due to greater organic matter inputs having increased the numbers of actinomycetes (see also Workneh & van Bruggen, 1994b). Similarly, Sivapalan *et al.* (1993) found a number of soil-borne pathogens, including *Alternaria brassicicola*, *Botrytis cinerea*, and *Rhizoctonia solani*, only on conventional vegetable plots. Antagonistic fungi, including species of *Aspergillus*, *Fusarium*, *Penicillium* and *Trichoderma*, were found more frequently in organic plots, apparently due to the addition of organic matter (Sivapalan *et al.*, 1993). In a Danish study, Knudsen *et al.* (1995) compared the occurrence of fungi antagonistic to the brown foot rot caused by *Fusarium culmorum* between a biodynamic and a conventional farm. A greater number of antagonistic fusaria species were present on the biodynamic farm and this was attributed to a number of management differences, including the use of farmyard manure on the biodynamic farm (see also Elmholt, 1996).

SOIL MICRO-ORGANISM/PLANT SYMBIOSES WHICH ENHANCE PLANT NUTRIENT UPTAKE

As alternative farmers do not use synthetic soluble fertilizers, they may apply less nutrients, particularly if large volumes of organic matter are not being applied, and they may apply nutrients in relatively insoluble forms (Reganold *et al.*, 1993; Small *et al.*, 1994; Derrick, 1996). Hence, it is possible that symbiotic relationships between plants and soil micro-organisms which directly improve plant nutrition may be of particular importance on alternative farms.

While there appear to be no comparisons of the levels of biological nitrogen-fixation on conventional and alternative farms, utilizing the legume-*Rhizobium* bacteria symbiosis to supply nitrogen is a feature of many alternative agricultural systems. On three paired biodynamic/conventional dairy farms in southern Australia, the frequency of *Rhizobium* nodules on white clover (*Trifolium repens*) was found to be greater on the conventional farms (Table 1), apparently because clover growth on the biodynamic farms was phosphorus-limited (Ryan, 1998).

Alternative farms are often reported to have higher levels of vesicular-arbuscular mycorrhizal (VAM) fungi than conventional neighbours (Lengnick & King, 1986; Bokhorst, 1989; Werner *et al.*, 1990; Sattelmacher *et al.*, 1991; Ryan *et al.*, 1994; Werner, 1997). VAM fungi provide their host plant with nutrients, particularly phosphorus (Thompson, 1994), and may also influence plant water uptake (Kothari *et al.*, 1990), reduce the effects of pathogenic organisms (Thompson & Wildermuth, 1989) and improve soil structure (Tisdall & Oades, 1979).

In a four-year study of VAM fungi on wheat properties in southern Australia, crops on alternative farms consistently had significantly higher levels of VAM colonization than neighbouring conventional farms (Ryan, 1998). Applications of soluble phosphorus fertilizers on the conventional farms were responsible for

TABLE 1

Concentrations of nutrients in soil (0–10 cm) and whole pasture, and characteristics of the soil community, in permanent pasture fields on paired biodynamic (BD) and conventional (Con.) irrigated dairy farms in southern Australia.

	BD	Con.	Level of significance
Soil extractable P (μg g^{-1} Olsen)[a]	8.4	19.2	$p<0.01$
Whole pasture P (%)[a]	0.24	0.35	$p<0.001$
Soil total N (μg g^{-1})[a]	3600	3500	ns
Whole pasture N (%)[a]	2.1	2.0	ns
Soil organic carbon (%)[a]	2.62	2.57	ns
Microbial biomass carbon (μg g^{-1} soil)[a]	655	642	ns
Earthworm biomass (g m^{-2})[b]	59	87	$p<0.05$
Percentage of clover root length colonized by VAM fungi[c]	71	48	$p<0.001$
Rhizobium nodules on clover (number 10 cm^{-1} roots)[d]	3.9	5.7	$p<0.05$

[a]From ten farm pairs sampled in March 1993 (Small *et al.*, 1994)
[b]From ten farm pairs sampled in September 1992 (Small *et al.*, 1994)
[c]From ten farm pairs sampled in March 1993 (Ryan, 1998)
[d]From three farm pairs sampled in January 1994 (Ryan, 1998)

lowering colonization levels (Dann *et al.*, 1996). Other studies have also found phosphorus addition to be responsible for the lower colonization on conventional farms (Sattelmacher *et al.*, 1991). However, this is not always the case and other factors, such as fungicide applications (Werner *et al.*, 1990), pesticide applications (Werner, 1997) and the absence of vegetation around orchard trees (Werner, 1997), have also been suggested as responsible for reducing VAM colonization on conventional farms.

There is some evidence that VAM fungal communities exposed to several years of soluble phosphorus fertilizer applications may become less efficient at enhancing plant growth (Johnson, 1993). Indeed, alternative farms may develop VAM populations more beneficial for plant nutrient uptake than conventional farms (Scullion *et al.*, 1998). However, this does not always occur (Ryan 1998; Ryan & Ash, 1999) and both shifts in VAM communities and greater colonization by VAM fungi on alternative farms are unlikely to compensate, in terms of yield, for the non-application of soluble phosphorus fertilizers (Dann *et al.*, 1996; Ryan & Ash 1999).

CASE STUDY: BIODYNAMIC AND CONVENTIONAL DAIRY FARMS IN SOUTHERN AUSTRALIA

While the studies presented above often reported alternative systems to have enhanced soil communities, this was not always the case. The factors responsible for these exceptions are explored below using a case study from southern Australia where permanent pasture paddocks on ten pairs of biodynamic/conventional irrigated dairy farms were examined (Small *et al.*, 1994; Ryan, 1998). Lime was applied to all farms (average 40 kg ha^{-1} $year^{-1}$). The conventional farms had at least a 15 year history of regular applications of the readily soluble fertilizers superphosphate, diammonium phosphate and urea (average 27 kg ha^{-1} $year^{-1}$ of P and 17 kg ha^{-1} $year^{-1}$ of N). In contrast, the biodynamic farmers had not applied significant amounts of fertilizers for, on average, 17 years, instead applying the biodynamic homeopathic preparation BD500 one-two times each year (Small *et al.*, 1994). A similar volume of grain was supplied to cattle on all farms, synthetic medicines and biocides were used only on the conventional farms and the interval between irrigations was slightly longer on the biodynamic farms (Small *et al.*, 1994). There were no other major management differences between the farming systems and no large additions of organic matter in either system.

As a consequence of these management strategies, phosphorus concentrations in soil and pasture were lower on the biodynamic farms. Soil and pasture nitrogen concentrations were similar on all farms, presumably reflecting the role of the legume component of the pasture in biological nitrogen fixation. Soil organic carbon concentrations were also similar on all farms (Table 1).

Four measures of the soil biological community on these farms are presented in Table 1. Soil microbial biomass did not differ between the two management systems (Small *et al.*, 1994), reflecting the identical soil organic carbon levels. As mentioned earlier, the biomass of earthworms was higher on the conventional farms and two factors were considered responsible for this result (Small *et al.*, 1994). First, longer irrigation intervals over summer on the biodynamic farms may have reduced worm numbers. Secondly, low phosphorus status on the biodynamic farms appeared to result in lower milk production and hence less feed intake, a lower faecal output and, consequently, less food available for earthworms. Small *et al.* (1994) calculated faecal outputs to be 42 t ha^{-1} $year^{-1}$ (2.4 cows ha^{-1}) on the conventional farms and 26.4 t ha^{-1} $year^{-1}$ (1.9 cows ha^{-1}) on the biodynamic farms. The higher levels of VAM colonization and lower frequency of *Rhizobium* nodules on the biodynamic farms appeared directly due to lower plant phosphorus concentrations (Ryan, 1998; Ryan & Ash, 1999).

In a glasshouse trial using soil from three biodynamic/conventional farm pairs, plants grown in conventional and biodynamic soil responded in the same manner to addition of soluble nutrients (Ryan & Ash, 1999). This suggested that the biodynamic and conventional soils had not developed substantially different processes to enhance plant nutrient uptake.

Two factors were contributing towards some, perhaps even most, components of the soil community being reduced on the biodynamic farms relative to the conventional farms. These were the lack of large inputs of organic matter, and phosphorus limiting plant growth and thereby the productivity of the entire system. While addition of large quantities of organic matter, such as compost, slurry and manure, is often a feature of alternative systems of agriculture in Europe, in Australia, the extensive nature of most agriculture means that acquiring and spreading large volumes of organic matter does not occur (Conacher & Conacher, 1983). The low concentrations of phosphorus in many Australian soils (Lindsay, 1985) means that alternative farms, which apply either no phosphorus fertilizer or only relatively insoluble forms of phosphorus, often experience markedly reduced plant growth and yields (Dann *et al.*, 1996; Derrick, 1996; Ryan, 1998) and may have a negative phosphorus balance (Small *et al.*, 1994; Penfold *et al.*, 1995). Such a situation may eventually occur on alternative farms in more fertile regions of the world if the farms have a negative balance for any nutrients.

CONCLUSIONS

In general, the level of soil organic matter is the most important factor regulating the soil community. Increases in organic matter through direct applications, green manure crops, or inclusion of pasture phases in the rotation will cause, at least in the short term, increases in the biomass of the soil community and may encourage the presence of organisms antagonistic to soil-borne pathogens. Factors which increase the diversity of the system, such as weeds and diverse rotations, may also have a positive effect on the microbial biomass, mostly through their effects on soil organic matter. Management practices which reduce soil organic matter, such as tillage and stubble removal, may have a negative effect on populations. Hence, alternative farms which have increased organic matter inputs relative to conventional neighbours, will tend to have an enhanced soil biological community, although many years may be required to change the soil organic matter levels to permanently affect the soil community.

A number of other characteristics of conventional management may also decrease abundance of some sections of the soil community, although it appears that, in general, their effect is minimal. These include the addition of artificial soluble fertilizers, especially in regards to VAM fungi, and the use of pesticides.

However, alternative farms do not always have an enhanced soil biological community relative to conventional farms, particularly if large amounts of organic matter are not routinely applied or if the system is nutrient-limited, resulting in organic matter inputs to the soil in the form of dead plant material and animal faeces being reduced (Martyniuk & Wagner, 1978; Small *et al.*, 1994; Reganold & Palmer, 1995). It may also occur if large amounts of organic matter are also applied on conventional farms (Foissner, 1992) or if all farms are of a low intensity nature (Fettell & Gill, 1995).

When the biomass or composition of the soil community on alternative farms does differ from conventional farms, there is little information about the consequences of this for the functioning of the entire system (see Wander *et al.*, 1996). For instance, while it is likely that organic matter inputs encourage organisms antagonistic to pathogens, it is not known whether an enhanced soil community results in a system being more resilient to disturbances and stresses, such as drought, or if microbial action compensates plants for lack of soluble nutrient additions. In strongly nutrient-limited systems, it is unlikely that the soil community can fully compensate, in terms of plant yield, for lack of conventional inputs such as soluble fertilizers (Dann *et al.*, 1996; Ryan & Ash, 1999). However, it may be possible for alternative farmers to benefit from deliberately manipulating the soil community through mechanisms such as: diversifying rotations to discourage deleterious organisms which build up under monocultures (Dick, 1992; Pankhurst *et al.*, 1999); growing crops, such as brassicas, which may reduce the incidence of pathogens (Sarwar *et al.*, 1998); or through changing the type or frequency of tillage (House & Parmelee, 1985).

It is likely that important differences, as yet undetected, may exist between alternative and conventional systems in the occurrence or activities of particular groups or species of soil organisms. These differences may not be reflected in broad measures of microbial activity, yet may result in different pathways being present for processes such as disease suppression and plant nutrient uptake. However, given the broad range of environments, soils, agricultural practices and agricultural systems encompassed by organic and biodynamic farming, such differences may not be universal. In conclusion, an enhanced soil community, relative to conventional neighbours, cannot be stated as a definitive feature of alternative agricultural systems.

ACKNOWLEDGEMENTS

Julian Ash, Jim Derrick and John Angus provided helpful discussion. The author was funded by a Grains Research and Development Corporation Junior Research Fellowship.

References

Anderson, T.H. & Domsch, K.H. (1989). Ratios of microbial biomass carbon to total organic carbon in arable soils. *Soil Biology and Biochemistry*, **21**, 471–479.

AQIS (1997). *National Standard for Organic and Biodynamic Produce*. Australian Quarantine and Inspection Service; Canberra.

Bokhorst, J.G. (1989). The organic farm at Nagele. In *Development of Farming Systems*. Zadoks, Pudoc; Wageningen.

Conacher, A. & Conacher, J. (1983). A survey of organic farming in Australia. *Biological Agriculture & Horticulture*, **1**, 241–254.

Dann, P.R., Derrick, J.W., Dumaresq, D.C. & Ryan, M.H. (1996). The response of organic and conventionally grown wheat to superphosphate and reactive rock phosphate. *Australian Journal of Experimental Agriculture*, **36**, 71–78.

Derrick, J.W. (1996). *A Comparison of Agroecosystems: Organic and Conventional Broadacre Farming in South East Australia.* PhD thesis. Australian National University; Canberra.

Dick, P.R. (1992). A review: long-term effects of agricultural systems on soil biochemical and microbial parameters. *Agriculture, Ecosystems and Environment*, **40**, 25–36.

Elmholt, S. (1996). Microbial activity, fungal abundance and distribution of *Penicillium* and *Fusarium* as bioindicators of a temporal development of organically cultivated soils. *Biological Agriculture & Horticulture*, **13**, 123–140.

Elmholt, S. & Kjøller, A. (1989). Comparison of the occurrence of the saprophytic soil fungi in two differently cultivated field soils. *Biological Agriculture & Horticulture*, **6**, 229–239.

Fettell, N.A. & Gill, H.S. (1995). Long-term effects of tillage, stubble, and nitrogen management on properties of a red-brown earth. *Australian Journal of Experimental Agriculture*, **35**, 923–928.

Foissner, W. (1987). The micro-edaphon in ecofarmed and conventionally farmed dryland cornfields near Vienna (Austria). *Biology and Fertility of Soils*, **3**, 45–49.

Foissner, W. (1992). Comparative studies on the soil life in ecofarmed and conventionally farmed fields and grasslands of Austria. *Agriculture, Ecosystems and Environment*, **40**, 207–218.

Fraser, P.M. (1994). The impact of soil and crop management practices on soil macrofauna. In *Soil Biota: Management in Sustainable Farming Systems* (C.E. Pankhurst, B.M. Doube, V.V.S.R. Gupta & P.R. Grace, eds.), pp. 125–132. CSIRO; Adelaide.

Grace, P.R., Oades, J.M., Keith, H. & Hancock, T.W. (1995). Trends in wheat yields and soil organic carbon in the Permanent Rotation Trial at the Waite Agricultural Research Institute, South Australia. *Australian Journal of Experimental Agriculture*, **35**, 857–864.

Griffiths, B.S., Ritz, K. & Wheatley, R.E. (1994). Nematodes as indicators of enhanced microbiological activity in a Scottish organic farming system. *Soil Use and Management*, **10**, 20–24.

House, G.J. & Parmelee, R.W. (1985). Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. *Soil and Tillage Research*, **5**, 351–360.

Johnson, N.C. (1993). Can fertilisation of soil select less mutualistic mycorrhizae? *Ecological Applications*, **3**, 749–757.

Karlen, D.L., Wollenhaupt, N.C., Erbach, D.C., Berry, E.C., Swan, J.B., Eash, N.S. & Jordahl, J.L. (1994). Long-term tillage effects on soil quality. *Soil and Tillage Research*, **32**, 313–327.

Keeling, A.A., Griffiths, B.S., Ritz, K. & Myers, M. (1995). Effects of compost stability on plant growth, microbiological parameters and nitrogen availability in media containing mixed garden-waste compost. *Bioresource Technology*, **54**, 279–284.

Kirchmann, H. (1994). Biological dynamic farming—an occult form of alternative agriculture. *Journal of Agricultural and Environmental Ethics*, **7**, 173–187.

Knudsen, M.B., Elmholt, S., Hockenhull, J. & Jensen, D.F. (1995). Distribution of saprophytic fungi antagonistic to *Fusarium culmorum* in two differently cultivated field soils, with special emphasis on the genus *Fusarium*. *Biological Agriculture & Horticulture*, **12**, 61–79.

Kothari, S.K., Marschner, H. & George, E. (1990). Effect of VA mycorrhizal fungi and rhizosphere microorganisms on root and shoot morphology, growth and water relations in maize. *New Phytologist*, **116**, 303–311.

La Rooj, M. (1989). Soil fertility. In *Biodynamics: New Directions for Farming and Gardening in New Zealand*, pp. 18–24. Random House; Auckland.

Lengnick, L.L. & King, L.D. (1986). Comparison of the phosphorus status of soils managed organically and conventionally. *American Journal of Alternative Agriculture*, **1**, 108–114.

Lindsay, A.M. (1985). Are Australian soils different? In *Are Australian Ecosystems Different?* (J.R. Dodson & M. Westoby, eds.), pp. 83–97. Proceedings of the Ecological Society of Australia Vol. 14; Sydney.

Lopez-Real, J.M. (1985). Sustainable agriculture: the microbial potential—the microbiologists challenge. In *The Role of Micro-Organisms in a Sustainable Agriculture* (J.M. Lopez-Real & R.D. Hodges, eds.), pp. 1–8. Academic; Berkhamstead.

Macgregor, A.N. (1994). Beneficial soil biota in organic and alternative farming systems. In *Soil Biota: Management in Sustainable Farming Systems* (C.E. Pankhurst, B.M. Doube, V.V.S.R. Gupta & P.R. Grace, eds.), pp. 204–208. CSIRO; Adelaide.

Martyniuk, S. & Wagner, G.H. (1978). Quantitative and qualitative examination of soil microflora associated with different management systems. *Soil Science*, **125**, 343–350.

National Research Council (1989). *Alternative Agriculture*. National Academy Press; Washington, D.C.

Pankhurst, C.E., Hawke, B.G. & Magarey, R.C. (1999). Crop rotation-induced changes in the composition and functional diversity of soil microbial communities and its effect on yield decline in sugarcane. In *Proceedings of the First Australasian Soilborne Disease Symposium* (R.C. Magarey, ed.), pp. 5–8. Bureau of Sugar Experiment Stations; Brisbane.

Penfold, C.M., Miyan, M.S., Reeves, T.G. & Grierson, I.T. (1995). Biological farming for sustainable agricultural production. *Australian Journal of Experimental Agriculture*, **35**, 849–856.

Reganold, J.P. (1988). Comparison of soil properties as influenced by organic and conventional farming systems. *American Journal of Alternative Agriculture*, **3**, 144–155.

Reganold, J.P. & Palmer, A.S. (1995). Significance of gravimetric versus volumetric measurements of soil quality under biodynamic, conventional, and continuous grass management. *Journal of Soil and Water Conservation*, **50**, 298–305.

Reganold, J.P., Palmer, A.S., Lockhart, J.C. & Macgregor, A.N. (1993). Soil quality and financial performance of biodynamic and conventional farms in New Zealand. *Science*, **260**, 344–349.

Ritz, K., Wheatley, R.E. & Griffiths, B.S. (1997). Effects of animal manure application and crop plants upon size and activity of soil microbial biomass under organically grown spring wheat. *Biology and Fertility of Soils*, **24**, 372–377.

Robertson, F.A. & Morgan, W.C. (1996). Effects of management history and legume green manure on soil microorganisms under 'organic' vegetable production. *Australian Journal of Soil Research*, **34**, 427–440.

Ryan, M.H. (1992). *Soil Fungi on Two Adjacent Wheat Farms: Comparative Effects of Organic and Conventional Management*, Honours thesis, Division of Botany and Zoology. Australian National University; Canberra.

Ryan, M.H. (1998). *The Ecology of VAM Fungi in Contrasting Australian Agricultural Systems*, PhD thesis. Australian National University; Canberra.

Ryan, M.H. & Ash, J.E. (1999). Effects of phosphorus and nitrogen on growth of pasture plants and VAM fungi in SE Australian soils with contrasting fertiliser histories (conventional and biodynamic). *Agriculture, Ecosystems and Environment*, **73**, 51–62.

Ryan, M.H., Chilvers, G.A. & Dumaresq, D.C. (1994). Colonisation of wheat by VA-mycorrhizal fungi was found to be higher on a farm managed in an organic manner than on a conventional neighbour. *Plant and Soil*, **160**, 33–40.

Sarwar, M., Kirkegaard, J.A., Wong, P.T.W. & Desmarchelier, J.M. (1998). Biofumigation potential of brassicas. III. *In vitro* toxicity of isothiocyanates to soil-borne fungal pathogens. *Plant and Soil*, **201**, 103–112.

Sattelmacher, B., Reinhard, S. & Pomikalko, A. (1991). Differences in mycorrhizal colonization of rye (*Secale cereale* L.) grown in conventional or organic (biological-dynamic) farming systems. *Journal of Agronomy and Crop Science*, **167**, 350–355.

Schnürer, J., Clarholm, M. & Rosswall, T. (1985). Microbial biomass and activity in an agricultural soil with different organic matter contents. *Soil Biology and Biochemistry*, **17**, 611–618.

Schuster, E. & Schroder, D. (1990). Side-effects of sequentially-applied pesticides on non-target soil microorganisms: field experiments. *Soil Biology and Biochemistry*, **22**, 367–373.

Scullion, J., Eason, W.R. & Scott, E.P. (1998). The effectivity of arbuscular mycorrhizal fungi from high input conventional and organic grassland and grass-arable rotations. *Plant and Soil*, **204**, 243–254.

Sinnamon, L. (1996). Why grow food organically? *WellBeing Magazine*, **63**, 6–9.

Sivapalan, A., Morgan, W.C. & Franz, P.R. (1993). Monitoring populations of soil microorganisms during a conversion from a conventional to an organic system of vegetable growing. *Biological Agriculture & Horticulture*, **10**, 9–27.

Small, D., McDonald, J. & Wales, B. (1994). *Alternative Farming Practices Applicable to the Dairy Industry. Final Report on a joint project between Department of Agriculture Victoria and the Dairy Research and Development Corporation DAV 193.* Department of Agriculture, Victoria and The Dairy Research and Development Corporation; Kyabram, Australia.

Springett, J.A. (1994). The biodiversity of the soil fauna under two types of pasture management in New Zealand. In *Soil Biota: Management in Sustainable Farming Systems, Poster Papers* (C.E. Pankhurst, ed.), pp. 71–74. CSIRO; Adelaide.

Springett, J.A. & Gray, R.A.J. (1994). The distribution of pasture roots and earthworm burrows in the soil profiles of a conventional and an organic dairy farm. In *Soil Biota: Management in Sustainable Farming Systems, Poster Papers* (C.E. Pankhurst, ed.), pp. 137–138. CSIRO; Adelaide.

Thompson, J.P. (1994). Inoculation with vesicular-arbuscular mycorrhizal fungi from cropped soil overcomes long-fallow disorder of linseed (*Linum usitatissimum* L.) by improving P and Zn uptake. *Soil Biology and Biochemistry*, **26**, 1133–1143.

Thompson, J.P. & Wildermuth, G.B. (1989). Colonization of crop and pasture species with vesicular-arbuscular mycorrhizal fungi and infection by *Bipolaris sorokiniana*. *Canadian Journal of Botany*, **67**, 687–693.

Tisdall, J.M. & Oades, J.M. (1979). Stabilization of soil aggregates by the root systems of ryegrass. *Australian Journal of Soil Research*, **17**, 429–441.

van Bruggen, A.H.C. (1995). Plant disease severity in high-input compared to reduced-input and organic farming systems. *Plant Disease*, **79**, 976–984.

Vreeken-Buijs, M.J., Geurs, M., de Ruiter, P.C. & Brussaard, L. (1994). Microarthropod biomass-C dynamics in the belowground food webs of two arable farming systems. *Agriculture, Ecosystems, and Environment*, **51**, 161–170.

Wander, M.M., Dudley, R.B., Traina, S.J., Kaufman, D., Stinner, B.R. & Sims, G.K. (1996). Acetate fate in organic and conventionally managed soils. *Soil Science Society of America Journal*, **60**, 1110–1116.

Wander, M.M., Hedrick, D.S., Kaufman, D., Traina, S.J., Stinner, B.R., Kehrmeyer, S.R. & White, D.C. (1995). The functional significance of the microbial biomass in organic and conventionally managed soils. *Plant and Soil*, **170**, 87–97.

Werner, M.R. (1997). Soil quality characteristics during conversion to organic orchard management. *Applied Soil Ecology*, **5**, 151–167.

Werner, M.R. & Dindal, D.L. (1990). Effects of conversion to organic agricultural practices on soil biota. *American Journal of Alternative Agriculture*, **5**, 24–32.

Werner, M.R., Kluson, R.A. & Gliessman, S.R. (1990). Colonization of strawberry roots by VA mycorrhizal fungi in agroecosystems under conventional and transitional organic management. *Biological Agriculture & Horticulture*, **7**, 139–151.

Witter, E., Mårtensson, A.M. & Garcia, F.V. (1993). Size of the soil microbial biomass in a long-term field experiment as affected by different N-fertilizers and organic amendments. *Soil Biology and Biochemistry*, **25**, 659–669.

Workneh, F. & van Bruggen, A.H.C. (1994a). Microbial density, composition, and diversity in organically and conventionally managed rhizosphere soil in relation to suppression of corky root of tomatoes. *Applied Soil Ecology*, **1**, 219–230.

Workneh, F. & van Bruggen, A.H.C. (1994b). Suppression of corky root of tomatoes in soils from organic farms associated with soil microbial activity and nitrogen status of soil and tomato tissue. *Phytopathology*, **84**, 688–694.

Wynen, E. (1992). *Conversion to Organic Agriculture in Australia: Problems and Possibilities in the Cereal-Livestock Industry*. The National Association for Sustainable Agriculture Australia Ltd; Sydney.