Communities IN LANDSCAPES

Communities in Landscapes project
Benchmark Study of Innovators

Final Report November 2011

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THE UNIVERSITY OF SYDNEY

CARING FOR OUR COUNTRY

Working together to integrate conservation and production across Box-Gum Woodlands

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A multi-partner collaboration including Landcare NSW Inc, Conservation Management Network, Department of Environment Climate Change and Water, Industry & Investment NSW, CSIRO, University of Sydney, STIPA Native Grasses Association Inc, Greening Australia's Florabank and Birds Australia.

Disclaimer

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Contents

Executive Summary

This report was produced as part of the Communities in Landscapes project and provides the combined results of comparisons between 10 grazing innovators and more conventional neighbours from properties across three catchments in NSW.

The "*Communities in Landscapes*" (CiL) project aims to improve management of the Box Gum grassy woodlands and derived grasslands through the provision of targeted and relevant information to land managers in the relevant areas of the Murrumbidgee, Lachlan and Central West catchments. It is based on the logic that landscape-scale change can be achieved by working with farmers and their communities to identify and advise on management practices that will benefit ecosystem function in Box-Gum Woodlands, have positive outcomes for production and increase community capacity to carry on these practices beyond the life of the project.

There are nine (9) project partners: Landcare NSW Inc (lead organization), Grassy Box Woodland Conservation Management Network, Stipa Native Grass Association, CSIRO, Sydney University, Industry & Investment NSW (I&I), Department Environment, Climate Change & Water (DECCW), Greening Australia-Flora Bank and Birds Australia. These partners come from government, community, conservation, production and research sectors.

CiL identified rotational grazing management as a key innovation in the target area that integrates conservation and production objectives. Proponents were aiming to regenerate native perennial grasslands through rotational grazing management. Ten innovators were selected following selection criteria that included more than 5 years of implementation of rotational grazing and a suitable across fence line comparison paddock on a neighbour's property under more conventional management.

All innovator and comparison landholders were interviewed to collect relevant information about property and paddock history and management, all 10 sites were analysed for landscape function and vegetation diversity and basal perennial cover. Four sites were analysed for soil chemical, physical and microbial status.

Results showed that all sites had higher levels of perennial grass and litter cover (9/10 with native grasses) and significant improvements in landscape function as measured by Landscape Function Analysis (soil stability, water infiltration and nutrient cycling). Native vegetation diversity was higher on most sites. On all sites from which soil was sampled soil fertility was improved (higher pH, %N, %C, P (Bray) and lower bulk density) and soil microbial communities were different in several measures including abundance, diversity and activity.

Conclusions were that the rotational grazing practiced by the innovators was successful in beginning the process of the regeneration of native perennial grasslands whilst maintaining commercial viability.

1 Introduction

1.1 Communities in Landscapes project

The "*Communities in Landscapes*" (CiL) project aims to improve management of the Box Gum grassy woodlands and derived grasslands through the provision of targeted and relevant information to land managers in the relevant areas of the Murrumbidgee, Lachlan and Central West catchments. It is based on the logic that landscape-scale change can be achieved by working with farmers and their communities to identify and advise on management practices that will benefit ecosystem function in Box-Gum Woodlands, have positive outcomes for production and increase community capacity to carry on these practices beyond the life of the project.

Communities in Landscapes addresses 3 of the 6 priority areas of *Caring for Our Country*:

(i) Biodiversity and natural icons
(ii) Sustainable farm practices, and
(iii) Community skills, knowledge and engagement

It focuses on three key service areas:

1. Improved targeting of information and management support for land-managers and community groups;
2. Improved knowledge base to inform and support management decisions in Box-Gum Woodland landscapes;
3. Implementation of integrated on-ground activities across properties in six priority local landscapes.

There are nine (9) project partners: Landcare NSW Inc (lead organization), Grassy Box Woodland Conservation Management Network, Stipa Native Grass Association, CSIRO, Sydney University, Industry & Investment NSW (I&I), Department Environment, Climate Change & Water (DECCW), Greening Australia-Flora Bank and Birds Australia. These partners come from government, community, conservation, production and research sectors.

The range of skills and resources provided by these partners presents both challenges and opportunities. These partner organizations shared the broad vision for the project and were active in the target area at the beginning of the project. However, each had its own networks, priorities and ways of operating. A key challenge was to translate the shared vision into coordinated action which meant areas of difference needed to be worked through so that important key messages could be agreed upon.

One of the areas of difference at the outset was the role of livestock grazing and whether strategies existed that would enable farmers to continue profitable grazing enterprises that also generated conservation benefits in Grassy Box Woodlands and derived grasslands. The role of grazed native pastures is of critical importance with a recent managers' guide (Dorrough, Stol et al. 2008) reporting that they support significant plant, bird and reptile diversity (p6) that is higher with lower stocking rates and lower fertilizer use. Higher stocking rates and higher levels of fertilizer use can lead to replacement of native perennial plants by exotic annual species (p10). To increase biodiversity, the guide advocates a diversity of approaches, mentioning seasonal rest, rotational grazing for better control of stock pressure and distribution and continuous grazing at low density. It was guarded about the biodiversity benefits of rotational grazing.

One of the partners, Stipa Native Grasses Association, advocates short periods of high intensity grazing followed by long periods of rest as a means to encourage the recolonisation of cropping and grazing paddocks with perennial native grasses. This is claimed to generate multiple benefits. Whilst other partners were skeptical about the extent to which this was possible, it was agreed that a benchmark study was needed to understand more fully the impact of these grazing strategies and other landholder innovations and to make judgments about whether the project should recommend them as a means of integrating conservation and production in Box Gum Grassy Woodlands and derived grasslands.

1.2 Rotational grazing as a key innovation

The need for the benchmark study was reinforced in the early stages of the project through an interview survey using three participatory rural appraisals (PRAs), one in each catchment. Each of these brought project partners together with locals over 3 days to interview landholders and discuss issues that emerged from the interviews. A report called 'Understanding the context of the 'Communities in Landscapes' project (Ampt, Cross et al. 2010) was written which details the findings of these PRAs and how they helped to provide a reality check to ensure that the project was heading in the right direction.

Many innovative landholders were identified through the PRAs who were aiming to regenerate native grasslands through grazing management. They were convinced that the strategies they were using were making a difference. The project team was convinced that it was important to further investigate this innovation as it appeared to be effectively integrating production and conservation. As a result we set out to analyse its environmental, social and economic impacts through the Benchmark Study of Innovators.

1.3 Aims of the Benchmark Study of Innovators

The Benchmark Study of Innovators aimed to:

- Identify and comprehensively describe innovations that are widely recognized as helping to integrate biodiversity conservation and other environmental benefits with commercial production.
- Assess the economic, social and environmental impact of identified innovative practices.

The hypotheses that guided the study were:

- The key innovation that integrates conservation and production in the study area is grazing management that increases the influence of perennial native grasses across the landscape.
- Innovative landholders exist that have adapted grazing practices to their specific circumstances and have succeeded in increasing influence of perennial native grasses. This has led to positive economic, social and environmental impacts.
- Management principles elucidated from innovators, if widely implemented, will improve conservation and production outcomes.
- Knowledge gained through studying innovators and their management practices can generate understanding of how to have desirable practices more widely adopted.
- Participation of innovators in communication strategies will benefit the innovators themselves and help other landholders improve their conservation and production outcomes.

This report combines and analyses the data from 10 individual studies that were undertaken to compare an innovator with a suitable neighbour in order to analyse the impact of each innovator's management. These individual studies were evaluated and were pooled where appropriate so that broad conclusions could be reached. This report evaluates these conclusions and formulates recommendations about the role of the innovators and their practices on the CiL project and in the management of Box Gum Grassy Woodlands.

2 Methodology

1. Identify up to 10 innovative landholders that satisfy selection criteria and recruit them to the study across the three target catchments.
2. Interview each innovator about the history, nature and apparent impact of their innovative management.
3. Conduct a detailed on-site environmental investigation of the impact of the innovative practices in comparison to an adjacent area under conventional management. The investigation included collecting and analyzing data on landscape function, vegetation, soil physical and chemical properties, soil microbiology and soil invertebrates.
4. Analyse results and prepare an individual report for each comparison. Seek feedback from landholders and amend reports on the basis of the feedback.
5. Prepare a combined report that provides recommendations to the Steering Committee of the Communities in Landscapes project.
6. Analyse the process and produce scientific papers evaluating the effectiveness of the study.

To be able to make meaningful comparisons between sites under different management we identified ten paired sites on neighbouring properties that were similar in most aspects other than grazing management and have been under the current management regime for a minimum of five years (Section 2.1). Innovative grazing management practices were characterized as those that aim to integrate production and conservation by increasing the component of native perennial grasses in the pasture through different forms of strategic grazing, and were compared to more conventional set stocking or continuous grazing strategies.

Interviews (Section 2.2) were conducted with participating landholders to collect information about the history, nature and apparent impact of their grazing management. In addition, a detailed on-site environmental investigation was carried out (Section 2.3) to measure the impact of grazing management on the physical environment in terms of landscape function and vegetation diversity and density. On a subset of sites, soil chemical properties and microbial activity and diversity were also measured (Section 2.4). Invertebrate surveys were also carried out but were impacted on by adverse weather. They are yet to be analysed so will be reported on separately.

2.1 Site selection

Selection was purposive and based on the following criteria:

- successful adoption of a practice or suite of practices for a period of more than 5 years;
- recognition from peers that adopted practice/s have led to improved environmental and production outcomes;
- identification of a suitable sampling site on the property which is adjacent to a comparison site, either on the innovators property or the property of a neighbour; and
- willingness of the innovator and neighbour to participate.

If they appeared to fit the selection criteria and were willing, researchers visited them and a final assessment was made whether the innovator and the site were suitable. They were then formally asked to participate.

Ten benchmark sites were selected using the following procedure:

1. In each of the three catchments, a number of key informants were identified using existing partner networks. These informants were asked to identify a range of landholders in their area. These landholders were contacted and invited to be interviewed as part of the Participatory Rural Appraisals. About 30 landholder s were interviewed in each catchment during November 2009 and February 2010.
2. At each interview, the respondents were asked about people in the neighbourhood who were trying new and different things that might be of interest to the CiL project, especially if they were attempting to integrate production with conservation. These suggestions were added to a list. In most cases it was grazing management that was markedly different from others in the district.
3. People on the list, especially those who had been suggested by a number of people, were contacted about being a benchmark site. If they were apparently suitable and interested they were asked about the history of their changed management and about their neighbours. The criteria for selection at this stage were:
    a. Management that is clearly different and likely to be integrative of production and conservation and had been in place for at least 5 years, but preferably longer. Preference was given to those that had some sort of monitoring or other evidence that what they were doing was making a difference.
    b. A paddock on their boundary with a neighbour or neighbours whose management was more conventional and who, in the judgement of the innovator, would be receptive to being used as a comparison site.
4. The most suitable sites were visited and actual paired sites were selected and where possible, meetings were set up with neighbours. In some cases, it was the innovator who made the first contact with the neighbour and in others it was the researchers. What we were looking for each comparison was:
    a. Landholder willingness to be involved and curiosity about the likely results.
    b. Innovator and comparison paddocks next to each other and separated only by the boundary fence with similar aspect, slope, soil type and position in the landscape. In most cases this meant that they were next to each on either side of a fence that ran down the slope.
    c. No major complicating factors such as creek lines, stock camps, clumps of trees, use of the paddock in an atypical way (eg. use as a holding or sacrifice paddock) that would introduce ambiguity about what had caused observed differences.
    d. Both farmers having a clear idea of the history of the paddocks to be used with information such as cropping and fertilizer history, stocking rates, grazing management readily available.
    e. Likelihood that both farmers would be receptive to the site being monitored regularly in future.
5. When the final selections had been made the landholders were formally asked to participate. In each benchmark site both innovator and comparison landholders agreed to share the data for their property with the other.

Following this procedure we were able to establish 10 Benchmark sites: 3 each in the Murrumbidgee and Lachlan catchments and 4 in the Central West catchment and these were numbered (see Figure

1 below). In some cases it became clear after several visits that there were unforeseen complicating factors. Where this occurred it was recorded and taken into account when the data were analysed. For example, it became clear that in one case an absentee landholder's knowledge of the paddock history was minimal but by then it was too late to change to another site.

Soil chemical, physical and microbiological measurements were done at four of the benchmark sites: BM5, BM6, BM8 and BM10. We were unable to do these tests at all 10 sites due to budgetary and staffing constraints. These sites were chosen according to the following criteria:

- At least one site in each of the 3 catchments (see Table 1).
- Sites where the environmental measurements had shown clear differences between innovator and comparison.
- Landholders and properties that most closely fitted the site selection criteria.

Table 1: Site locations

Site Code	Closest Locality	Catchment	Environmental data	Soil data
BM1	Boorowa	Lachlan	Yes	No
BM2	Murringo	Lachlan	Yes	No
BM3	Book Book	Murrumbidgee	Yes	No
BM4	Narranderah	Murrumbidgee	Yes	No
BM5	Eurongilly	Murrumbidgee	Yes	Yes
BM6	Gulgong	Central West	Yes	Yes
BM7	Geurie	Central West	Yes	No
BM8	Wuuluman	Central West	Yes	Yes
BM9	Goolma	Central West	Yes	No
BM10	Boorowa	Lachlan	Yes	Yes

2.2 Landholder interviews

Each of the landholders was interviewed using a pro forma (Appendix 1) during 2010 by the same researcher. The interviews were conducted in the field, at the landholder's home or in 2 cases by phone. Interviews covered the following:

- the history and current use of the research paddock to be used in the study and how it was used in relation to the rest of property – this was to ensure that it was clear what was being compared and to identify any complicating factors;
- the history of the landholder and the property with particular reference to changes made to land management approach;

- changes in property condition over time particularly in relation to any changes in management approach;
- the contribution that their agricultural production makes to income compared to other sources of income – this is to ensure that the research paddock and property play a significant role in income generation, that is they have to pay their way;
- future uses of the research paddock and plans for the property and landholder.

The interviews were recorded and useful information was extracted and tabulated so that it could be incorporated in the analysis for each Benchmark Study site. A summary table of the information was included in a report to each landholder who were invited to check to see that the information was correct, or if not to suggest changes.

2.3 Environmental measurements at each benchmark site

2.3.1 Landscape Function Analysis

Landscape Function Analysis (LFA) is a procedure for the objective assessment of 'soil health' and reflects the capacity of the soil to act as a habitat for plants. LFA is easy to learn and needs only simple field equipment, yet is based on careful scientific research. It was developed over 30 years by David Tongway and other CSIRO scientists. The method used is publicly available via the CSIRO website (Tongway 2008) and its role in restoring landscapes is well documented (Tongway and Ludwig 2011). It is being widely used around the world and we believe it has great potential for use by landholders. Preliminary studies indicate that landholders readily grasp the key concepts of LFA and are competent users of LFA after a 2 day training program. It generally makes good sense to them in that it systematically assesses important processes and gives results quickly. Even if they don't use it to do formal assessments, it can become part of their approach to reading their landscape (Ampt, Tongway et al. 2008).

LFA involves a down slope transect which is divided into zones based on whether the slope is holding and using vital resources (patches) or losing them (interpatches). Each patch and interpatch is named and its length along the transect is recorded, as is the width of each patch. This stage is called landscape organisation (Fig 1). Each of the identified zones is then assessed for soil surface condition using 11 indicators of soil health. This stage is called Soil Surface Assessment (Fig 2).

Data from these two stages are entered into a specially designed computer program, which assesses how well each site is functioning in terms of:

- stability (is the surface eroding or at risk of erosion? Is material being lost or likely to be lost?)
- water infiltration (what is the likelihood that water that falls will soak in or run off? Will the flow of water be slowed down?) and
- nutrient cycling (is there evidence that the water and nutrients are being used and cycled by plants?).

Fig 1: Landscape Organisation

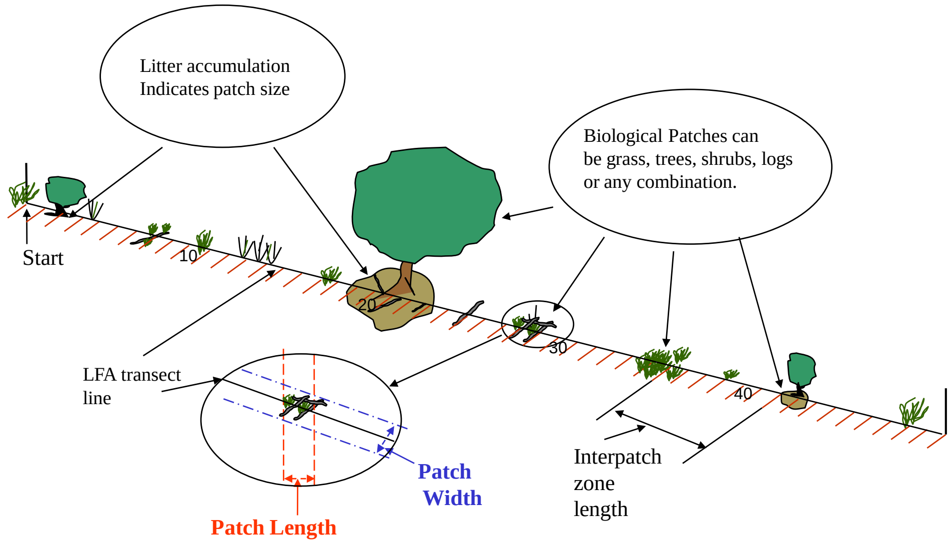
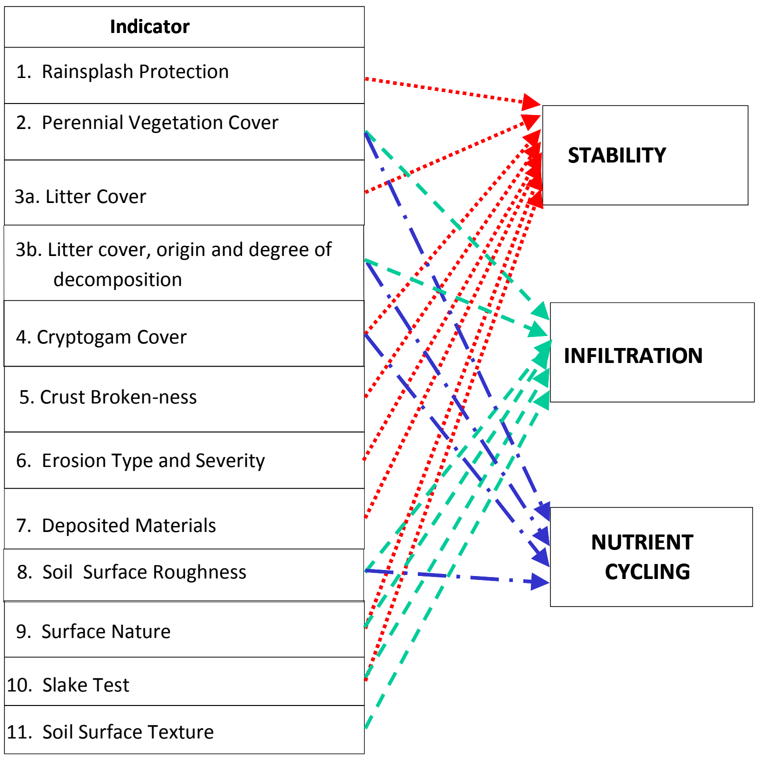


Fig 2. Soil Surface Assessment: Contribution of soil surface indicators to the three indices of Stability, Infiltration and Nutrient Cycling



Stability, Infiltration and Nutrient Cycling are expressed as numbers in a scale from 0 to 100, with higher values indicating better function. By comparing these values to reference sites, it is possible to work out how well a site is functioning. If you do LFA regularly, you can collect evidence for how your landscape is changing over time.

A landscape with high functionality has a high retention of vital resources such as water, topsoil and organic matter. Dense patches of perennial grasses cause overland water flow to slow down, increasing water infiltration and “sieving out” topsoil, litter and seeds. Dense perennial grasslands therefore have high landscape function.

By contrast, landscapes with a low functional status tend to lose or leak existing material resources, fail to capture sufficient incident rainfall and are unable to capture new replacement materials. A reduction in the size, number, spacing or effectiveness of perennial grass patches may be an indication of degradation. Degraded grasslands with few perennial grass patches are unable to retain resources flowing across the landscape and therefore have low functionality.

The LFA indicator values do not absolutely indicate the functional state of a site. Rather, they are a tool to monitor change over time, or to compare the functionality between sites in a particular landscape. For this study, initial benchmark data was collected to as the first step for potential long-term monitoring and to compare sites with different management regimes at the same time and location.

LFA transects were set up on each of the 20 sites and analyses were completed by the same person during April and May 2010. The first 2 sites were re-done after all others had been completed to ensure that the methodology had been consistently applied throughout.

2.3.2 Vegetation analysis

On each site plant species diversity (number of different plant species) was assessed along the LFA transect and two more 50m parallel transects at least 5m either of the LFA transect . At every one meter interval along the three transects the plant species intersecting the meter point across its basal parts was recorded. This resulted in a maximum of 150 plant records per site, with data points recorded as litter or bare soil if no basal hits were made. Plants were identified according to the list of species and genera in Table 3 and amalgamated into species groups.

Basal perennial cover of the dominant perennial grass was estimated using the Point-Centred Quarter (PCQ) method, widely recognised as being a reliable plot-less method for quantifying components of vegetation (Mitchell 2007). If the distance between perennials was too large, the Wandering Quarter (WQ) method was used instead. Both PCQ and WQ procedures followed those described as part of the suite of methods called Landscape Function Analysis (Tongway and Hindley 2005) p68-9. These methods allowed the basal perennial cover of the dominant perennial grass to be estimated in each site.

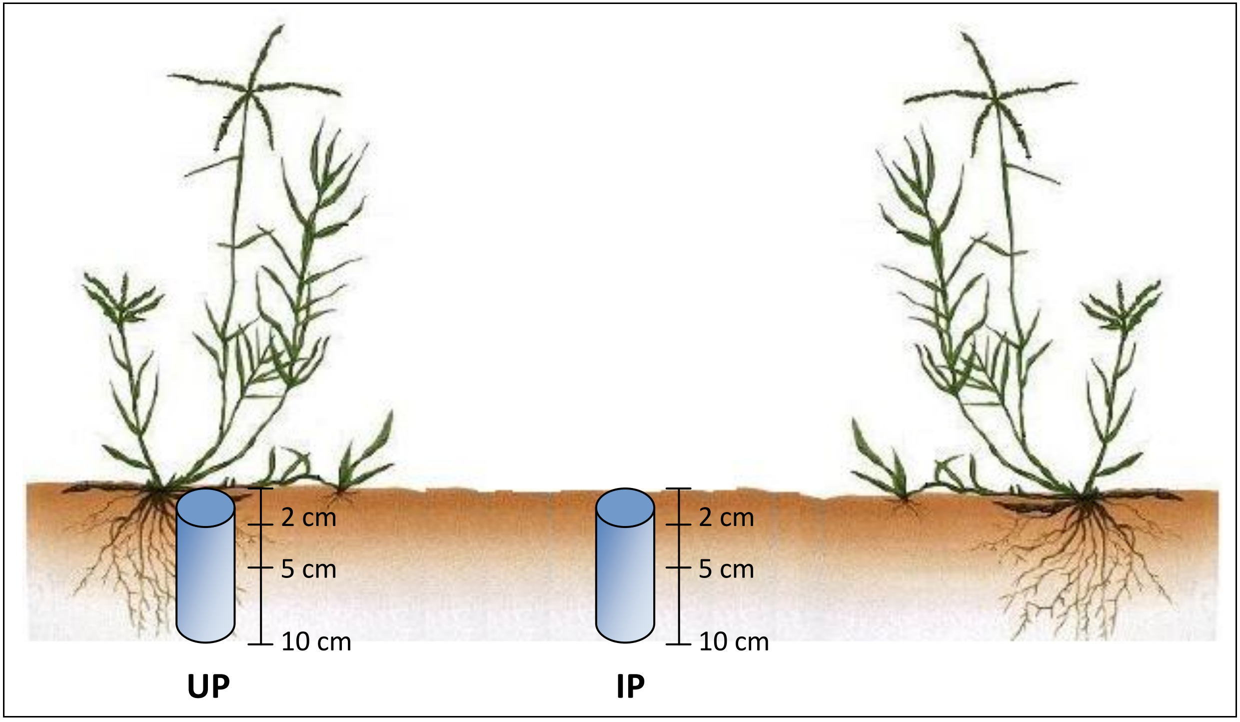
2.4 Soil measurements at four benchmark sites

Soil chemical, physical and microbiological measurements were done at four benchmark sites: BM5, BM6, BM8 and BM10. We were unable to do these tests at all 10 sites due to budgetary and staffing constraints.

2.4.1 Soil chemical and physical properties

Soil samples were collected along the LFA transect at the dominant perennial grass species and from in between perennial grass plants. The dominant perennial grass plant was determined based on basal area and abundance. On each site, 15 target plants of the dominant perennial grass species with a minimum butt size of 4 cm^2 were marked and soil samples taken from right underneath the plant (UP) at three depth intervals; 0-2cm, 2-5cm and 5-10cm as shown in Figure 3. Another 15 samples at the same depth intervals were collected at inter-plant locations (IP) in between sampled grass plants and the next perennial grass plant with at least 10cm to the next perennial plant on either side.

Fig 3. Sampling locations and depth intervals for UP and IP soil samples



The following soil chemical and physical tests were done.

1. Soil pH (1:5 water) Rayment and Higginson 4A1
2. Soil Conductivity (1:5 water µS/m) Rayment and Higginson 4B1
3. Soil P (Extractable Bray |Phosphorus mg/kg P) Rayment and Higgins
4. Total Carbon %C (LECO CNS2000 Analyser) which equates to organic carbon due to low pH
5. Total Nitrogen %N (LECO CNS2000 Analyser)
6. Carbon/Nitrogen Ratio (calculated from 4 and 5)
7. Soil Bulk density

2.4.2 Soil Microbial analysis

Soil micro-organisms regulate a majority of ecosystem processes in soil that are essential for plant growth, soil health and sustained productivity. These organisms play an important role in facilitating nutrient uptake by plants, improving soil quality through build-up of higher soil organic matter, reducing disease incidence in plants and reducing environmental degradation through soil erosion and nutrient losses. To do this soil microbes require carbon and nutrient sources for their growth, organic matter and suitable soil physical and chemical conditions to support their activity. In Australian pasture systems, factors that are known to limit microbial activity are soil compaction, lack of carbon and available nutrients, chemical inputs and unsuitable moisture conditions.

Soil micro-organisms are extremely abundant (up to 10 billion per gram of soil), diverse (many millions of different species of bacteria and fungi exist in soils) and poorly understood by science. Microbiological research is currently being revolutionized with the use of gene technologies. There is no single test or technique that is widely accepted as the best way to 'measure' them or to assess their impact in different locations or under different management regimes. We wanted to assess, if possible, the broad types of organisms present, how abundant they were, and whether there were any measurable differences in the way the mix of organisms present functioned in the soil. For this project we used the services of a consultant qualified and experienced in soil microbiological techniques which he uses in the reclamation of mine sites.

Soil samples for microbial analysis were collected to a depth of 10 cm at the same locations as for soil chemical properties (UP and IP). Samples were analysed for soil moisture content, microbial numbers and community functionality. Standardized sample treatments and isolation media were utilized to distinguish the numbers - as colony forming units (CFU) - of different populations of non-filamentous bacteria, actinomycetes (bacteria that produce filaments) and fungi. Abundance of each group was estimated by counting CFUs.

The functional properties of the bacterial and fungal communities were determined using BIOLOG microtitre plates that measure the activity of microorganisms through their utilization of 95 different carbon sources. Microbial communities in soils consist of many millions of different species. The mix of species in any soil community changes depending on the carbon sources available in the soil environment. Samples with similar carbon use profiles contain a similar microbial community which means that the soil environment from which they came was similar. Samples with different carbon use profiles contain different microbial communities with a different mix of species. This means the soil environment from which they came was different.

Microbial diversity was estimated from the number of different C sources in BIOLOG plates used by each microbiological community, and activity by the extent to which different C sources on the BIOLOG plates were utilized by each community.

Results were compared between sites (innovator and comparison) as well as between sample locations within sites (under plant (UP) or in between plants (IP)) to test for significant differences in microbial numbers and functionality.

3 Results and discussion

Data from each of the ten benchmark sites were analysed. An individual comparison report was prepared for each of the ten benchmark sites and circulated to research advisers and project partners for feedback. The report for each benchmark site was also sent to the relevant innovator and comparison landholder for feedback. These reports were then edited and made available via the Communities in Landscapes website. Data from all ten sites was then combined where appropriate and analysed for this report.

The research paddocks were part of the normal grazing routine on all sites and were not considered by any of the innovators to be their best paddocks. Researchers asked to be shown paddocks considered to better examples of management. In most cases there was greater apparent plant diversity in the innovators' 'best' paddocks than in the research paddock although this wasn't measured. In all cases innovators viewed the research paddock as a 'work in progress' on which changed management had had an impact but more improvement was expected. In most cases they intended to further sub-divide the research paddock to achieve a more intense and more uniform grazing, which they anticipated would lead to recruitment of more desirable perennial native grass species.

Considerable time and thought went into deciding whether it was valid to include all ten separate comparisons in a combined analysis. This was done by examining the measured differences in landscape function and vegetation between the two sides for each Benchmark site in relation to the management information for each site. From this an assessment of the validity of the comparison for each benchmark site was made and summarised in Tables 2a, b and c. Whilst there were some differences due to factors other than grazing management, the judgement was made that the most significant factor that is likely to have contributed to the differences at each site was rotational grazing.

Table 2a: Assessment of the validity of the comparison for each site in the Murrumbidgee Catchment

Site Code	Observed differences in the paddock		Impact of management differences and assessment of the validity of the comparison
	Landscape Function Summary	Vegetation Summary	
BM3	Innovator side is dominated by perennial native grass patches and is more stable, more capable of retaining water and more able to cycle nutrients due to higher overall perennial grass and litter cover.	Plant species diversity is similar on both sides, innovator side consists mainly of native perennial grasses, comparison side annual forbs and grasses (native and introduced).	Innovator applying 1 day high intensity grazing and about 100 days rest, very low current SR (1DSE/ha) and no P since 1999. Comparison extreme SR (30DSE/ha) continuous grazing with regular P application. Neither strategy is stabilised: innovator in transition aiming for more productive, higher functioning native pastures; comparison in process of inter-generational succession which was unresolved.
BM4	Dominant patch types on the innovator side (grass and litter patches) more highly functional than the less functional grass patches and 60% bare soil inter-patches on the comparison side. As a result innovator side was more stable, more capable of retaining water and more able to cycle nutrients.	Plant species diversity was low on both sides: higher number of introduced weedy forbs and legume species on comparison side, rather than native species. Basal cover of perennial grasses higher on innovator side and likely to be an underestimate.	Cropping dominated landscape: innovator strategy radical for the area aiming (through opportunistic pasture cropping and intermittent grazing with long rests) for productive and profitable grazing on perennial native pasture system. Comparison is conventional winter cropping (7 years) then lucerne (3 years) - last grazing break failed in test paddock due to drought. Significant environmental benefits apparent due to innovator management despite limitations in implementation of rotational grazing.
BM5	Innovator side is more stable, more capable of retaining water and more able to cycle nutrients due to the dominant patch types (shrub, dense grass and sparse grass patches) covering all of the innovator side - >40% bare soil on the comparison side.	Recorded plant species diversity was higher on the innovator side (22 species) than on the comparison side (13 species). Innovator side had higher diversity of native grasses and forbs than comparison side, but also higher diversity of weedy forbs.	Innovator managing for native grass seed production with extremely low SR continuous grazing and occasional strategic short heavy grazing. Comparison short rest rotational grazing, at low SR. Length of rest is the key difference and is having significant impact on function and diversity.

Table 2b: Assessment of the validity of the comparison for each site in the Lachlan Catchment

Site Code	Observed differences in the paddock		Impact of management differences and assessment of the validity of the comparison
	Landscape Function Summary	Vegetation Summary	
BM1	Innovator side is more stable, more capable of retaining water and more able to cycle nutrients due to higher perennial grass and litter cover.	Species diversity was low, consisting mostly of annual grasses on both sides, higher diversity likely with more sampling on innovator side. *Phalaris* very dominant on the innovator side; Wallaby grass relatively abundant on the comparison side.	Clear example of rotational (smaller paddocks, longer rest) and cessation of P use compared to set stocking with a higher P application. Innovator has cattle, comparison has sheep. Innovator paddock dominated by *Phalaris* which has positive impact on function and negative impact on diversity.
BM2	Innovator side more stable, more capable of retaining water and more able to cycle nutrients mostly due to higher perennial grass and litter cover. The dominant patch type on the innovator side (Red grass patch 76%) is more highly functioning than patch types on the comparison side.	Species diversity higher on innovator than on comparison side and difference would increase with more sampling. Diversity on innovator side was due to native perennial grasses and forbs. Diversity on the comparison side mainly due to introduced perennial and annual grasses.	Innovator - short duration high intensity grazing with lower SR and fertilizer application compared to less 'severe' rotational system with pig manure application and higher SR on comparison side. Benefits of rotational grazing on function and native plant diversity clearly evident.
BM10	Landscape Function is significantly better on the innovator side due to dominance of native perennial grass and less bare ground. As a result the innovator side is more stable, more capable of retaining water and better able to cycle nutrients than the comparison side.	Higher proportion of native perennial grasses and lower proportion of native forbs on innovator side but *Erodium cicutarium* (Common Storksbill) main native forb on comparison side considered pasture weed. Several desirable native grasses present on innovator side are absent or less abundant on comparison side.	Innovator runs cattle at very low current SR due to poor inherited land condition and drought; rotational grazing more severe in past 5 yrs and no fertilizer application for 18 yrs. Comparison raises fat lambs using yearly fertilizer application, higher SR, infrequent, short and variable rest. Clear example of the benefits of higher perennial grass and litter due to rotational grazing system.

Table 2c: Assessment of the validity of the comparison for each site in the Central West Catchment

Site Code	Observed differences in the paddock		Impact of management differences and assessment of the validity of the comparison
	Landscape Function Summary	**Vegetation Summary**	
BM6	Difference between the sides largely due to more litter and the dominant patch type (perennial grass patch) covering most of transect on innovator side. As a result innovator side more stable, more capable of retaining water and more able to cycle nutrients.	Species diversity was very low on the innovator side with a total of 6 species with 19 on the comparison side. Native perennial grasses were dominant (87.6%, red grass 73.3%) on the innovator side and annual grasses (41.5%, stink grass 19.3%) on the comparison. Native forbs were not recorded on either side.	Innovator side has higher SR, higher intensity shorter duration grazing with longer rest and pasture cropping. Comparison has conventional cropping followed by introduced pasture. Higher innovator SR suggests innovator system more productive with better overall environmental outcomes although less plant diversity.
BM7	The differences between sides largely due to more litter on innovator side and 100% cover by perennial patches compared to 25% on comparison side. As a result the innovator side is more capable of retaining water and more able to cycle nutrients due to higher perennial grass and litter cover.	Plant species diversity good both sides which would rise with more sampling. Innovator 13 species (5 native perennial grasses with combined basal cover of 73% including important BGGW species Queensland bluegrass); 12 on the comparison side (native perennial grasses 26.7% annual grasses 20.7%). Good litter cover between plants on innovator side, bare ground on comparison.	Innovator side had rotational grazing cattle and sheep at very high intensity, very short duration grazing with very long rest, with minimal cropping disturbance and compost teas applied. Comparison had more cropping disturbance and higher fertilization for hay production (as main income source), shorter rests from cattle only grazing, longer and less intense grazings. Innovator apparently sustaining higher production with less fertilizer and better environmental outcomes.
BM8	Large and significant difference in landscape function between two sides due to dense perennial grass patches on the innovator side. As a result innovator side more stable, more capable of retaining water and more able to cycle nutrients than comparison side, mostly due to higher perennial grass and litter cover.	Native perennial grasses were dominant species group on both sides but innovator also had 15% introduced perennial (cocksfoot). Diversity of native forbs greater on comparison side, greater weedy forbs diversity on innovator. Several species important for Box Gum Grassy Woodlands recorded on both sides.	Innovator - decade of rotational grazing (past 6 yrs at higher intensity shorter duration moderate rest) preceded by decade of regular P fertilizer application with introduced pasture. Comparison - long term low input continuous grazing, no fertilizer applied, no introduced pasture ever established, very low stocking rate. Excellent comparison of traditional low input strategy with moderate intensity rotational grazing strategy resulting in higher production with better environmental outcomes except possibly native plant diversity.
BM9	Difference largely due to patch types on the innovator side being more highly functional in terms of water infiltration and nutrient cycling than patch types on comparison side. As a result innovator side more capable of retaining water and more able to cycle nutrients due to higher perennial grass and litter cover.	Species composition and abundance very different on both sides. Innovator - native perennial grasses were dominant species group in terms of diversity and basal cover including several native species highly significant for BGGW. Comparison - native perennial grasses & legumes co-dominant in terms of basal cover and larger proportion weedy forbs than innovator side.	Innovator stud merinos and cattle, organised and methodical rotational grazing, fertilizer application stopped 5 yrs ago. Comparison - cattle only, haphazard grazing, some periods of neglect and overgrazing, No fertilizer application for 15 yrs. Innovator more intensive and more productive than comparison with better overall environmental outcomes.

3.1 Management

Table 3 presents a summary of the management systems described by participants during the interviews. All innovators practiced a form of adaptively managed grazing which was broadly consistent with 'holistic time-control grazing methods' and the principles of cell grazing as defined by McCosker (McCosker 2000). All innovators had either a formal or an informal method for monitoring the impact of grazing that resulted in frequent variations to their grazing plans due to shifting environmental and market conditions. All were highly adaptive in their approach to grazing management and all were working to better understand how their land and livestock respond to changing conditions. All emphasized the need to be flexible and conservative and none were apparently applying a rigid formula. However, they did share similar management principles such as: maintain 100% ground cover; generate enough stock impact to turn most standing plant material into litter; don't graze the same paddock at the same time every year; match the amount of feed to the grazing pressure; and provide sufficient time for recovery after each grazing to allow growth to more than replace material removed at the last grazing.

All innovators expressed the view that their management enabled them to reduce their exposure to risk. Examples mentioned included: maintaining groundcover reduced the risk of soil loss from storm events; having standing feed increased the interval between the onset of a dry period and running out of feed, making it possible to reduce stock numbers before risking damage and before others were doing the same; and reducing purchased inputs reduced the risk of adverse economic consequences when returns are lower than expected.

One property (BM5) was an outlier in that it was a small property from which the primary income generating enterprise was the harvest of native grass seed. A small number of stock that had the run of the property most of the time were grazed at a very low stocking rate (<1DSE/ha) with additional grazing impact from a significant kangaroo population In addition, the property had a periodic short intense grazing from a large mob usually less often than once a year when the conditions were considered suitable. One other property (BM4) was in a prime cropping area and didn't yet have the infrastructure or management options to properly implement the desired grazing management regime. Both BM4 and BM5 implemented long rest periods consistent with the other innovators so were included in the multi-site comparison.

The remaining 8 innovators were mostly well-set up for rotational grazing and were implementing a system which involved short grazings (1 to 7 days) of sufficient intensity that the whole paddock would be disturbed relatively uniformly (standing grasses trampled, plants grazed to a pre-determined level) in the time the animals were on the paddock. The paddock would then receive a rest of between 50-240 days with most between about 90-120 days.

All innovators did some form of feed budgeting which involved estimating the amount of feed in a paddock just prior to the next grazing to determine how many grazing days were available in that paddock. From this, and assessments of paddocks further ahead of the stock, they adjusted numbers well in advance of running out of feed. Further south where rainfall is usually winter dominant, this meant having sufficient standing feed in paddocks in late spring to last for the entire summer. Any pasture growth due to summer storms was considered a bonus that provided litter and feed beyond budgeted requirements.

Table 3: Summary of management

Characteristic	Innovators	Comparisons
Property Size (ha)	121-2832 average 1526	199-2711, average 1052
No. of paddocks	36-200	8-39
Enterprises include:	wool stud, wool, cattle, lamb, cropping, native grass seed	wool, lamb, cattle, crops
Ave paddock size (ha)	7-40 (some larger but temp fencing used)	Big variation
Research paddock (ha)	3-72	14-202, average 59
Years of current management*	6-18	9 to 60
Grazing management *	8 do rotational grazing, 2 less systematic but consistent long rest periods	Most continuous grazing, some with short rests, 1 fodder crops
Average stocking rates		
(DSE/ha) MCMA	7.4 (Current v. low), <5, <1	30 (VH#), 5, 4
LCMA	6-8, 4-5, 2.4-3.2	7.4, 6.5, 6.3
CWCMA	6.2 (H#), 4.7(H#), 3.6, 5(H#)	3.7, 2.5, 2, 5
Grazing period /cycle*	1 to 7 days for rotational grazers	6 – 365 days
Rest period / cycle*	80-180 days	0 - 60 days
Fertilizer inputs *	2 under crop only but reducing, others none	2 none, all others regularly - usually with cropping
Cropping cycle *	2 only crop, 1 every 4 yrs, the other occasionally	Varied
Pasture type *	All native, some introduced species remain, none sown.	Mostly native, some introduced, 1 fodder
Landholder objectives	Maintain or improve income primarily from grazing enterprises while increasing native perennial grass and litter cover, manage climatic and market risk, manage for increased biodiversity, function and 'grassland succession', many influenced by HM type approaches.	More varied objectives, with a mix of income and succession related objectives. No stated 'environmental' objectives apart from one who aimed to improve soil. Many in transition.

*On research paddock # H (high) or VH (very high) for district (see Appendix 2)

In order to be this flexible, some had abandoned stock breeding and had simplified their livestock enterprises to allow fewer mobs. Some were trading in stock to have maximum flexibility. Others had a nucleus breeding herd or flock that was small enough to require no hand feeding in all but the worst droughts. Three innovators maintained Merino studs and compromised their rotational grazing systems during lambing when they generally left lambing ewes alone until after lambing marking. One operated a relatively intensive beef and lamb production enterprise.

Comparison sites were usually grazed more or less continuously, with the exception of when the paddock looked bare and needed a rest. Stocking rates overall varied from very low to above average for the district. In some sites innovators' stocking rates were higher than comparisons' (BM6, 7 & 8).

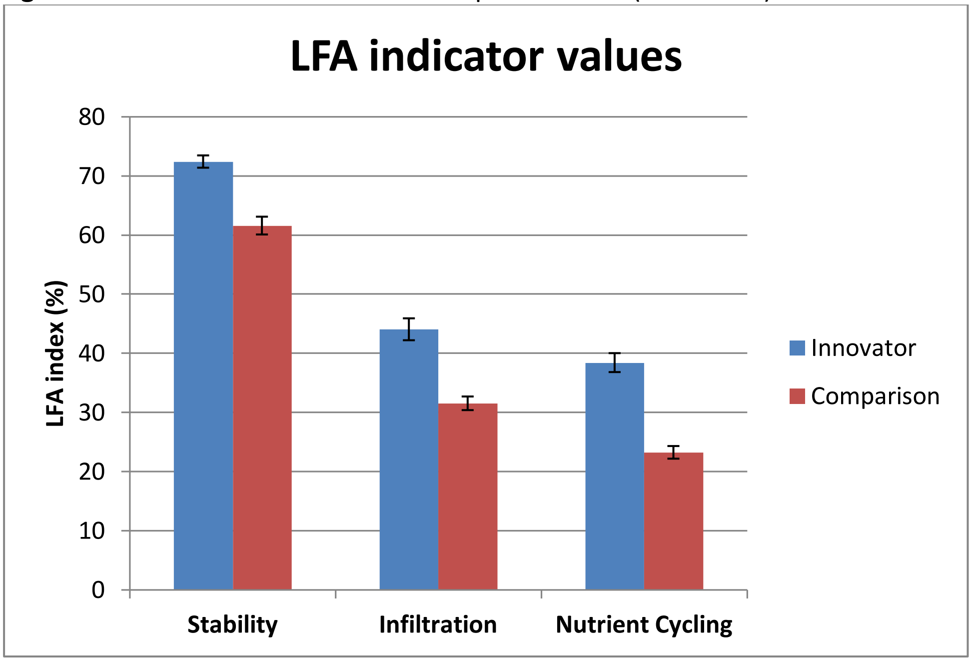
3.2 Landscape Function

On all sites the innovator side showed increased values for all three landscape function indices. These increases were all statistically significant and highly likely to reflect higher levels of soil stability, water infiltration and nutrient cycling. Table 4 and Figure 4 show the result when all sites were analysed together using a paired t test.

Table 4. Differences in LFA indicator values between innovator and comparison sites (mean ± SE) and the p-values for paired t-tests.

LFA indicator	Innovator	Comparison	Difference	p-value	% increase
Stability	72.4 ± 1.0	61.6 ± 1.5	10.8 ± 1.1	<0.001	17.5
Water Infiltration	44.0 ± 1.9	31.5 ± 1.2	12.5 ± 1.0	<0.001	40
Nutrient Cycling	38.4 ± 1.6	23.2 ± 1.1	15.2 ± 0.9	<0.001	65

Fig 4. LFA indices for innovator and comparison sites (mean ± SE)



The data from the comparison side were normally distributed but the innovator side was not, suggesting that values were approaching a threshold value on the innovator side. Non-parametric tests were applied to these data due to the lack of normality and the differences were again shown to be statistically significant.

The stability indicator increase is 17.5%. This suggests that the risk of soil loss through erosion is reduced because there are few if any visible signs of erosion or transport of soil on the slope due to the combined effects of greater rain splash protection, higher litter cover, and a more open and stable soil fabric. The magnitude of that reduction is not clear from the data as it would depend on soil type. Where soil aggregate stability has been plotted against LFA Soil Stability index a strong correlation has been obtained. An increase in the soil stability indicator means that soil loss has been reduced as a result of the rotational grazing practices.

The water infiltration indicator increase is 40%. This indicates that in any rainfall event, more water will infiltrate the soil due to the combined effects of greater soil surface protection, more open soil fabric and greater soil aggregate stability and higher perennial plant and litter cover interrupting and slowing the movement of water down the slope. It is not possible to say by how much water infiltration would be increased without directly measuring it, but the increase in the water infiltration index suggests it would take a higher intensity rain event for a longer duration to generate run-off from the rotationally grazed surface. As a result a higher percentage of the rainfall in any but the lightest rain events would infiltrate, leading to an increase in moisture in the soil profile over the comparison site.

In a semi-arid rangeland study which used LFA in parallel with rainfall simulation and the measurement of runoff and sedimentation (Munoz-Robles, Reid et al. 2011) data were collected that suggested that LFA index of water infiltration correlated with measured runoff and LFA index of soil stability correlated with sedimentation rate (unpublished data, N Reid 2011: Pers. Com).

The nutrient cycling indicator increase is 65%. This is a very substantial increase caused by the combined effects of greater perennial cover, more litter and a greater degree of litter decomposition. It suggests that more plant material is being produced and a larger proportion is becoming litter, and that litter is being actively decomposed to produce plant available nutrients and soil carbon. When measurements have been done there is a strong correlation between nutrient cycling index and measured soil respiration and soil carbon levels (D Tongway 2010: Pers. Com.).

Taken together these LFA data suggest that the grazing management strategies of the innovators are shifting the landscape towards a perennial native grassland that is more capable of retaining vital resources of water, soil and litter and utilizing them to produce plant material that generates positive feedback leading to further improvement.

3.3 Vegetation

Vegetation data generated a comparison of native and exotic plant richness and percentage cover and mature perennial grass basal cover (Table 5). These data show a small but statistically significant increase in live vegetation cover and a large and significant increase in the amount of the ground that is covered by perennial grasses. In all but one innovator site the perennial grasses were native. Whilst the differences in native and exotic plant richness and cover were not statistically significant, the trend is for an increase in native plant richness and native plant cover on the innovator side.

Table 5. Differences in species richness (number of species) and abundance (% basal cover) between innovator and comparison sites (means ± SE) and the p-value for paired t-tests.

Variable	Innovator	Comparison	Difference	p-value
Native plant richness	8.2 ± 1.6	7.0 ± 1.3	1.2 ± 1.3	n.s.
Exotic plant richness	5.5 ± 0.7	6.3 ± 0.7	-0.8 ± 1.3	n.s.
Native plant cover (%)	58.2 ± 7.5	45.2 ± 7.2	13.0 ± 9.0	n.s.
Exotic plant cover (%)	30.8 ± 7.6	37.3 ± 6.5	-6.6 ± 8.6	n.s.
Live vegetation cover (%)	89.2 ± 3.9	82.8 ± 5.1	6.4 ± 2.3	<0.05
Mature perennial grass basal cover (m^2/ha)	515.0 ± 118.9	194.6 ± 72.2	320.4 ± 92.1	<0.01

Note: basal cover based on PCQ and WQ data, all others based on vegetative diversity transects.

Native vegetation diversity on the innovator side was similar or higher on 8 of the 10 sites (see Tables 2a, 2b and 2c). On the 2 sites where it wasn't:

- BM6 innovator side was dominated by red grass and was subject to higher stocking rates than its comparison.
- BM8 innovator side had lower native diversity including fewer native forbs than its comparison. This can be explained by the long history of pasture improvement including regular P application on the innovator side and very low historic stocking rates and no pasture improvement on the comparison side.

Some answers are not so clear: in some cases this strategy has led to less plant diversity probably because the paddock became more uniform with a larger proportion covered by dominant perennial grasses (native in all cases but one) with increased litter cover between plants. This backs up the work by CSIRO as described in (Dorrough, Stol et al. 2008) which suggests that continuous grazing of native pastures at low stocking rates without fertilizer application generates more plant diversity than rotational grazing systems. This probably means that rotational grazing may not help with conservation of rarer, more grazing sensitive forbs, but will have other benefits. For example, is it better to have more land at a more highly functional state through rotational grazing at the expense of rarer plants, or to favour these plants over functionality and productivity? Again (Dorrough, Stol et al. 2008) recommend a diversity of approaches, suggesting that it is good for some land to be under each strategy. Given the diversity of landholders and their variable readiness to change, recommending rotational grazing more widely is sensible.

These data indicate that the innovator side has vegetative characteristics that are closer to native grassland than the comparison side. We can cautiously say that the rotational grazing strategies that are the main differences between innovators and comparisons are leading to shift towards native grasslands.

Vegetation surveys done over time in these and other properties will shed light on the extent to which the dominant perennial changes with the seasons and with the length of time a given paddock is under a particular type of management. The community of practice suggests that it is possible to facilitate a succession from hardier, more grazing tolerant species such as *Aristida*, *Austrostipa* and *Bothriochloa* towards more productive and palatable species such as *Microleaena*, *Austrodanthonia*. This was supported on BM5, 9 & 10 where these latter species were more abundant on the innovator side. On the other sites, while rotationally grazed paddocks may be dominated by a small number of species at any one time, these species may change with different seasons and with management. Ongoing data collection on these sites would provide evidence of whether this does occur.

3.4 Soil chemical and physical properties

The key soil properties relevant to plant growth (pH, P, C, N and bulk density) are significantly improved under the innovators' strategies (Table 6). This is despite generally lower current levels of fertilizer application and fewer legume plants than the comparisons'. The range of P levels (3-13 mg/kg) is low for maximum growth of crops and introduced pastures but is consistent with levels usually found in native grasslands. While the innovators' P levels were higher they were not in the range (>20) that is generally considered to reduce the persistence of native grasses and native trees.

These data are consistent with the increased nutrient cycling index and the higher basal cover of perennial grasses. It suggests that the perennial grasses are accessing a larger volume of soil and are probably generating more plant growth, a larger percentage of which is returning to the ground as litter, and being decomposed leading to higher levels of C, N and P in the soil. The higher nutrient levels in the top layers of the soil support this interpretation. The increased biological activity and higher soil carbon levels in the top layers are apparently leading to larger soil pores which is evidenced by the 14% lower bulk density on the innovators' sides. This is also consistent with increased water infiltration and soil stability as measured by LFA. This, together with increased soil pH suggests that the innovators' grazing management is increasing overall soil fertility.

In recent years the application of P to pastures has declined for reasons including increasing cost of fertilizers, ongoing drought conditions and a perception that the response gained does not compensate for the cost. With continued removal of crops and animal products this could lead to depletion of soil reserves. Rotational grazing appears to assist in the utilization of soil reserves of plant nutrients probably through increased rhizosphere volume and production and decomposition of more litter. This study has not revealed any depletion but with ongoing production and no fertilizer application this may occur in future. Ongoing monitoring of production and landscape function should reveal this should it occur in future.

Table 6. Soil chemical and physical properties on innovator and comparison sites (means ± SE) and their p-value for a paired t-test.

	Innovator	Comparison	Difference	p-value
Soil PH (1:5 water) (0-10 cm)#	**5.48 ± 0.2**	**5.23 ± 0.23**	**0.26 ± 0.16**	**n.s.**
0-2cm	5.57 ± 0.10	5.38 ± 0.12	0.19 ± 0.08	<0.05
2-5cm	5.40 ± 0.12	5.15 ± 0.12	0.25 ± 0.10	<0.05
5-10cm	5.50 ± 0.09	5.21 ± 0.11	0.29 ± 0.09	<0.01
Soil Conductivity (1:5 water dS/m) (0-10 cm) #	**0.12 ± 0.02**	**0.10 ± 0.01**	**0.01 ± 0.03**	**n.s.**
0-2cm	0.23 ± 0.04	0.17 ± 0.02	0.06 ± 0.04	n.s.
2-5cm	0.12 ± 0.01	0.11 ± 0.01	0.01 ± 0.01	n.s.
5-10cm	0.07 ± 0.00	0.08 ± 0.00	0.00 ± 0.00	n.s.
Extractable Bray I Phosphorus (mg/Kg P) (0-10 cm) #	**6.81 ± 1.58**	**5.40 ± 0.53**	**1.41 ± 1.07**	**n.s.**
0-2cm	13.79 ± 1.25	11.11 ± 0.84	2.68 1.19	<0.05
2-5cm	7.10 ± 0.64	5.31 ± 0.21	1.79 ± 0.61	<0.01
5-10cm	3.84 ± 0.28	3.17 ± 0.11	0.67 ± 0.26	<0.05
Total Carbon (% C) (0-10 cm) #	**2.61 ± 0.16**	**1.93 ± 0.21**	**0.69 ± 0.11**	**<0.01**
0-2cm	5.19 ± 0.16	3.40 ± 0.18	1.78 ± 0.19	<0.001
2-5cm	2.65 ± 0.08	2.02 ± 0.09	0.62 ± 0.08	<0.001
5-10cm	1.56 ± 0.04	1.28 ± 0.06	0.28 ± 0.07	<0.001
Total Nitrogen (%N) (0-10 cm) #	**0.22 ± 0.01**	**0.16 ± 0.02**	**0.06 ± 0.01**	**<0.01**
0-2cm	0.45 ± 0.01	0.29 ± 0.01	0.16 ± 0.01	<0.001
2-5cm	0.23 ± 0.01	0.17 ± 0.01	0.06 ± 0.01	<0.001
5-10cm	0.12 ± 0.00	0.10 ± 0.00	0.02 ± 0.00	<0.001
Carbon/Nitrogen ratio (C:N) (0-10 cm) #	**12.57 ± 0.25**	**12.37 ± 0.36**	**0.21 ± 0.30**	**n.s.**
0-2cm	11.63 ± 0.15	11.75 ± 0.06	-0.12± 0.14	n.s.
2-5cm	11.67 ± 0.15	12.07 ± 0.09	-0.40 ± 0.16	<0.05
5-10cm	13.49 ± 0.18	12.79 ± 0.23	0.70 ± 0.26	<0.05
Bulk Density (g/cm^3) (0-10 cm) #	**1.21 ± 0.05**	**1.30 ± 0.04**	**-0.08 ± 0.03**	**n.s.**
0-2cm	0.90 ± 0.03	1.04 ± 0.04	-0.14 ± 0.04	<0.01
2-5cm	1.13 ± 0.03	1.24 ± 0.03	-0.11 ± 0.04	<0.01
5-10cm	1.39 ± 0.03	1.43 ± 0.02	-0.04 ± 0.03	n.s.

0-10cm figures calculated by weighting the 0-2, 2-5 and 5-10cm data by 0.2, 0.3 and 0.5

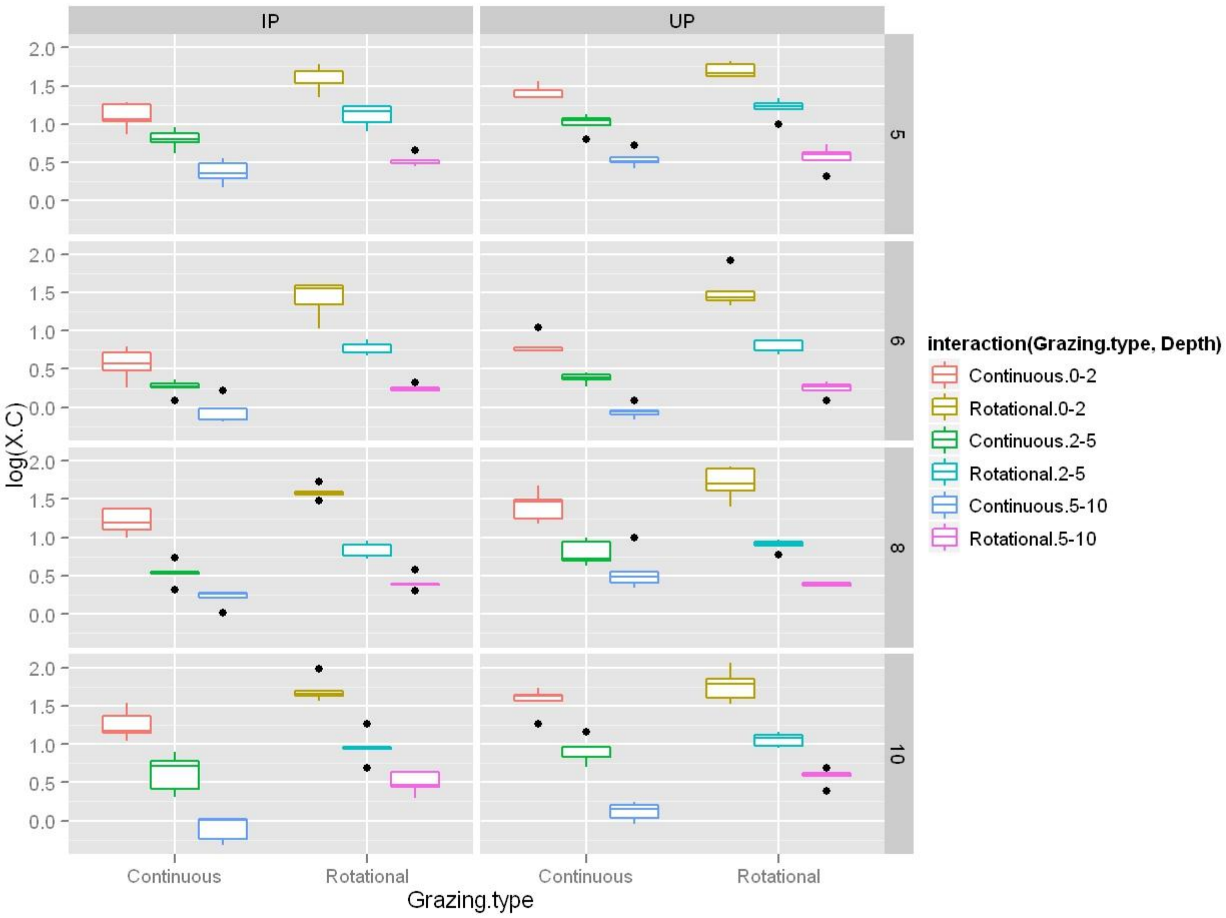
3.4.1 Percentage Carbon model

Log (%C) is determined by grazing type (rotational or continuous), depth (0-2, 2-5 or 5-10 cm) and sampling location (under perennial grass plants (UP) or in between perennial grass plants (IP), with depth having the greatest effect (table 7). The results indicate that log (%C) increases under rotational grazing, is higher under perennial grass plants than in between perennial grass plants and decreases with increasing depth. However, there is a significant two-way interaction between grazing type and depth as well as between grazing type and sampling location, indicating that there is a different response of log (%C) at different depth and sampling locations for rotational and continuous grazing.

Table 7. Generalized least squares model fit by REML of log(% C) . Response coefficients and their standard error, t-value and p-value are shown.

Coefficients	**Value**	**SE**	**t-value**	**p-value**
(Intercept)	1.11	0.06	19.12	0.00
Grazing type (Rotational)	0.57	0.08	6.98	0.00
Depth	-13.67	1.20	-11.38	0.00
Sampling location (UP)	0.30	0.05	6.56	0.00
Grazing type (Rotational) : Depth	-3.95	1.68	-2.35	0.02
Grazing type (Rotational) : Sampling location (UP)	-0.20	0.07	-3.01	0.00
Depth : Sampling location (UP)	-1.85	0.99	-1.86	0.06
Grazing type (Rotational) : Depth : Sampling location (UP)	1.01	1.38	0.73	0.47

Fig 5. Log (%C) under rotational and continuous grazing for different depth increments (0-2, 2-5 and 5-10 cm) and sampling locations (under perennial grass plants (UP) and in between perennial grass plants (IP) at four paired sites, showing variation between as well as within sites.



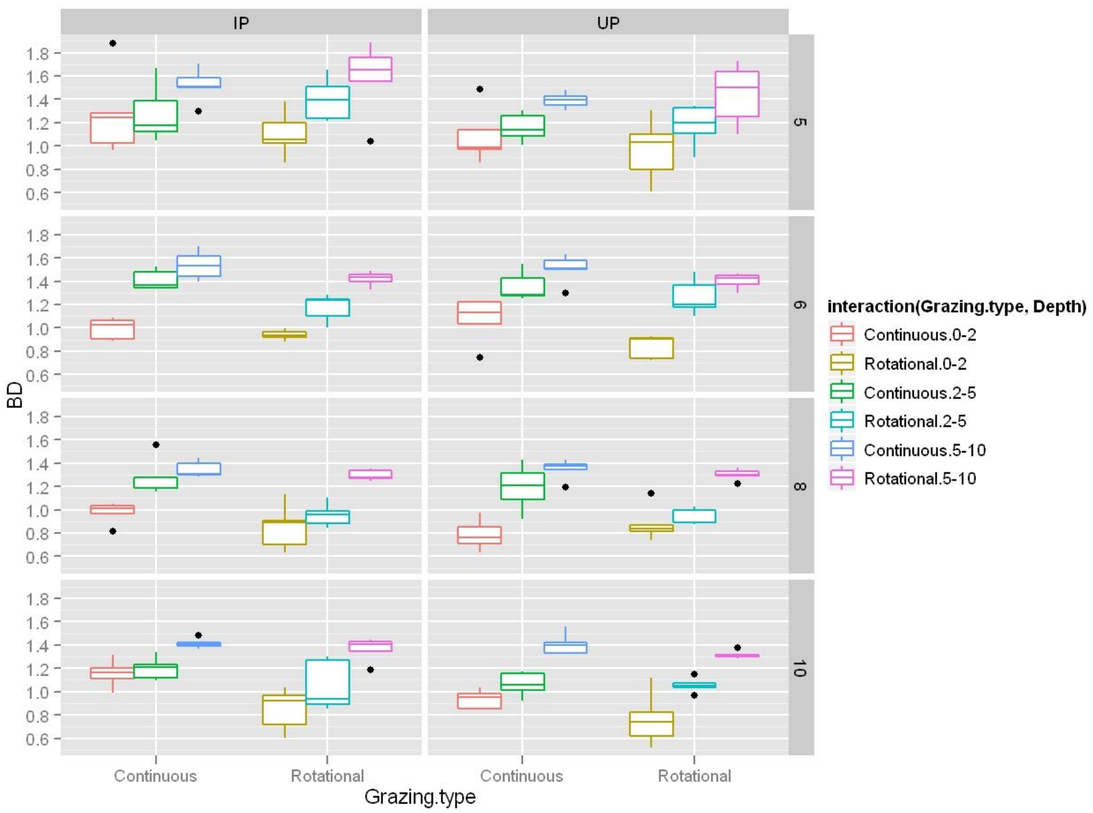
3.4.2 Bulk density model

Bulk density is determined by grazing type (rotational or continuous), depth (0-2, 2-5 or 5-10 cm) and sampling location (under perennial grass plants (UP) or in between perennial grass plants (IP), with depth having the greatest effect (table 8). The results indicate that bulk density decreases under rotational grazing, is lower under perennial grass plants than in between perennial grass plants and increases with increasing depth. Two or three-way interactions between coefficients aren't significant, indicating that bulk density is determined only by the main effects of grazing type, depth and sampling location.

Table 8. Generalized least squares model fit by REML of bulk density. Response coefficients and their standard error, t-value and p-value are shown.

Coefficients	Value	SE	t-value	p-value
(Intercept)	1.07	0.04	25.61	0.00
Grazing type (Rotational)	-0.19	0.06	-3.27	0.00
Depth	5.33	0.87	6.14	0.00
Sampling location (UP)	-0.15	0.06	-2.49	0.01
Grazing type (Rotational) : Depth	1.82	1.22	1.49	0.14
Grazing type (Rotational) : Sampling location (UP)	0.08	0.08	0.91	0.36
Depth : Sampling location (UP)	1.36	1.21	1.12	0.26
Grazing type (Rotational) : Depth : Sampling location (UP)	-0.67	1.70	-0.39	0.70

Fig 6. Bulk density (g/cm^3) under rotational and continuous grazing for different depth increments (0-2, 2-5 and 5-10 cm) and sampling locations (under perennial grass plants (UP) and in between perennial grass plants (IP) at four paired sites, showing variation between as well as within sites.

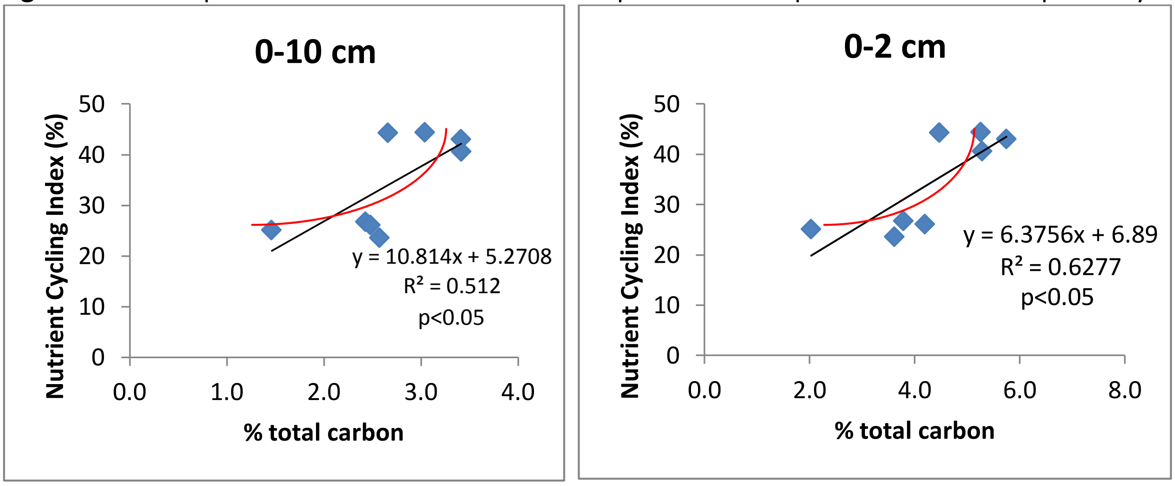


These data reinforce the finding that innovators' strategies are causing a decrease in soil bulk density and an increase in % soil carbon.

3.4.3 Regression analysis of soil C and nutrient cycling index

There is a strong positive linear relation between % total carbon in the top 10 cm of the soil and the Nutrient Cycling Index and this relationship was expressed most strongly in the top 0-2 cm of the soil with R^2=0.63 (fig 7).

Fig 7. Relationship between % total carbon in the top 10 cm and top 2 cm of the soil respectively



The red curved lines on the diagrams have been added to indicate that it is likely that this relationship may be non-linear. In fact it is likely that both the nutrient cycling index and the % total carbon both approach an upper limit which may be at around 44% and 6% respectively. Previous experience with LFA suggests that soil and climate factors set the upper limit for LFA indices. However the addition of shrub and tree vegetation cover and the increase in course woody litter may increase both.

These data and analyses suggest that the LFA nutrient cycling index is a potentially useful indicator of % total soil carbon because if the nutrient cycling values increase it indicates that % total carbon will also be increasing. This is logical because LFA primarily uses perennial vegetative cover and litter cover, origin and degree of decomposition to derive the index for nutrient cycling.

Given that conventional soil chemical and physical analysis is expensive due to the extensive sampling required as a result of soil heterogeneity, LFA has potential as a cheap monitoring technique that could be widely used for ongoing monitoring of the impact of management on soil carbon and broader landscape processes over time and space.

It is the investment that perennial plants make in their root systems, root exudates and the decomposition of litter and the resultant microbial diversity and activity that builds soil organic matter which is predominantly soil C. In functioning and productive grassland ecosystems, nutrients such as total nitrogen and carbon and plant available phosphorus tend to accumulate in the surface layers of soil due to plant growth, litter fall and decomposition. The actions of ecosystem engineers such as earthworms and other soil macrofauna and cycles of perennial plant root growth and death and associated microbial activity should gradually spread the nutrients deeper. Soil sampling was not conducted at sufficient depth in this study to determine whether this surface effect was having an influence deeper in the profile.

3.5 Soil microbes

The soil microbial analysis was undertaken by a consultant who generated a separate detailed report. The most relevant components from the separate report have been summarised below.

Across all four sites there were differences between Innovator and Comparison in the abundance of different groups of microorganisms (Table 9). These data suggest that innovator sites had higher bacterial and fungal abundance. The higher actinomycete abundance was not statistically significant. Tables 10 and 11 summarise differences between the four sites. Possible trends emerging from these data include differences between Innovator and Comparison sides and between sampling locations under and between dominant perennial plants (UP and IP):

- In addition to higher overall abundance of non-filamentous bacteria and fungi, all innovator sides showed increases in some other microbial characteristics consistent with less disturbance and/or with greater perennial basal cover and litter cover. This suggests that these features are making a difference to the microbial ecology. BM6 stands out in that it alone had an increase in actinomycete and fungal abundance.
- On 3 of the 4 innovator sites the soil bacterial and fungal communities under plant (UP) and between plant (IP) were similar. By contrast, on 3 of the 4 comparison sites the soil bacterial and fungal communities under plant (UP) and between plant (IP) were different.

The similarity of UP and IP soil microbial communities on the innovator farms is probably due to the maintenance of UP-type soil microbial communities in the IP areas. The processes responsible for this include the migration of microorganisms from the edge of plants into between plant areas and the maintenance of a reservoir of microorganisms in the between plant areas due to decreased extinction. The rate of immigration of microorganisms into IP soils will depend upon their arrival as air-borne propagules and via litter inputs and upon their direct ingress from surrounding UP soils. Smaller IP areas could be expected to develop soil microbial communities similar to those of surrounding patches more rapidly than larger IP areas. The loss or extinction of microbial communities from soils as IP areas develop will depend upon the effects on soils of animal grazing and hoof impact. Increased soil disturbance by animals is predicted to result in a smaller reservoir of 'UP-type' soil microorganisms in the IP area. Thus, rotational grazing practices which create smaller IP areas and which cause less soil disturbance in the IP areas will increase microbial immigration into and decrease microbial extinctions in IP areas.

If the IP areas are considered to be islands within the perennial grass pasture then other ecological approaches such as island biogeography theory (Wildman 1992) may offer useful ways to examine the microbial community dynamics of these grassland areas. In addition, the importance of disturbance in shaping the community structure in terrestrial and aquatic systems has been extensively discussed in the scientific literature since the 1970s (White 1979) and disturbance theory offers another potentially useful approach for examining microbial communities in perennial grassland areas. For example, the intermediate disturbance hypothesis (Grime 1973)posits that local species diversity is maximized when ecological disturbance is neither too rare nor too frequent. Therefore intermediate disturbance levels (such as rotational grazing) might be predicted to increase soil microbial species diversity over that of undisturbed (or ungrazed) or more heavily disturbed (such as continuously grazed) areas.

Microorganisms are increasingly recognized as an important element in the rehabilitation of disturbed soils because of their role in nutrient cycling, plant establishment, geochemical transformations and soil formation. A primary function of many soil microorganisms is to promote organic matter turnover and nutrient cycling through their diverse metabolic functioning. This study has shown that rotational grazing practices can maintain the soil microbial community structure in native perennial pastures through reduced soil disturbance which, in turn, reinforces the aforementioned positive functions of microorganisms in the soils.

Table 9. Differences in CFU counts (in Millions) for non-filamentous bacteria, actinomycetes and fungi on innovator and comparison sites (mean ± SE) and their p-value for a paired t-test.

	Innovator	Comparison	Difference	p-value
Non-filamentous bacteria	77.19 ± 7.41	53.63 ± 4.19	23.56 ± 6.97	<0.01
Actinomycetes	4.24 ± 0.48	3.16 ± 0.37	1.09 ± 0.59	n.s.
Fungi	0.51 ± 0.03	0.44 ± 0.03	0.07 ± 0.03	<0.05

Table 10: Summary of site differences between microbial characteristics

Site	Bacterial CFU	Actinomycete CFU	Bacterial C source richness	Bacterial C source activity	Bacterial community functionality	Fungal CFU	Fungal C source richness	Fungal C source activity	Fungal community functionality
BM5	UP>IP Inn=Comp	UP=IP Inn=Comp	UP>IP	UP>IP	UP Inn=Comp IP Inn not= Comp	UP=IP Inn= Comp	UP=IP Inn= Comp	UP=IP Inn= Comp	Inn UP = Comp UP Inn IP not = Comp IP
BM6	UP=IP Inn=Comp	UP=IP Inn>>Comp	UP=IP Inn=Comp	UP=IP Inn=Comp	UP Inn=Comp IP Inn not= Comp	IP>UP Inn>Comp	Inn>Comp	Inn>Comp	UP not = IP Inn UP = Comp UP
BM8	UP=IP Inn>>Comp	UP=IP Inn=Comp	Inn>Comp	Inn>Comp	UP=IP Inn not= Comp	UP>IP Inn>Comp	Comp>Inn	UP>IP both	UP = IP Inn not = Comp
BM10	UP=IP Inn>>Comp	UP=IP Inn>>Comp	Inn>Comp	Inn>Comp	(Inn UP = Inn IP = Comp IP) not= Comp UP	UP>IP Inn=Comp	Inn>Comp	Inn>Comp	Inn UP = IP Comp UP not = Comp IP Inn not = Comp

CFU – colony forming unit; UP – under plant; IP – in between plants; Inn – innovator; Comp – comparison; > - greater than; = - equal to; not = - not equal to

Table 11: Descriptive summary of differences in microbial abundance, diversity, activity and functionality between sites

Site	Summary
BM5	Bacterial abundance, diversity and activity higher under plants than between plants on both sides. Comparison has greater functional difference in bacterial and fungal communities between UP and IP
BM6	Innovator actinomycetes more abundant; Innovator fungi more abundant, diverse and active IP fungi more abundant than UP on both Innovator and Comparison
BM8	Innovator has greater bacterial and fungal abundance, and greater bacterial diversity and activity. Different bacterial and fungal community functionality between Innovator and Comparison
BM10	Innovator bacteria more abundant, diverse and active; Innovator fungi more diverse and active Comparison has greater bacterial and fungal functional difference between UP and IP

4 Conclusions

The innovators that are the focus of this study all share the philosophy that they want to work with rather than against nature. They are all trying to regenerate and manage grasslands or grassy woodlands so that they can make a profit from a complex system in such a way that it reduces their exposure to risks (such as a sudden feed deficit due to a dry spell necessitating either large expenditure on feed and/or loss inducing forced stock sales). All have used their own management of livestock to implement some form of rotational grazing. Each of the innovators has reached a similar conclusion: that the rotational grazing that they have been practicing for more than 5 years is working well for them. The purpose of this study was to understand their systems and to attempt to objectively measure whether or not they are heading in the right direction by comparing them with a more conventional continuously grazed system across a boundary fence.

Whilst each of the 10 comparisons were slightly different, some answers are very clear: carefully managed short duration (1 to 7 days), high intensity grazing (enough stock per unit area to create the 'right level' of disturbance) followed by long rest periods (60-180 days) can increase the perennial (usually native) component of a pasture and increase the litter. These changes implemented over for more than 5 years have led to:

- Improved landscape function values as measured by Landscape Function Analysis which indicate that soil stability, water infiltration and nutrient cycling will increase. This means less soil loss, more water available for plant growth, less run-off water of higher quality, and more available nutrients.
- Improved soil fertility through increases in pH, soil carbon, available P and soil nitrogen and a decrease in soil bulk density. These findings indicate that more nutrients were cycled and overall fertility increased without applying fertilizers in comparison with more conventional management.
- A change in the composition of the pasture, in most cases towards greater dominance of perennial native grasses. These findings indicate that it is possible to cause a shift to a

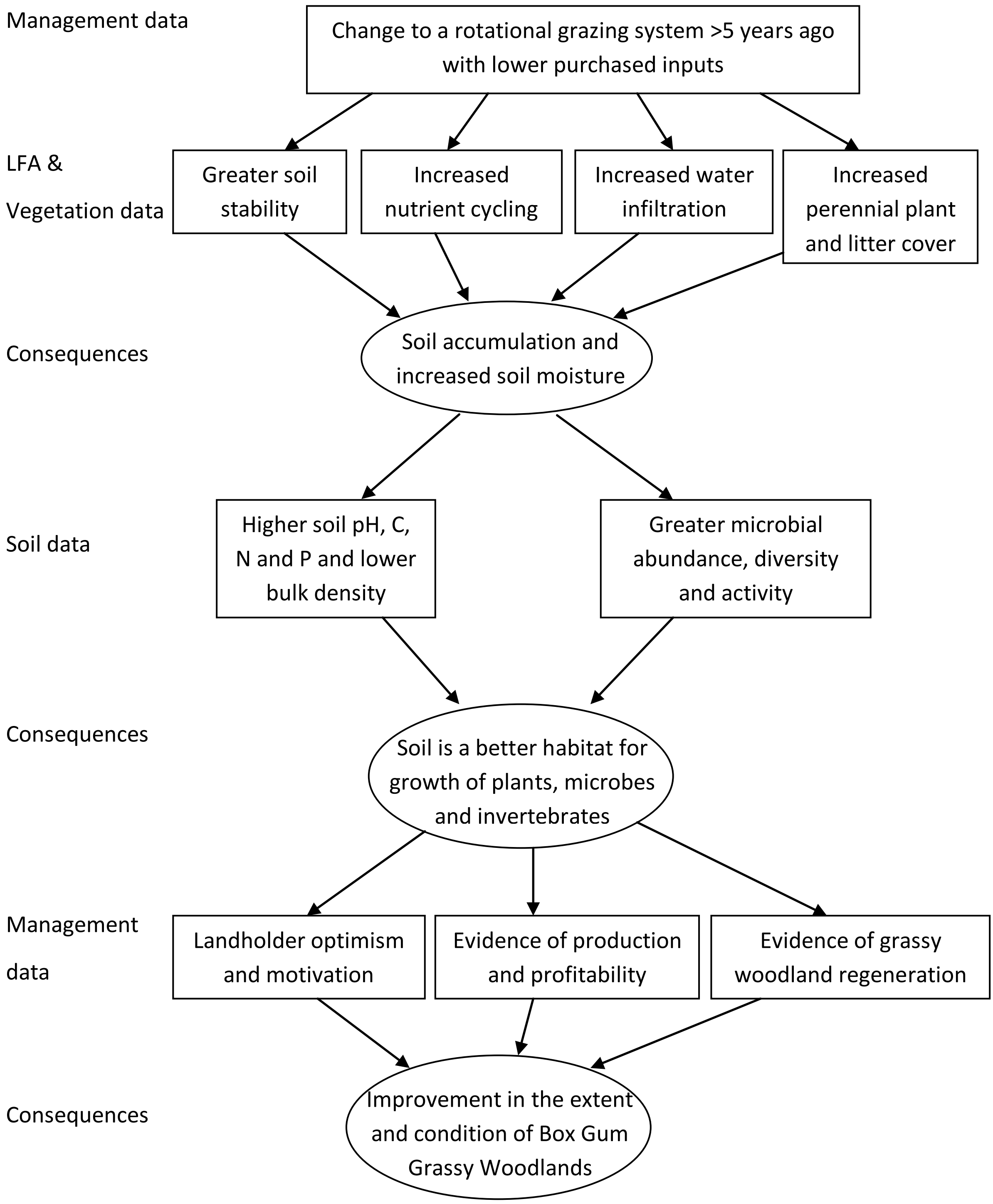
dominance of native perennial grasses, with at least two sites providing strong evidence of the return of more productive and palatable species over time.

- A change in soil microbial ecology was observed that was consistent with lower disturbance and greater perennial basal cover and litter cover and decomposition on the Innovator sides, resulting in general in greater microbial abundance, diversity and activity. On the innovator sides this had resulted in the whole slope acting like a continuous sward in terms of microbial ecology, while on the comparison sides the perennial grasses were more ecologically separate from each with the between plant spaces having a different microbial profile.
- Under this type of rotational grazing there is strong evidence that the slope acts more like a uniform sward whilst under more conventional grazing individual plants act as islands in a less functional and more biologically different matrix which consists of bare soil or soil with minimal litter or annual cover. There may also be differences in soil chemistry between under plant and in between plant fertility but the statistics hasn't yet been done on this.

The additive and probably synergistic effects of each of these changes are highly likely to result in higher overall system productivity as indicated by Figure 8. This is summarized as more soil (due to organic matter accumulation and no soil loss) with increased soil moisture (due to greater infiltration and reduced runoff) and improved soil fertility (due to a greater soil volume being accessed by more extensive root systems of perennial grasses, a higher percentage of increased plant growth being returned to the soils as litter, and the decomposition of the litter by more abundant, diverse and active microbial ecology) under predominantly perennial vegetation undergoing succession (greater species diversity over time with increasing influence of more productive and palatable species), results in greater plant production of species that are part of Box Gum Grassy Woodland endangered ecological community.

It has been possible to achieve this with minimal use of purchased inputs such as fertilizers and herbicides, without reducing stocking rates much below recommended levels, and without necessarily abandoning existing stock enterprises, including stud breeding. The combined effect of this is sufficient to support the more widespread use of similar forms of adaptive rotational grazing.

Figure 8: Summary of measured changes and their consequences on grassland system



This study supports the hypotheses as summarized below (Table 12).

Table 12:

Hypothesis	Conclusion
The key innovation that integrates conservation and production in the study area is grazing management that increases the influence of perennial native grasses across the landscape.	Supported.
Innovative landholders exist that have adapted grazing practices to their specific circumstances and have succeeded in increasing influence of perennial native grasses. This has led to positive economic, social and environmental impacts.	Supported.
Management principles elucidated from innovators, if widely implemented, will improve conservation and production outcomes.	Supported, not clear the extent to which it will directly increase biodiversity in a way that is favorable for BGGW
Knowledge gained through studying innovators and their management practices can generate understanding of how to have desirable practices more widely adopted.	In progress
Participation of innovators in communication strategies will benefit the innovators themselves and help other landholders improve their conservation and production outcomes.	Yet to be tested

There are also many questions raised by these practices and this study. The emerging community of rotational grazing practice is grappling with these questions:

1. When is the best time to graze in which situation?
2. How much off-take and trampling by grazing animals is too much, or too little?
3. What is the best way to estimate the current feed and potential future feed in paddocks ahead of stock?
4. How much rest and recovery is too much, or too little?
5. If perennial grasses dominate at the expense of legumes, will increased nutrient cycling and changes in soil ecology compensate for the reduction in legume N fixation?
6. If rotational systems are pushed hard, when will they end up needing fertilizer to maintain productivity?

For the Communities in Landscapes project it is clear that the rotational grazing practices by these innovators, if adopted more widely, would make a strong positive contribution to the extent and quality of grasslands derived from box gum grassy woodlands.

5 Appendices

5.1 Appendix 1: Benchmark Study of Innovators – interview pro forma

(Questions in italics only asked of innovators)

Research paddock

1. General

- Name of paddock
- Size of paddock
- Topography, soil, vegetation types
- Main function of paddock
    - Grazing
    - Cropping
    - …

2. 2. Historic management

- Management history of the paddock:
    - Dating back to when?
    - Main function
    - Type of livestock
    - Stocking rate
    - Rotation
    - Inputs – what and how much?
    - Crops

3. 3. Current management

- Main function of paddock
- Current management of the paddock:
    - Since when?
    - Type of livestock
    - Stocking rate
    - Rotation
    - Inputs – what and how much?
    - Pastsure type – sown/native?
- Is this paddock typical of your current management on the property as a whole?

4. 4. Future management

- Goals
- Plans
- Succession
-

Whole property

1. **General information**

- How long have you been managing this property?
- What's the size of the property?
- What is the main function of the property?
- Please describe the property in terms of area/paddocks that consist of
  - Native pasture
  - Sown pasture
  - Crops
  - Woodland
  - Other
- How many head of cattle and or sheep or DSE do you currently have?
  - Is this typical?
  - Has it changed much over time?
- How many people live/work on the farm?
- Do you make a living from the property?
- To what extent do you rely on off-farm sources of income?

2. **2. Property management**

- How would you describe the way you manage your farm?
- Is your management based on a certain philosophy (HM, natural sequence farming etc)?
- Is there a long-term property management plan in place? Formal/informal?
- What formal or informal education/training on farm/environmental management have you had?
- Please give detailed descriptions of your grazing management:
  - Type of livestock
  - Number and size of paddocks
  - Number and size of herds (typically)
  - Rotations (typically)
  - Flexibility
  - Other?
- What do you base your grazing management decisions on?
  - Stocking rate
  - When to move stock
  - Rest period
  - ….
- Please give detailed description of current inputs in terms of fertilizer and/or chemicals
- Have you made any significant changes to how the land's been managed over time, particularly with regards to grazing management?
  - When did you implement the change?
  - What triggered the change?
  - What did the change entail?
  - What difficulties did you encounter/what adaptations did you have to make?

3. **3. Property condition**

- *Please describe the condition of the property when you started your new grazing regime.*

- *Have you noticed any changes in the landscape on your property since you started or since implementation of the new (grazing) management regime with regards to e.g.*
    - *Productivity*
    - *Biodiversity/wildlife*
    - *Resilience*
    - *Soil structure/ quality*
    - *Runoff/ infiltration*
    - *erosion*
    - *plant diversity/ pasture composition*
    - *Input required*
- *Particularly, has the new (grazing) management regime resulted in a significant increase in the quantity and/or quality of native perennial grasses?*
- *When did these changes become apparent?*
- *Have they become more pronounced over time?*
- *What do you think the main differences are between the benchmark site on your property and the conventionally grazed comparison site on your neighbour's property?*
- *What do you perceive to be the main benefit(s) of your (grazing) management regime?*
- *What do you perceive to be the main obstacles/problems associated with your (grazing) management regime?*
- *Is the property financially viable under the current management regime? Has your economic viability improved? What is your forecast of your future economic viability?*
- *Would you be willing to disclose financial details of your grazing enterprise and how it integrates with your overall business?*

4. 4. Ongoing involvement in CiL

- Can we include you in ongoing communications about the CiL project?
    - Are you willing to be actively involved in ongoing activities eg field days where your property might be featured?
    - Place stories in which we tell the story of your property and your innovations?

5.2 Appendix 2: Notes on Soil analyses

Notes:

1: ECEC = Effective Cation Exchange Capacity = sum of the exchangeable Mg, Ca, Na, K, H and Al

2: Exchangeable bases determined using standard Gilman and Sumpter (1989) digest (Method 15E1) with no pretreatment for soluble salts. When Conductivity ≥0.25 dS/m soluble salts are removed (Method 15E2).

3. ppm = mg/Kg dried soil

4. Exchangeable sodium percentage (ESP) is calculated as sodium ($cmol^+/Kg$) divided by ECEC

5. All results as dry weight DW - soils were dried at 6O^{o}C for 48hrs prior to crushing and analysis.

6. Aluminium detection limit is 0.05 $cmol^+/Kg$; Hydrogen detection limit is 0.1 $cmol^+/Kg$.
However for calculation purposes a value of 0 is used.

7. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm

8. 1 $cmol^+/Kg$ = 1 meq/100g

9. Methods from Rayment and Higgins, 1992. Australian Laboratory Handbook of Soil and Water Chemical Methods.

10. Conversion of cmol+/Kg to mg/Kg multiply cmol+/Kg by:
230 for Sodium; 391 for Potassium; 200 for Calcium; 122 for Magnesium; 90 for Aluminium

5.3 Appendix 2: Estimated carrying capacities

Estimated carrying capacities for pasture types in NSW From Table 2 (Russell 2010)

Region	Pasture Types	Range DSE/ha	Average DSE/ha (where estimated)
Southern Slopes	Sub clover/ryegrass + fertiliser	5–10	
	Sub clover/ryegrass plus lucerne and superphosphate	9–15.0	
Northern Slopes	Natural pasture (no seed or fertilizer)	1.2-3.8	2.1
	Improved natural pasture (above + seed + fertilizer)	3.9-7.4	5.7
	Perennial grass/clover + fertiliser	5.6–14.4	10.3
	Extensive lucerne	6.7–11.6	8.7
	Intensive lucerne (rotationally grazed)	9.6–11.6	12.8

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