Soil Biology Research Review

Australian Government
Cotton Research and Development Corporation

Cotton Catchment Communities CRC

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Definition

There has been considerable debate in the literature about terminology such as 'soil health', 'soil quality' and 'soil fertility'. In the context of this review, only one aspect of the broader definition of soil health is considered - soil biology

Aims

The overall aims of the Review were:

- to review key recent research results
- to identify areas which may need greater extension of current knowledge to industry
- to identify and prioritize areas for future research
- to discuss projects where collaboration and coordination can occur either between researchers and/or industries (eg. Grains industry)

Introduction

Cotton growers generally recognize crop performance or yield as the best indicator of soil biology. The record yields of recent seasons indicate that farmers are generally looking after their soils well from the perspective of plant nutrition and control of soil-borne diseases. However, there are a number of concerns which may impinge on the continued success of cotton crop performance. These include questions such as:

(i) Are current cotton growing practices sustainable in the long term?
(ii) Will declining soil carbon levels present problems in the future?
(iii) Is the quality/biology of cotton soils under threat?
(iv) Are there better ways of looking after our soils?

Crop yield can be primarily driven by a combination of factors associated with soil chemical and physical fertility and best practices in crop selection and management. However, for a more complete integration of all components of soil biology into decision-making tools used by cotton farmers, there is increasing recognition of the contribution of soil biological processes to 'healthy' soil.

The 'soil health' concept

A recent survey of '*Soil health issues for Australian cotton production' (Shaw 2005)*, found that farmers consider "nutrition, sodicity, soil biology, salinity, soil management, disease, VAM, residual herbicides, organic matter levels, water logging, water-use efficiency and education" are significant soil biology issues which may limit production. Seven of the 20 top areas requiring research, as identified by the Emerald Soil Health Forum 2005, related to fertilizers and fertilizer scheduling, cotton nutrition, soil and tissue tests.

While soil biological, physical and chemical processes are interrelated and all contribute to the 'health' of soil, there is a belief that biological components of soil biology can be overridden by addition of chemical fertilizers and that productivity can be primarily driven by chemical fertility with little input from biological processes. However, fertilizer alone will not be able to overcome the soil borne diseases currently threatening the profitability of cotton production. This dilemma needs to be at the core of debate about the relative contributions of soil biological, chemical and physical processes to the 'health' of soil for cotton production (see Appendix 2 - Preface to a book edited by Abbott and Murphy).

Clearly, Australian cotton production is already achieving the world's highest yields, so whether or not this can be increased or maintained in a sustainable manner is a challenging question. For this reason, discussion of soil biology needs to refer separately to the various components of soil 'health' as well as to their integrated role in contributing to soil biology overall. If only a holistic discussion of soil biology is made, it is difficult to determine whether the contributions from physical, chemical and biological processes are all being considered. Consequently it is difficult to attribute contributions to biological, chemical or physical characteristics either separately or together. Thus, there is an argument for a focus to be given to 'soil biology' or 'soil ecology', and this needs to be presented within the broader framework to include individual and interrelated contributions associated with other aspects of soil health.

Based on the arguments above and elsewhere, soil biology should not be considered in isolation from soil chemistry and soil physics because biological processes are linked to chemical and physical processes. For example, the roles of Arbuscular Mycorrizae (AM) fungi include interrelationships between chemical (phosphorus nutrition) and physical (soil structure) processes. However, when soil biology is considered with the other components, it is important to retain a focus on the biology and not to have it integrated to such an extent that the contributions from biological processes are hidden (and/or most probably overridden by chemical processes, especially those processes associated with plant nutrition).

The soil biology research agenda

Soil biology research in the field has been largely ignored until recently (except for studies of plant pathogens) because it has been regarded as 'too hard and complex'. Greater interest and awareness has been generated in recent years by the profusion of biological preparations and remedies being promoted largely by testimonial, partial science and misinformation. These treatments have included seaweeds, humic acid, humates, micronutrients, compost teas, radionic homeopathic remedies, magnets, etc.

Many of the questions being asked by growers arise from their interactions with those promoting these alternative products. Several comprehensive lists of questions/issues have been generated in the last few years in association with soil biology workshops:-

Research Review - Scientists Perspective - September 2005
Emerald Soil Health Forum - September, 2005
Soil Health Issues for Australian Cotton Production, a Growers Perspective - August 2005
Soil Health Workshop - Farming Systems Forum - December 2001

The Australian Cotton Industry needs to have clear and sound objectives that identify and address the important issues that will provide growers with the best guidelines for managing our valuable soil resource. The research agenda should not be dictated by the claims made by those promoting alternative products and strategies. Although there has been a long history of research in identifying appropriate chemical inputs, there is a relatively short history of interest in alternatives to the conventional inputs. The proliferation in variety and form of alternative inputs makes it almost impossible to conduct research on each one. The industry promoting such products needs to ensure that benefits are scientifically well founded if they are claimed. There is potential for some generic research to be supported across this area, but it cannot take the form of the historical research conducted in relation to the use of chemical fertilizers due to the extensive variety of alternative inputs that are now available. Some researchers have done tests on some of these products in the past, and this information is ready to be used in extension material.

Current soil biology research in the Cotton Industry

A wide range of soil biology topics is currently being investigated with support from the Cotton industry. Projects range from fundamental studies of microbial diversity, models of soil function and impact of management on disease (Table 1). The inclusion of both fundamental and applied research gives a broad perspective (especially in relation to scale) associated with biological processes, and is therefore valuable.

Many of these issues can be addressed by the extension of existing research results, however it is worth noting the areas where further research would be most useful:

Possible new CRDC - Cotton CRC research objectives in 'Soil Biology'

Based on the research in progress and the issues being identified by growers and researchers, the following research objectives have been identified as potential areas for future work:

1. Characterising and measuring soil biodiversity

This work is essential, but needs to be carefully targeted to avoid the 'so what?' factor. i.e. researchers could spend years showing that microbial diversity is different with different rotation regimes but so what? Unless it is linked to soil ecology and function it won't answer the question of whether or not farming practices are sustainable. We need to know how stable our soil ecosystems are. The response of ecosystems to disturbance can be measured by their resilience - the time taken to return to equilibrium; and resistance - the degree of change resulting from the disturbance under the pressures imposed by cropping. These measures would give a good understanding of sustainable practices. Biodiversity is one aspect that should be included and function is the other.

This area of research would include use of molecular approaches to investigate microbial diversity. It would strengthen fundamental knowledge of the impact of management practices on microbial communities (including management practices identified by cotton farmers - see Appendix 1). It would also enable visualization of changes in microbial community structure that could be used within extension tools to inform cotton farmers of the complex biological resource within the soil that they manage. Extension of this information to farmers would contribute to raising the awareness of soil biological processes within the broader framework of soil biology and facilitate discussions of the relative magnitude of contributions of nutrients from chemical and biological sources.

Organisms to be investigated could include microbes generally (fungi and bacteria) and more specifically (AM fungi, *Fusarium*), and invertebrates. Investigation of interrelationships between soil biodiversity and pathogen suppression would also be relevant under this heading.

Other projects could include:

- Benchmarking of soil biota.
- Effects of rotation crops on soil biota

2. Optimising nutrient cycling in soil

The important role of organic matter in nutrient cycling in soil necessitates a good understanding of processes involved in all management practices that influence soil carbon. There is a need to understand the influence of different forms of organic matter on carbon dynamics in soil, and how this has a flow on effect to other nutrients, especially nitrogen. Links between chemical and physical conditions in soils can also be strongly associated with how organic matter is managed, so this is an area of fundamental importance to soil biology specifically and soil biology generally. However, not all nutrients are cycled in parallel with carbon in soil, and therefore it is also relevant to understand processes associated with chemical-transformation of nutrients (e.g. N (nitrification and denitrification); P and S transformations). Finally, some of these processes may have indirect relationships with carbon dynamics, which highlights the need to understand interrelationships between nutrient cycling processes.

Research projects could include:

- Application/placement of nutrients and whether it has a negative effect on soil microbes
- Research into the interactions between soil biota and cotton plant and its subsequent effect on yield potential
- How to raise organic carbon levels and their effect on soil: structure, compaction & organic carbon levels; and determination of sustainable levels of organic matter in heavy clay soils.
- Farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology

3. Establishing interactions between soil functions

Developing a framework for determining the impact of management practices on the balance between soil biological, chemical and physical processes in soil could be an additional outcome from studies in (1) and (2) above. A modeling approach could assist in demonstrating and predicting shifts in the relative contributions of these aspects of soil biology and could be used to alert farmers to a need to modify practices to redress potentially negative balances in any direction. We need to be clear whether or not we are talking about something that has a negative impact on crop productivity or a negative impact on the soil ecosystem. A synthesis of information could be used to develop a soil function model as a powerful extension tool.

For example: long-term farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology

Other research and extension projects could include:

* Extension of information on 'High N rates: effects on soil biota'; Research into the interactions between soil biota and cotton plant and its subsequent effect on yield potential; Information comparing NH3 and Urea and their effects on pH and soil biota

* Extension of existing information on how to measure soil biology, using: soil pits, Electro Magnetic (EM) surveys, yield maps, biological tests and soil tests

* Extension of credible information on benefits of biological tests
* Interpreting plant tissue and soil test results or 'trends'
*How to raise organic carbon levels and its effect on soil: structure, compaction & organic carbon levels. (See 2 above)

4. Controlling soil borne diseases

Research is required to identify patterns in distribution and abundance of soil-borne pathogens in relation to soil type and land use practices and would need to be clearly defined. This would include investigation of pathogen ecology and integrated disease management strategies in parallel with changes in other soil characteristics, including shifts in biodiversity and both quantitative and qualitative changes in soil biodiversity (either overall or according to selective groups - as in (1) above).

Other research projects could include:

- Farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology
- Rotation crops impact on soil biota and link it to ecological function, and extension of the large body of work on pathogens that has already been completed.
- Extension of existing information about the relationship between soil biota and disease as well as further research into this issue.

5. Impact of new farming systems and technologies

The processes discussed above in (1), (2) and (3) could also be addressed specifically in terms of the impacts of the use of herbicides, GM technology and soil management practices specific to the Cotton Industry, including soil physical manipulation (cultivation) and existing and potentially new rotational practices.

Other research projects could include:

- Application/placement of nutrients and whether it has a negative effect on soil microbes
- How to raise organic carbon levels and its effect on soil: structure, compaction & organic carbon levels (see 2 above)
- Farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology
- Rotation crops impact on soil biota

Education and extension of sound science will be essential.

Extension of information to farmers would contribute to raising the awareness of soil biological processes within the broader framework of soil biology and facilitate discussions of the relative magnitude of contributions of nutrients from chemical and biological sources.

Extension Projects could include:

- Iinformation on water-injected inoculum - however, this needs to be specific
- Information on how to measure soil biology using e.g. soil pits, EM surveys, yield maps, biological tests and soil tests
- Credible information on benefits of biological tests
- Interpreting plant tissue and soil test results or 'trends'
- Relationship between VAM and nutrition

- How to raise organic carbon levels and its effect on soil e.g. structure, compaction & organic carbon levels
- Trials on biological products
- Effects of residual herbicides on soil organisms & diseases
- Information needed on the relationship between nematodes and Fusarium, and how to mange this problem
- Farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology
- The impact of rotation crops on soil biota
- Information about the relationship between soil biota and disease
- Research comparing and verifying the credibility of chemical soil testing and alternative biological soil testing; and the extension of these results.

Opportunities for Collaboration

Existing and proposed research in soil biology are addressed by major programs in Grains Research & Development Corporation (GRDC) and Land & Water Australia (LWA).

(i) GRDC - Soil Biology Initiative

This initiative is drawing to a close with the intention of integration into main-stream programs (particularly in terms of extension).

Goals

(i) Develop a suite of practical methods and cost-effective products for growers
(ii) Overcome biological constraints to crop performance
(iii) Help improve profit margins in grain cropping systems
(iv) Develop soil biology as an integral part of sustainable farming systems

Opportunities for combined workshops with the Cotton Industry should be explored

Funding

$10M over 5 years - scheduled to finish in July 2006.
Related areas in GRDC's R&D portfolio included the following:

General Area	% of budget committed
New inoculants	16%
Root diseases	24%
Plant nutrition	29%
Rhizosphere	11%
Farm management	18%
Pasture Alliance	2%

(ii) Land and Water Australia - 'Healthy soils for sustainable farms program'

LWA is coordinating a new "Healthy soils for sustainable farms program" which is funded by the Natural Heritage Trust. This program will be focusing on extension and training projects that will enhance soil biology (i.e. physical, chemical, biological aspects) on farms. A Cotton Industry proposal could be submitted to this program and could place considerable emphasis on soil biology and its integration with the chemical and physical soil disciplines.

Table 1. Summary of current soil biology projects relevant to the cotton industry.

Who & Where	Key findings/messages/Questions	Significance	Extension Activities?
David Midgley Sydney University	*Developing molecular methods for quantifying biodiversity *Some Prokaryotic diversity appears to be unaffected by land management *Diversity of Actinobacteria and fungi appear to be significantly reduced in cropped soils - *Species which may compete with or suppress emerging pathogens (eg: Penicillium, Actinobacteria) appear to be uncommon in cropping soils.	*Cropping may select for microbes that lack the capacity to competitively interact (eg with pathogens such as Fov, Black root rot). *It may be possible to directly reduce both current and future seedling diseases in cotton by manipulation of microbial biodiversity.	Results of project yet to be finalised
Stella Loke Sydney University	*Developing molecular methods for characterizing diversity of AM fungi *No difference in numbers but small spored types more prevalent in cropped soils cf. under native vegetation *Greater diversity of genetic than morphological types of AM fungi	*Could more efficient species be introduced to cropped soils? * More than one genetic type within single AM fungus may enable functional variation for crop production.	Results of project yet to be finalised
Leonie Whiffen Sydney University	* AM fungi contribute to soil carbon directly, via deposition of fungal structures and protein, and indirectly through aggregate formation. * Recalcitrant soil protein contributes to a higher proportion of total organic carbon and there are much higher levels of total protein in soils from under native vegetation cf. cropped soils.	*Can management of AM fungi offer a means to increase soil organic carbon?	Results of project yet to be finalised
Peter McGee Sydney University	*Soil biology includes microbe diversity *Diversity of microbes is low and the community is limited in cropping soils	*The level of diversity required to provide adequate levels of the required functions is "not yet clear"	Results of project yet to be finalised
Bo Wang CSIRO Canberra	*Cultivation changes the Fusarium profile in soils. Lineage B isolates decrease while lineage E and lineage A isolates increase. *There is clear evidence that interactions with other soil organisms can significantly alter the expression of Fusarium wilt in the field	*Cotton growing placed selection pressure on native Fusarium populations *Can manipulation of other soil organisms provide a degree of control of Fov?	Results of project yet to be finalised
Curt Brubaker CSIRO Canberra	*The Fov causing Fusarium wilt of cotton in Australia is native to Australia. *There are 28 haplotypes of Fov in Australian cotton fields that vary in virulence. There are competitive interactions among Fov haplotypes.	*Cotton growing placed selection pressure on native Fusarium populations	In progress Results of project yet to be finalised

Usha Pillai-McGarry UQ - Gatton	*What indices of soil physical, chemical and biological properties can be used to ensure a balanced nutrient system? *Will healthy plants withstand disease?	*Still planning the research	Results of project yet to be finalised
David Nehl NSW DPI, ACRI	*Drought-enforced fallows of up to 41 months did not adversely affect VAM development in seedling cotton. *Human activity is the main factor in the spread of Fusarium wilt and black root rot. *Integrated disease management strategies are required for the control of Fusarium wilt and black root rot	*VAM deficiency is not a problem after drought enforced long fallows. *Farm hygiene is important *There are no simple single solutions for Fusarium wilt and black root rot.	In progress
Gupta Vadakattu CSIRO Adelaide	*The effects of herbicides on soil micro-biology are only transitory (4-8 weeks) *The previous crop and its management practices leave a 'foot print' in the soil biology of a field.	*The use of herbicides does not have long term impacts on soil biology. *Cropping history is important.	Results of project yet to be finalised
Oliver Knox CSIRO ACRI	*The microbiology of the rhizosphere varies between varieties. *There is no evidence of significant microbiological differences between GM and non-GM lines of the same variety.	*Future selection based on rhizosphere qualities? (Designer rhizospheres?)	Extension planed via the Environmental team.
Geoff Baker CSIRO Canberra	*An industry-wide perspective on the status of soil invertebrates under cotton is needed. *A holistic approach to management of invertebrates and diseases is required.	*Can earthworms impact on the ecology of the Fusarium wilt pathogen?	Results of project yet to be finalised
Damien Field (Matt Colloff) USyd	* Building a soil function model	*Interactions between soil functions and enable farmers to identify management options	Results of project yet to be finalised
Nikki Seymour QDPI&F	*Avoiding fallows and including a pasture-ley rotation is good for restoring soil Carbon	*GRDC sponsored findings	In progress
Joe Kochman QDPI&F	*Fallows are best for minimising build-up of Fov	*No recommended crops for rotation with cotton	In progress

APPENDIX 1

Summary of R&E Priorities from Grower Survey and also as identified by researchers at Soil 'Health' Research Review, September 2005:

1. Research & Extension into Soil Biota dynamics: High N rates: effects on soil biota; interactions between soil biota and cotton plant and its subsequent effect on yield potential; comparing NH3 and Urea and their effects on pH and soil biota
2. Application, timing and placement of nutrients and whether it has a negative effect on soil microbes
3. Simple tool for in-field use to measure VAM levels
4. Information on water-injected inoculum
5. Information on how to measure soil biology, using: soil pits, EM surveys, yield maps, biological tests and soil tests
6. Credible information on benefits of biological tests
7. Interpreting soil and petiole test results or 'trends'
8. Benchmarking of soil biota
9. Relationship between VAM and nutrition
10. How to raise organic carbon levels and its effect on soil: structure, compaction & organic carbon levels
11. Trials on biological products
12. Farming systems trial comparing 3 systems: one being - pull, rake and burn; another using Best Management Practice principles; and a third system looking at biological management and their subsequent effects on soil biology
13. Rotation crops impact on soil biota
14. Information about the relationship between soil biota and disease
15. Research comparing and verifying the credibility of chemical soil testing and alternative biological soil testing; and the extension of these results.

The above list is not intended to be a definitive list of proposals for future research, nor does it imply that other suggestions in the 'Grower Survey' (full title here) are not important nor valid. Those suggestions listed above are the research and extension suggestions which were raised both by growers and researchers.

APPENDIX 2

Abbott, L.K and Murphy, D.V. (Eds) (2003) Soil Biological Fertility: A key to sustainable land use in agriculture. Kluwer Academic Publishers, Dordrecht. pp 264. [Included here with permission of publisher - Springer NL]

PREFACE

This book reviews the influences of management practices on soil biota and associated processes that contribute to soil biological fertility in the context of agricultural land use. Although it is generally acknowledged that physical, chemical and biological factors are all important to soil fertility (Figure 1), more attention is usually given to management of the soil chemical and physical environment than to the soil biological environment. Clearly, changes to the chemical and physical environment in soil influence biological processes and subsequently the contribution that they make to soil fertility overall. Certain soil biological processes are stimulated by soil amendments and this includes processes that have both positive and negative effects on plant growth. However, it is possible to override the contributions of some beneficial soil biological processes by solely focusing on chemical inputs to modify the chemical environment. Such an approach undervalues the potential for some key soil biological processes to contribute to plant productivity.

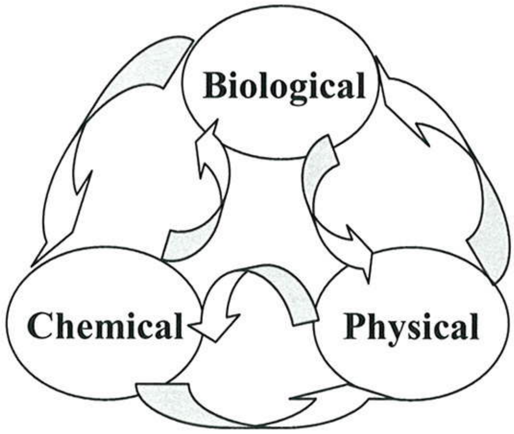

Figure 1 Soil biological, physical and chemical processes are interrelated.

A number of soil biological processes are linked, while others are not. Consideration of the mass of microorganisms in soil as a whole (microbial biomass) is not sufficient for complete interpretation of the effects of land management on soil biological fertility. When one group of organisms or biological processes is altered, others may be affected positively, negatively or not at all. Knowledge of these complex responses can support decision-making aimed at achieving sustainable use of agricultural land. However, the goals are not clearly defined as the biological characteristics of a particular soil type that is specifically managed to sustain the soil resource might be quite different for contrasting land uses such as food production, agroforestry or natural vegetation. Although the level of soil biological activity depends on the soil type, it also depends on the management practices used, particularly the management of organic matter.

Efficient use of nutrients requires a balance between those that are added to soil and those that are released during biological degradation of recent additions of plant/animal residues and older organic matter in soil. Aspects of soil biological activity that contribute to suppression of disease and efficiency of nutrient acquisition by plants are also essential for profitable and environmentally responsible agricultural production systems. Although management practices need to be appropriate for soil and climatic conditions if soils are to be sustained in a suitable biologically active state, many important questions remain unanswered before this can be achieved.

This book provides information about how agricultural land management practices alter aspects of soil chemical and physical fertility with consequences for soil biological processes and *vice versa*. Both fauna (Chapter 2) and microorganisms (Chapter 3) contribute significantly to chemical transformations of nutrients in soil. These contributions are not necessarily independent as the complexity of the food web in soil creates a dynamic interface for changes in nutrient pools. Carbon is an essential component in these transformations whether they are carried out by organisms that derive their carbon from organic matter, especially from plants (living or dead), or from atmospheric CO_2. In concert with chemical transformations of various kinds, both fauna (Chapter 4) and microorganisms influence their physical surroundings to various degrees. These processes are primarily dependent on predator-prey relationships and consequently on the form, availability and chemical state of the original source of carbon. The root environment is a significant component of soil biology and provides carbon to a wide range of soil organisms (Chapter 5). Rhizosphere organisms have major influences on plant nutrient availability and some, such as rhizobia, form specific associations with legumes (Chapter 6) which greatly influence the C:N ratio of plant material. Less specific, although almost ubiquitous associations between agricultural plants and arbuscular mycorrhizal fungi have the potential to increase the efficiency of use of phosphorus in agricultural ecosystems as well as improve soil structure (Chapter 7) but the extent to which is occurs in field soils is difficult to determine and disputed.

If agricultural management practices take account of biological processes in soil, there is a possibility of avoiding development of some severe plant diseases, especially those caused by root pathogens (Chapter 8). However, the complexity of soil biological processes is such that each process cannot be considered independently (Chapter 9). Therefore, an holistic approach to agricultural land management (Chapter 10) requires practices that are based on specific principles (Chapter 11) that ensure the whole range of important biological processes is not overridden. Only then can we develop sustainable farming systems for the future (Chapter 12). The goal is to take this knowledge and apply the principles to the improvement and modification of current farming practices on a localised and regional basis.

This book highlights the pivotal role of soil biology in agricultural ecosystems and demonstrates the responsiveness of soil biological fertility to changes in soil physical and chemical conditions imposed by agricultural management practices. A number of aspects of soil biology are not covered in depth here but they are certainly important to the holistic concept of soil biological fertility. They include the specific impacts of soil microorganisms on physical aspects of soil, the concept and importance of soil biodiversity, and the emerging new methodologies for investigating soil biodiversity and function.

Finally, we are extremely grateful to Merome Purchas for her valuable editorial assistance and general support throughout the preparation of this book.

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