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Adding Value to Organic Pasture

Microbes and minerals

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Microbes and minerals

by J Carson, A Harley, LK Abbott and D Gleeson

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Researcher Contact Details

Lyn Abbott
Winthrop Professor
School of Earth and Environment
The University of Western Australia
Crawley WA 6009

Email: lynette.abbott@uwa.edu.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

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Foreword

The increasing interest in organic production systems within Australia requires research to investigate the effectiveness of certified organic practices, especially during the conversion phase prior to certification. Relatively few studies of organic agricultural systems have been conducted in Western Australia. Fertilisers made from ground rocks and minerals have been proposed as inputs into organic agriculture, but there has been relatively little research into their capacity to supply nutrients, especially under field conditions. This project sought to quantify potential benefits of two kinds of ground rock fertilisers, rock phosphate and ground silicate rocks and minerals, as phosphorus and potassium fertilisers for organic beef pasture and to investigate interactions between ground rock fertilisers and soil microorganisms.

Organic beef producers and researchers interested in nutrient cycling processes and farm nutrient budgets, especially during the conversion phase to organic certification, will benefit from the research.

Realistic applications of ground rock fertilisers were found to be sufficient to supply pasture with phosphorus and potassium during the conversion phase to organic production. The ground rock fertilisers did not have significant effects on the components of soil biological fertility which were assessed, but they did change the structure of the microbial community in the soil, by altering the relative abundance of organisms present in localised soil micro-sites. In economic terms, there was no detectable difference in pasture production between treatments with the organic and conventional soil amendments. Any difference in production costs between the treatments would have been directly related to the actual costs of the fertiliser inputs.

Addition of ground rocks introduces a new niche within the soil that can support a microbial community with different characteristics to that which is present in the rest of the soil. While there was little evidence that these changes had an effect on soil fertility in the short-term, the observed changes may contribute to the establishment of microbial communities which can release nutrients from recalcitrant sources over longer periods of time.

This project was funded from RIRDC core funds, which are provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our Organics R&D program, which aims to deliver R&D to facilitate the organic industry's capacity to meet rapidly increasing demand, domestically and globally.

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Craig Burns
Managing Director
Rural Industries Research and Development Corporation

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Abbreviations

AM	arbuscular mycorrhizal
ANOVA	analysis of variance
AQIS	Australian Quarantine Inspection Service
ARISA PCR	Automated Ribosomal Intergenic Spacer Analysis Polymerase Chain Reaction
Ca	Calcium
DAFWA	Department of Agriculture and Food Western Australia
K	Potassium
MDS	multidimensional scaling
Mg	Magnesium
N	Nitrogen
NASAA	National Association of Sustainable Agriculture Australia
P	Phosphorus
PCO	Principal Co-ordinate
PERMANOVA	permutational multivariate analysis of variance
RISA	Ribosomal Intergenic Spacer Analysis

Contents

Tables

Figures

Executive Summary

What the report is about

There is increasing interest in organic agricultural production systems in Australia although relatively little research is available to develop a clear understanding of the effectiveness of the practices used. This study investigated an aspect of organic farming practice related to the supply of nutrients for beef production through management of nutrients using ground rock fertilisers.

Who is the report targeted at?

This report is targeted at growers and researchers who are interested in the nutrient cycling processes and farm nutrient budgets that underpin organic management systems, especially during the conversion phase to organic certification.

Background

This project investigated the impacts of a suite of certified organic nutrients applied to pasture used for beef grazing during the conversion phase to a certified organic system. It also investigated interactions between soil microorganisms and ground rock fertilisers in pasture soil to determine the potential mechanisms for release of nutrients from rock surfaces in the soil environment. Experiments were conducted in both the field (application of organic fertilisers) and laboratory (interactions between rock fertilisers and microorganisms). The research sought to promote greater understanding of organic fertiliser treatments and the effects these have on soil chemical, physical and biological processes, and to determine potential economic impacts of organic rock fertilisers during the conversion phase of certified organic pasture systems.

Aims/objectives

The aims were to

1. determine whether application rates of ground rock fertilisers could maintain levels of phosphorus and potassium in soil and pasture plants during the conversion phase, and

2. investigate interactions between soil microorganisms and ground rock fertilisers in pasture soils. A key aspect of the research was the use of realistic application rates of ground rock fertilisers under field conditions to investigate the effects on soil and pasture.

Methods used

The research consisted of both field and glasshouse studies that addressed practical aspects of the nutrition of pasture species during the conversion to certified organic pasture production. In order to investigate the effectiveness of use of ground rock fertilisers during the conversion phase to organic beef production, a farm at the beginning of the conversion phase was selected within a suitable climatic zone and with a suitable soil type for pasture production (near Harvey, south-western Western Australia). This site and the rock fertilisers used were the basis of each experiment. Treatments varied between the experiments included duration, application rate of ground rock fertilisers and grain size of the ground rocks used to investigate interactions with soil microorganisms.

Results/key findings

The key findings were:

1. Realistic applications of ground rock fertilisers were sufficient to supply pasture with phosphorus and potassium during the conversion phase to organic production under field conditions.

2. Realistic application rates of ground rock fertilisers did not increase the biomass of microorganisms in soil, but they did change some microbial activities (e.g. enzyme activity) under field conditions.

3. Higher pasture uptake of potassium from ground mica fertiliser when it was co-applied with rock phosphate indicates that the effectiveness of ground rocks as potassium fertilisers may be increased by co-applying rock phosphate. In addition, the pasture uptake of phosphorus was higher when ground mica was applied.

4. Ground rock fertilisers altered the composition and relative abundance of soil microorganisms in association with their surfaces compared with those in the bulk soil.

5. In economic terms, there was no detectable difference in pasture production between treatments with the organic and conventional soil amendments. Any difference in production costs between the treatments would have been directly related to the actual costs of the fertiliser inputs.

Implications for relevant stakeholders

At the industry level, this study contributes to understanding processes involved during the conversion to certified organic production. It identified a potential role of ground rock fertilisers in altering the physical habitat in soil for microorganisms. Much of the beef production in the south-west of Western Australia occurs on sandy soils, which contain relatively few of the small pores in which soil microorganisms and organic matter are protected. Overall, microbial activity in these soils is lower than soils that are less sandy. This may create problems in organic systems that rely more heavily on soil microorganisms to make nutrients available to plants than do conventional systems. Adding finely ground rock fertilisers to sandy soils, may increase the number of small pores in the soil, increasing the microbial activity. Further work to examine this possibility may show that a single large addition of ground rock fertilisers to a pasture soil may increase the activity of soil microorganisms over more than one season.

An implication of this research for policy makers is that there is a need to match organic certification criteria to suit a range of field conditions which depend on environmental conditions and soil types.

Recommendations

1. Further research is recommended to evaluate longer-term impacts of high levels of soil biological activity on the supply of nutrients from ground rock fertilisers.

2. It is necessary to understand the relationships between nutrient supply from certified organic inputs and soil biological processes in different soil types and environments.

3. An evaluation of the effectiveness of mineral rock fertilisers in soils with different levels of soil biological fertility (arising from different management histories) should be made to enable greater understanding of the biological processes that optimise nutrient supply in all types of farming systems.

Introduction

Organic Farming in Australia

The development of sustainable agricultural practices has become a central goal of agricultural research in Australia. Sustainable practices can be defined as those which fulfil the requirement to enhance or maintain (i) the economic viability of agricultural production, (ii) the natural resource base, and (iii) other ecosystems which are influenced by agricultural activities (Australian Agricultural Council 1991). The sustainability of some current practices has been questioned because of their negative effects on the resource base and other ecosystems and due to their heavy dependence on high inputs of agrochemicals for economic viability (Dumaresq and Derrick 1990; Penfold 1990, Roberts 1995). The Australian Agricultural Council (1991) identified several areas where further progress was required to achieve agricultural sustainability, including land degradation, water use and quality and chemical use in agriculture. These areas have continued to be of significance within the Australian landscape.

Organic farming has attracted interest in Australia because of its potential to be economically and environmentally sustainable. Potential benefits of moving to 'chemical-free' systems have been explained in terms of external and private costs (Wynen and Edwards 1990) and these become even more relevant with increasing fertiliser costs associated with demands for biofuel and other non-food agricultural production systems. In 2000, the domestic sale of Australian organic products was estimated at worth $A200-250 million and annual growth in the sector was 20-30%. In 1995, the average premium for organic products was approximately 35% (McCoy and Parlevliet 2000). The Clean Agriculture Project identified a number of agricultural products that had potential to increase Australia's share in valuable export markets for organic produce including fruit, vegetables, wheat, wine and beef (McCoy and Parlevliet 2000). Organic farming has also attracted interest because of its potential to improve environmental sustainability. Although not extensive, Australian research has shown that organic farming can have positive effects on soil properties that reflect fertility and on surrounding ecosystems (Lytton-Hitchins et al. 1994; Conacher and Conacher 1995; Dumaresq and Greene 2001).

Challenges for Organic Farming in Australia

Despite discussion about the potential economic strengths and environmental sustainability of organic farming systems, there is limited published information, and hence uncertainty, about the effectiveness of fertilisers approved for certified organic farming systems in Australia. Farmers who consider adopting certified organic management practices can be faced with a lack of information about practices appropriate to Australian conditions across climatic zones and soil types. This lack of knowledge is particularly obvious in the key areas of (i) the phase of conversion to organic certification and (ii) fertiliser strategies appropriate for organic production. Lack of information can cause hesitation among farmers contemplating the transition to certified organic practices.

Another key challenge to organic farming in Australia is the acquisition of fertilisers acceptable within certified organic standards which have the capacity to maintain adequate plant nutrition. This is a particular problem for phosphorus nutrition because Australian soils are generally inherently low in phosphorus and dependent on external inputs. Several Australian studies have reported that phosphorus availability limits production on organic livestock-crop farms (Dann et al. 1996; Deria et al. 2003; Derrick and Dumaresq 1999; Ryan and Ash 1999). Deria et al. (2003) noted that several organic grain-livestock farms in their study did not use fertilisers and that those that did used only small amounts of poultry manure (40 kg ha^{-1}). Published nutrient budgets comparing organic and conventional farms in Europe, have focussed on nitrogen (N), phosphorus (P) and potassium (K), and indicate that it is possible to balance nutrient budgets in organic farming systems (Fortune et al. 2001; Watson et al. 2002). However, these systems rely heavily on nutrient inputs from animal manures which is not practical in most Australia farming systems. Therefore, alternative fertilisers and nutrient management strategies are required for Australian conditions.

The importance of supplying adequate nutrients cannot be understated because if organic farming exploits soil reserves, it has the potential to be unsustainable (Derrick and Dumaresq 1999; Gosling and Shepherd 2005; Kirchmann and Ryan 2004). For organic farming to be environmentally sustainable, the nutrients removed in harvested products must be balanced by nutrient inputs from fertilisers. In some cases, nutrients ‘mined’ in organic farming systems were previously added as fertiliser when the land was farmed using conventional practices. Indeed, it has been suggested that a way to maintain adequate phosphorus under organic farming practices in Australia is to purchase and farm land that has a long history of phosphate fertilisation and high levels of ‘stored’ soil phosphorus (Penfold 2000). Further research is required to investigate the availability of appropriate nutrient sources, especially for soils with inherently low chemical fertility.

For organic beef production in Australia to continue to develop, further research is needed to address the two key weaknesses of organic farming knowledge in Australia: the conversion phase and the options for maintaining pasture nutrition. Organic beef was one of five agricultural products identified by the Clean Agriculture Project as having potential for conversion to organic production methods. In recognition of the lack of information about organic production methods under Australian conditions and more farmers producing and exporting organic beef, a production guideline for organic beef was written (McCoy and Parlevliet 2001). The guideline introduces farmers to organic methods of beef production. However, information about management practices during the conversion stage to certified organic production is still limited. The supply of adequate nutrients is also an area of concern for organic beef production.

Ground Rock Fertilisers

Fertilisers made from ground rocks and minerals have been proposed as an input for organic agriculture, especially in pastures where the root morphology of perennials and lower external requirements provide a greater opportunity to access these slow release sources. Microorganisms are currently being trialled *ad hoc* to release nutrients from both the rocks and minerals themselves and from existing pools of nutrients, especially P. Improvement of soil health and microbial activity have also been observed. The conversion to organic beef production is gaining momentum due to the relative ease of conversion to organic operations and expansion of both domestic and export markets. Improvement of feed, especially prior to slaughter, is required and finding adequate sources of phosphorus, especially during the conversion phase, is a potential limitation in expanding organic beef production.

Ground rocks may be an important source of nutrients for broadacre farmers in Australia using organic production methods. Nutrient inputs permitted in certified organic farming systems, and in some cases the amount that may be applied, are restricted by organic certification standards. The nutrient sources permitted in organic farming systems can be loosely divided into organic materials and naturally occurring rocks and minerals. Organic materials are usually not an important source of nutrients for broadacre organic production in Australia because manure is generally unavailable (Condron et al. 2000) and relatively low amounts of organic matter are returned to the soil from crops and pastures. This means that in Australia, broadacre production, including beef production, relies more heavily on rocks and minerals with significant nutrient contents than in other climates. Ground rock fertilisers permitted under organic farming certification include rock phosphate, silicate rocks and minerals such as basalt and mica, lime, gypsum, guano, elemental sulphur and dolomite. Complete lists of nutrient sources permitted in organic farming systems can be found in the various organic certification standards. Silicate minerals and rocks composed of silicate minerals are used in organic farming as both nutrient sources and soil ameliorants. Silicate minerals are the main components of igneous and many metamorphic rocks and vary in their composition and dissolution rates.

Research on plant uptake of nutrients from ground silicate rocks has focused on release of K and several researchers have concluded that ground silicate rocks have potential as slow release fertilisers (Coroneos et al. 1996; Gillman 1980; Hildebrand and Schack-Kirchner 2000; Hinsinger et al. 1996). However, their effectiveness varies greatly and ground silicate rocks high in silica (e.g. feldspar and granite) may be only poor sources of K (Bakken et al. 1997; Bakken et al. 2000; Blum et al. 1989). Incubation experiments and field and pot trials have shown that between 1 and 10 % of the K in feldspar is released up to 14 months after application (Coroneos et al. 1996; Hinsinger et al. 1996; Sans Scovino and Rowell 1988) and granite was only 14 % as effective as a potassium fertiliser compared to potassium chloride (Barrow 1985; Bolland and Baker 2000).

Fertilisers made from ground silicate rocks may also provide plants with calcium, magnesium and some micronutrients. Ground rocks such as amphibolite, basalt, diabase, dunite, gneiss, granite, phenolite, serpentine, syenite and a volcanic ash have been investigated as sources of calcium and magnesium for plants (Blum et al. 1989; Chittendon et al. 1964; Chittendon et al. 1967; Gillman 1980; Gillman et al. 2001; von Fragstein et al. 1988). Experiments on seven highly weathered, tropical soils in Queensland showed that exchangeable potassium, calcium and magnesium were increased when basalt was applied at application rates between 1 and 50 tonnes ha^{-1} (Gillman et al. 2001). For five of these soils, 5 tonnes basalt ha^{-1} increased exchangeable cations but on one soil, exchangeable magnesium was increased by as little as 1 tonne basalt ha^{-1}.

Ground silicate rocks have also been advocated as soil amendments (Harley and Gilkes 2000; Hildebrand and Schack-Kirchner 2000) especially for lateritic soils in tropical climates (Gillman et al. 2001; Leonardos et al. 1987; Leonardos et al. 2000). They may increase soil pH, although not as effectively as lime (Gillman 1980; Hildebrand and Schack-Kirchner 2000; Hinsinger et al. 1996; von Mersi et al. 1992). Ground silicate rocks have also been shown to increase cation exchange capacity. Gillman et al. (2001) found that after nine months, granite applied to a highly weathered soil at 300 t ha^{-1} increased the soil cation exchange capacity from 9 to 14 meq/100 g soil. Ground silicate rocks and minerals may also increase water-holding capacity (Kahnt et al. 1986). Highly weathered soils in tropical climates have most to gain from use of silicate minerals as soil ameliorants.

Nutrient release from ground silicate rocks depends on their dissolution in soil which is influenced by rock properties, soil properties and climatic conditions. Dissolution of silicate rocks is improved by small grain size (Gillman 1980; Gillman et al. 2001, 2002; Niwas and Dissanayake 1987). Dissolution is greater in soils with low pH, high moisture and temperature and soil solutions that are not in equilibrium with mineral surfaces (Harley and Gilkes 2000). Thus, the dissolution of ground silicate rocks and their effectiveness as fertilisers is different in every soil. When the dissolution of ground granite in 20 acid soils from Western Australia was measured, few soils showed an increase in exchangeable calcium or magnesium and nine soils showed an increase in exchangeable K (Hinsinger et al. 1996). Highly weathered, tropical soils are most suited to the use of ground silicate rocks because they are acidic and nutrient deficient and the heavy rainfall events increase dissolution. Leaching soils, especially sands, are also suited to the use of ground rock fertilisers (Coroneos et al. 1996; Harley and Gilkes 2000; Hinsinger et al. 1996; Leonardos et al. 1987). However, even in suitable soil types, ground rock fertilisers are less effective than the soluble fertilisers used in conventional agriculture.

The relative effectiveness of rock phosphate also varies greatly depending on soil and mineral factors. It has been shown to be affected by rock phosphate properties (reactivity, particle size, surface area), soil factors (pH, titratable acidity, phosphorus and calcium availability and retention, sand content, organic matter content, moisture, temperature) and plant factors (phosphorus and calcium demand, root structure, rhizosphere pH) (Hinsinger and Gilkes 1997; Hughes and Gilkes 1994; Kanobo and Gilkes 1987; Kanobo and Gilkes 1988; Khasawneh and Doll 1978). Variations in these factors can result in a rock phosphate being either as effective as superphosphate or almost inert (Khasawneh and Doll 1978) and it can be difficult to predict relative effectiveness. For example, differences in the reactivity of 14 rock phosphates reactivity caused a ten-fold difference in dry matter yield between the least and most reactive sources (Léon et al. 1986).

Options for increasing the effectiveness of ground rock fertilisers include (i) making the nutrients in ground rock fertilisers more available to plants, (ii) plant selection (Van Bueren 2002), and (iii) interactions with soil microorganisms (Richardson 2001). These procedures have been summarised by Davis and Abbott (2006). One method of making the nutrients in ground rock fertilisers more available to plants is high-energy milling. This procedure is permitted under organic certification and can increase the solubility of ground silicate rocks and rock phosphate by changing their mineral structure and bonding (Lim et al. 2003; Priyono and Gilkes 2004). Another method of increasing the availability of the nutrients in ground rock fertilisers involves using combinations of rock phosphates and silicate minerals with compost to increase the relative effectiveness of some relatively insoluble elements (Garcia-Gomez et al. 2002). Plant selection can increase the effectiveness of ground rock fertilisers because plants can increase their dissolution. Nutrient uptake by plants prevents equilibrium between minerals and soil solution from being reached, stimulating further dissolution (Harley and Gilkes 2000; Hinsinger 1998; Wang et al. 2000). Also, plants release organic ligands which attack mineral surfaces and form complexes and lower soil pH by releasing H+ ions and organic acids into the soil. Plant species and varieties vary in their ability to increase rock dissolution and careful plant selection may enhance mineral dissolution (Wang et al. 2000). The role of microbial interactions in increasing the dissolution of ground rock fertilisers is discussed in the next section.

Interactions with Soil Microorganisms

Soil microorganisms are a key component of any healthy soil system and have special significance in organic farming. Microbial communities in soil are extremely diverse and perform key functions, including cycling of carbon and nutrients, maintaining soil productivity and water quality, dissolution of minerals, decomposing contaminants and controlling atmospheric composition and climate. Chemical fertility and sustainability of organic farming may rely more on soil biological fertility than in conventional farming systems (IFOAM 2002; Le Guillou and Scharpé 2000). Microorganisms can mediate or improve the processes governing nutrient release from the relatively insoluble nutrient inputs permitted in organic farming systems (IFOAM 2002; Lampkin 1990; Stockdale et al. 2001). Researchers have speculated about the proposition that organic farming alters the function of the soil microbial community, increasing its ability to release nutrients from organic and poorly soluble sources thereby compensating for the absence of soluble nutrient inputs (AQIS 1998; Oberson et al. 1993; Penfold et al. 1995; Ryan 1999).

There is potential to increase the effectiveness of poorly soluble rock fertilisers by managing soil biological processes. Microorganisms can increase the dissolution of ground rock fertilisers by releasing organic ligands, H^+ ions and organic acids into the soil (Barker et al. 1997; Hinsinger et al. 2001; Richardson 2001). In nutrient limiting soils, microorganisms may preferentially colonise and dissolve ground rock fertilisers if they contain nutrients limiting their growth. Rogers and Bennet (2004) showed that in a phosphorus-limiting environment, microorganisms selectively colonised the surface of minerals containing P. The plant availability of rock phosphate can be improved by activities of arbuscular mycorrhizal (AM) fungi (Barrow et al. 1977; Pairunan et al. 1980). Plant breeding in sub-optimal nutrient conditions may produce varieties with greater capacity form associations with more beneficial AM fungi (Hinsinger et al. 2001; Marschner and Rengel 2003; Ryan and Graham 2002). The ability of these processes to increase nutrient availability to plants might be maximised if specific practices, inputs or plant varieties can be found to target and increase the populations of the soil organisms involved.

Considerable commercial attention is being given to the development of microbial products that stimulate release of nutrients and benefit plant growth in organic farming systems (Welbaum et al.

2004). Many forms of organic (plant, animal and microbial) nutrient sources are permitted by organic certification standards, but most have not been scientifically investigated under field conditions and effects may be site specific. Further research is required to validate the capacity of allowable materials to enhance soil fertility in the long-term. Studies could include materials used singly or in combination, and in association with various management practices, especially organic matter management. Claimed effects of specific nutrient sources or microbial stimulants remain anecdotal without well-replicated scientific studies.

Studies examining the effect of ground rock additions to soil have largely ignoring effects on soil microorganisms. They have instead centred on the potential of ground rocks as slow release fertilisers for pastures and focused on their effect on soils and plant growth (Hughes and Gilkes 1994; Hinsinger et al. 1996; Bolland et al. 2001; Priyono and Gilkes 2004). Ground rock additions to soil are likely to affect microbial communities, both through the indirect effects on physicochemical conditions in soil (Hinsinger et al. 1996; Gillman et al. 2002; Longanathan et al. 2002; Priyono and Gilkes 2004) and increased plant growth (Sanz Scovino and Rowell 1988; Bolland et al. 1995; Coroneos et al. 1996; Bakken et al. 2000).

Ground rock fertilisers may directly affect soil microorganisms through their nutrient composition (Certini et al. 2004; Rogers and Bennett 2004; Gleeson et al. 2005; Gleeson et al. 2006). Studies have shown that microorganisms colonising mineral surfaces in other environments, (such as ground water aquifers) were influenced by mineral chemistry (Thorseth et al. 1995; Ullman et al. 1996; Barker et al. 1998; Welch et al. 1999). Recent studies using molecular fingerprinting techniques related specific bacterial and fungal ribotypes (or species) to the presence of particular chemical elements in the minerals that microorganisms were colonising (Gleeson et al. 2005; Gleeson et al. 2006). In soil most microorganisms live attached to mineral or organic matter surfaces and are therefore likely to be influenced by mineral chemistry (Hazen et al. 1991; Holm et al. 1992; Banfield et al. 1999). However, none of the studies to date have been performed in a soil environment and questions remain regarding the effect of mineral composition on soil microorganisms. Certini and colleagues do report a different microbial community structure in rock fragments compared to the surrounding soil (Certini et al. 2004). In nutrient poor soils (like many soils in Western Australia), minerals containing limiting nutrients may exert an even greater influence on microbial community structure by providing substrates for microbial growth.

Broad Project Aims

This project investigated the impacts of a suite of certified organic nutrients applied to organic pasture used for beef grazing during the conversion phase to a certified organic system. It also investigated interactions between soil microorganisms and ground rock fertilisers in pasture soil to determine the potential mechanisms for release of nutrients from rock surfaces in the soil environment. Experiments were conducted in both the field (application of organic fertilisers) and laboratory (interactions between rock fertilisers and microorganisms). The research sought to promote greater understanding of organic fertiliser treatments and the effects these have on soil chemical, physical and biological processes, and to determine potential economic impacts of organic rock fertilisers during the conversion phase of certified organic pasture systems.

The research specifically investigated (i) application rates of ground rock fertilisers to maintain levels of phosphorus and potassium in soil and pasture plants during the conversion phase, and (ii) interactions between soil microorganisms and ground rock fertilisers in pasture soils. A key aspect of the research was the use of *realistic application rates* of ground rock fertilisers applied under *field conditions* to investigate the effects on soil and pasture.

Specific Research Questions

A number of experiments were conducted based on questions associated with use of ground rock fertilisers and their interactions within the soil environment. Experiments in the field were complemented by experiments conducted under controlled glasshouse conditions. The specific research questions addressed in this research and their origins are explained below.

In-Conversion Phase Experiment

(1) Do realistic application rates of ground rock fertilisers maintain levels of phosphorus and potassium in soil and pasture during the conversion phase?

The impact of application of realistic rates of ground rock fertilisers in terms of their contributions to phosphorus and potassium has not been determined for Australian beef production. This information is relevant to farmers who are considering a transition to certified organic methods of beef farming. If ground fertilisers are not able to maintain levels of phosphorus and potassium in soil and pasture plants under Australian conditions, the sustainability of the system would be in question. To address this issue, a three-year field experiment was performed in south-western Western Australia.

(2) Does the use of ground rock fertilisers alter soil pH?

Increasing the pH of acidic soils improves productivity but also reduces the dissolution of ground rock fertilisers. If the ground rock fertilisers increase soil pH significantly, this issue will need further attention. This may become an important issue for organic farming in Australia. This was addressed in the three-year field experiment.

(3) Do ground rock fertilisers increase the biomass or activity of microorganisms in pasture soils?

The role of soil microorganisms is potentially very important in organic farming. Therefore, it is important to know what effect fertilisers used in organic farming have on soil microorganisms. Increased microbial biomass or increased activity of soil microorganisms might increase the rate of important beneficial processes mediated by soil microorganisms such as nutrient release from organic matter and improvement of soil structure. The three-year field experiment was also used to investigate this question.

Co-Application Experiment

(4) Does the application of rock phosphate increase plant uptake of potassium from silicate minerals?

If rock phosphate increases plant uptake of potassium from silicate minerals, there would be an increase in the incentive to apply rock phosphate. Many broadacre farmers apply no phosphate fertilisers in organic farming systems because of their low effectiveness and high cost. While the economic benefits for pasture production may not always be economically justified, the practice is unsustainable. The added benefit of increasing potassium uptake by plants may make it more economical to apply silicate minerals, increasing their use and the sustainability of organic production. To answer this research question, a second field experiment was conducted over a period of four months.

Microbial Community Experiment

(5) Do ground rock fertilisers alter the structure of the microbial community in pasture soils?

A change in soil microbial community structure would demonstrate an interaction between ground rock fertilisers and soil microorganisms. Such an interaction may eventually prove useful for maximising the role of soil microorganisms in stimulating nutrient release from ground rock fertilisers or for other beneficial soil processes. To answer this question, a glasshouse experiment was performed.

Rock Surface Experiment

(6) Are there differences between the community structure of the microorganisms on grains of ground rock fertilisers and the community structure of microorganisms in the rest of the soil?

A difference in soil microbial community structure on the surfaces of grains of ground rock fertilisers and in the rest of the soil would demonstrate that soil microorganisms are affected by the chemical composition of the ground rock fertilisers. This opens the possibility that microorganisms are involved in dissolution of the ground rock fertilisers, releasing nutrients into the soil for use of plants and/or soil microorganisms. Further research may enable the harnessing of microbial dissolution of ground rock minerals. This research question was answered by a second glasshouse experiment.

Methodology

To investigate the use of ground rock fertilisers during the conversion phase to organic beef production, a farm at the beginning of the conversion phase was selected within a suitable climatic zone and with a soil type suitable for pasture production and the dissolution of rock fertilisers (near Harvey, south-western Western Australia). This site and the rock fertilisers used were the basis of each experiment. Treatments varied between the experiments included duration, application rate of ground rock fertilisers and grain size of the ground rocks. The variables are discussed below in the Experimental Design for each of the four experiments.

General Methods

Site and Management History

The field experiment was conducted at Cookernup (latitude 32˚60’, longitude 115˚50), 130 km south of Perth and 10 km north of Harvey, Western Australia. The climate is Mediterranean, with warm, dry December to March and cool, wet April to November. The average annual rainfall at Yarloop (5 km north of Cookernup) is 983 mm, with 84% falling in the May to October growing season. The site was cleared in 1957 and used as dairy pasture until 1988 and beef pasture until the present. The dominant pasture species was Italian ryegrass (*Lolium multiflorum*) with some annual ryegrass (*Lolium rigidum* cv Wimmera) and lotus minor (*Lotus subbiflorus*).

Since 1998, 3:2 superphosphate/muriate of potash (5.5 % P, 19.5 % K) was applied every year at the rate of 120 kg ha^{-1}. Nitrogen was applied twice in that time at the rate of 6 kg ha^{-1} [NPK Blue Special 12 % N]. Lime was applied to the pasture in 2003 at 1 t ha^{-1} and dolomite in 2004 at 0.5 t ha^{-1}. The last time conventional fertilisers were used was during autumn 2003.

Soil

The soil is classified as a semi-aquic podosol (Isbell 2002) and a Haplic Podzol (FAO 1998) and the 0-10 cm layer (<2 mm) had 99.8% sand, 3.5% organic carbon, and a pH of 4.7 (1:5 soil/water). The parent material is windblown, siliceous marine sand (McArthur 2004) and the soil contains few minerals other than silica (SiO_2). The elemental composition of the soil before rock fertilisers were added was determined by x-ray fluorescence (Philips PW1404 XRF) (**Table 1**). As a result, the soil has a low capacity to retain cations (6.4 cmol kg^{-1} soil) and is naturally deficient in nutrients, especially phosphorus.

Ground Rock Fertilisers

The following ground rocks and minerals were used in this experiment: mica, basalt and rock phosphate. The mineral composition of each ground rock was determined by x-ray diffraction (PW 1830, Philips) (Carson et al. 2007). The elemental composition of each rock fertiliser was determined using x-ray fluorescence (PW 1404, Philips)`. Before use in the experiments, the ground rocks were prepared by sieving to <250 µm.

Scale of Experiments

The In-Conversion Phase Experiment was conducted in the field. In this experiment the two broad aims of the project were addressed under conditions which were as close to realistic farm practice as possible. Realistic application rates of a commercially available ground rock fertiliser were used and the experiment was maintained for the three years required for a farm to convert to certified organic production. However, the practical nature of this experiment also had disadvantages, which are discussed in more detail later. The limitations inherent in all field-based experiments made it particularly important that in this project they be complemented by glasshouse experiments. The Co-Application Experiment (Experiment 2) was also conducted under field conditions. However, the plots were significantly smaller than those used in the In-Conversion Phase Experiment. This reduced the variation in soil and pasture properties between plots and made it easier to detect differences due to the rock fertiliser treatments. The experimental designs for the four experiments are summarised in **Table 1**.

Table 1 Summary of experimental designs for the four experiments.

1. In-Conversion Phase Experiment	This field experiment was a randomised complete block with three treatments: two application rates of a composite ground rock fertiliser permitted under NASAA's organic certification program (300 and 600 kg ha-1 yr-1) and one conventional application rate of soluble fertilisers (100 kg ha-1 yr-1). Plots measured 16 m x 24 m. In Year 1 there were five replicates per treatment (a total of 15 plots). In Years 2 and 3, the number of replicates was reduced to three (a total of nine plots).
2. Co-Application Experiment	This field experiment was a randomised complete block with two factors: ground mica (two levels, 0 and 10 t ha-1) and ground rock phosphate (three levels, 0, 5 and 50 kg P ha-1 yr-1) with six replicates, randomised in 6 blocks. The two ground mica treatments were 0 and 10 t ha-1. Each plot measured 3 m x 3 m and there were a total of 36 plots.
3. Microbial Community Experiment	This glasshouse pot experiment had two factors: rock fertiliser (five levels) and plant (three levels), with four replicates. Rock fertiliser treatments consisted of a control with no rock fertiliser addition, additions of either mica, basalt or rock phosphate separately, and a final treatment containing all rock fertilisers. Pots were planted with annual ryegrass (Lolium rigidum cv. Concord), subterranean clover (Trifolium subterraneum cv. Trikkala), or remained unplanted.
4. Surface Experiment	This glasshouse pot experiment had two factors: rock fertiliser (five levels) and plant (three levels), with four replicates. Rock fertiliser treatments consisted of a control with no rock fertiliser addition, additions of either mica, basalt or rock phosphate separately, and a final treatment containing all rock fertilisers. Rock fertilisers were 1-2 mm in size. Pots were planted with annual ryegrass (Lolium rigidum cv. Concord), subterranean clover (Trifolium subterraneum cv. Trikkala), or remained unplanted.

Experiments 3 and 4 were conducted in a glasshouse and provided a higher level of experimental control than was possible in the In-Conversion Phase Experiment conducted in the field. These experiments were used for more detailed investigations into the interactions between different ground rocks and soil microorganisms.

1. In-Conversion Phase Experiment

Research Questions

The experiment was designed to answer the research questions:

1. *Do realistic application rates of ground rock fertilisers maintain levels of phosphorus and potassium in soil and pasture during the conversion phase?*
2. *Does the use of ground rock fertilisers alter soil pH?*
3. *Do ground rock fertilisers increase the biomass or activity of microorganisms in pasture soils?*

Experimental Design

The field trial was a randomised complete block experiment. There were three treatments, each with five replicates, randomised in five blocks. The three treatments were: two application rates of a ground rock fertiliser permitted under NASAA's organic certification program and one application regime of soluble fertilisers. Each plot measured 16 m x 24 m and there were a total of 15 plots. After the first year of the experiment the number of replicates of each treatment was reduced from five to three due to unavoidable circumstances.

The ground rock fertiliser (Eco Prime-Natural) contained a mixture of rock phosphate, K_2SO_4, lignite, gypsum, lime and silicate minerals that had been ground and prilled. The ground rock fertiliser contained 6.6% P and 23.4% K. The conventional fertiliser was 3:2 superphosphate/muriate of potash (5.5% P and 19.5 % K) applied at 100 kg ha^{-1} yr^{-1}. Commencing in June 2004 the fertilisers were applied in autumn and spring each year at the rates shown in **Table 2**. Both fertilisers were applied using a multi-spreader and left on the soil surface. Cattle were not excluded from the trial area except for 2-3 months over winter. Initially, it was planned to include treatments with a commercial microbial inoculum in addition to the composite rock fertiliser, but due to the scale of the experiment in the field, it was not practical to include the number of treatments that this would have required, therefore emphasis was given to the composite rock fertiliser in the first instance.

Table 2 **Time and rate of phosphorus (P) and potassium (K) applied (kg ha^{-1}) to the three treatments of the In-Conversion Phase Experiment.**

Time	Treatment					
	Organic 300kg ha^{-1} y^{-1}		Organic 600kg ha^{-1} y^{-1}		Conventional	
	P	K	P	K	P	K
Jun 2004	8.7	9.0	17.4	18.0	2.8	9.8
Aug 2004	4.4	4.5	8.7	9.0	2.8	9.8
Apr 2005	8.7	9.0	17.4	18.0	2.8	9.8
Sep 2005	8.7	9.0	17.4	18.0	2.8	9.8
Apr 2006	8.7	9.0	17.4	18.0	2.8	9.8
Sep 2006	4.4	4.5	8.7	9.0	2.8	9.8

Scale of Experiment

The In-Conversion Phase Experiment addressed the two broad aims of the project under conditions as close to realistic as was possible. Realistic application rates of a commercially available ground rock fertiliser were used and the fertiliser was surface applied to large plots using normal farm machinery. The application rates chosen were i) the rate recommended by the manufacturer of the composite rock fertiliser and ii) twice the manufacturer's recommendation. The experiment was maintained for the three years required for a farm to convert to certified organic production. However, the realism of this experiment also had disadvantages. The realistic application rates, surface application, variable climate, soil and pasture conditions and relatively short time scale make it more difficult to observe statistically significant changes in soil, plant and microbial properties. In addition, unavoidable circumstances at the beginning of Year 2 reduced our replication in this experiment increasing the difficulty of detecting statistically significant differences between the fertiliser treatments.

Measurements

Pasture phosphorus and potassium content and pasture production

To measure pasture production, plant material 5 cm above ground level was sampled from six 0.1 m^2 areas in each plot at the end of Year 1. In Year 2 and Year 3 it was not possible to measure pasture production because plots were grazed. Pasture samples were collected at the end of Year 2 and Year 3 of the experiment to measure P, K, Mg and Ca content. After collection, pasture samples were dried at 70°C for 4 days before nutrient analysis.

Soil Colwell phosphorus and potassium

Soil Colwell P and K were determined by extracting 0.5 g soil in 50 ml 0.5 M Na_2CO_3 (pH 8.5) for 16 hours at 25°C (Colwell 1963; Rayment and Higginson 1992). Inorganic P in the extract was determined colorimetrically using the ascorbic acid (molybdenum blue) method (Murphy and Riley 1962). Total K in the extract was determined by flame emission on an atomic absorption spectrometer (AAnalyst 300, Perkin Elmer).

Soil pH

Soil pH was measured in a 1:5 soil:water mixture after shaking 4 g soil in 20 ml DI (deionised) water for one hour (Rayment and Higginson 1992).

Microbial biomass carbon

Microbial biomass carbon (C) was measured using fumigation extraction (Brookes et al. 1985; Sparling and Zhu 1993). For each replicate, 20 g of soil was fumigated with chloroform for 7 days and extracted for 1 hour in 40 ml 0.5 M K_2SO_4. Total organic carbon in the extracts was measured using a total organic carbon analyser (TOC 5000A, Shimadzu) and microbial biomass C calculated according to the method of Joergensen (1996).

Acid phosphatase activity

Acid phosphatase activity of soil was determined by colorimetric estimation of the p-nitrophenol released by acid phosphatase after 1 g of soil was incubated with buffered (pH 6.5) sodium p-nitrophenol phosphate solution at 37°C for 1 hour (Tabatabai and Bremner 1969).

Cellulase activity

Cellulase activity was determined by colorimetric determination of reducing sugars released after 1 g of soil was incubated for 16 hours at 37°C (Hope and Burns 1987). For both enzyme assays, there were two replicates and two controls per plot.

Statistical analysis

Differences between fertiliser treatments and sampling times in the measured parameters were tested by two-way analysis of variance (ANOVA) and the least significant difference calculated for the 95% confidence interval using Genstat Version 8.2 (Rothamsted, UK).

2. Co-Application Experiment

Research Question

The experiment was designed to answer the research question:

(4) Does the application of rock phosphate increase plant uptake of potassium from silicate minerals?

This experiment was also relevant to Research Questions *(2)* and *(3)* concerning the effect of ground rock fertilisers on soil pH and microbial biomass and activity.

Experimental Design

The experiment was a randomised complete block experiment. The experimental design consisted of two factors: ground mica, a silicate mineral, (two levels, fixed) and ground rock phosphate (three levels, fixed) with six replicates, randomised in six blocks. The two ground mica treatments were 0 and 10 t ha^{-1}. The three ground rock phosphate treatments were 0, 5 and 50 kg P ha^{-1}. Each plot measured 3 m x 3 m and there were a total of 36 plots. The mineral and elemental composition of the mica and rock phosphate is given in **Table 1**. Ground rock fertilisers were applied to the surface of each plot. Soil samples were collected four months after they were applied. Pasture samples were collected four months after application of the ground rocks.

Scale of Experiment

The Co-Application Experiment used a large application rate of ground mica (10 t ha^{-1}) to ensure that pasture uptake of K was affected in the short time available for the experiment. The large application rate of ground mica made it necessary to have small plots to reduce the total amount of ground mica needed for the experiment. This made it impossible to use normal farm machinery. However, the small size of the plots had the advantage of reducing the variation in soil and pasture properties within the experiment area and within each plot.

Measurements

Pasture P and K content, soil Colwell P and K, and microbial biomass C were measured according to the methods described for the In-Conversion Phase Experiment.

Microbial respiration

Respiration was determined after pre-incubating 20 g soil for 7 days at 25°C and measuring the CO_2 content of 10 ml of headspace gas using an infra red gas analyser (Series 225, Analytical Development Company, Hoddesdon, England).

Statistical analysis

Differences between ground mica and rock phosphate treatments in the measured parameters were tested by two-way analysis of variance (ANOVA) and the least significant difference calculated for the 95% confidence interval using Genstat Version 8.2 (Rothamsted, UK).

3. Microbial Community Experiment

Research Question

The experiment was designed to answer the research question:

(5) Do ground rock fertilisers alter the structure of the microbial community in pasture soils?

This experiment was also relevant to Research Questions *(2)* and *(3)* concerning the effect of ground rock fertilisers on soil pH and microbial biomass and activity.

Experimental Design

The experimental design consisted of two factors: rock fertiliser (five levels, fixed) and plant (three levels, fixed), with four replicates. Rock fertiliser treatments consisted of a control with no rock fertiliser addition, additions of either mica, basalt or rock phosphate separately, and a final treatment containing all rock fertilisers. Pots were planted with annual ryegrass (*Lolium rigidum* cv. Concord), subterranean clover (*Trifolium subterraneum* cv. Trikkala) or remained unplanted.

Rock fertilisers were sieved to <250 µm and mixed with the soil at rates of 5 g kg $soil^{-1}$ (equivalent to 4 t ha^{-1}) for mica and basalt (Coroneos et al. 1996; Hinsinger et al. 1996; Bolland and Baker 2000) and at 1.7 g kg $soil^{-1}$ for rock phosphate (Bolland et al. 1995). The application of rock fertilisers to a soil largely composed of silica (**Table 1**) represents an alteration in the mineral composition of the soil, its nutrient content and the diversity of mineral substrates available for the soil microbial community. Microcosms had a high plant density to ensure all soil was influenced by plant roots and could therefore be considered rhizosphere.

Microcosms were prepared by weighing 80 g dry soil (sieved to <2 mm) into lined 105 ml round pots. Microcosms were incubated in a temperature controlled glasshouse (20°C day/15°C night) in a randomized block design from February to April 2005. Nutrients were added to permit adequate plant growth in the highly nutrient deficient soil. Nutrients contained in each rock fertiliser were omitted from microcosms containing that rock fertiliser (mica K, basalt Ca and Mg, rock phosphate P and Ca). Therefore, each mineral was a source of nutrients that were deficient in the soil. Microcosms were watered daily to field capacity (24% water content w/w, -10 kPa) with deionised water and destructively sampled on day 78.

Scale of Experiment

Conducting the Microbial Community Experiment under controlled conditions increased the opportunity to detect the effect of ground rock fertilisers on soil microorganisms. It can be difficult to observe the effects of treatments on microbial activity in experiments conducted under field conditions. Microbial activity in soil not only varies rapidly across time but also across space because soil is an extremely heterogeneous environment. In addition, because the ground rock fertilisers were applied to the field experiment at the recommended rate, which was relatively low, their distribution across each plot would have been patchy.

Several aspects of the experiment were included to maximise the ability of the experiment to detect effects of ground rock fertilises on soil microorganisms in only 11 weeks. The considerably higher application rate of 4 t ha^{-1} was a balance between being low enough to approximate what a farmer might add in a once-off application and high enough to affect soil properties and plant growth in only 11 weeks (Coroneos et al. 1996; Hinsinger et al. 1996; Bolland and Baker 2000). The fine grain size of the ground rock fertilisers and their incorporation in the soil in each pot maximised contact between ground rock grains and soil microorganisms, soil particles and plant roots.

Measurements

Soil pH, microbial biomass C, soil Colwell P and K and plant nutrient content (P, K, Mg and Ca) were measured as described for the In-Conversion Phase Experiment. Microbial respiration was measured as described for the Co-Application Experiment.

Dehydrogenase activity

Dehydrogenase activity was measured by estimating the rate of reduction of triphenyltetrazolium chloride in 0.4 g soil after a 24 hour incubation at 30°C (Thalman 1968; Alef 1995).

Community structure of soil microorganisms

Total soil DNA was extracted using the MoBio PowerSoil™ DNA isolation kit (Carlsbad, CA, USA) with the following modifications: 0.5 g soil was used; samples were homogenised using a Mini-BeadBeater-8 (Biospec Products Inc., Bartlesville, OK, USA) at 3200 rpm for 2 minutes.

Bacterial and fungal ARISA PCR was performed using the method of Gleeson et al. (2006) and Gleeson et al. (2005) using forward primers labelled with Beckman Coulter fluorescent dye D4 (Proligo). PCR products were mixed with 38.4 µl deionised formamide, 0.2 µl of Beckman Coulter size standard 600 and 0.4 µl of custom-made marker (Bioventures, Murfreesboro, TN, USA).

Analysis of intergenic spacer profiles was performed using a Beckman Coulter (CEQ8000) automated sequencer and Beckman Coulter CEQ 8000 fragment analysis software, algorithm v 2.1.3 (Gleeson et al. 2005). Shannon diversity index was calculated for bacterial and fungal communities from each replicate using Primer 6 (Primer-E Ltd, UK).

Plant biomass

Plant root and shoot material were removed, dried at 70°C, and weighed.

Statistical analyses

Differences between rock fertiliser and plant treatments in microbial, soil and plant measurements, number of ribotypes and Shannon diversity index were tested by two-way analysis of variance (ANOVA) and the least significant difference calculated for the 95% confidence interval using Genstat Version 8.2 (Rothamsted, UK).

The differences in the structure of the microbial community between rock fertiliser treatments were examined using multivariate statistical analyses (Primer 6, Primer-E Ltd, UK; PERMANOVA, Anderson 2001). Principal Co-ordinate (PCO) plots were created to visualise the differences in bacterial and fungal community structure in different rock fertiliser treatments. In the PCO plots, samples that are furthest apart have the communities with the greatest difference in their structure (composition and relative abundance).

4. Rock Surface Experiment

Research Question

The experiment was designed to answer the research question:

(6) Are there differences between the community structure of the microorganisms on grains of ground rock fertilisers and the community structure of microorganisms in the rest of the soil?

This experiment was also relevant to Research Question *(3)* concerning the effect of ground rock fertilisers on microbial biomass and activity.

Experimental Design

The experimental design consisted of two factors: rock fertiliser (five levels, fixed) and plant (three levels, fixed). There were four replicates of each treatment. Rock fertiliser treatments consisted of a control with no rock fertiliser addition, additions of either mica, basalt or rock phosphate separately, and a final treatment containing all rock fertilisers. Pots were planted with annual ryegrass (*Lolium rigidum* cv. Concord), subterranean clover (*Trifolium subterraneum* cv. Trikkala) or remained unplanted.

Microcosms were prepared by weighing 80 g dry soil (sieved to <2 mm) into lined 105 ml round pots. Rock fertilisers were 1-2 mm in size and mixed with the soil at rates of 100 g kg^{-1} for mica (M), basalt (B) and rock phosphate (P) (equivalent to 80 t ha^{-1}). Because the soil was largely composed of silica, the added rock surfaces represented a microbial environment with a different composition and nutrient content from the soil. The large grain size of the rock fertilisers meant that at the end of the experiment it was possible to separate the rock particles from the rest of the soil. Microcosms had a high plant density to ensure all soil was influenced by plant roots and could therefore be considered rhizosphere.

Microcosms were incubated in a temperature controlled glasshouse (20°C day/15°C night) in a randomized block design for 10 weeks. Nutrients were added to permit adequate plant growth in the highly nutrient deficient soil. Nutrients contained in each rock fertiliser were omitted from microcosms containing that rock fertiliser (mica, K; basalt, Ca and Mg; rock phosphate, P and Ca). Therefore, each mineral was a source of nutrients that were deficient in the soil. Microcosms were watered daily to field capacity (24% water content w/w, -10 kPa) with deionised water and destructively sampled on day 70. Rock fertilisers were separated from soil by passing soil through a 1 mm sieve.

Scale of Experiment

As in the Microbial Community Experiment, conducting the Rock Surface Experiment under controlled conditions increased its ability to detect the effect of ground rock fertilisers on soil microorganisms. Incorporating the rock fertiliser in the soil maximised contact between ground rock grains and soil microorganisms, soil particles and plant roots. The large grain size of rock fertilisers used in this experiment permitted them to be separated from the soil at the end of the experiment by sieving. The application rate was increased to compensate for the reduced surface area of rock fertiliser in the soil and to ensure sufficient rock fertiliser was retrieved for the molecular analyses.

Measurements

To determine if the bacteria living on the surface of each rock fertilisers were different from those living on other rock fertilisers and those living in the soil, molecular methods were used to analyse the DNA of bacteria. At the end of the experiment, the measurements were performed to determine whether the rock fertiliser treatments had affected the activity of the microbial community: microbial biomass, dehydrogenase activity and soil respiration.

Microbial biomass C was measured as described for the In-Conversion Phase Experiment and microbial respiration as described for the Co-Application Experiment. Dehydrogenase activity, community structure of microorganisms in soil and associated with grains of ground rock fertilisers and statistical analyses were measured as described for the Microbial Community Experiment.

Results and Implications

The combined data for the four experiments are presented below in relation to the Research Questions addressed in this study. The experimental designs are summarised in **Table 1**.

Research Question 1. Do realistic application rates of ground rock fertilisers maintain levels of phosphorus and potassium in soil and pasture during the conversion phase?

After three years of applying two levels of ground rock fertiliser and one level of conventional fertiliser to the pasture, there was no difference between treatments in the content of P or K in pasture plants when sampled at the end of 2005, the end of 2006 or during late winter in the first year (2004) (**Figure 1**). In contrast, the P content of the pasture plants was higher at the end of the third year (2006) of the In-Conversion Phase Experiment than at the end of the second year of sampling (2005). The K and P concentrations observed were adequate for plant growth at all sampling times.

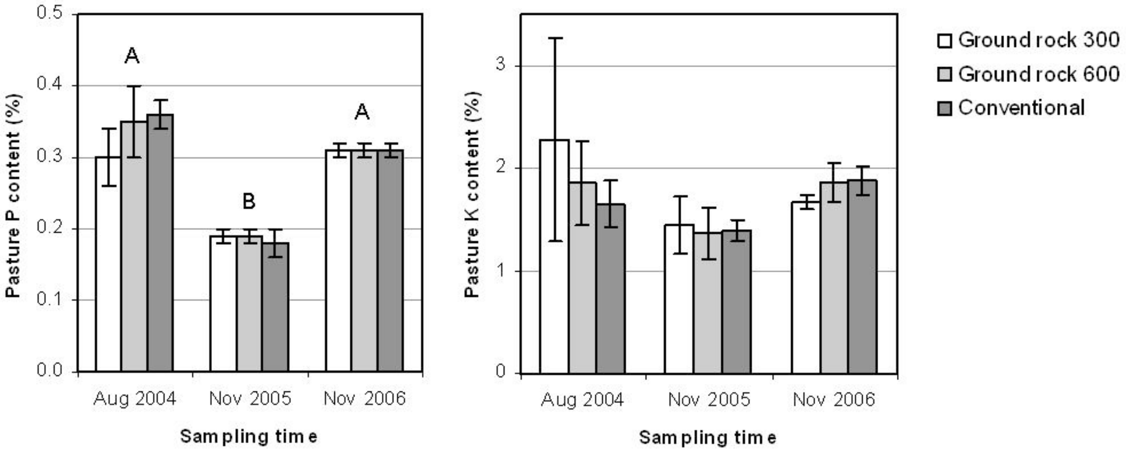

Figure 1 **Pasture content of P and K (%wt/wt) harvested at three sampling times during the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Sampling times topped by different uppercase letters have significantly different means ($p<0.05$). Within each sampling time, bars labelled with different lower case letters are significantly different. When no letters are shown there are no significant differences between sampling times or fertiliser treatments. (Error bars are standard error, n = 3.)**

After three years of applying ground rock fertiliser or conventional fertiliser to pasture, there was no difference between treatments in the content of Ca or Mg in pasture (**Figure 2**). At the start of the experiment the pasture that had ground rock fertiliser applied at 300 kg ha^{-1} y^{-1} had lower Mg content than the other two fertilisers but this did not occur at later sampling times. The pasture content of Ca was lower at the end of the In-Conversion Phase Experiment than the other sampling times. Overall, there was no evidence that the concentration of either Ca or Mg in the pasture was different for the two levels of application of ground rock fertiliser or the application of conventional fertiliser.

There was consistently more available P in soil that had ground rock fertiliser applied at 600 kg ha^{-1} yr^{-1}, compared to soil that had received either the conventional fertiliser or the ground rock fertiliser applied at 300 kg ha^{-1} yr^{-1} (**Figure 3**). This effect was consistent across the six sampling times of the three year In-Conversion Phase Experiment and was largely due to higher amounts of available soil P in one of the plots with ground rock fertiliser applied at 600 kg ha^{-1} yr^{-1}.

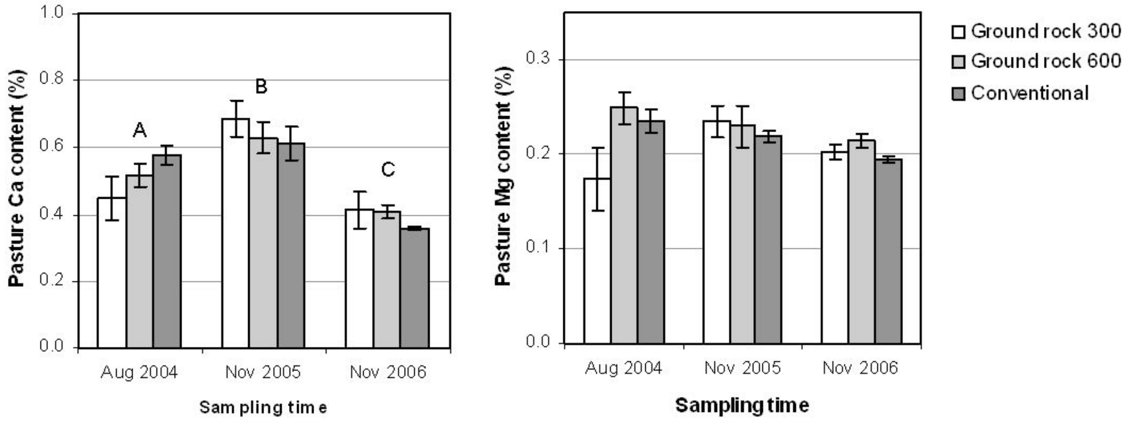

Figure 2 **Pasture Ca and Mg content (%wt/wt) at three sampling times during the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Statistical representation as in Figure 1.**

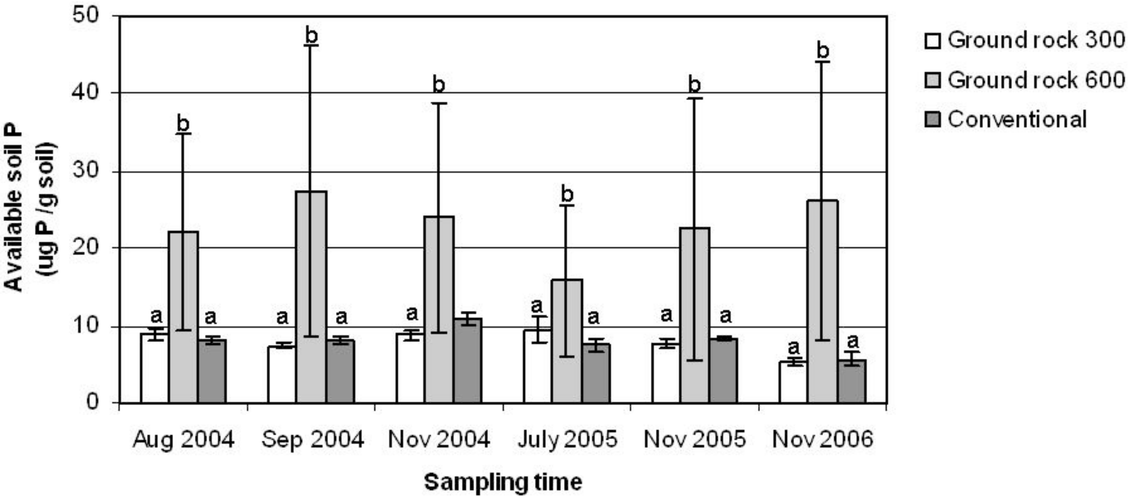

Figure 3 **Available P (µg P g soil-1) in soil during the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha-1 y-1 or conventional fertiliser. Statistical representation as in Figure 1.**

There was no difference between the three fertiliser treatments (two levels of ground rock fertiliser and conventional fertiliser application) in the amount of available K in the soil at any sampling time during the three year In-Conversion Phase Experiment (Figure 4). There was an indication that this may have been increasing over time for all treatments, including the non-organic fertiliser treatment, but this was not confirmed statistically in this experiment. No detectable difference was observed in pasture production in Year 1 for any of the treatments in the In-Conversion Phase Experiment (data not presented). The mean of pasture production for the three fertiliser treatments in Year 1 was 0.84 kg pasture m^{-2}.

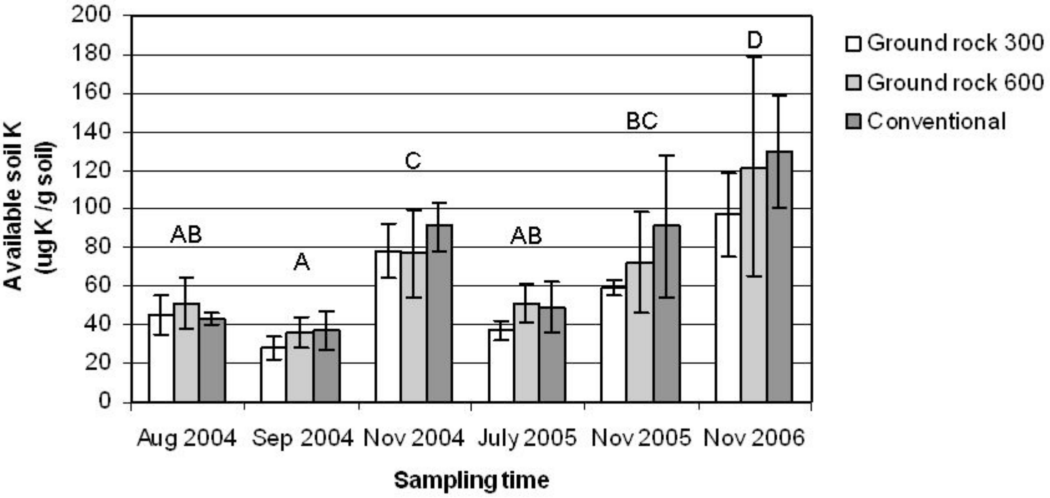

Figure 4 **Available K (µg K g soil^{-1}) in soil during the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Statistical representation as in Figure 1.**

Concluding statement

There was no detectable difference in pasture production between treatments with the organic and conventional soil amendments. Therefore in economic terms, any difference in production costs between the treatments would have been directly related to the actual costs of the fertiliser inputs. It was not possible to analyse this further because it was not possible to measure beef production for each pasture management in this small plot design. In order to fully evaluate the economics of the production systems studied here, the financial return on beef sales would need to be considered in addition to the pasture production. In the absence of differences in pasture production and as no measurements were made of beef production for the different management systems economic differences are unlikely, but cannot be predicted based on this study. The absence of a statistically significant difference between the rock fertiliser and soluble fertiliser treatments may also have been due to the low number of replicates in the In-Conversion Phase Experiment in Year 2 and 3. Due to unavoidable circumstances at the beginning of Year 2, the replication was reduced from five to three. The remaining experiments had more replicates and are therefore an important complement to the In-Conversion Phase Experiment.

The results of the In-Conversion Phase Experiment suggest that the relative profitability of using ground rock fertilisers may depend on factors other than yield. In the In-Conversion Phase Experiment, there was no difference in pasture production when ground rock and conventional fertilisers were used. Therefore, the profitability of pasture production would not have been altered by use of ground rock fertilisers in the organic pasture system except if (i) the ground rock fertilisers were more expensive that the conventional fertilisers on a $ g nutrient^{-1} basis, and (ii) organic beef received a price premium compared to beef produced using conventional methods. Consequently, as pasture production was similar in both systems, the final profitability of the organic pasture production system using ground rock fertilisers will depend on whether the premium received for the organic product is greater than the higher cost of the ground rock fertilisers.

Research Question 2. Does the use of ground rock fertilisers alter soil pH?

The pH of the soil measured four months after application of the ground rock fertilisers (0, 5 or 50 kg P ha^{-1}) was not affected by the application of ground mica, a silicate mineral, at 10 t ha^{-1} (**Figure 5**). Similarly, in the three year In-Conversion Phase Experiment, the soil pH was not altered by the use of ground rock fertilisers at either 600 or 300 t ha^{-1} y^{-1} compared to conventional fertiliser at any sampling time during the experiment (**Figure 6**). In contrast, in the Microbial Community Experiment which was conducted under laboratory conditions, the addition of some ground rock fertilisers increased soil pH compared to the control that had no ground rock fertilisers (**Figure 7**).

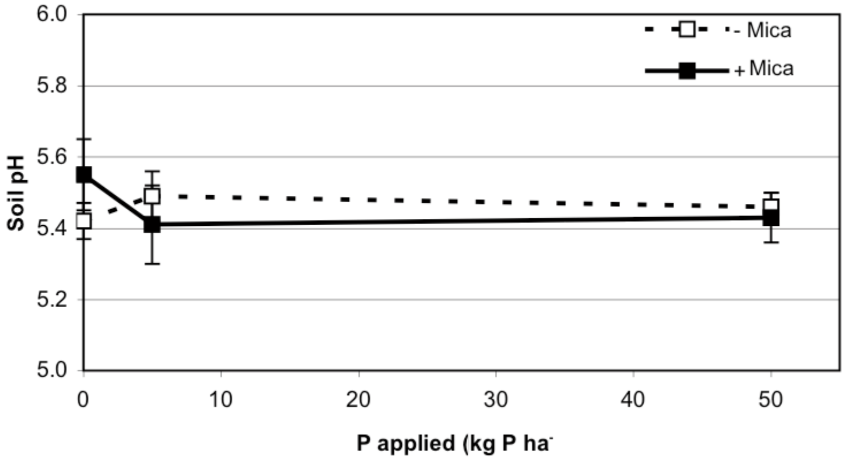

Figure 5 Soil pH with and without ground mica and at different rates of rock phosphate application in the Co-application Experiment. (Error bars are standard error, n = 6, lsd = 0.18)

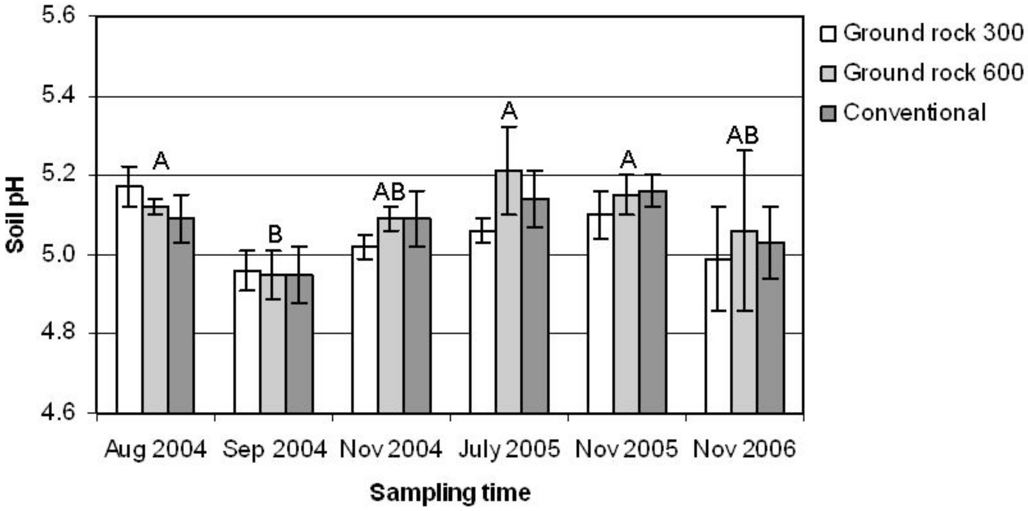

Figure 6 Soil pH during the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Statistical representation as in Figure 1.

When either of the pasture species was grown the soil with no added ground rock fertilisers, the soil had lower pH than when ground rock fertilisers were added singly or in combination (**Figure 7**). In the unplanted soil, there was no effect of addition of the ground rock fertilisers either singly or in combination on soil pH (**Figure 7**). Addition of mica reduced soil pH in the presence of subterranean clover, but not in the presence of ryegrass.

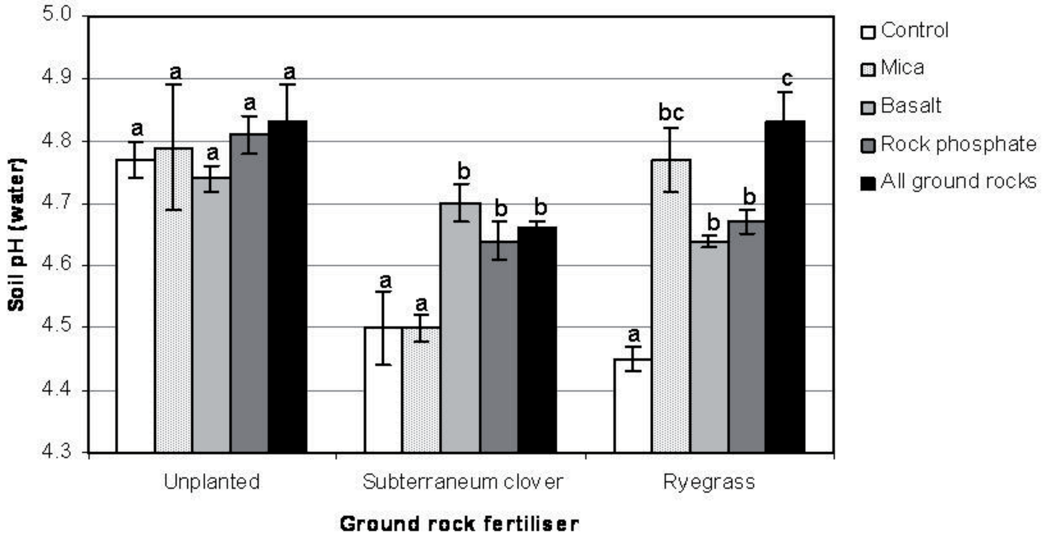

Figure 7 **Soil pH with different ground rock fertilisers and different pastures species in the Microbial Community Experiment. The ground rock fertiliser treatments were control (no fertilisers added), mica, basalt, rock phosphate and all ground rocks applied together (mica, basalt and rock phosphate). Within each pasture species, bars labelled with different lower case letters are significantly different ($p<0.05$). (Error bars are standard error, n=4 and least significant difference = 0.14.)**

Concluding statement

The addition of ground rock fertilisers did not appear to alter soil pH in either of the field experiments, although there were minor changes in soil pH, irrespective of soil amendment, throughout the duration of the experiment. By contrast, in the Microbial Community Experiment, soil pH increased when pasture was grown and either basalt, rock phosphate or all the ground rocks were applied. When pasture was not grown, soil pH was not affected by the use of rock fertilisers. The pastures may have increased soil pH by increasing the dissolution of ground rocks. This finding illustrates the important role of plants in increasing the effectiveness of ground rocks and emphasises that ground rocks are most suited to use on pastures because they have a higher plant density than crops.

The increase in soil pH observed in the Microbial Community Experiment was most likely due to conditions being more favourable to the dissolution of ground rocks than in the field experiments: the grain size of ground rocks was smaller (<250µm), soil was always moist (maintained at field capacity) and the rock fertiliser was incorporated through soil instead of broadcast. This finding suggests that for pasture production, the dissolution of ground rocks and their effectiveness as liming materials and fertilisers could be increased by using the finest grain size that is practical and incorporating rock fertilisers rather than broadcasting them. In other production systems, the dissolution and effectiveness of ground rocks might be increased by using organic amendments or mulches to increase water retention in soil.

Research Question 3. Do ground rock fertilisers increase the biomass or activity of microorganisms in pasture soils?

In the field experiments there were few differences in microbial biomass and activity between soils with conventional fertiliser or two levels of ground rock fertiliser applied. The large seasonal variation in the activity of soil microorganisms under field conditions makes it more difficult to measure treatment effects under field conditions than in glasshouse experiments, where environmental conditions vary less dramatically.

During the In-Conversion Phase Experiment the level of microbial biomass carbon in the soil was the same when either conventional fertiliser or one of the two levels of ground rock fertiliser were applied (**Figure 8**). There were differences in microbial biomass carbon when measured at the three times reflecting the dynamics of this measure at different times of the year rather than in response to soil amendments. Similarly, in the Microbial Community Experiment conducted under controlled conditions in glasshouse, microbial biomass carbon was not affected by the addition of any of the ground rock fertilisers in the presence or absence of ryegrass or subterranean clover (data not presented). The amount of microbial biomass carbon was lower in the controlled glasshouse experiment (250-300 µg C g soil^{-1} compared with 300-600 µg C g soil^{-1} in the field experiment).

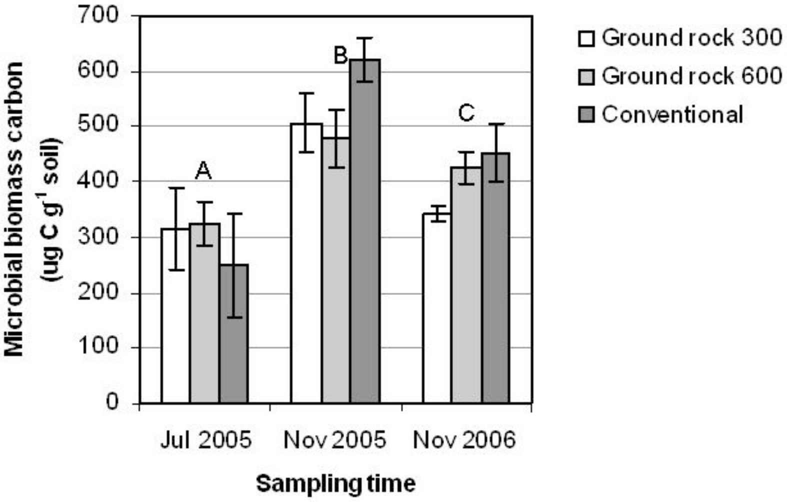

Figure 8 Microbial biomass carbon (µg C g soil^{-1}) in soils from the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Statistical representation as in Figure 1.

In the In-Conversion Phase Experiment, there was no difference in cellulase activity of soil treated with the different amounts or types of fertilisers at any sampling time (**Figure 9**). However, cellulase activity did differ between different sampling times, being highest in July 2005 and lowest in August 2004 and November 2006. Phosphatase activity was higher when conventional fertiliser was applied than when either rate of the ground rock fertiliser was applied (**Figure 10**). The phosphatase activity in soil also differed between sampling times and was higher at the November 2005 sampling than the other sampling times (**Figure 10**). In the Co-Application Experiment, soil respiration was not affected by the application of either rock phosphate or ground mica (data not shown).

In the glasshouse experiments, the differences between soluble fertilisers (controls) and three different ground rocks on microbial biomass and activity were more pronounced. This reflects conditions that were less variable and more favourable for the dissolution of ground rocks.

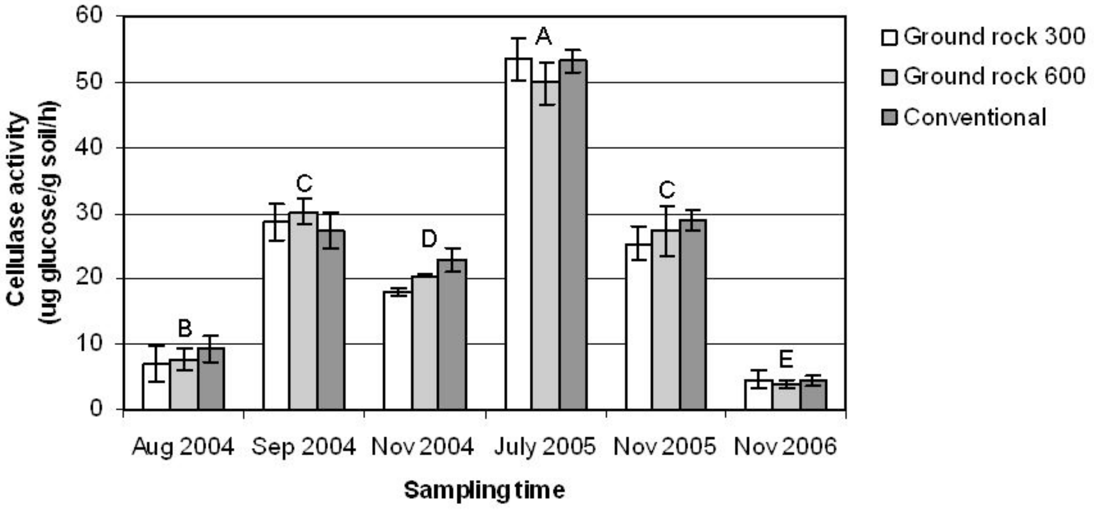

Figure 9 **Cellulase activity in soils from the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha^{-1} y^{-1} or conventional fertiliser. Statistical representation as in Figure 1.**

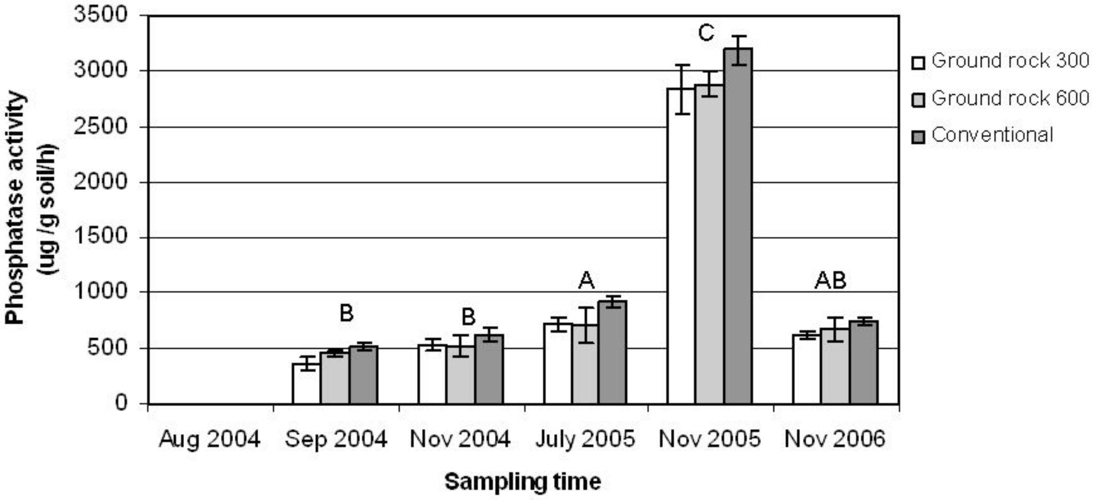

Figure 10 **Phosphatase activity in soils from the In-Conversion Phase Experiment. Pastures were fertilised with ground rock fertiliser at either 300 or 600 kg ha-1 y-1 or conventional fertiliser. Statistical representation as in Figure 1.**

In the Microbial Community Experiment soil respiration was lower when mica or basalt were added compared to the other rock fertiliser treatments and soluble fertilisers (**Figure 11**). Soil respiration was the same when all ground rock fertilisers were added and when soluble fertilisers were added (control) in both the Microbial Community Experiment (clover and ryegrass soils only) and in the Rock Surface Experiment (**Table 3**). Also in both experiments, soil respiration was higher when pasture was grown than when soil was unplanted.

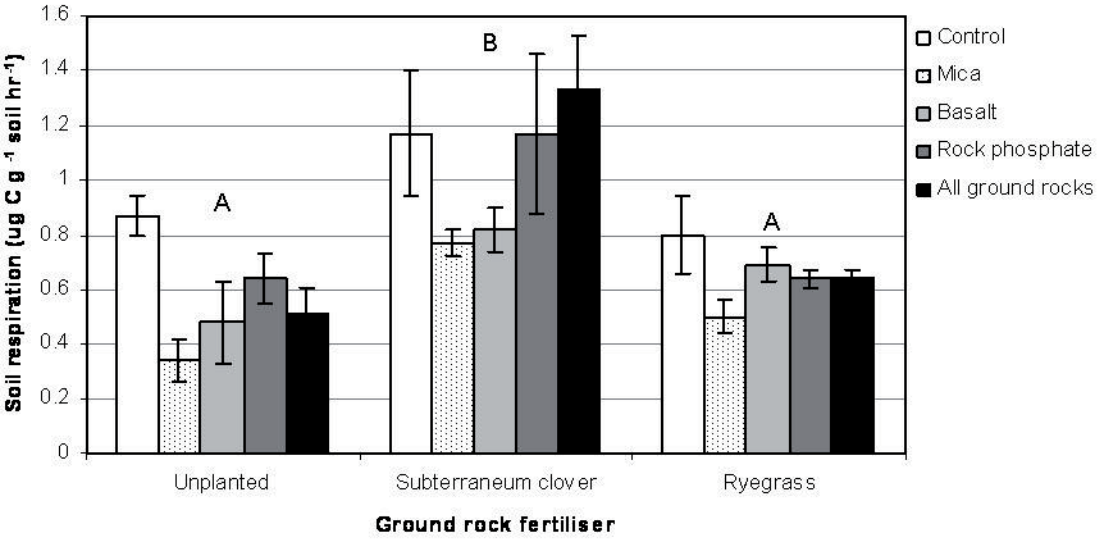

Figure 11 Soil respiration with different ground rock fertilisers in the Microbial Community Experiment. Legend to treatments as in Figure 7. Pasture species labelled with different upper case letters are significantly different ($p<0.05$). (Error bars are standard error, n=4 and least significant difference = 0.43.)

Dehydrogenase activity was higher when all the ground rock fertilisers were added to soil than when they were added separately in both the Rock Surface Experiment (**Table 3**) and the Microbial Community Experiment (clover and ryegrass only, **Figure 12**). In the Microbial Community Experiment dehydrogenase activity did not differ when mica, basalt and rock phosphate were added separately. In the Rock Surface Experiment, dehydrogenase activity decreased in the order basalt > mica > rock phosphate and control.

Table 3 **Soil microbial activity and biomass carbon with different rock fertiliser additions and different pasture treatments in the Rock Surface Experiment. Within mineral or plant treatments, different letters indicate treatments that are significantly different from each other ($p<0.05$). (SED = standard error of the difference. Data courtesy of Louise Campbell.)**

	Dehydrogenase activity	**Respiration**	**Microbial biomass**
	(µg TPF g^{-1} dry soil)	**(µg CO_2-C g soil^{-1} hour^{-1})**	**(µg biomass-C g^{-1} dry soil)**
Rock fertiliser treatments			
Combined	278.8a	0.74b	272.3a
Basalt	210.8b	0.71ab	295.4a
Mica	166.8c	0.69ab	331.7a
Rock phosphate	87.0d	0.65a	312.9a
Control	63.2d	0.75 b	311.0a
SED	10.4	0.024	23.1
Plant treatments			
Ryegrass	193.5a	0.94a	248.3a
Clover	158.4b	0.79b	327.9b
Bare soil	132.0c	0.38c	337.8b
SED	8.1	0.019	17.9

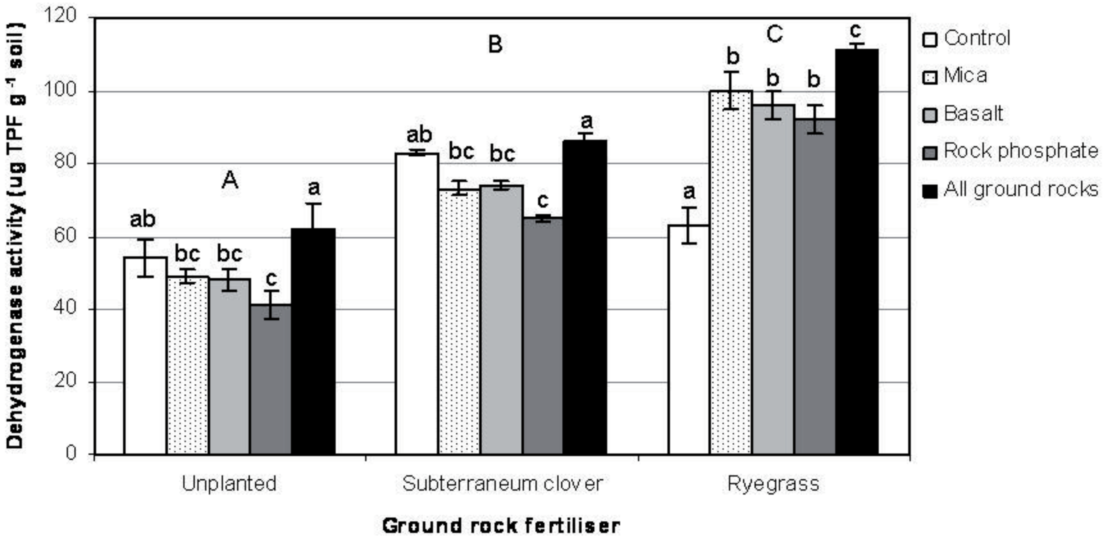

Figure 12 **Dehydrogenase activity with different ground rock fertilisers in the Microbial Community Experiment. Legend to treatments as in Figure 7. Within each pasture species, bars labelled with different lower case letters are significantly different ($p<0.05$). (Error bars are standard error, n=4 and lsd = 11.)**

Concluding statement

Under field conditions microbial biomass carbon, cellulase activity and soil respiration did not respond to the addition of rock fertilisers. However, under field conditions phosphatase activity was higher with conventional fertiliser than with either rate of the organic fertiliser. In the glasshouse experiments there were significant effects of different ground rock fertilisers on respiration and dehydrogenase activity. The greater effect of ground rock fertilisers of soil microorganisms in the glasshouse experiments was probably due to conditions in the glasshouse experiment being more favourable to the dissolution of ground rock fertilisers.

It is likely that the effect of ground rock fertilisers on soil microorganisms was mediated by changes in plant growth. When either pasture plant was grown in the glasshouse experiments, respiration, dehydrogenase activity and microbial biomass carbon increased compared to when no plants were grown. This is probably due to increased plant growth causing greater exudation of carbon compounds into the rhizosphere, in turn increasing microbial biomass and activity. Therefore, when ground rock fertilisers increase plant growth, they are likely to also increase microbial biomass and activity.

Research Question 4. Does the application of rock phosphate increase plant uptake of potassium from silicate minerals?

The application of ground mica, a silicate mineral, only increased the concentration of K in the pasture when rock phosphate was also applied (**Figure 13**). When rock phosphate was not applied, the application of ground mica had no effect on pasture K concentration. The co-application of ground mica and rock phosphate also increased the pasture P content (data not shown). When rock phosphate was applied at 50 kg P ha^{-1}, pasture P content was greater with ground mica application than without ground mica. There was no effect on K availability in soil (data not shown). Available P content of soil increased with addition of ground mica, but this only occurred in the absence of addition of rock phosphate.

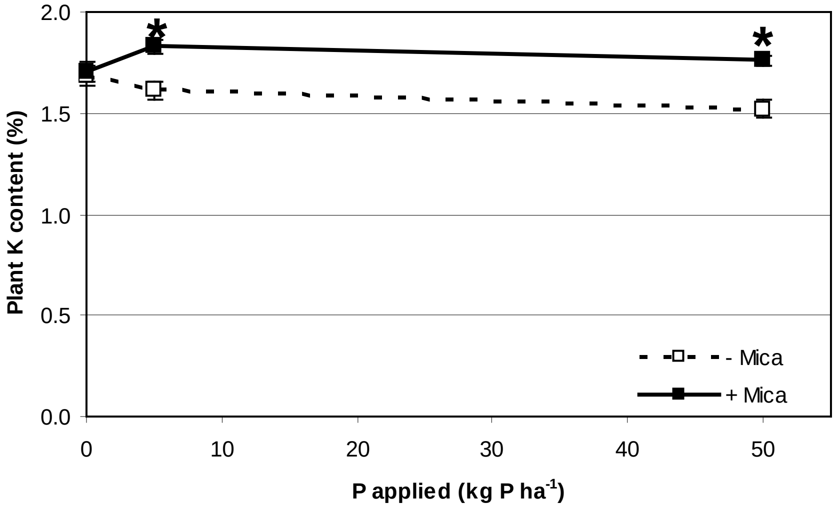

Figure 13 **Pasture K concentration (%) grown with and without ground mica and at different rates of rock phosphate application from the Co-Application Experiment. Within each rate of rock phosphate, asterisks indicate points are significantly different. Where no asterisks occur, there were no significant effects of mica addition. (Error bars are standard error, n = 6, lsd = 0.13.)**

Concluding Statement

Higher pasture uptake of K from ground mica, a silicate mineral, when it was co-applied with rock phosphate indicates that the effectiveness of ground rocks as K fertilisers may be increased by co-applying rock phosphate. In addition, the pasture uptake of P was higher when ground mica was applied. These results suggest that organic farmers may be able to increase the effectiveness of ground rock fertilisers and the economic returns on their cost.

Research Question 5. Do ground rock fertilisers alter the structure of the microbial community in pasture soils?

The Microbial Community Experiment demonstrated that when ground rock fertilisers are used under field conditions, they may be altering the composition and relative abundance of the microbial community in the soil. It is not known if the effects on the microbial community will cause changes in the functions they perform in soil. Results from the field experiment showed no changes in the activity of soil microorganisms. However, in that experiment the ground rocks were added at a much smaller rate and conditions were less favourable to the dissolution of ground rock fertilisers. In both the clover and unplanted soils, the number of bacterial species (ribotypes) (**Figure 14**) of the bacterial community were lowest in the treatment containing mica and the control, and highest when all ground rocks were added. In the ryegrass microcosms, the ground rock additions had no effect on the number of ribotypes or Shannon diversity index. Addition of ground rock fertilisers to pasture soil altered the structure of the bacterial community (data not presented).

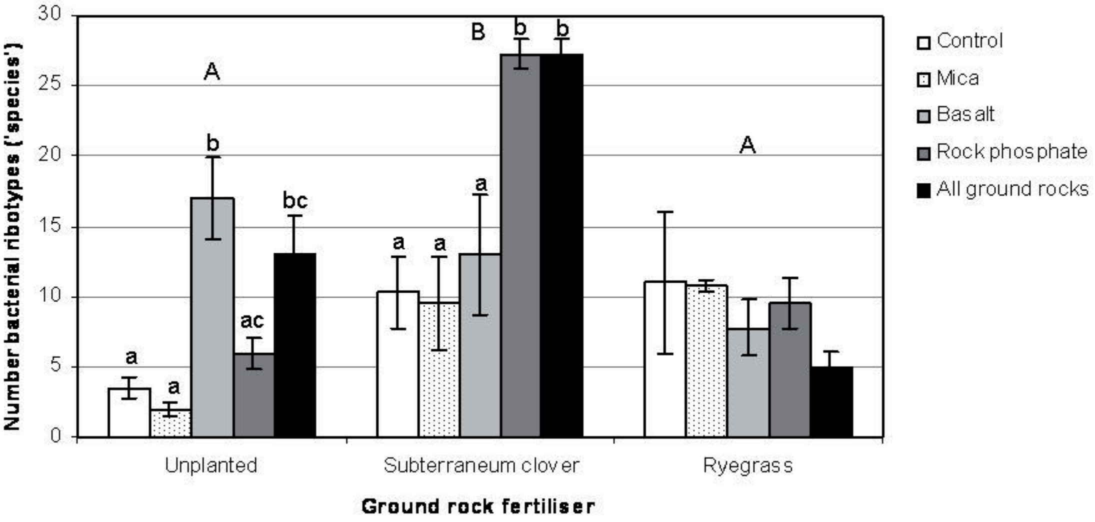

Figure 14 Number of bacterial ribotypes (or species) with different ground rock fertilisers in the Microbial Community Experiment. Within each pasture species, bars labelled with different lower case letters are significantly different (p<0.05). Pasture species labelled with different upper case letters are significantly different. (Error bars are standard error, n = 4, lsd = 8.5.)

When clover was grown, the bacterial communities associated with rock phosphate and with the treatment containing all the ground rocks were different from other ground rock treatments. The remaining treatments, mica, basalt and the control, were not separated from each other, indicating that their microbial communities were relatively similar. When ryegrass was grown the bacterial communities associated with each ground rock fertiliser treatment were different (separated) from each other. When no plants were grown, the bacterial communities associated with each ground rock fertiliser treatment were not clearly separated. This may indicate that plants play an important part in the effect of the ground rock treatments on soil microorganisms

Ribotype number and Shannon diversity index of fungal communities were less affected by rock fertiliser treatments than the bacterial communities. For fungal communities in ryegrass and clover, ground rock treatment had no effect on ribotype number and Shannon diversity index. In the unplanted treatment, fungal ribotype number and Shannon diversity index were lowest when rock phosphate was added and highest with basalt and in the control (**Figure 15**).

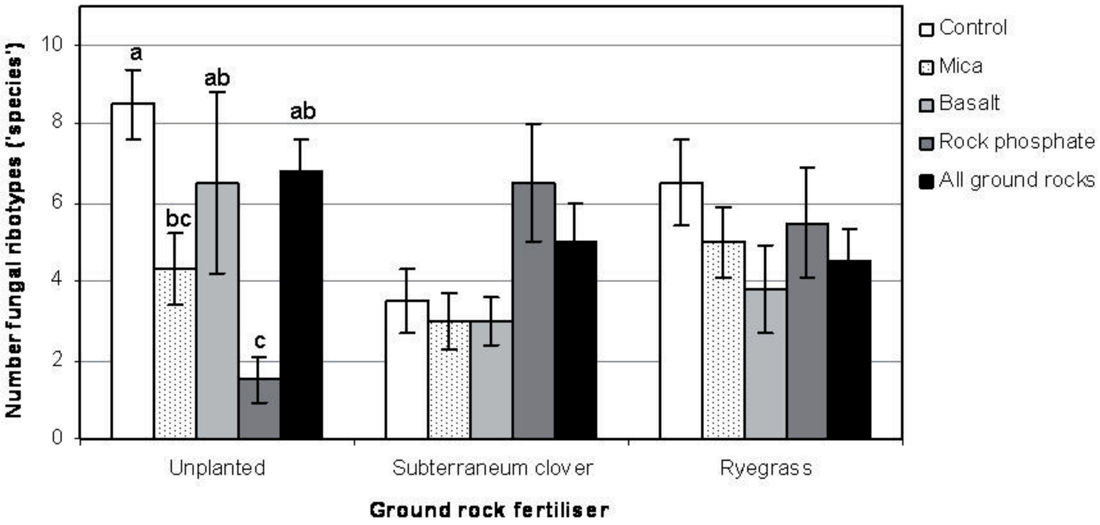

Figure 15 Number of fungal ribotypes (or species) with different ground rock fertilisers in the Microbial Community Experiment. Within each pasture species, bars labelled with different lower case letters are significantly different (p<0.05). Where no letters are shown, values are not significantly different. (Error bars are standard error, n = 4, lsd = 3.7.)

The structure of the fungal community was also altered by adding ground rock fertilisers (data not shown). When clover was grown, the fungal community associated with ground rock phosphate and the treatment containing all the ground rock fertilisers were different from those associated with other ground rocks (as indicated by separation of points). When ryegrass was grown the fungal communities associated with each different ground rock were different from each other.

Concluding Statement

When ground rock fertilisers are used under field conditions, they may alter the composition and relative abundance of the soil microbial community but it is not known whether this will change the functions the soil microbial community performs in soil. When no plants were grown, the bacterial community associated with ground mica added was not the same as that associated with other ground rocks. When clover was grown, the bacterial communities associated with different ground rocks were all different, and when ryegrass was grown the bacterial community associated with ground rock phosphate was different to that associated with other ground rocks.

The structure of the fungal community was also altered by adding ground rock fertilisers. The fungal community associated with subterranean clover was not the same in the presence of ground rock phosphate and other ground rocks. A similar effect was observed for ryegrass. Overall, bacterial community structure was best correlated with soil pH, dehydrogenase activity and root weight and the fungal community structure was best correlated with dehydrogenase activity and root weight. For further information see Carson et al. (2007).

Research Question 6. Are there differences between the community structure of the microorganisms on grains of ground rock fertilisers and the community structure of microorganisms in the rest of the soil?

The results of the Rock surface Experiment suggest that using ground rock fertilisers provides microorganisms with an alternative mineral substrate to colonise. This could allow a different set of microorganisms to multiply. Again, the experiment did not show whether the altered community of microorganisms would results in changes to the functions performed by the microbial community.

The multidimensional scaling (MDS) plots revealed that bacterial communities differed between different rock fertilisers and between soils with different rock fertilisers added. MDS plots are similar to PCO plots in that the distance between individual points reflects the difference between the community structure (composition and relative abundance) of the microbial communities in those samples. The MDS plot shows that adding different rock grains to soil with ryegrass caused changes in the structure of the bacterial community in the soil (**Figure 16**) as shown by the separation of the symbols for the soils that had different rock grains added. Also, the separation of the symbols for the different rock grains shows that the bacterial communities living on the surface of the different rock grains were different from each other. However, the number of bacterial species (ribotypes) did not differ significantly between the microbial communities on the rock surfaces and in the soil.

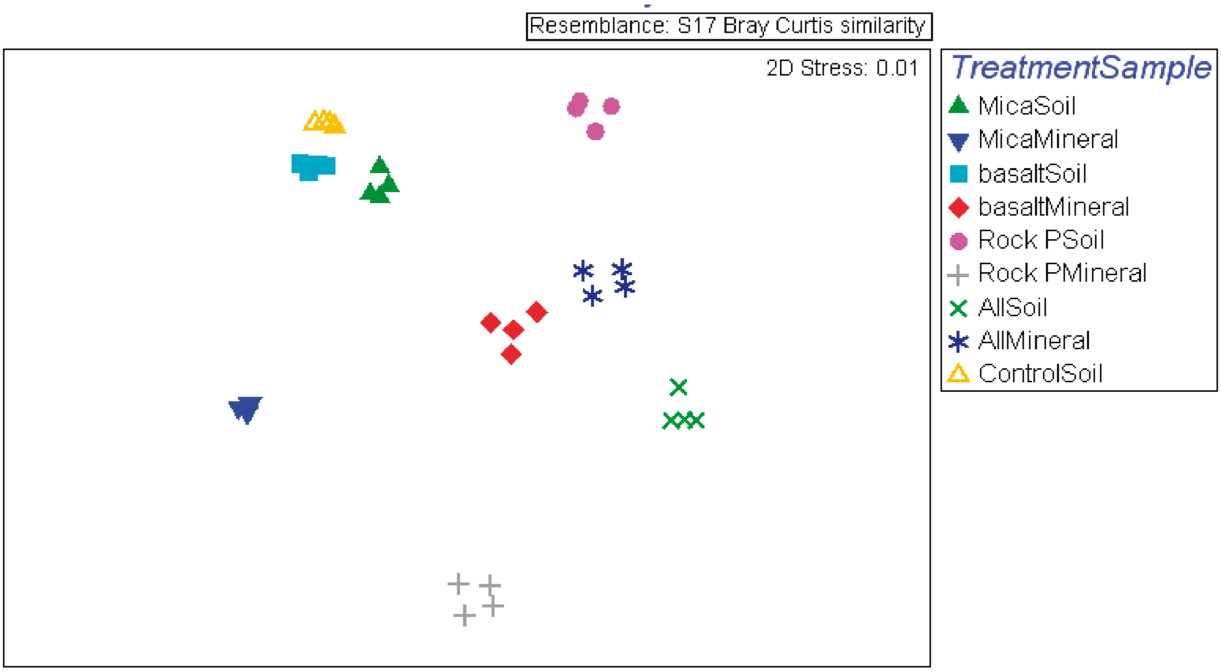

Figure 16 **Two-dimensional, non-metric multidimensional scaling (MDS) ordinations for bacterial communities assessed using Ribosomal Intergenic Spacer Analysis (RISA). Bacterial communities from the soil and rock fertiliser fractions of the four rock fertiliser treatments and control are represented by symbols. Stress = 0.01. (Data courtesy of Louise Campbell.)**

Concluding Statement

The rock fertilisers provide microorganisms with an alternative mineral substrate to colonise but it was not possible to relate any changes to changes in microbial function. It was shown that the bacterial communities living on the surface of the different rock grains were different from each other. For further information see Carson et al. (2009).

Key Findings

1. Realistic applications of ground rock fertilisers were sufficient to supply pasture with P and K during the conversion phase to organic production under field conditions.

2. Realistic application rates of ground rock fertilisers did not increase the biomass of microorganisms in soil, but they did change some microbial activities (e.g. enzyme activity) under field conditions.

3. Higher pasture uptake of K from ground mica fertiliser when it was co-applied with rock phosphate indicates that the effectiveness of ground rocks as K fertilisers may be increased by co-applying rock phosphate. In addition, the pasture uptake of P was higher when ground mica was applied.

4. Ground rock fertilisers altered the composition and relative abundance of soil microorganisms in association with their surfaces compared with those in the bulk soil.

5. In economic terms, there was no detectable difference in pasture production between treatments with the organic and conventional soil amendments. Any difference in production costs between the treatments would have been directly related to the actual costs of the fertiliser inputs.

Future Research

Future work should consider the potential role of ground rock fertilisers in altering the physical habitat in soil for microorganisms. Much of the beef production in the south-west of Western Australia occurs on sandy soils, which contain relatively few of the small pores that soil microorganisms prefer. This means that microbial activity in these soils is lower than soils that are less sandy. This may create problems in organic systems that rely more heavily on soil microorganisms to make nutrients available to plants than do conventional systems. Adding finely ground rock fertilisers to sandy soils, may increase the number of small pores in the soil, increasing the microbial activity. Further work to examine this possibility may show that a single large addition of ground rock fertilisers to a pasture soil may increase the activity of soil microorganisms over more than one season.

Further investigation of the impact of changes in microbial community structure in response to the addition of rock fertilisers to soil needs to be conducted over long periods of time. This would correspond with the expectation that improved soil biological fertility would be established in organic farming systems. It would also be of interest to determine whether these processes play a significant role in the supply of nutrients from poorly soluble rocks and minerals under field conditions.

Conclusion

In economic terms, pasture production was similar for organic (ground rock) and conventional soil amendments for the levels of application used. These levels were selected according to those normally used on-farm. In order to fully evaluate the economics of the production systems studied here, the financial return on beef sales would need to be considered in addition to the pasture production. In the absence of differences in pasture production and as no measurements were made of beef production for the different management systems, economic differences are unlikely but cannot be predicted from this study. Overall, there was greater pasture uptake of potassium from ground mica fertiliser when it was co-applied with rock phosphate, indicating complex interactions within the root zone.

While there were differences in microbial biomass carbon measured at different times, it did not respond to the addition of rock fertilisers. In contrast, other measures of biological activity in soil (e.g. some enzymes) responded to both ground rock fertiliser and the presence of plant species. Soil respiration was not affected by the application of either rock phosphate or ground rock, and there were indications that there were interactions between microbial activity, plants and ground rock fertilisers. Furthermore, there were different effects of soil amendments on bacterial and fungal components of the soil microbial community. Thus, different combinations of ground rock and plant species create diverse habitats which alter the structure of microbial communities in soil. The importance of these influences for plant nutrition is not understood.

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Adding Value to Organic Pasture

Microbes and minerals

By J Carson, A Harley, LK Abbott and D Gleeson

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This project investigated the impacts of a suite of certified organic nutrients applied to pasture used for beef grazing during the conversion phase to a certified organic system. It also investigated interactions between soil microorganisms and ground rock fertilisers in pasture soil to determine the potential mechanisms for release of nutrients from rock surfaces in the soil environment.

This report is targeted at growers and researchers who are interested in the nutrient cycling processes and farm nutrient budgets that underpin organic management systems, especially during the conversion phase to organic certification.

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