Soil Management and Ecosystem services in Viticulture



FINAL REPORT
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For Toondi

PREFACE

This report presents the results of a one year pilot project in the McLaren Vale wine area of South Australia. This project on '*The influence of soil management on ecosystem services in viticulture*' was conducted during a one year stay of Associate Professor Maarten van Helden as a visiting scientist at the Plant protection group of the University of Adelaide (School of Agriculture, Food and Wine, Waite Campus) under the supervision of Professor Mike Keller. This project also involved a number of other research groups in the School of Agriculture, Food and Wine, including the Soil ecology group (Timothy Cavagnaro); the Wine innovation Cluster (Cassandra Collins) and the Soil Sciences Unit (Cameron Grant).

This experiment conducted in the McLaren Vale area was a pilot experiment both for a larger European study (PromESSinG) on soil management and viticulture starting in January 2015, but also -and more importantly- for a possible future European-Australian intercontinental collaboration that we hope to be able to develop in the near future.

This project used a typical 'agro-ecology' approach. A relatively simple manipulative experiment created and compared three soil management practices in 14 vineyard blocks. A large spectrum of 'ecosystem functions' were measured using mainly well-known simple techniques. It is this multidisciplinary approach, combining different measurements and looking for interactions, that produces real insights into the underlying processes.

Whereas 'agro-ecology' research is extremely widespread in Europe and North America, it is not yet very well developed in Australian agriculture.I It should gain momentum in the coming years, offering a more 'integrated' and holistic approach compared to the still dominant research-discipline-oriented research. A more holistic approach is of special importance for soil management in a perennial crop in rather harsh conditions, such as Australian viticulture (White 2010). Many different ecosystem functions are related to soil quality and soil health (White 2010), and interactions between management / functions and 'service providers' are not always well known or understood.

The experimental design in itself was a test to see if (1) the existing diversity of vineyard blocks would not mask differences in soil-treatments, and to see if (2) the strategic choice of having no replicates inside the block (just three elementary plots, one for each treatment) would show treatment differences by limiting the risk of intra-block variability, while (3) revealing the diversity that can occur among blocks of different ages, on different soils and with overall varying management (fertilisation, irrigation…).

We tested many different techniques in this experiment, often very simple, or even seemingly simplistic, since available time, equipment and budget were limited. However, together, they provide a lot of information. This is a hallmark of agro-ecological research: the integration of diverse data sets to gain a more complete picture. The individual observations on one block have little 'value' but the large volume of data shows clear tendencies, and often significant correlations and interactions, while also highlighting 'exceptions' due to local differences, thus increasing understanding.

These data together give a more 'holistic' vision of the influence of changes in soil management on grape growth and on ecosystem services. This will help the farmers to optimise their decisions for soil management, a very important element for the sustainable management of a grape vines where short and long term objectives can be contradictory.

The project raised quite a few new questions, but two are key issues. First we must determine the longer term effects (multi-annual) of the tested soil management options. Second, the effect of other non-tested but existing management options, such as the use of winter-cover crops, should be

evaluated. These will be tackled in the European PromESSinG project and hopefully also in the larger and longer Australian project that we will propose.

Doing a 'sabbatical' year in Australia has been an immense pleasure, being able to leave administration and teaching behind me for one year, focussing on research, and experiencing a very different culture, wine styles, food, and climate. Being out in the field again was a very refreshing (well, sometimes a bit warm) experience. The (too little) I have been able to observe of Australia's natural richness has made a big impression on me!

My stay at the Waite Campus and the experiment were made possible by the kind help and equipment I obtained from many different people from both Adelaide University and SARDI, too many to thank individually (but see appendix 4) except for a few. Special thanks to Katja for helping a fellow Dutchy to get to know his way around; for Mike, for giving me the freedom and support to conduct this project. And last but not least Toondi for your help in organising my Oz life, cultural and gastronomical affairs, critical views and all things we share.

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Maarten van Helden

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1. ABSTRACT

Suppression of the inter-row permanent ground cover sward by tillage or herbicide strongly affected ecosystem services in McLaren Vale Shiraz. Ground cover suppression increased yield (berry size) by 15% (0-40%) due to increased nitrogen availability. Overall water stress (measured as must $\delta^{13}C$) was not significantly affected but was related to Leaf Area Index. Soil Organic Matter (SOM), entomopathogens and seed predation were unchanged. SOM decomposition and meso-fauna abundance increased in tillage while bulk density and compaction decreased. Arthropod biodiversity was highest in Sward. Optimising soil management requires variation over time to conciliate long term positive and negative impacts, increasing resilience for the grower. A three year collaborative project including winter cover crops and more regions is in preparation.

2. EXECUTIVE SUMMARY

In viticulture, a perennial cropping system, sustainable soil management is of major importance to maintain production quantity, quality and regularity over the life-span of a vineyard block. Vineyards are often established on agronomically 'marginal' soils that allow production of good quality grapes for wine making, limiting rather than maximizing yield in order to increase the quality of the grapes and the wine. This also implies a risk that such marginal parameters will evolve over time to unfavourable conditions and a negative impact on production.

Different soil management options are available for -and used by- grape growers: Ground cover (natural or sown, permanent or not), herbicide applications, tillage or a combination of these. Growers often tend to opt for a single strategy in a block and maintain it over many years. However, over time a chosen soil management practise can also show adverse effects, such as too much or not enough competition, or a decrease in soil organic matter (SOM), leading to a shift in plant performance. The use of a permanent sward (ground cover) is the most frequently chosen option in the McLaren Vale region and this has a number of advantages, such as improving soil strength, but also imposes risks, such as strong competition with grapevines, that are not always well recognized by growers and consultants.

In this experiment we quantified the effects of the suppression of the sward by tillage or herbicide application on provisioning (yield, plant growth), supporting (soil organic matter, soil fertility) and regulating (seed predation, soil organic matter degradation) ecosystem services. We also determined the effects of these practices on a number of potential 'service providers' i.e. organisms involved in these processes (soil arthropods, nematodes, micro-organisms). In such an 'Agro-Ecology' approach, we were primarily interested in interactions between different factors.

The suppression of inter-row permanent ground cover by tillage or herbicide strongly affected ecosystem services in McLaren Vale Shiraz. Ground cover suppression increased yield (berry size) by 15% (0-40%) due to increased nitrogen availability in soil. Leaf chlorophyll, leaf area index (LAI) and must nitrogen were clearly increased. Accumulated water stress was significantly correlated to LAI, as vines with less water stress showed higher LAI values. Surprisingly accumulated water stress (measured as must $\delta^{13}C$) was not affected by treatment, suggesting that this increased canopy growth due to higher water availability early in season is 'compensated' by increased late season stress.

SOM, Insect pathogens in the soil and seed predation were unchanged, but the duration of the experiment would probably not have been enough to reveal differences.

Organic Matter decomposition (Tea-Bag Index litterbag system) and meso-fauna abundance increased in tillage, whereas bulk density and soil compaction decreased.

Arthropod biodiversity (Berlese and Pitfall trapping) was highest in the Sward treatment.

Changing soil management (in this case sward suppression) had clear (short term) beneficial effects, increasing yield and remediating some problems, while degrading other ecosystem services.

Variation in results for most parameters was more important when comparing blocks than when comparing treatments, but the number of blocks (14 replicates) and adapted statistical treatment revealed clear significant treatment effects. 'Outliers' were often linked to specific soil conditions or management history, thus helping to identify special risks and bottlenecks.

A much clearer image of the main effects that can be observed and possible interactions was made possible by crossing multiple observations from different disciplines (plant physiology, soil sciences, flora and fauna studies).

Overall we have shown the very strong influence of SOM on many different supporting and regulating ecosystem services and service providers, and finally on the main provisioning service 'yield'. SOM is clearly a key factor in many soil-related processes.

The results have already made growers reconsider and adapt the management of their blocks, especially in those cases where non-optimal situations were observed (extreme soil compaction, strong sward competition, loss of soil structure). But it will be important for this type of experiment to continue the same treatments on the same plots for several years to determine the extent and strength of effects over the long term. The options of growing winter cover crops as 'green manure', and additional measurements (water stress, arboreal mycorrhiza, plant nutritional status, etc….), should be included in future experiments.

The participating growers have become aware that none of the tested treatments are 'permanent' and sustainable options. Participative research of this project has shown a clear advantage for the (bidirectional) transfer of knowledge as recommended by White (2010) that has permitted addition of some measurements and research questions (such as water efficiency) as identified by the growers.

It seems important to also approach vineyard ground cover as part of an agro-ecological system: Any grassy vegetation (either sown or 'volunteer') is in ecological terms a rather immature plant community. Such a 'prairie' will evolve over time through natural succession processes to a more woody vegetation, unless there is a selection by animals (grazing) or human interventions (mowing) in favour of herbaceous plants of these grassy communities. Management is needed to optimise the services provided by the sward and more generally to manage the vineyard agro-ecosystem, but these 'disturbances' will also have other impacts on the soil and vine growth, such as compaction by machinery.

The multidisciplinary approach of agro-ecology and the many scientists involved in the project have created a real synergy to reach a more holistic and comprehensive approach to address a real practical management question for the growers and industry.

Optimising soil management requires variation to balance long term negative and positive impacts, thereby increasing 'resilience' for the grower. While it is impossible to avoid some long term negative effects of agricultural management, such as compaction, interventions such as tillage, subsoiling or green manure can be tried as a means of remediation, but growers should be aware of the negative effects that are also possible. Therefore a 'formalisation' of a set of decision rules seems needed to be able to adapt soil management according to a set of simple observations.

We recommend initiating formal long term collaboration with the European PromESSinG project (www.promessing.eu) through a parallel 3 year / 3 management options / 3 viticultural regions project in Australia including a set of measurement that will be in common between the two projects and some more specific to the Australian situation. This will have a benefit of being able to adapt and optimise soil management for the diversity of pedoclimatic conditions (terroir) observed in the Australian wine industry and allow better expression of local growing conditions, therefore increasing quality and improving competitiveness.

3. INTRODUCTION

Agriculture and the 'disturbances' it includes on the soil in which the crop grows has a strong influence on the soil structure and functioning (Oldeman 1994; Carter et al 1997; Slavich, 2001, Eswaran et al 2001; Brabant 2010). Pedoclimatic conditions, soil management and more general agricultural management: tillage (Klavidko 2001), herbicide (House et al 1987), compaction, fertilization (Ayuke et al 2011) and irrigation (Holland et al 2013) all have strong direct disturbance effects on soil structure and soil biota such as macro and meso-fauna (mites, springtails; other arthropods; earthworms etc.) (Evans et al 2011; Vikram et al 1995) and micro-fauna (fungi, bacteria) (Goulding et al 2010). The soil biota are of major importance for the mechanical stability of the soil, its resilience after perturbation (Jouquet et al 2006) and therefore its sustainability for agricultural production.

Meso-fauna in particular is involved in the incorporation and degradation of SOM which is in turn of major importance for soil mechanical stability and water retention (Neher and Barbercheck 1999). These organisms, together with the micro-fauna, ultimately make the recycled SOM available as minerals for the plants (Larochelle et al 1993; Giller et al 1997; Jouquet et al 2006). Reduction of soil fauna due to disturbance effects can result in a decrease in the ecosystem services provided such as lowering soil nitrogen availability, soil permeability and soil degradation (Mulder et al 2011).

In Australia soil properties, pedoclimatic conditions and water quality used for irrigation make the agricultural soils particularly at risk to erosion, acidification, salinization, and soil structural decline (Conacher and Conacher 1995; Carter et al 1997; White 2010). Agricultural soils are an important resource that needs protecting through careful and sustainable management.

In viticulture sustainable soil management is of major importance to maintain production quantity, quality and regularity. Vineyard soils often are agronomically 'marginal' soils that allow production of good quality grapes for wine making, limiting rather than maximizing yield in order to increase the quality of the grapes and the wine. Soil characteristics (nutrient availability, water availability, soil structure, etc.) directly influence plant growth, grape yield and quality. Different soil management options are available for (and used by) the growers: ground cover (natural or sown, permanent or not), winter crops as green manure, herbicide applications, tillage or a combination of these (Thomson et al 2009, Boyer 2013). Below the vine row soil is generally kept weed-free, in between the rows differences exist according to the pedoclimatic conditions and production goals. Differences in management exist not only between rows and inter-rows, but also between inter-rows (alternation of cover and no cover rows, alternating winter crops) on the same plot, among plots, among soil types and types of viticulture.

Fertilizer applications are done using both organic fertilizers (compost, manure, biodynamic preparations) and 'chemical' fertilizer, which influence soil biota (Ayuke et al 2011). Irrigation has a strong influence on soil parameters (humidity, salinity …) that would also influence soil fauna (Holland et al 2013).

Soil management in viticulture is often primarily focused on optimising yield and fruit quality at the scale of the growing season, but sustainability of the vineyard over a longer period has to be taken into account for such a perennial crop (Riches et al 2013). The soil health review by White (2010) highlights the importance of long term strategies, and the questions growers have, and identifies the lack of good benchmarks, adapted to regional conditions in Australia. Growers are aware that soil properties can contribute to a better resilience of the vines to extreme weather conditions. Main effects of the soil and ground cover management as recognised by the grower

generally are management of plant vigour (through water and nitrogen competition) and soil structural stability (to avoid erosion and to facilitate mechanisation). Ground cover and soil management contribute considerably to soil biota 'activity' (Renaud et al 2004, Borer et al 2012), acting upon other ecosystem functions such as water retention (linked to SOM), soil permeability (much influenced by plants and macro-fauna such as earthworms, ants and termites), pesticide degradation etc. These other ecosystem services are less recognized by most of the growers except for those more actively involved in environmental management such as those producing according to organic or biodynamic rules.

As suggested by White (2010), Riches et al (2013) and Oliver et al (2013) recently reviewed the knowledge on soil quality in Australian viticulture and insisted on the lack of good biological indicators (benchmarks) and monitoring tools over longer time series, but in Europe these data are also lacking.

A study in the Bordeaux area of France comparing meso-fauna of 25 plots during spring and summer (Boyer, 2013) showed large meso-fauna variability between different blocks as a result of soil types and soil management. Overall abundance and morpho-species diversity varied 5 to 10-fold among plots (Boyer 2013). Explaining these differences is often difficult because additional variability (soil type, climate, exposure, fertilisation, irrigation, landscape elements) vary among plots and do influence meso-fauna (Chodelski 2013, Boyer 2013). Therefore it is important to limit differences in these factors as much as possible in an experimental setup (Chodelski 2013).

Though some data on the influence of soil management on meso-fauna in European viticulture do exist (Favretto et al 1992, Renaud et al 2004, Boyer 2013), the effect of these differences on soil *functioning* has rarely been studied. More recently interest has focused on such 'ecosystem services' and also on landscape effects in Australia and Europe (Chodelski 2013; ongoing QuESSA and PromESSinG project). This should allow seeing the practical implications of the observed differences.

Therefore the objective of this project was to link soil meso-fauna composition and abundance to soil *functioning* (mainly organic matter recycling and nutrient availability) and finally to the optimisation of ecosystem services for the crop. This project has associated meso-fauna observation to the measurement of ‘services’ either through plant and soil analysis and simple sentinel systems (litterbags) or more sophisticated techniques (PCR of soil nematode fauna; Biolog® plates, others).

Since pedoclimatic conditions and crop management (irrigation) vary largely among 'cold climate' viticulture in Europe and 'warm climate' viticulture in Australia we used the opportunity of a ‘sabbatical’ year for Maarten van Helden to perform a pilot experiment in the 2014/2015 season in the McLaren Vale region, to select the most appropriate techniques and experimental setup and identify possible specific questions related to Australian viticulture.

4. PROJECT AIMS AND PERFORMANCE TARGETS

The aim of this project was to identify how soil management strategies influence different soil-related ecosystem functions and soil-biota.

Since this was a one year pilot study the main aim was to develop and test experimental setup and methods that can be used in upcoming research projects, both in Australia and Europe.

The second objective was to develop a more 'integrated' understanding of positive and negative effects of soil management techniques on ecosystem services, allowing the development of a set of decision rules for soil management for growers, taking into account the diversity of production aims, pedoclimatic conditions and management strategies.

Our vision was to produce the knowledge required to justify the establishment of a longer term project, by identifying the effects of a set of soil management techniques on the main ecosystem services, with special attention to those that are of major importance for improving yield and fruit quality while limiting Inputs (costs) and possible detrimental environmental effects.

5. EXPERIMENTAL SETUP

Experimental design: The experiment started in August 2014 and ended in June 2015. 14 vineyard blocks belonging to growers that volunteered to participate were used for this experiment. All blocks (annex 6) were planted with Shiraz, were at least 7 years old and had a permanent sward (inter-row ground cover), either volunteer or sown. Planting densities were between 1100 (3 x 3 meters) and 4400 (2.5 x 1.5m) plants/ha. Most blocks were clone SA1654, and only one block (Manjalda) was grafted, on 1103 Paulsen. Blocks were spur pruned and either single or double cordon. Drip irrigation was used in all blocks, limited to 1 Ml/ha/year (100 mm). Blocks were located all over the McLaren vale area (Figure 34 annexe 6).

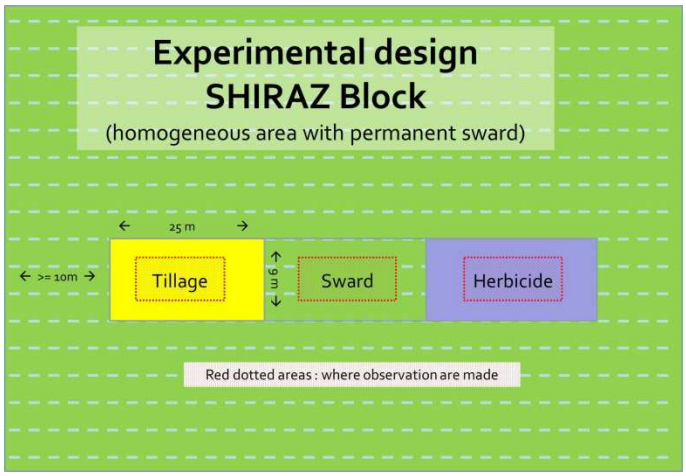


Figure 1: Setup of three elementary plots in an individual block

In each block, inside an area that was considered homogeneous, we created three 'elementary plots' (Referred to as 'Herbicide', 'Sward', and 'Tillage' in this report) as illustrated in Figure 1. Each plot was three inter-rows wide and 5 to 6 panels long (approximately 9 x 25 metres). Spraying (glyphosate) was done before bud burst (First half of September) in 'Herbicide'. Tillage was done once between early September and early October using a rotary hoe. Treatments were not repeated during season. Sward was mown in October in most blocks

Observations started from mid-October 2014 and continued till June 2014. Observations were always performed in the 'central inter-row of the elementary plots and on the two adjacent vine rows.

Observations

Plant growth and yield:

The following observations on plant growth were performed

- Leaf Area Index (LAI): Using the APP LAIcanopy© as developed by The University of Adelaide, we made three photos of each of the two central rows (so six per plot) in each plot using an Iphone4 on November 11th and again on December 24th. Data were processed using Matlab.
- Chlorophyll content: 30 leaves were measured on November 14th and again on December 24th using a Minolta SPAD meter. While moving through the central mid-row 15 measurements (1 per plant) were made on each row on mature leaves (number 5 to 8 from shoot base).
- 200 berries were collected on each plot on February 1st (1 to 4 weeks before harvest). Berry weight, Sugar content (Brix), total acidity and pH were measured.
- Must values for $\delta^{13}C$ and Nitrogen content were determined by Analytical Chemistry Group of CSIRO Canberra
- Canopy and soil temperature: Two measurements were done :

- December 27th: An infrared thermometer ('scanning mode)' was aimed at the vegetation horizontally (1.5 m height) from 1.5 meter distance while moving through the vegetation at approximately 5km/h, scanning the three central panels of each plot. This was repeated on the opposite row.
- Soil surface temperature scanning was performed in the same way, this time aiming the thermometer vertically to the soil in the mid-row.
- February 2nd: An infrared camera was used to take photos from the canopy. 4 photos were made in each plot, 2 left and 2 right of the central mid-row. Camera was positioned at 1,5 meters of the row and aimed at areas with 'fully developed' vegetation.

o Sward biomass and diversity: Total biomass at the start of the experiment was estimated by sward height. Plant diversity and abundance (percentage ground cover) was determined on December 30th.

Soil sampling and analysis:

Soil samples were collected using a simple auger sampling 10 cm deep and 2.5 cm diameter. Ten to 30 samples distributed evenly over the whole sampling area of each plot were collected on each sampling date. Samples were stored in zip-bags in an ESKI and stored in the lab at 4°C until processing. Samples were collected on 13/10/2014 (sample series 1), 18/11 (2), 27/11 (3), 15/12 (4), 15/1/2015 (5); 24/2 (6), 1/4 (7) and 24/4 (8).

The following observations of soil characteristics were performed on these samples

- o Soil moisture: A small soil sample of sample series 1, 2, 3, 4 and 5 (approx. 20 grams) was dried in an oven at 105°C for 48 hours.
- o Standard Soil Chemical analysis (sample series 8) were done by the Phosyn laboratory (analysis type Soil fertility S3). This includes major and minor elements (N, P, K, Mg, Ca, S, Mn, Bo, Cu, Fe, Zn), SOM, CEC, pH and EC.
- o Soil particle size: The particle size fractions (Sand, Silt, Clay) of samples were determined in the lab using standard sieving, precipitation and drying techniques. Only one analysis was done per block.
- o Soil compactness: A simple 'sliding weight' penetrometer was used to measure soil mechanical resistance. Measurements were done on April 9th with the soil moistened by recent rainfall. 5 observations (number of 'beats' to get to 15 cm depth) were made in each plot, eliminating those where mechanical resistance (stones, roots) were hit.
- o Bulk density, water storage capacity. Undisturbed soil cores were collected on February 24th. Stainless steel cylinders (86.9 cm^3) were inserted in moistened soil, lifted and stored in the lab at 4°C. These were trimmed to exact size, saturated with water for 24 hours, 'dried' to water capacity on a ceramic plate at -0.1 bars for 48 hours, weighed and dried. This allows bulk density and water capacity measurement.
- o Wilting point: Undisturbed soil clods (about 2-5 g) were saturated with water on a ceramic plate and exposed to -15 bars in a pressure chamber for 36 days. The soil was weighed, dried in a 105°C oven for 24 hours and re-weighed to determine volumetric and gravimetric wilting point.
- o Available water was calculated using volumetric Water storage capacity and wilting point

	Block / Plot	HERBICIDE				SWARD				TILLAGE				Sward Biomass and Diversity at start of experiment			
N°	Plant cover at 30/12/2014	% Green	% Stubble	% Mulch	% Bare Soil	% Green	% Stubble	% Mulch	% Bare Soil	% Green	% Stubble	% Mulch	% Bare Soil	SOWN ?	Plant Diversity (species/M^2)	Estimated biomass	REMARKS
1	Chalk Hill	5	20	40	35	15	30	30	25	10	5	30	55	?	4	+	Naturalized, Presence of native saltbush Species
2	Coriole	1	20	10	70	30	15	15	40	3	0	2	95	-	6	+	Volunteer, Herbicide biomass quickly degraded
3	Craig Camm	1	70	25	5	3	70	5	20	1	0	70	30	-	4	+/-	Volunteer, Biomass seems very stable, Wild barley straw
4	Hawthorn Ridge	0	70	20	10	1	70	20	10	0	0	90	10	YES	1	++	Strong sown Sward of Tall Fescue
5	James Cooter	50	10	5	35	1	5	30	60	1	0	10	90	?	3	+/-	Naturalized, Glyphosate resistant Couch grass in 'Herbicide'
6	Kay brothers	0	60	40	0	10	60	30	0	5	0	50	50	YES	2	+++	Very strong sown Sward of Tall Fescue
7	Kirwin	0	30	30	40	1	60	30	10	1	0	5	90	-	3	-	Weak volunteer Sward
8	Leconfield 1	0	0	5	95	5	10	20	65	1	0	5	95	YES	1	-	Weak sown Sward Ryegrass (Lolium)
9	Leconfield 2	0	20	20	60	5	60	15	20	10	0	10	80	YES	2	+	Medium sown Sward Ryegrass (Lolium)
10	Manjalda	1	20	5	75	20	60	0	20	5	5	10	90	-	4	-	Weak volunteer Sward
11	Redwind	0	10	30	60	10	30	10	50	5	0	15	80	-	6	+/-	Medium volunteer Sward
12	Reedy Creek	5	30	25	30	5	40	30	20	5	0	80	15	YES	4	++	Strong sown Sward of mixed grasses
13	Sam. Gorge 1	3	40	25	30	5	50	40	10	3	0	10	90	-	6	+/-	Medium volunteer Sward
14	Sam. Gorge 2	1	3	20	80	20	3	10	60	1	3	3	95	?	10	-	Weak volunteer Sward
	MEAN	5	29	21	45	9	40	20	29	4	1	28	69				

Table 1 : Description of the Sward of each block and plot on December 30 2015 (mid-season, blue; brown and green sections) and at the start of the experiment (Yellow section). Colour codes : Blue = Herbicide, Brown = Sward, Green = Tillage). Yellow cell (in third Column) shows Herbicide plot in James Cooter Block where couch grass developed in the sprayed out section. Green cells in yellow section: plots with a particularly strong growing (sown) Sward.

Supporting ecosystem functions:

SOM degradation.

- The litterbag system of the tea bag index protocol (http://www.decolab.org/tbi/protocol.html) was used to mimic organic matter breakdown. In each plot three pairs of teabags (Rooibos and Green tea) were buried in the middle of the mid-row on October 14th 2014 and dug up on January 23rd 2015. After drying in an oven at 65°C for 72 hours. The residual weight of the tea in the bags was determined in the lab.



Figure 2: Installation of litterbags (teabags)

Regulatory ecosystem functions:

- Seed predation

  Seed cards (approximately 9 x 4 cm) were prepared as described by Westerman et al 2003 using 80 grit sandpaper. Seeds were fixed using Elmer's Repositionable Mounting Spray Adhesive™. 10 Seeds of each of 3 plant species were used. Two seed cards were fixed in the middle of the row in each plot using big roofing nails. One seed card was covered using a small 10mm mesh cage (Figure 3). Remaining seeds were observed after approximately two weeks. Three series were done: 29/10 - 11/11 using *Malva parviflora* (Mallow); *Plantago major* (Plantain) and *Lolium multiflorum* (Annual Ryegrass); 30/12 – 09/01 using *P. major*, *Pennisetum glaucum* (Millet) and *Medicago sativa* (Alfalfa) and 27/03 to 07/04 using *P. major*, *Sinapis alba* (White Mustard) and *M. sativa.*



Figure 3. Seed card with cage (series 1)

- **Insect pathogens detection**

  The presence of insect pathogens in the soil top layer was tested using the 'galleria bait method' (Zimmerman 1986). Soil samples from 24/2 sampling were sieved through a 2 mm sieve. 50 ml of air-dry soil was transferred in a plastic cup and moistened with 20ml of water (approximately 50% of field capacity) and mixed. This was left for 1 week and mixed again. Wax moth (*Galleria mellonella*) larvae of about L4 stage were prepared as described by Zimmerman (1986) by dipping in 56°C water for 10 seconds and 10 larvae were introduced in each cup. Cups with soil and larvae were closed with perforated lids and maintained in the laboratory. Cups were inverted every 3-4 days. Larvae were observed after 14 days and dead larvae were washed in 1% chlorine solution, and transferred individually in 2ml Eppendorf tubes, closed with moistened cotton and perforated lids. After 2 weeks at room temperature larvae were scored for entomopathogenic fungi, nematodes or 'atypical' mortality under a stereo microscope (10-40x).

Soil Biota:

- Soil arthropods were extracted once per month (samplings 1, 2, 4, 5, 6, 7 and 8) using Berlese funnels. 275 ml of soil from each plot was transferred to a Berlese funnel (1mm mesh) on the day of sampling or the next day and extracted for 48 hours. Samples were collected and stored in 70% ethanol until identification. Identification was done using the Rapid Biodiversity Assessment (RBA) approach, identifying order (for insects, hexapoda and spiders) or class (centipedes, millipedes, etc.) and then in 'morpho-types'.
- Pitfall traps were installed for 5 weeks (January 30th till March 11th) and changed every week. Samples were collected in 50% polypropylene glycol. Samples were stored in the laboratory until identification, using the same RBA approach as for Berlese samples.
- Free living nematodes: Soil samples (approximately 300 grams) from the sampling 4 (15/12) were processes by SARDI for DNA extraction and identification of free living nematodes.
- Biolog Ecoplates: All 42 samples from December 15th soil sampling were extracted and processes as described by Govaerts et al (2007). Plates were read at 24, 48 and 72 hours.

DATA ANALYSIS:

Results have been presented as histograms showing the 14 different blocks and three plots in each block (see opposite page). The rightmost three bars represent geometric mean values over all plots. Since results in the same block are clearly dependent, this is strictly speaking not a good representation, but just a visual aid. Data were analysed as 'pairwise' samples comparing treatments: SWARD (S, 'control') with either 'Herbicide' (H) or 'Tillage' (T) using the two tailed T-test for 2 dependent means. In some cases separate tests were done to compare Herbicide and Tillage. Significance levels of pairwise T-tests are indicated using *** = ($p < 0.01$); ** = ($0.01 < p < 0.05$) or * = ($0.05 < p < 0.1$). No statistical comparison between blocks was made; this is not an objective of this experiment and no replicates are available inside each block.

Some point graphs are presented when looking for correlations among parameters. Correlations are indicated in graphs showing the equation and R^2. We only considered linear correlation in these analyses. In some cases correlations for each treatment are presented separately (three regression lines with Equation and R^2 indicated using the same colour codes, plus an overall correlation (42 values) in bright red.

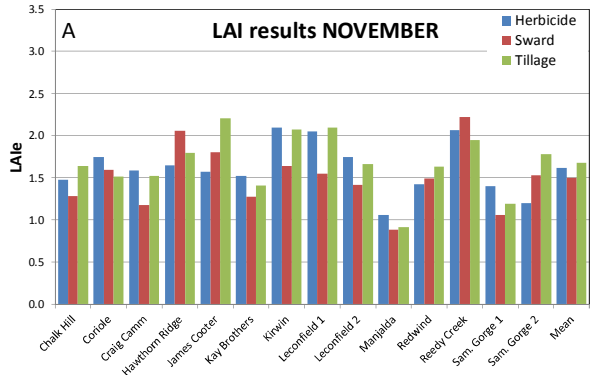
Where correlation coefficients R^2 are indicated (in graphs) the trend can be considered significant at the following R^2 values (Critical Values of the Pearson Product-Moment Correlation Coefficient):

For series of 14 blocks comparing two variables <u>inside the same treatment</u>, or comparing one variable for two treatments; 14 – 2 = 12 degrees of freedom.

$\alpha < 0.1$	$R^2 > 0.21$	indicated as *
$\alpha < 0.05$	$R^2 > 0.28$	indicated as **
$\alpha < 0.01$	$R^2 > 0.44$	indicated as ***

When comparing two variables <u>over all plots, 3 treatments and 14 blocks</u>: (14 x 3) – 2 = 40 degrees of freedom.

$\alpha < 0.1$	$R^2 > 0.07$	indicated as *
$\alpha < 0.05$	$R^2 > 0.09$	indicated as **
$\alpha < 0.01$	$R^2 > 0.15$	indicated as ***



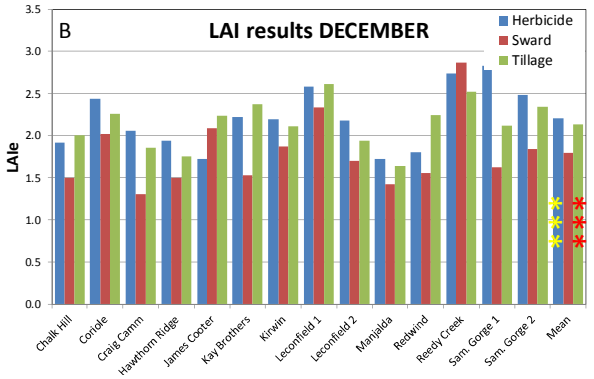
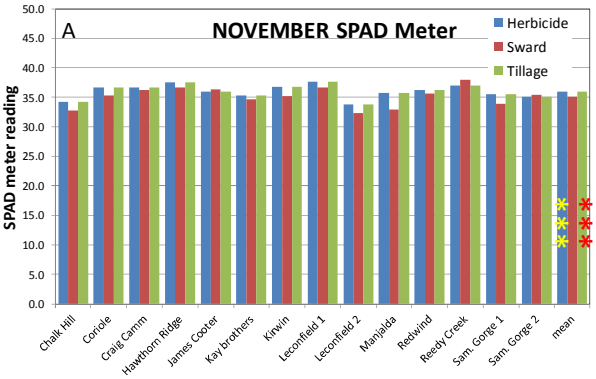


Figure 4A and B: LAI Values in November (A) and December (B).
***: Difference compared to Sward at p<0.01



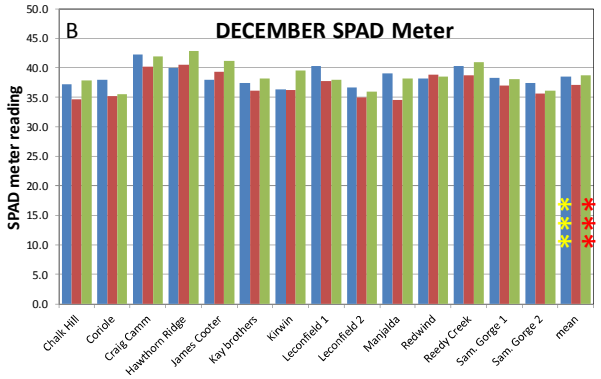


Figure 5A and B: SPAD meter results in November (A) and December (B).
***: Difference compared to Sward at p<0.01

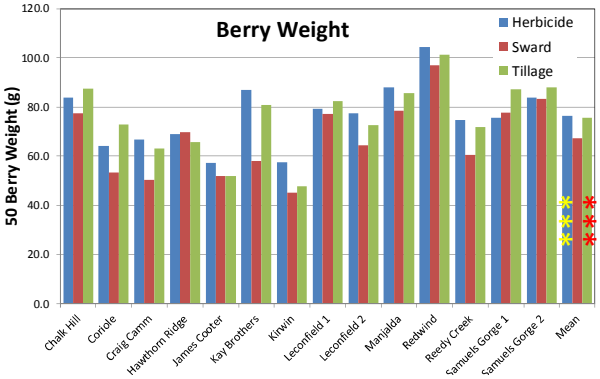


Figure 6: Berry weight
***: Difference compared to Sward at p<0.01

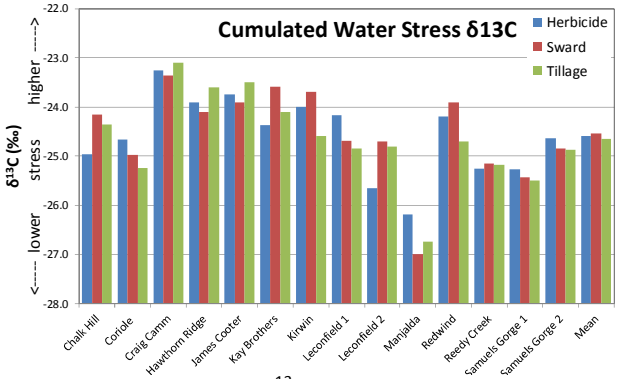


Figure 7: $\delta^{13}C$ values in must
No significant treatment effects

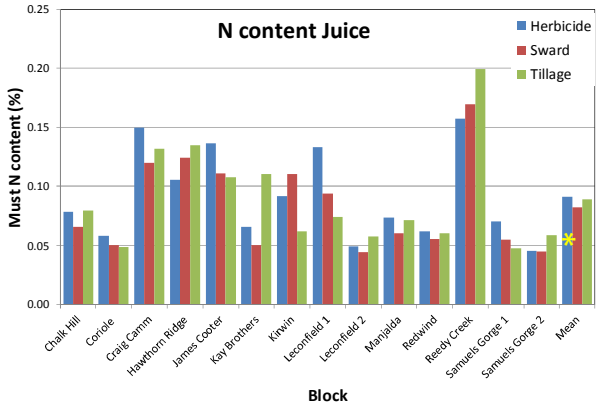


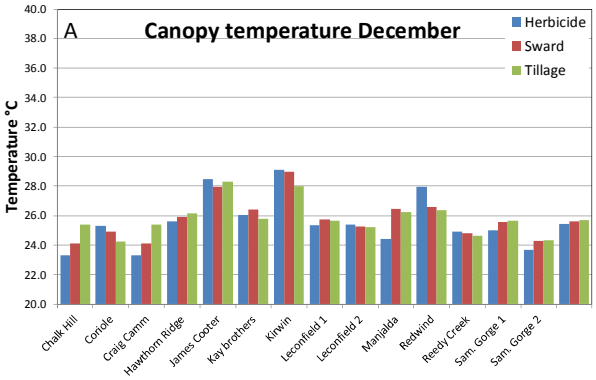
Figure 8: Must N content (% weight)
*: Difference compared to Sward at p<0.01

6. RESULTS

PLANT GROWTH AND YIELD:

- **LAI data** (Figure 4a and B) showed big differences among blocks. LAI was higher for H and T compared to Sward, but differences were significant at $p < 0.01$ for December only. H and T were not significantly different at either of the two dates.
- **Chlorophyll content** as expressed by SPAD meter reading (no units, Figure 5 A and B) was significantly higher in T and H at both dates, $p<0.01$). Block values and differences seemed more important during the second measurement (Mean 38.2 +/- 2.1 SD) then during the first observation (Mean 35.7 +/- 1.4 SD).
- **Berry Weight** (Figure 6). Block differences in average 50 berry weights were very big. Berry weight was significantly higher in T and H ($p<0.01$). Berry size was on average 15% higher, ranging from -3 to +50%. Tillage and Herbicide were not significantly different and showed similar tendencies.
- **Brix, pH and total acidity** were not significantly different between treatments at $p<0.01$ (data not shown).
- **$\delta^{13}C$ values** were clearly very different among blocks but not significantly different among treatments (Figure 7). Low stress values were observed on block 'Manjalda', the only block grafted on 1103 Paulsen rootstock. Other blocks showed Weak ($\delta^{13}C < -24.5$) to Moderate ($\delta^{13}C < -23$) Stress.
  For Reference : Water stress / $\delta^{13}C$ values were classified as proposed by van Leeuwen et al (2009):
  - $\delta^{13}C < -26$ NO stress
  - $-26 < \delta^{13}C < -24.5$ WEAK stress
  - $-24.5 < \delta^{13}C < -23$ MODERATE stress
  - $-21.5 < \delta^{13}C < -23$ HIGH stress
  - $-21.5 < \delta^{13}C$ SEVERE stress
- **Must Nitrogen content** (Figure 8) was very different among blocks, ranging from <0.05 to 0.2 %, but treatment differences were only significant comparing H and S ($P<0.1$).
- **Canopy and soil temperature**:
  - **Canopy temperature** (Figure 9 a and b) was slightly but significantly higher ($P<0.1$) in T and H compared to S on the second (December) observation round only.
  - **Soil temperature** (Figure 10) was significantly different among all treatments ($p<0.01$), with 'Sward' being at 51.7 °C, Herbicide at 57.2°C and Tillage at 61.3°C.

- **Sward biomass and diversity**: Table 1 shows data for estimated sward biomass, plant diversity and soil coverage by green plants, Stubble, Mulch and bare soil in December.
  - Very few 'actively growing' plants were visible at this time, even in 'Sward', due to dry conditions.
  - Tillage (green section) has highest values for 'bare soil' and 'mulch' and, obviously no stubble).
  - Some regrowth of plants (mainly plantain) was observed in Tillage areas.



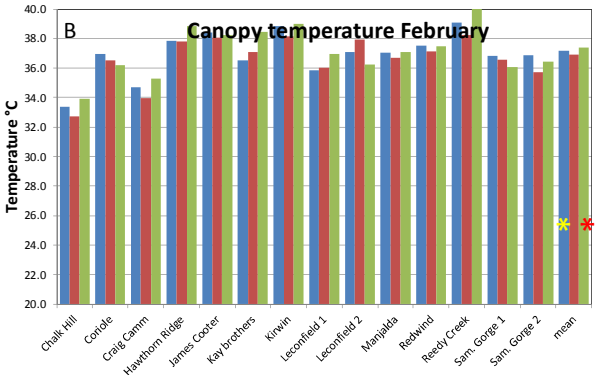


Figure 9A and B: Canopy temperatures in December and February
*: Difference compared to Sward at p<0.1)

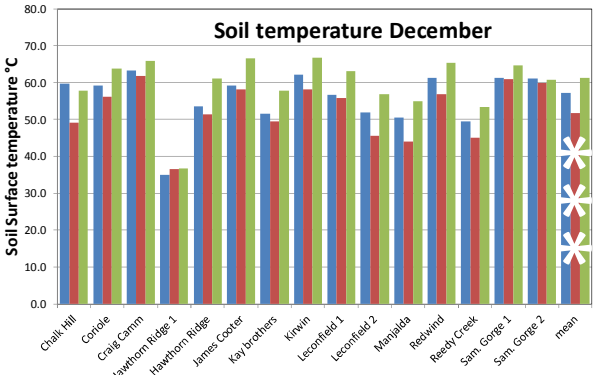
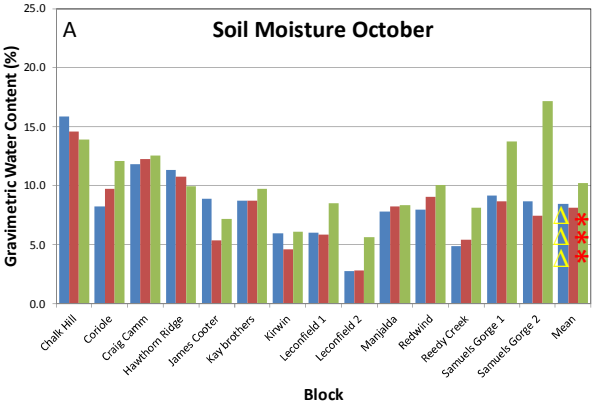
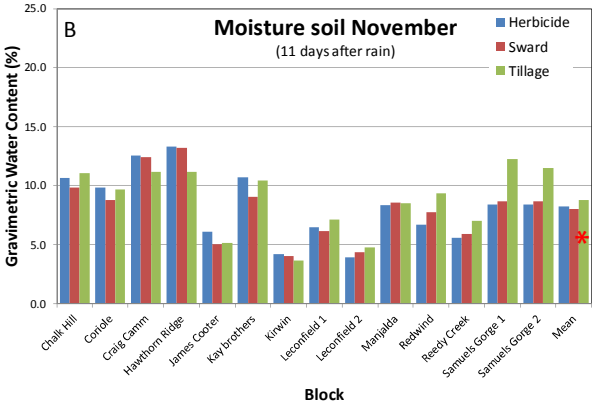
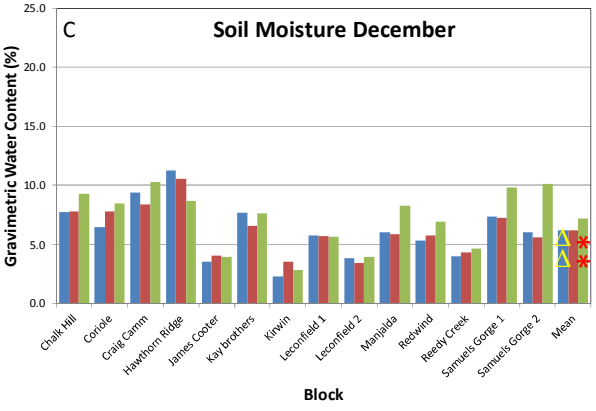


Figure 10: Soil temperatures in December
***: Sward < Herbicide < Tillage at p<0.01







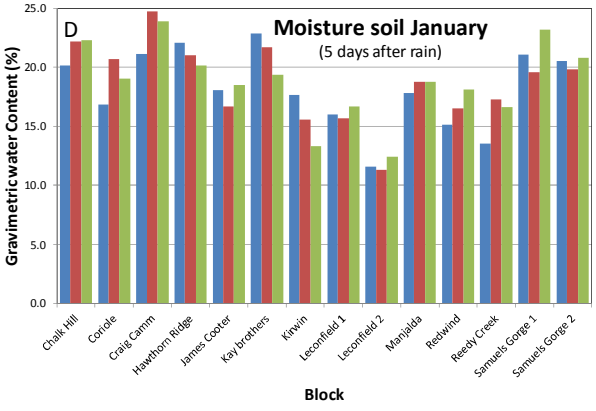


Figure 11A-D: Gravimetric Water content in top soil at 4 different dates
*/**/***: Difference compared to Sward at p<0.1/0.05/0.01)
ΔΔ / ΔΔΔ Difference compared to Tillage at p0.05/0.01)

SOIL SAMPLING AND ANALYSIS:

- **Soil moisture:** Soil gravimetric water content (Figure 11A-D) was generally low except for those cases where rain preceded the sampling (January). Block differences were big. Soil moisture in Tillage was significantly higher than Sward during sampling 1 (October 13th, $p<0.01$), 3 (November 27th, $P<0.1$) and 4 (December 14th, $p<0.05$). Soil moisture in Tillage was also significantly higher than Herbicide at October ($p<0.01$) and December ($p<0.05$) sampling.
- **Standard Soil Chemical analysis** (sample series 8) showed few significant differences among treatments.
  - Soil analysis showed significant differences in Nitrogen (NO_3^-) content (Figure 12), being higher in Tillage and Herbicide compared to Sward ($p<0.01$). Differences between blocks were very big (ranging from <10 to > 40 ppm), treatment effects were extreme in some cases (Hawthorn Ridge, Kay Brothers).
  - Soil Phosphor content (Figure 13) ranged from 20 to 160 ppm. Block differences were large. P was slightly higher in Tillage compared to Sward ($p<0.05$)
  - SOM content (Figure 14) in the first 10cm of soil ranged from 2.5 to 8.5%. There was no significant different among treatments
  - None of the other parameters showed significant treatment effects.

- **Soil particle size** is shown in Figure 15. Most blocks show a 'loam' or 'sandy loam' structure, with only block 9 Leconfield 2 (Sandy) and Block 1 Chalk Hill (Sandy-Clay-Loam) being very different;
- **Soil Compactness**: Figure 16a shows the results for soil compactness. On the clay soil 'Chalk Hill' the tool did not penetrate to 15 cm (default value set at 200). Comparison on all other plots showed that 'Tillage' was significantly lower than Herbicide ($p<0.1$) and Sward ($p<0.05$) though some exceptions occurred (Kirwin, James Cooter) where clear surface sealing was observed.
- **Bulk density** (Figure 16b) Bulk densities showed differences among block (min 1.05, max 1.43 g/cm^3), but no significant difference occurred between treatments.
- **Water Holding capacity** varied from 0.3 to 0.5 g/cm^3 (Figure 16c) In Tillage this is slightly but significantly higher than in Sward and Herbicide ($p<0.1$)
- **Wilting point**: (Figure 16d): Volumetric wilting point varied from 6% to 24% among blocks, Tillage was significantly lower than Sward ($p<0.05$) and Herbicide ($p<0.1$)
- **Available water** (Water holding capacity – Wilting point) varied from 0.17 to 0.37 g/cm^3. Tillage was significantly higher than Sward ($p<0.05$) and Herbicide ($p<0.05$) (Figure 16e)

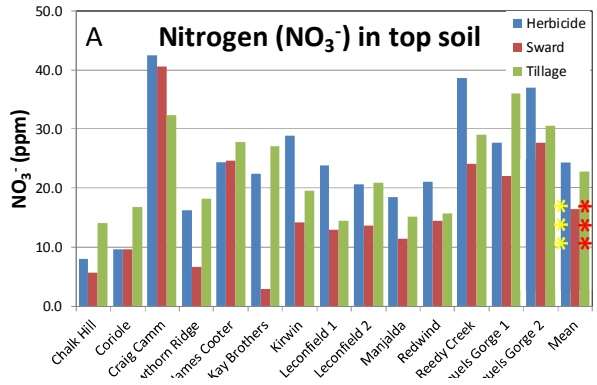


Figure 12: Nitrate (NO_3^-) content in top soil (ppm)
***: Difference compared to Sward at p<0.01

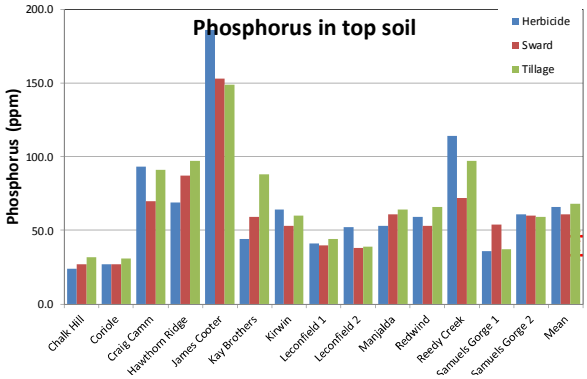


Figure 13 Phosphorus content in top soil (ppm)
**: Difference compared to Sward at p<0.05

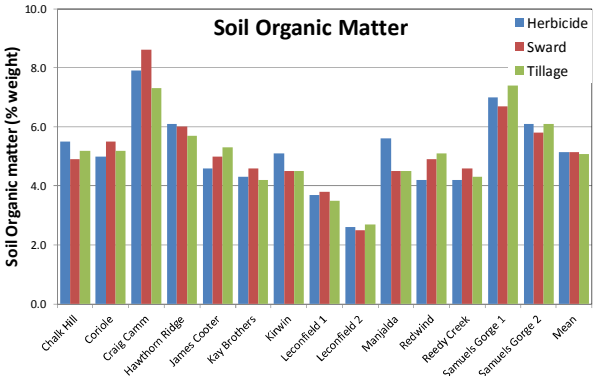
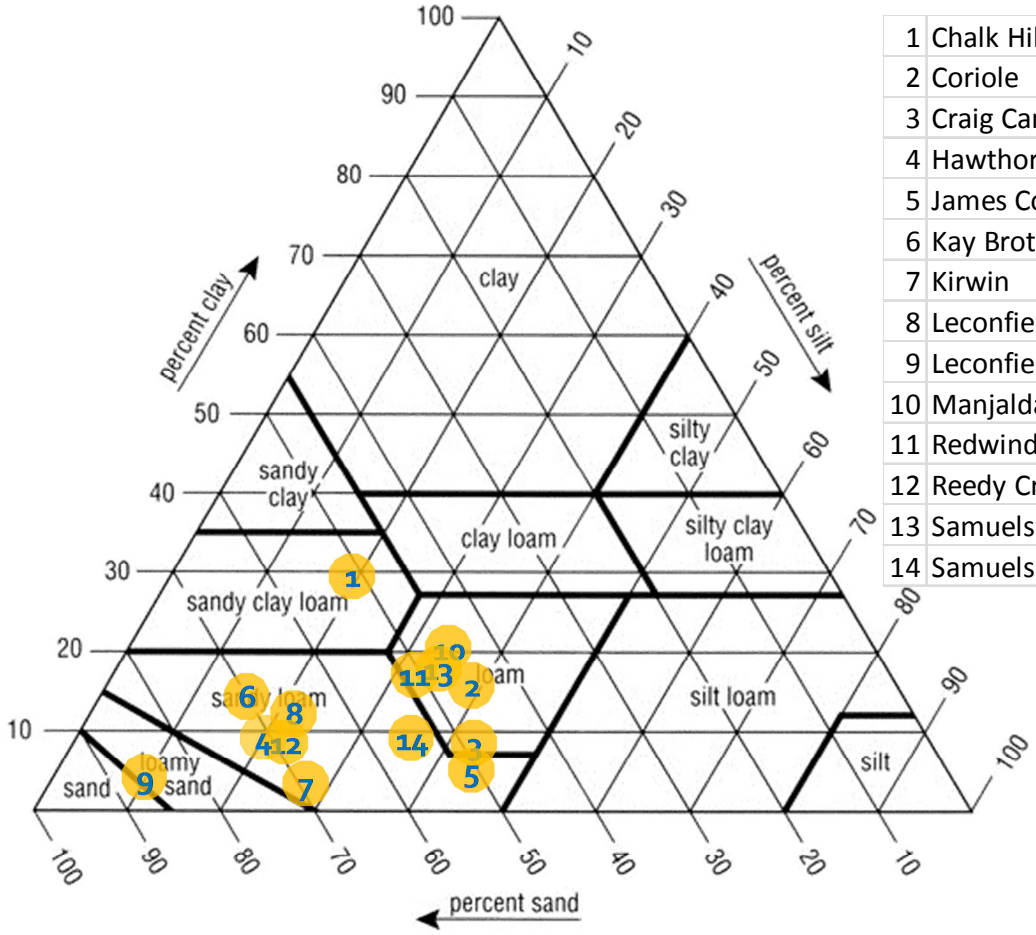


Figure14: Soil Organic matter content (% Weight)
No significant treatment effects



1	Chalk Hill
2	Coriole
3	Craig Camm
4	Hawthorn Ridge
5	James Cooter
6	Kay Brothers
7	Kirwin
8	Leconfield 1
9	Leconfield 2
10	Manjalda
11	Redwind
12	Reedy Creek
13	Samuels Gorge 1
14	Samuels Gorge 2

Figure15: Particle size distribution of Top Soil

SUPPORTING ECOSYSTEM FUNCTIONS:

SOIL ORGANIC MATTER DEGRADATION.

- The degradation of tea-bag litterbags is shown by the remaining weight in Figures 17 a and b. Differences between individual plots were large. One block (Leconfield 2) showing lower degradation rates for Rooibos tea in 'Sward' and 'Herbicide'.
  - For green tea the remaining weight was about 0, 84 grams (<50% of the initial weight) and treatment differences were not significant.
  - For rooibos tea he remaining weight was about 1.6 grams (80% of initial weight). Remaining weight in Tillage was significantly lower than Sward ($p<0.05$)

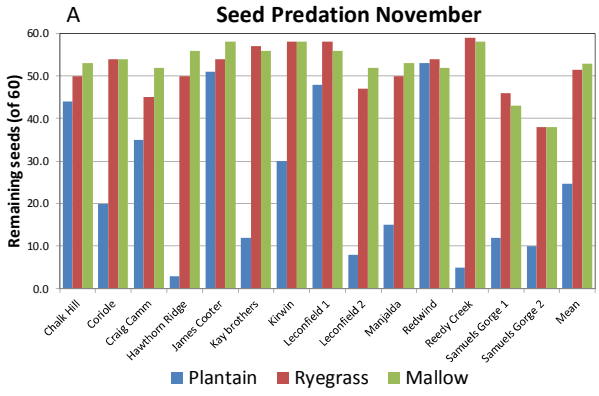
REGULATORY ECOSYSTEM FUNCTIONS:

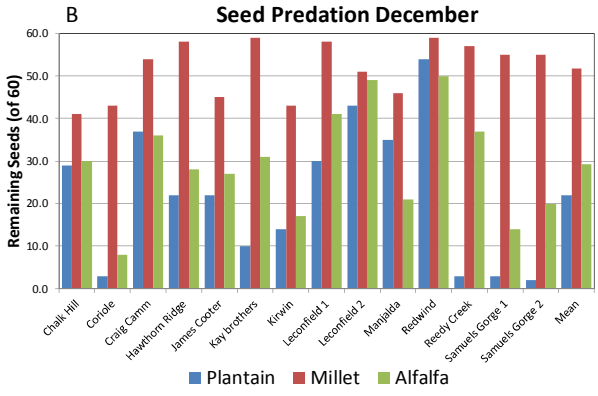
- **Seed predation**

  Seed predation showed large variation among observation dates, seed types and blocks (Figure 18 a, b, c, below). Differences were not significant among treatments (data not shown).

- **Insect pathogens detection**

  Mortality of the galleria larvae (Figure 19, below) showed large variation among blocks and plots. Mortality values ranged from 20% to 95%. There seemed to be higher values for the Leconfield 2 block. Differences among treatments were not significant.





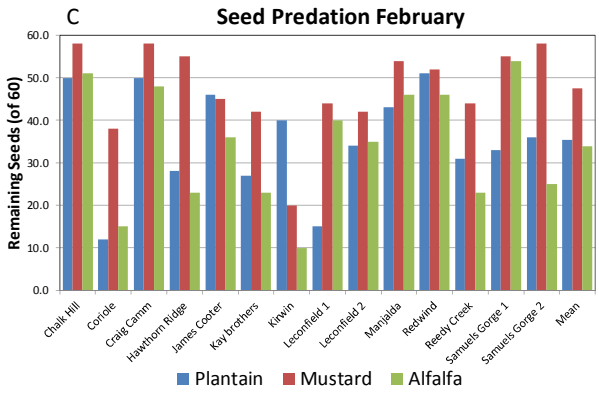


Figure 18 A-C: Seed predation per block in October, December and February.
Different seeds were used in subsequent trials.

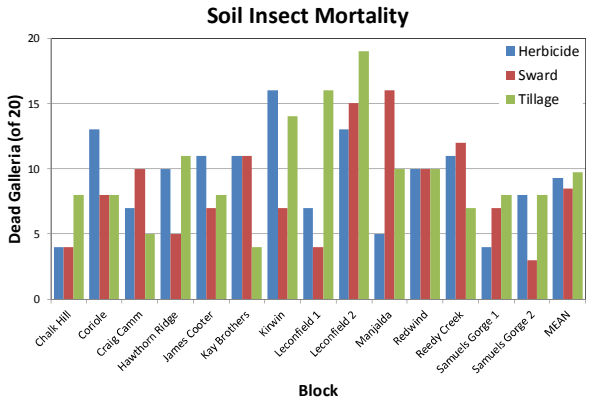
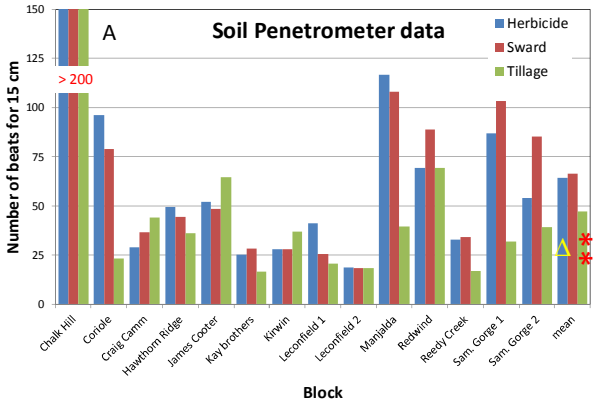
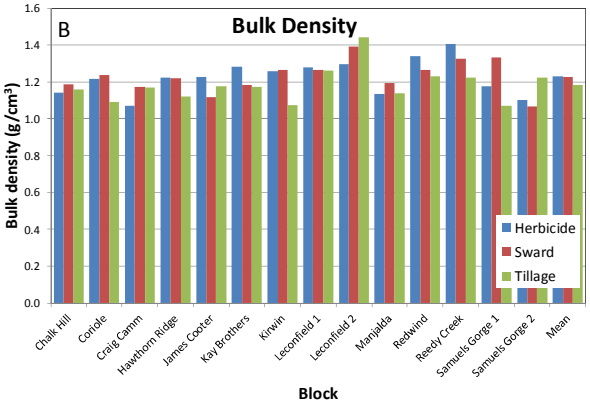
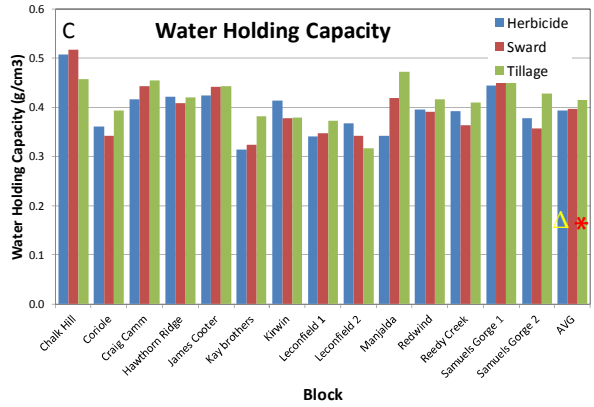
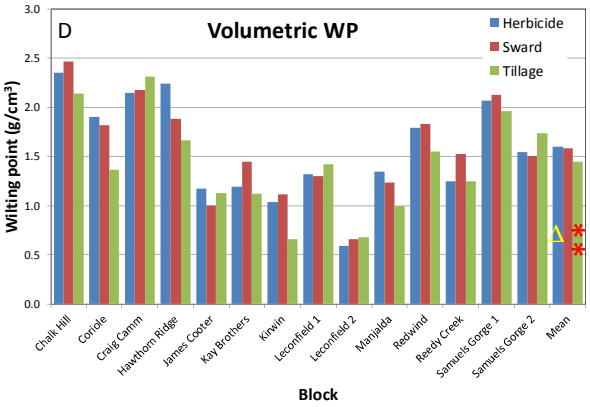


Figure 19: Mortality of Galleria Larvae in moist soil of each plot.
No significant treatment effects









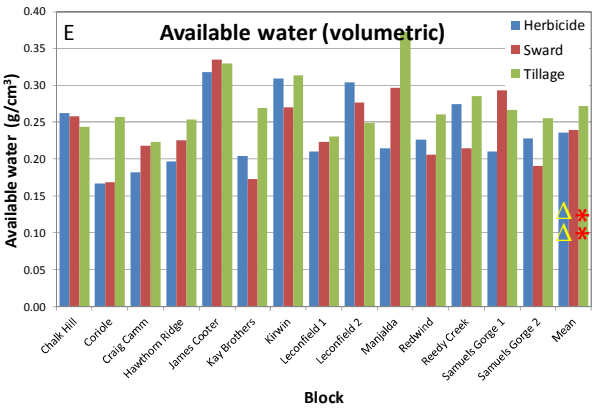
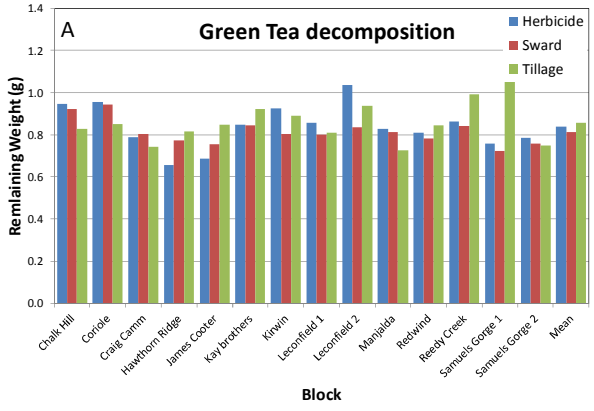


Figure 16 A-E: Soil Compactness (A), Bulk density (B), Water Holding capacity (C), Volumetric Wilting Point and Maximal Available water
*/**: Difference for Tillage compared to Sward at p<0.1/0.05)
Δ / ΔΔ: Difference for Herbicide compared to Tillage at p<0.1/0.05)



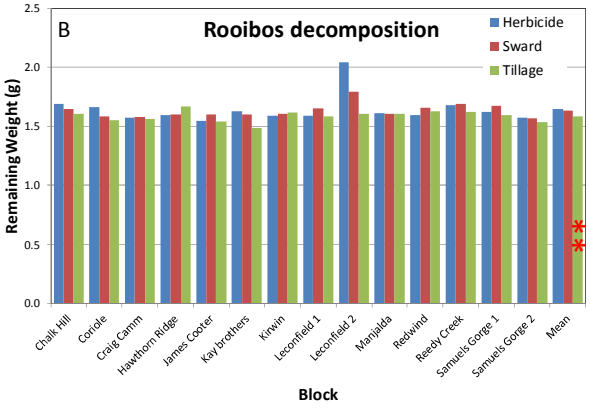


Figure 17A and B: remaining weight of Green Tea (A) and Rooibos (B) tea bags
**: Difference for Tillage compared to Sward at p<0.05)

SOIL BIOTA:

SOIL ARTHROPODS

- A total of 4097 individuals were caught and classed in 97 different morpho-types (MT). Most diversity was observed in the mites (Acari). Most abundance in Mites and Collembola (Figure 20 a and b).
- Communities seemed quite comparable between plots in the same block (not analysed), the same species were observed in each plot and often in each sample. Some morpho-types seemed 'block specific (example of pseudoscorpions in 'Craig Camm' block
- **Abundance** (Nr of individuals) varied strongly over the sampling period, decreasing to very low values in the (dry) summer months (Figure 21a).
- Berlese samples showed very large variation in 'cumulated abundance' among blocks and plots (Figure 21b), total abundance per block (all samples from all plots in the same block) ranging from 70 to >1100 individuals.
- **Abundance** per plot (Figure 21B) was significantly higher in Tillage than Sward ($p<0.01$) and Herbicide ($p<0.05$) during the first sampling round only (Figure 21a, one month after tillage took place); differences on later dates were not significant.
- **Cumulated Richness** per block (number of morpho-types in all samples from the same block) varied from 19 to 45 morpho-species.
- **Richness** was significantly lower in Herbicide compared to Sward ($p<0.01$) (Figure 21C).

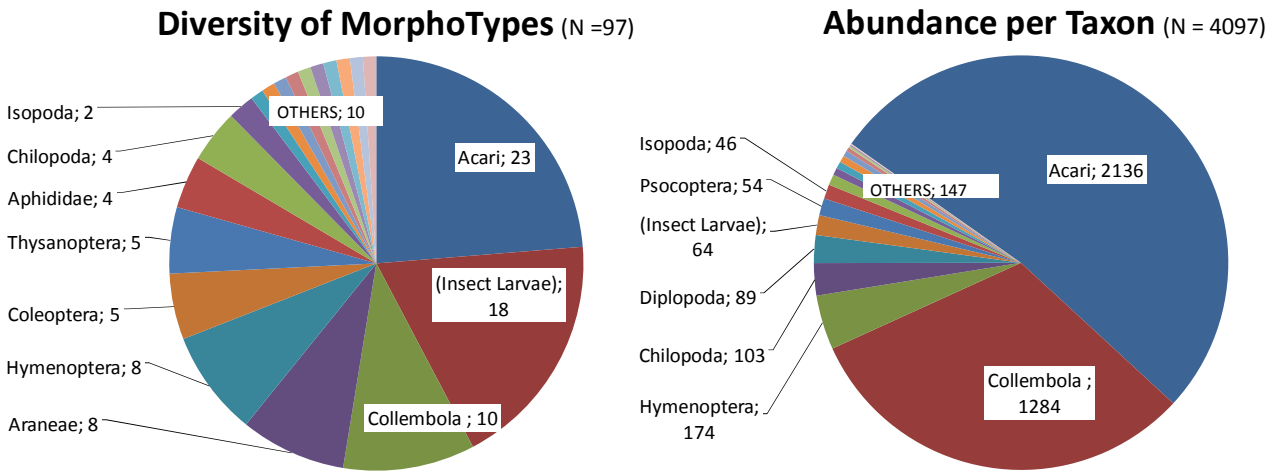
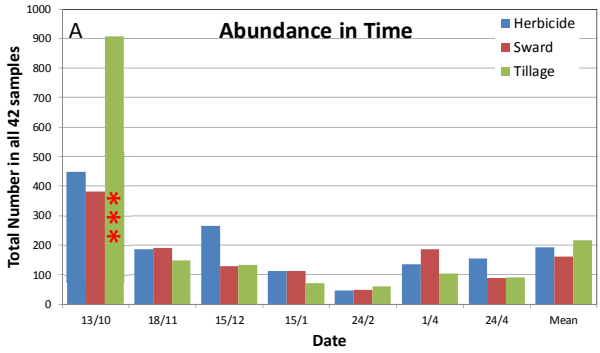
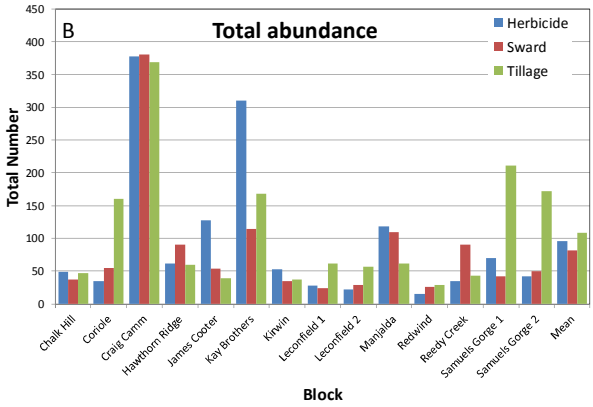


Figure 20A and B: Abundance and diversity of different taxons in Berlese samples





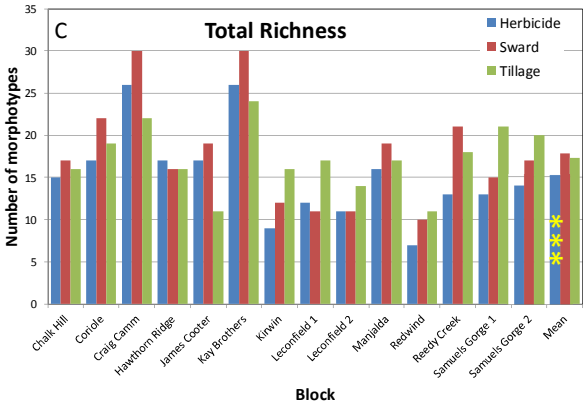
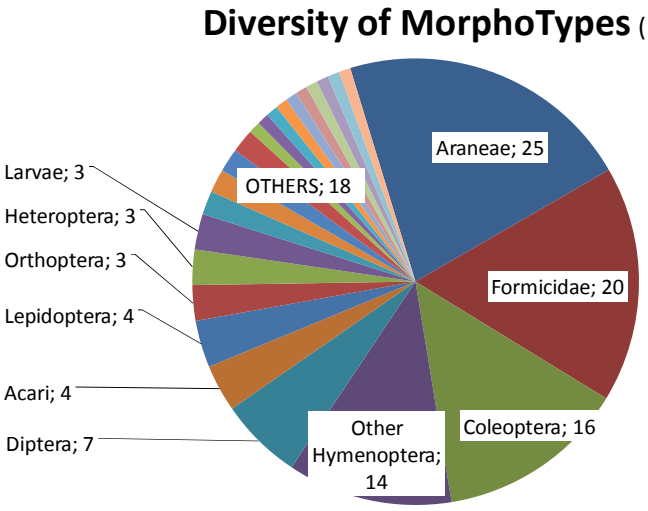


Figure 21A, B and C: Berlese sampling results:
Abundance per treatment over Time (A), Abundance (B) and Richness (C) per plot.
***: Difference compared to Sward at p<0.01



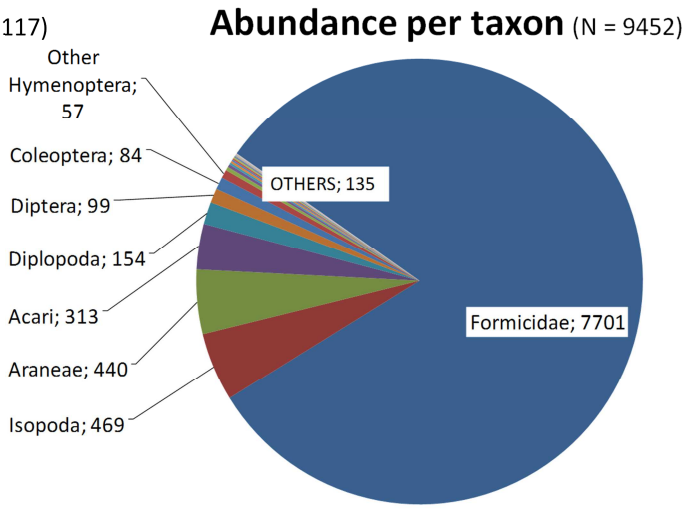


Figure 22A and B: Abundance and diversity of different taxons in Pitfall samples

SOIL DWELLING ARTHROPODS

- A total of 9500 individuals was identified and classed in 118 different morpho-types (MT). Most abundance (Figure 22B) was observed in the ants (>7000 individuals) and highest diversity was observed in the hymenoptera (42 MT, including 23 ants) and spiders (24 MT) (Figure 22A)
- **Abundance** (Nr of individuals) varied strongly among blocks and plots (Figure 23a), with values very strongly influenced by Ants
  - Up to 430 of a single ants species were observed in the same sample and >1300 ants accumulated in 4 samples in the same single plot (Samuels Gorge herbicide).
  - The three treatments in this same block accumulated almost 2800 ants.
  - Other blocks (Manjalda, Coriole) accumulated < 25 individuals in some plots and <100 ants over all plots and samples.
  - Communities seemed quite comparable between plots in the same block.
- No difference bin abundance between treatments was observed, even when ants were eliminated from the analysis.
- **Cumulated Richness** (number of morpho-types in all samples from the same block) varied from 23 to 45 morpho-species
- **Richness** showed a treatment effect (Figure 23b), when compared to SWARD it was significantly lower in both Herbicide ($p<0.05$) and Tillage ($p<0.01$).
- Due to harvest and animal disturbance some traps were destroyed. We obtained only 4 samples from the 5 sampling weeks for each plot.

FREE LIVING NEMATODES

- Soil samples showed large numbers of DNA copies belonging to most of the nematodes groups that were
- Differences among blocks (Figure 24) and differences among plots of the same plot were big.
- Significant differences at the $p<0.01$ level did not occur between treatments.
- Pratylenchus and Meloidogyne (potential vine pests) were not detected in the samples.

Biolog Ecoplates

- Biolog Ecoplates : Samples showed some qualitative differences between blocks.
- No significant difference was observed between treatments (data not shown).

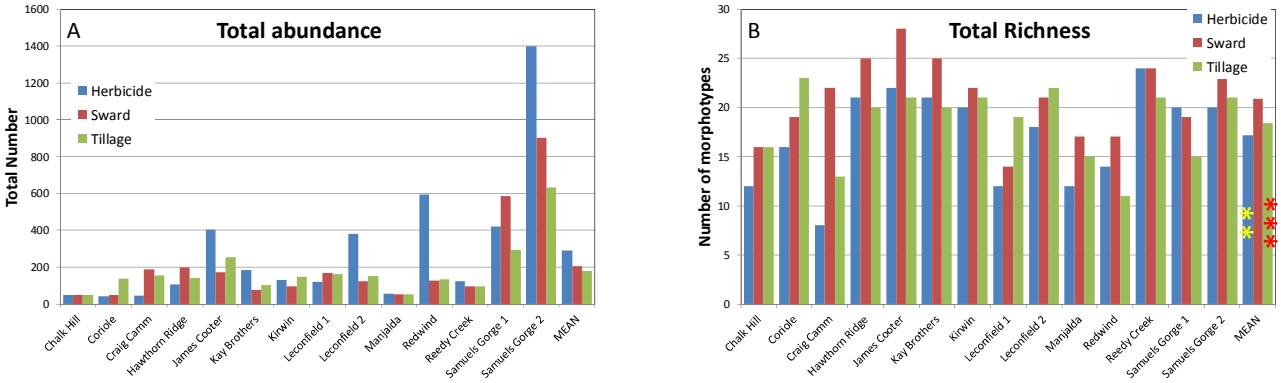


Figure 23 Aand B Pitfall sampling results: Abundance (B) and Richness (C) per plot.
/*: Difference compared to Sward at p<0.05 / p<0.01

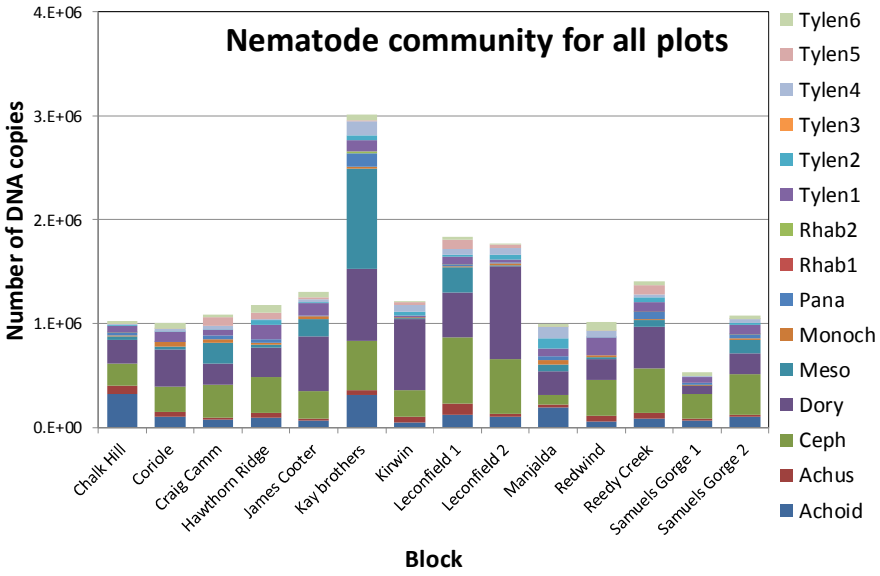


Figure 24: DNA Copies of nematode detected in soil samples per Block.

7. DISCUSSION

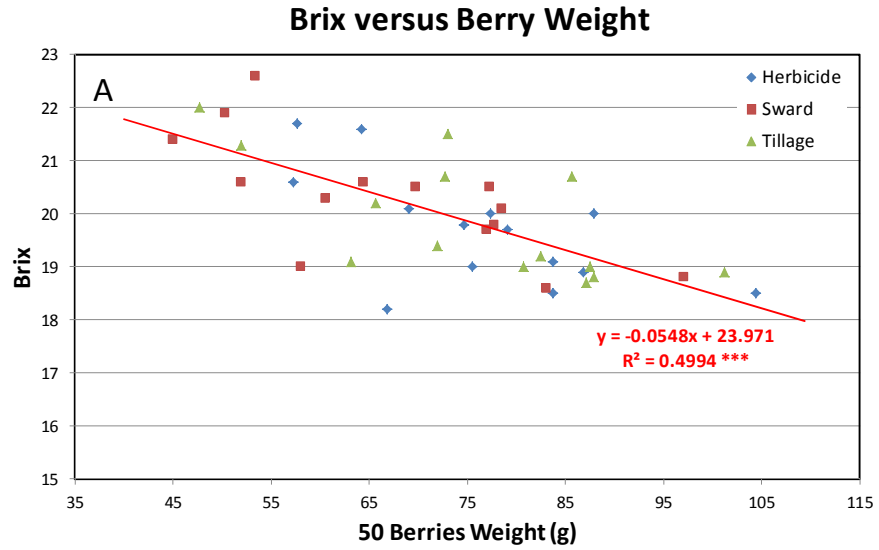
The multiple parameters observed during this study show clear effects of the treatments on many ecosystem services. Apart from the direct (single factor) effects that are observed, the aim of this project is to see how different parameters correlate to get a clearer picture of what explains the differences observed, and to identify gaps in observations and understanding.

Explaining Plant growth and yield:

- Berry size, leaf and shoot growth and Chlorophyll content are all clearly increased by both tillage and herbicide. In viticulture plant growth is often limited by the competition of ground cover, either through an increase in water deficiency or low nitrogen availability (Celette et al 2009). The differences between blocks, but also the differences in 'reaction' to the sward suppression are quite important. For the grower the increase in berry size in when herbicide or tillage are applied is not always a benefit (service) since grape quality might change (van Leeuwen et al 2010). Our samples showed highly significant correlations, negative between berry size and Brix values (explaining almost 50% of the variation Figure 25a) and negative (but weaker) correlation (R^2 = 0.2) between berry size and pH (Figure 25b).

NITROGEN:

- NO_3^- values in the top soil are rather low (< 25 ppm). In the deeper soil layers the values are undoubtedly even lower. This indicates a risk for nitrogen deficiency may limit vine growth considerably.
- This is confirmed by the very low nitrogen values in the must.
  - Nitrogen seems a major limiting factor for vine growth in these blocks and the presence of a (nitrogen storing) sward increases this deficiency for the vines. Suppression of the Sward not only reduces competition, but sward biomass degradation liberates nitrogen for vine growth.
  - These very low must nitrogen values will interfere with fermentation; most wine-makers will add di-ammonium phosphate (DAP) to correct for this deficiency.
- The effect of sward suppression on chlorophyll content seems very quick. The SPAD meter values in November suggest that this happens slightly quicker in Tillage than in Herbicide. SPAD meter values in December are strongly (R^2 = 0.5) and significantly correlated to must N (Figure 26).
- Soil nitrogen (NO_3^-), even late in season, is clearly increased by sward suppression and this is extreme in plots with 'strong' swards (High biomass swards of sown tall fescue at Kay brothers and Hawthorn Ridge).
- In this experiment it seems that the main effect of sward suppression is an increase in the availability of Nitrogen in the soil (NO_3^-, Figure 12), as detected in leaves (SPAD meter, Figure 5) and berries (Must, Figure 8).
- However, nitrogen indicators and berry size increase are not always strongest on the plots showing low nitrogen values and/or vigorous sward, so this clearly is not the only explanatory factor.



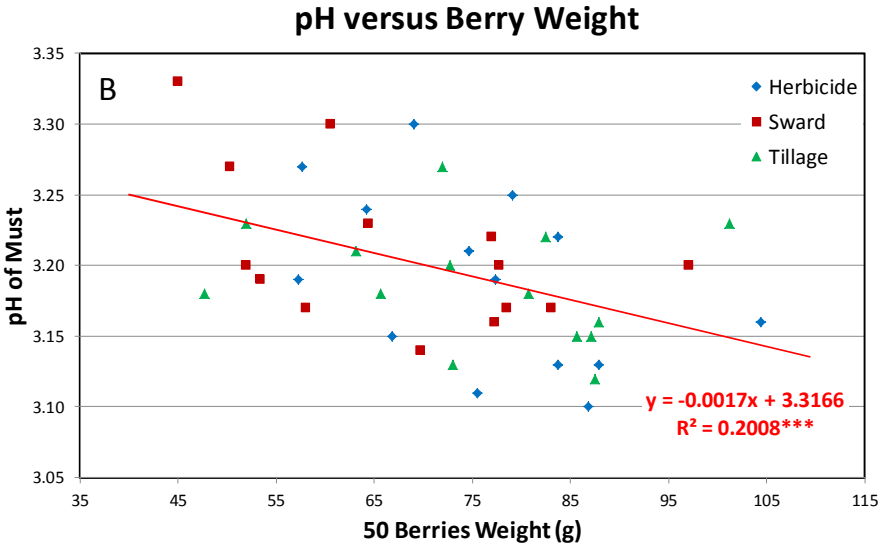


Figure 25Aand B: Correlations between berry weight and Sugar content (A) or pH of the Must (B)
Overall correlations significant at p<0,01

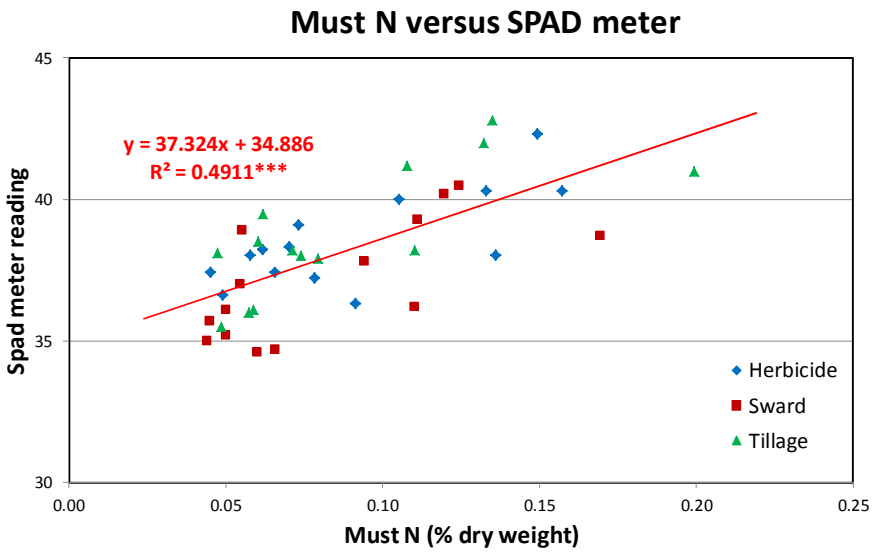


Figure 26 Correlations between Must N and SPAD meter
Overall correlation significant at p<0.01

WATER AVAILABILITY:

- Increased shoot growth and berry size seem to indicate increased water availability.
- Berry size is normally strongly related to water availability between bunch closure and veraison (Tregoat et al 2002)
- The suppression of the sward (Through tillage or herbicide) normally would decrease the water uptake, and make more water available to the vines.
- However tillage and herbicide were applied in late spring in already rather dry conditions (September/October). Therefore the uptake and evaporation of water after treatments was probably limited (even in 'Sward') since soil moisture was below or close to the wilting point.
- We did however observe (significantly) higher water content in the top soil of tillage. This can be attributed to the 'mulching' effect where capillary connection between the top soil and lower layers is broken by the tillage, this reducing surface evaporation (Unger et al 1991). Our data do however not allow quantifying the change in available water for the vines.
- In future experiments assessing the amount of available water in the root zone should be done regularly (monthly), for example using neutron probes and permanent tubes.
- Correlation between LAI and $\delta^{13}C$ (Figure 27A) is significant (the Paulsen grafted block was eliminated from this dataset), explaining about 25% of variability for all treatments individually but also all treatments together. This shows that leaf growth is related to water stress.
- Surprisingly no treatment effect on overall water deficiency ($\delta^{13}C$) was observed.
  - Others have observed similar effects (Pieri et al 1999; Lebon et al 2003; Celette et al 2005). This suggests that increased water availability at the start of season (in tillage and herbicide) results in increased shoot and leaf growth, but that this increased LAI increases evaporation and water deficiency later in season, the overall effect being neutral.
  - To test this water stem potential measurements could be taken during this period.
  - Water stress is very much depending on annual rainfall, 2014/2015 was globally a dry year, but results could be very different in wet or dry years.
- The low accumulated water stress of the Paulsen rootstock block shows the potential for rootstock to help decrease water stress.
- As water availability (deficiency) and irrigation related risks such as salinity damage are a major issue in many warm-climate vineyards (including McLaren Vale, White 2010) the use of rootstocks should be considered.

BERRY SIZE

- Berry size normally is strongly correlated to water stress between bunch closure and veraison (Tregoat et al 2002), but we did not measure this (see above). Correlations between accumulated water stress ($\delta^{13}C$) and berry size are weak ($R^2 = 0.159$) but significant at $p<0.01$ (Figure 27B) but differences in the 'timing' of the water stress might have influences the correlation level (see above). The differences in soil nitrogen availability will also change berry size but correlations between NO_3^- and berry size are not significant. Berry size and must N seem weakly negatively correlated at $p< 0.05$ (Figure 27C).
- Other factors that could explain berry size differences are clonal variations, but nearly all blocks were the same SA1654 (except Kay Brothers and Chalk Hill) and other factors such as pip numbers (pollination), virus diseases, or other deficiencies. We have no indication that there were differences between these factors among blocks (or treatments).

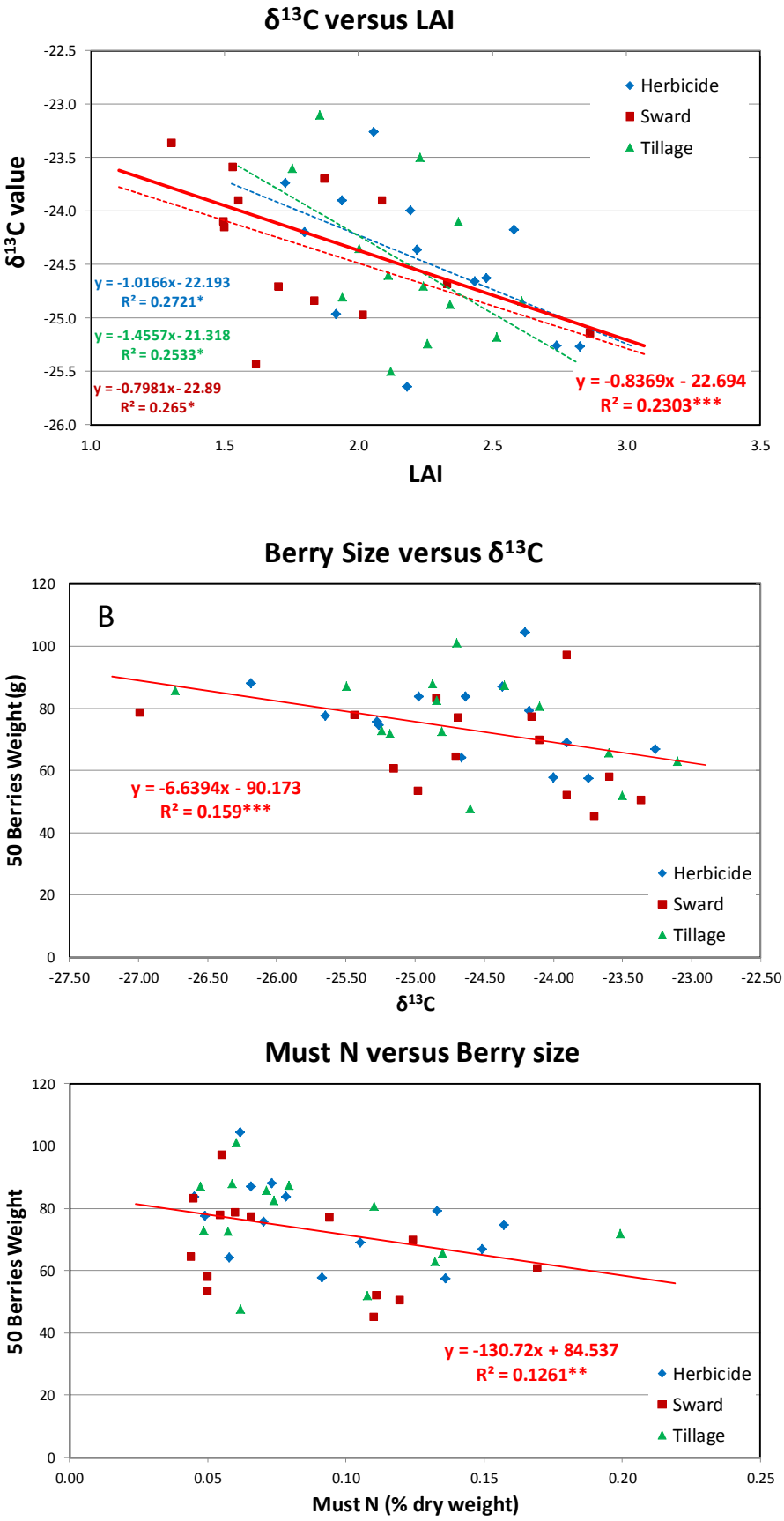


Figure 27A-C: Correlations between LAI and Water Stress (A); Berry Weight and Water stress (B) and Must Nitrogen (C)
*/**/*** Overall correlations significant at p <0.1/0.05/ 0.01

CANOPY AND SOIL TEMPERATURE:

- This type of observation is influenced by row orientation and changing air temperature and sun angle during the day. This caused differences in values among blocks, but differences among treatments (always measured shortly after each other in the same block) were less influenced.
- The soil-surface temperatures were clearly higher with tillage, but canopy temperature seems only very weakly increased with tillage, and only on the second observation. It is not clear if this increase in canopy temperature is due to increased soil temperatures or the effect of reduced evaporation due to increased water stress.
- We did not measure soil temperature variation over the day; differences in radiation overnight might also lead to differences between treatments.
- Living plants (cooling through evaporation) and to a lesser extend plant mulch (straw, reducing radiation absorption of the soil) seem to be efficient in reducing soil surface temperatures
- The changes in soil temperature might influence plant development and berry ripening, but this cannot be observed with our dataset. Micro-vinification may provide better indications.
- Higher soil temperatures (as observed in tillage) could increase the risk of 'sunburn' on grapes and leaves. This was not observed in this trial, but the experimental plots were probably too small to be able to observe possible treatment effects.
- The higher canopy temperatures in tillage during then second observation round might be an indication that water stress at that time was increased, the plant closing its stomata and leaf temperature increasing. The differences between treatments were however quite small. Once again water stem potential could be used to quantify this.

SWARD BIOMASS AND COMPOSITION

- Sward Biomass estimation showed very large differences among blocks. In some blocks (Samuels Gorge 1, Kirwin, Leconfield 1, Manjalda) there was a very small amount of sward biomass while some blocks had a high biomass of 60-70 cm high Tall fescue in September.
- We were not able to quantify this precisely since the amount of nitrogen fixing winter-annual plants (legumes such as Medicago, and Lotus sp) and winter-growing perennials such as soursob (*Oxalis pes-caprea*) seems quite important in the volunteer sward types, and our plot selection was done in September only.
- The amount of sward and its composition will have influenced the effect of the treatments significantly. Sward can store and (if dying or destroyed) release considerable amounts of biomass and thus nitrogen, either soil nitrogen, because the plants take up nitrogen (case of tall fescue sward in Kay Brothers) or by fixing air nitrogen (legumes). When destroying the sward this nitrogen is released and becomes available for the vine plants, the most significant increase in berry weight was indeed observed in 'Kay Bothers' block that had the highest estimated biomass when treatments were applied.
- So in subsequent experiments we should quantify the amount of biomass in each treatment and it's composition in major elements and plant functional groups (grasses, legumes and 'other dicots') at least two times per year (in winter and at bud-break) to gain better understanding of its role in organic matter build-up and nitrogen provision or competition.

- We have no data on the actual water use of the sward and its influence on competition. Rainfall being low and concentrated in the winter months, the soil never reaches 'field capacity'. However the sward is very active during the winter period, potentially evaporating a large amount of the rainfall, thus reducing winter 'reloading' of the soil.
- The presence of a Sward can also improve water infiltration (Celette et al 2005), so the overall result is unsure. As mentioned before, in future experiments it would be useful to measure actual water content in the root-zone regularly. This could be done using neutron probes (see section on water availability)

SOIL MOISTURE:

The significantly higher soil moisture in the top 10 cm of Tillage compared to both Sward and Herbicide clearly shows the mulching effect of the tillage. The few weedy plants that 'survived' the tillage (mainly plantain) showed strong growth but it cannot be confirmed that this also stimulated grape growth (see under Water Availability). The higher soil moisture can be expected to interfere positively with the biological activity and the degradation of the incorporated biomass (see under soil biota and litter-bag results).

SOIL CHEMICAL ANALYSIS:

- The chemical analysis of the soil showed that the only treatment effects were a clear increase in available soil nitrate (NO_3^-) and a slight increase in Phosphorus in Tillage (Figures 12 and 13).
- Treatment differences in top-soil NO_3^- were very variable among blocks (Figure 12); this was probably related to the big differences in block Sward Biomass, a 'strong' sward containing a lot of nitrogen, released upon destruction.
- Differences in Sward composition (Monocots, Legumes, other dicotyledonous plants) will also have influenced the result but were not quantified.
- More frequent analysis of Nitrogen availability, just after treatment application, mid-season and at harvest time) would have improved interpretation, and would probably have shown differences in nitrogen release dynamics between Tillage and Herbicide.
- Soil samples were taken in the mid-row. Irrigation and under-row management might produce very different values under the rows, for example for salinity and EC, but this was not the aim of this study.

SOIL ORGANIC MATTER:

- SOM content (Figure 14) in the first 10 cm of soil ranged from 2.5 to 8.5%. These values are higher than in standard (30 cm) soil samples because most SOM is concentrated in this top layer.
- Block differences are very large, showing that differences in management history, soil type and sward management have very large effects on SOM build-up or decrease. Lowest values occurred in sandy soil, highest values in the Craig Camm block where the volunteer sward is mainly composed of Barley Grass (*Hordeum leporinum*), a plant that produces a straw with a very high C:N ratio, apparently adding to SOM.
- Comparing these values to some available 'standard' soil analysis from the blocks showed that top-soil values were around 3x the 'normal' values. A 'Standard analysis' SOM value (considered optimal in viticulture) of about 1.5 % would translate to about 4.5% in the top soil.

- Plots that have lower values of SOM are at risk of a loss of soil structure and a lack of nitrogen release from the naturally occurring SOM degradation. This is the case on many blocks of the current study (see also MUST N discussion).
- No treatment effect on SOM was observed. This may seem surprising, but the incorporated (green) Sward with a low C/N value probably has been degraded almost completely, adding Nitrogen, but very little to the stable SOM fraction (White 2010). Increasing or decreasing the stable SOM fraction in agricultural soil is a long lasting process.
- SOM degradation provides Nitrogen to the vine plants, correlation between SOM and Nitrate in the soil is moderate but significant at $p<0.01$ (Figure 28). Correlations for individual treatments were significant for Sward and Tillage ($p< 0.05$).
- As can be observed actual NO_3^- values and correlation trends for Tillage and Herbicide are above the values for Sward, This indicates again that the destruction of the Sward contributes to an increase in Soil Nitrate.
- Soil samples were taken close to harvest, dynamics of soil nitrate probably were much stronger earlier in season and most Nitrogen released by biomass decomposition has already been taken up by the plants (White 2010, Proffit et al 2012).

SOIL PHYSICS:

- The particle size analysis 14 different blocks showed that our experiment represents most soils typical of the McLaren Vale area. Most blocks are Loamy or Sandy-Loam, with the two exceptions Chalk Hill (*Bay of Biscay* type Soil: cracking clay : Sandy-Clay-Loam) and Leconfield 2 (Sandy).
- CEC values are often quite low showing a low fertility level of the soils. When CEC and Clay contents are low (as is often the case) management of SOM is important to preserve enough fertility, plant vigour, and soil structure.
- We did not look deeper into soil profiles and root profiles. Rooting depth can be a particularly important factor modifying water availability etc. Most vineyard soils in the McLaren Vale area have a clearly layered soil profile.
- Soil compaction (penetrometer values) is strongly and positively correlated to soil clay content (Figure 29, $p<0.01$) for Sward and Herbicide.
    - Measurements were made on moist soil, after some rain, but the clay-rich *Biscay* soil of 'Chalk Hill', where most rain penetrated through soil cracks was still too dry for the measurement. These data were excluded from the analysis.
    - Absence of correlation for Tillage showed the mechanical action of decompaction on the top soil.
    - In some blocks (with high Clay contents) the effect of Tillage on decompaction seemed strong; suggesting that the top soil of was in fact quite compacted, because the soil had not been worked over for many years (Samuels Gorge, Coriole, Manjalda).

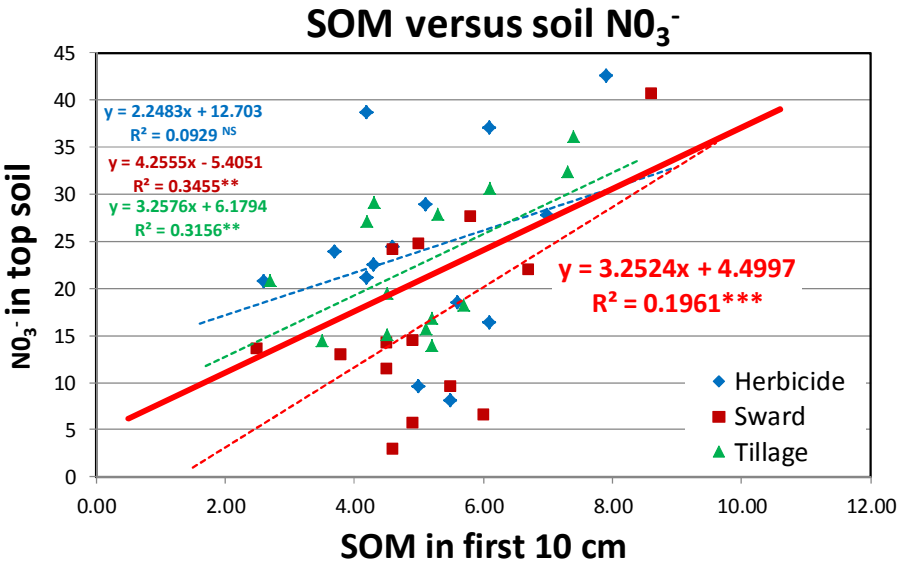


Figure 28 Correlations between SOM and NO_3^- in soil samples.
/* Correlations significant at p < 0.05/ 0.01

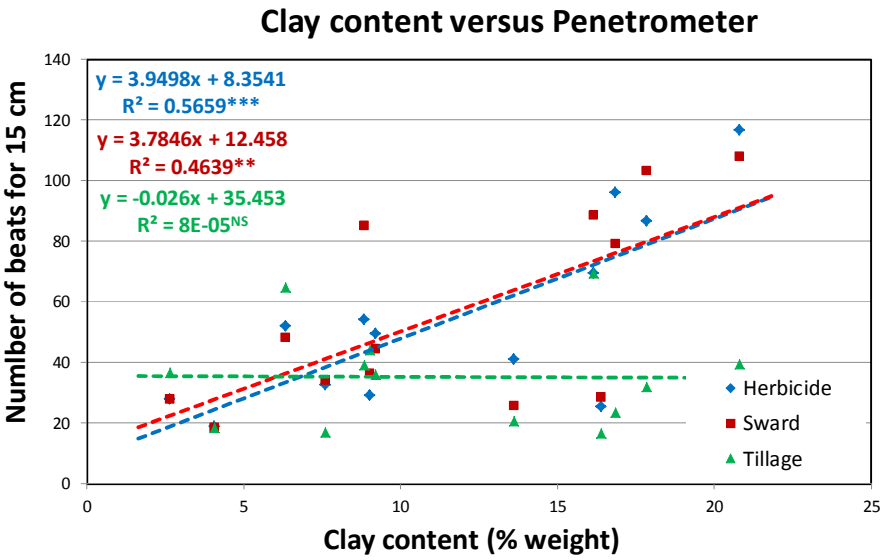


Figure 29 Correlations between Clay Content and penetrometer readings
/* Correlations significant at p < 0.05/ 0.01

- In these blocks with higher Clay content (right part of graph 29), the tilled soil maintained a crumbly structure throughout the season. On such soil a shallow tillage can be performed on a regular basis (every 2 to 4 years) to avoid surface compaction, without the risk of surface sealing on loamy soils as observed at James Cooter and Kirwin.
- In some other blocks, on sandy or sandy-loamy soils (left part of the graph), the initial effect of the tillage disappeared quickly after rains and values of tillage were similar or higher then Sward or Herbicide, showing a tendency for surface compaction and potential risk for runoff (James Cooter, Kirwin, Craig Camm) in the absence of sward.
- The compaction of the deeper layers was not observed but we presume that there is serious a risk of deep compaction on several blocks on these soil types; hampering plant root growth and uptake (see below section Bulk density).

o Bulk density
  - Bulk densities of these soils was very well correlated to the theoretical bulk densities (Figure 30) as calculated based on granulometry and SOM content according to Saxton et al (1986).
  - Since most soils had quite similar theoretical bulk densities of the mineral fraction, it is in fact the SOM value that is most strongly (R^2 = 0.33***) correlated to Bulk density (Figure 31).
  - On these loamy and sandy-loamy soils, the already high bulk densities in deeper soil layers where SOM content is lower are likely to reach values that can restrict root growth.
  - Avoiding (or curing) compaction is essential to maintain a healthy soil where vine roots are able to grow. Farmers should consider this risk in their management strategy.
  - Decompaction can be done using mechanical tools (subsoiler, ripper), but using plants such as cereals as 'biological' de-compactors creating porosity, also would allow increasing deep soil SOM content, a more efficient and natural soil decompaction that also ensures sustainability and resilience of the decompaction. This seems an interesting option to test in future experiments using green manure.

o The Water Holding Capacities (WHC=) observed (0.3 to 0.5 g/cm^3) are 'normal' values,
  - These soils can theoretically store 30 to 50 cm of water per meter depth, a value close to annual rainfall, which in reality will never be reached.
  - The small increase of WHC in Tillage is probably due to a (temporal) increase in porosity.
  - WHC is significantly positively correlated to SOM (Figure 32)

o The Wilting Point (WP) is very strongly positively correlated ($p<0.01$) to the SOM content (Figure32).

o Theoretically Available Water (TAW): The overall effect of these two parameters is the TAW (=WHC-WP) that varied from 0.17 to 0.37 g/cm^3.
  - Due to the 'inverse' effects on TAW and WP, the TAW is NOT significantly related to SOM.
  - Tillage was significantly higher than Sward ($p<0.05$) and Herbicide ($p<0.05$) due to the increased WHC (Figure 16e).
  - In the case of low rainfall and limited irrigation viticulture, where the soil never reaches full WHC, a higher SOM content will not improve the water available for the plants since the SOM 'retains' the water very efficiently, increasing the WP.

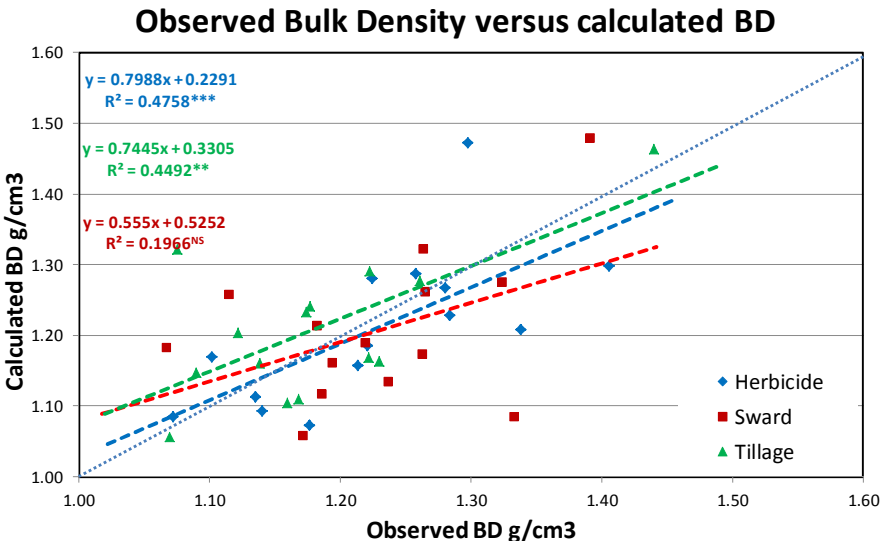


Figure 30 Correlations between observed and calculated Bulk density
/* Correlations significant at p < 0.05/ 0.01

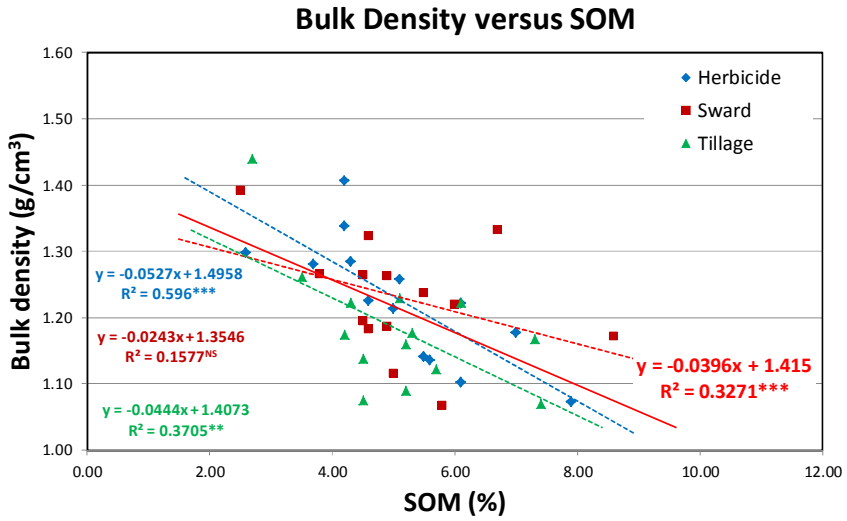


Figure 31 Correlations between Bulk density and SOM content
/* Correlations significant at p < 0.05/ 0.01

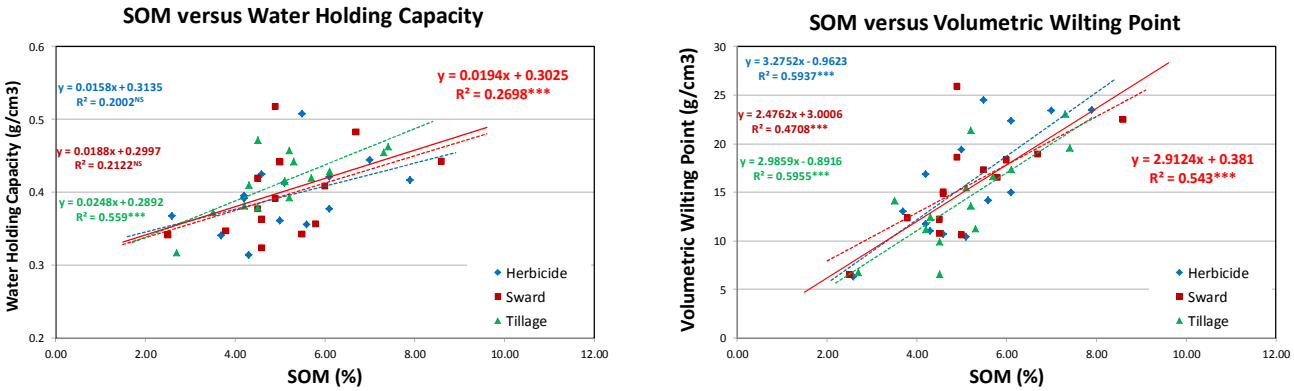


Figure 32 A et B Correlations between SOM and Water Holding capacity (A) and Volumetric Wilting Point (B)
/* Correlations significant at p < 0.05/ 0.01

SUPPORTING ECOSYSTEM FUNCTIONS

SOIL ORGANIC MATTER DEGRADATION

The litterbag system used in this experiment is a simple, standardized setup. The two types of tea represent the 'green' biomass (green tea) with a low C/N ratio. The Rooibos tea is more 'woody' material representing high C/N biomass.

Teabags were buried in mid-October in already very dry conditions. During the three following months very little rainfall was observed, soil moisture was low to very low (Figure 11) and soil temperature probably very high (Figure 10).

- Degradation of the green tea is relatively quick (> 50% decrease in 3 months), for Rooibos it is much less (80% weight remaining). This clearly shows that woody, high C/N material contributes much more to stable SOM build up than 'green' (low C/N) material (Figure 17).
- Taking into account the high soil temperatures (certainly above 25°C, with possible peaks during heatwaves) the actual degradation is a little lower than expected from data in other studies (Keuskamp et al, 2013). This might be due to extreme low soil moisture that might have limited bacterial and fungal activity.
- This seems to be confirmed by the low degradation of Rooibos (and to a lesser extend Green tea) observed at 'Leconfield 2' especially in Herbicide and Sward. The sandy soil with low SOM of this Leconfield 2 Block is the driest of all blocks.
- The slightly higher degradation of Rooibos observed in Tillage (all blocks) could be due to the same factor, Tillage soil moisture being slightly higher, could maintain microbial activity a little better then sward or herbicide.
- This same effect would also apply to the degradation of the incorporated biomass during Tillage. When tillage is done in early spring on a 'green' sward, the moist, low C/N biomass will degrade very quickly and release a high amount of nitrogen quickly. Incorporating a dry (high C/N) sward 'straw' later in season in a dryer soil would contribute more to SOM build-up and reduce the nitrogen flush. This effect might orient the choice of green manure plants and the time of tillage.
- The tea-bag system is a very promising, simple and standardized technique to observe this ecosystem service.
- The lack of differences between treatments could be due to the fact that the treatments were applied only in spring. We can assume that over time differences will develop.
- In future experiments it would be interesting to compare measurements of biomass degradation in different periods of the year, when soil moisture will not be limiting and temperatures will be more optimal.

REGULATORY ECOSYSTEM FUNCTIONS:

SEED PREDATION

- Seed predation experiment did not show differences between treatments or between seeds, but did highlight that differences among blocks do exist (Figure 18). However, the results of the three 'replicates' seem quite comparable.
- The origin of these differences is unclear, but it seems that variation is very large (variation between blocks from < 10 to >90% predation in 14 days, variation for different seeds from <5 to >80%), showing that this service can be influenced strongly by block and seed characteristics.
- No effort was made so far to identify the actual seed predators but the absence of difference between 'cage protected' and exposed seed cards suggest that the predators are mainly small animals, probably arthropods. Millipedes and ants were observed consuming seeds during the experiments, but other organisms are surely involved.
- Seed predation percentages of >80% in two weeks (as reached on some blocks and seeds during all three replicates) show the importance of this action for weed control. On a longer time scale predation levels can approach 100%.
- Some improvements were made in the setup (exposure, use of cages, types of seeds) during the three replicates. The setup now seems to be good enough to perform these measurements on a more routine basis, focussing on weed-seed types that are 'naturally' available on the plots. Plantain, Alfalfa and wild Mustard seem a good choice.
- As for other services it seems interesting to test this service at different periods of the year.
- The lack of differences between treatments could be due to the fact that the treatments were applied only in spring. We can assume that over time differences will develop.

INSECT PATHOGENS DETECTION

- The 'galleria bait method' was tested for the first time in this experiment. Some adaptations were made for larval preparation, soil 'activation' (adding enough water and letting microbial activity develop for two weeks), larval extraction and conservation. Only two tests were done, so data are insufficient for a good statistical analysis.
- As for seed predation mortality of the galleria larvae showed large variation among blocks. Mortality values ranges from 20% to 95%. Differences among treatments were not significant.
- The higher rate of entomopathogenic fungi that seems to exist on the Leconfield 2 block could be linked to the low SOM content, the lack of nitrogen resources from plant origin selecting for organisms capable of exploiting other resources.
- Though we did not identify the pathogens involved, we presume that *Metarhizium* and *Beauveria* sp were the main fungi, based on macroscopic aspects.
- No entomopathogenic nematodes were observed, but the soil was collected during very dry and warm conditions, not favourable for the survival of these nematodes.
- The setup can be used on a more routine basis, and should include different periods of the year.
- It would be most interesting to test the same setup using Light Brown Apple Moth larvae, which would be able to show a possible impact on this pest insect.

SOIL BIOTA

SOIL ARTHROPODS

- Berlese extraction proved to be a good technique to show differences between blocks, between treatments and over time.
- The strong decrease in abundance in summer (Figure 21a) shows that the activity of these arthropod communities is strongly decreased in dry and hot conditions. In future experiments autumn and winter observations should be included.
- Results seem consistent in time and space, tenfold difference in abundance (Figure 21b) and fourfold variation in richness (Figure 21C) show that soil meso-fauna is potentially a good quality indicator for soil health, even though sampling effort is high.
- Blocks with higher SOM content showed significantly higher overall diversity (Richness) Figure 33) and abundance (Figure 34). The effect on abundance was clearer (R^2 = 0.35) and also seems to show that below 3% SOM soil meso-fauna is really reduced.
- The very high abundance observed in Tillage in the first observation round (one month after the treatment was applied) shows how much these arthropods are favoured by the incorporation of the sward. These arthropods (mainly Collembola and Mites) are involved in the first steps of biomass fractionation, essential to make it available for microbial communities. This result also shows that, in spite of the mortality of Collembola that can be expected during the mechanical tillage, this population builds up rapidly.
- Collembola almost disappeared in summer samples, with a minor increase observed in late autumn samplings. It seems they are very dependent on soil moisture.
- The similarity in communities observed between sampling dates and different treatments of the same block is remarkable. Some morpho-types being observed only on one block and in almost all samples and dates (example: Pseudo-scorpions in Craig Camm block).
- Formal community analysis was not performed but should be tempted in future experiments since some species might be suitable indicators for specific soil conditions or management strategies.
- The lower Richness and Abundance in Herbicide compared to Sward seems to indicate a detrimental effect of the herbicide application on at least some morpho-types. A more detailed analysis to identify what taxons are involved could yield good indications on eco-toxicity.
- Samples were collected in the mid-row. Under-row populations could be very different as a result of irrigation, fertilizer, mulch and compost applications and various weed suppression techniques using either herbicide or mechanical weeding. In future experiments ‘under vine management should be ‘standardized’ and or included as an additional variable, for example comparing mechanical and chemical weeding.

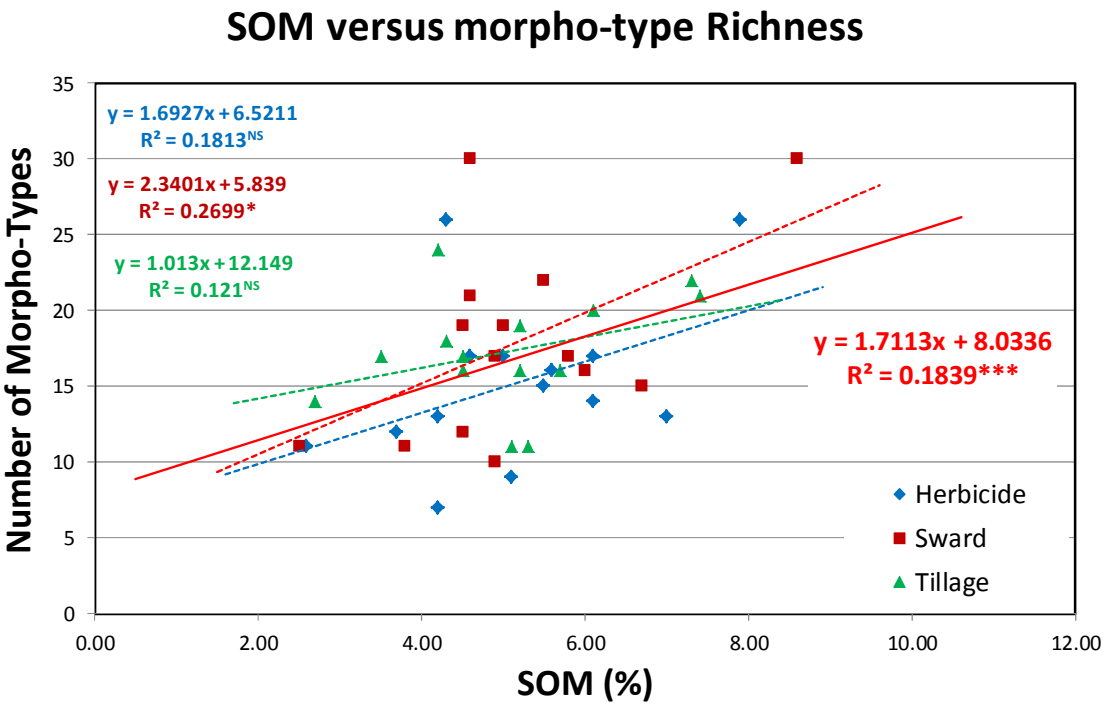


Figure 33 Correlations between SOM and accumulated Morpho-Type Richness in Berlese samples
*/*** Correlations significant at p < 0.1/ 0.01

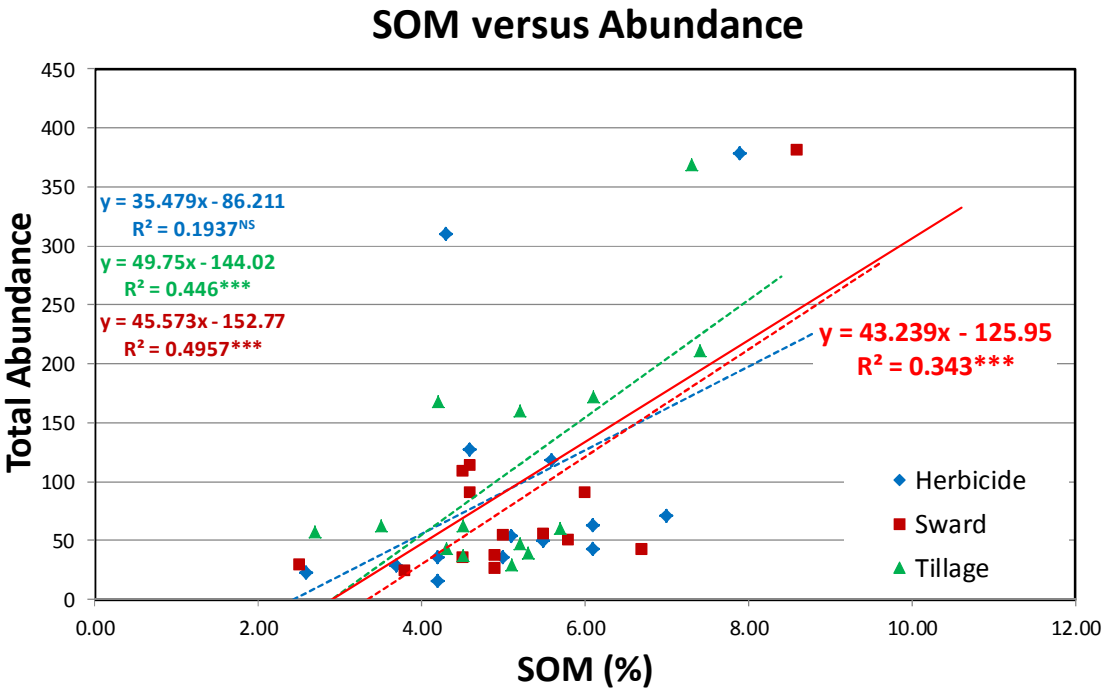


Figure 34 Correlations between SOM and accumulated Abundance in Berlese samples
*** Correlations significant at p < 0.01

SOIL DWELLING ARTHROPODS

- Pitfall trap results showed several limits of this technique.
  - Pitfall arthropods are clearly larger and more mobile than meso-fauna; individuals captured in a trap in plot can originate from neighbouring plots.
  - Another possible bias in Pitfall trapping is the difference in 'mobility' of soil dwelling arthropods in the different soil surface conditions of the treatments, influencing capture probability. Pitfall trapping is 'population-activity' estimation.
  - The high abundance of ants (80% of all individuals) is a problem for the analysis of these samples. Ant captures will be very much influenced by distance to nests and pathways to food resources and do not represent reliable population estimation.
  - Only 4 weeks were analysed for each plot, but this represented a rather large workload.
- Because of these drawbacks only richness was used for comparisons.
  - A two-fold variation was observed in accumulated richness between blocks (Figure 23)
  - Communities between plots of the same block were comparable (but see above, there can be an exchange between plots)
  - We observed a slightly lower (but statistically significant) richness in Herbicide and Tillage compared to Sward, especially for spiders. Since this represents a clear functional group of predators it could have an overall effect on pest insect regulation.
- In future experiments Berlese extraction should be preferred over pitfall trapping.
- The RBA approach seems quite well adapted, but when differences are detected between treatments additional taxonomic precision seems required.

FREE LIVING NEMATODES

- The results of the detection of markers for free living nematodes though DNA extraction and PCR from 250-300g soil samples showed no consistent results.
- No clear differences were observed between treatments, but large differences exist among blocks (Figure 24).
- The results did reveal a major problem for some groups where very large variation was seen between samples, including absence of detection of some ubiquitous species like Rhabditidae.
- The origin of these problems can be either a problem in soil sampling, where soil samples made of at least 10 cores do not always permit to obtain a representative sample of patch populations, or problems in conservation or processing of some samples.
- More testing needs to be done to see if this technique is useful for this type of experiments in the future.

BIOLOG ECOPLATES

- The results of this technique were quite disappointing. This technique showed no clear qualitative effects among blocks and no consistent differences among treatments.
- Only micro-organisms that can actually develop on the medium provided can be detected through this technique.
  - This apparently is only a very small fraction of micro-organisms in the soil.
  - The absence of substrate utilisation in the ecoplate therefore does not show absence of other organisms that could still use the substrate.
  - The technique therefore seems not well adapted to small changes in communities or abundance.
- In future experiments other approaches for microbial activity should be tested.
- Soil respiration can give a first quantitative approach to see if soil microbial activity is influences by treatments.
- DNA fingerprinting (using genomic techniques) of soil extracts could be a better approach to soil microbial communities.
- New techniques are rapidly developing in this field, and with expertise in this area at the Waite, Australia has an opportunity to be at the forefront of this research.

8. OUTCOME AND CONCLUSIONS

- The primary aim of this pilot project was to test and further design the experimental setup, treatments and techniques for an agro-ecology approach of soil management and ecosystem services in viticulture.
- This objective has been almost fully reached and the results of this project have already been used to optimise experimental setup of the European Biodiversa project PromESSinG that started in Europe in January 2015.
- Apart from the selection and testing of specific techniques the results we obtained have also been helpful to optimise the timing and intensity of observations (number of replicates, time of year) for future experiments.
- The results show the very strong and direct influence of changing soil-management of the mid-row on vine performance. These effects were more direct and stronger than expected.
  - The most important explaining factor for the differences seems to be the release of nitrogen from the degrading sward biomass.
  - Water efficiency seems also to be influenced, but additional measurements are needed to confirm this.
- Overall we have shown the very strong influence of SOM on many different supporting and regulating ecosystem services and service providers, and finally on the main provisioning service 'yield'. SOM is a key factor in many soil related processes.
- The obvious increase in yield of 'Tillage' and 'Herbicide' compared to 'Sward' seems a good indication that there is room for improvement by variation in soil management practices, but we have noted the risks associated to these techniques in the long term (such as loss of SOM and soil structure) but also on short term, the clear interaction between berry size and grape quality (sugar content, pH, …).
- Clear block and treatment differences were observed, including some of direct importance to the growers, such as the increase in grape berry weight, canopy growth and nitrogen use.
- The variation in the results due to the use of 14 different vineyard blocks (but only one replicate per block) on different soils and with different overall management has shown the 'robustness' of our observations, and even led to explanations for some 'outlier' results that are likely to be due to block specificities in soil characteristics and/or management. This has helped us to identify some elements (for example soil compaction) that should be addressed in future experiments.
- The experiments on regulating services (SOM degradation, Seed predation, Entomopathogens, Biolog Ecoplates) and observation on soil biota were more challenging. In almost all cases we were able to test and 'approve' new techniques or adapt the experiments to our needs.
- Crossing multiple observations on provisioning, supporting and regulating ecosystem services and a number of potential 'service providers' has allowed to get a much clearer image of the main effects that can be observed.
- Strong significant correlations between parameters have made it possible to better identify the underlying processes that regulate ecosystem services, especially the effects on vine growth that seem to be mainly limited by nitrogen availability, even in these water limited situation.

- Doing this experiment in 'warm climate' and 'limited irrigation' vineyards has also highlighted some elements that are of primary importance in the Australian situation (water efficiency, salinity) that need to be addresses in this context.
- The total workload of the project as described here was quite high. On average we have conducted 1.5 field-days per week during the experimental period. In future experiments this should be optimised but workload will still be quite big.

- Growers clearly will have a benefit from optimising soil management. It is important to note that they have become aware that none of the tested treatments is in itself a 'permanent' and sustainable option.
  - The results have already made growers reconsider and adapt the management of their plots, especially in those cases where non-optimal situations were observed (extreme soil compaction, strong sward competition, loss of soil structure).
  - It seems to us that the notion of 'permanent sward' is often taken too literally; some management (mowing, rotary hoeing, subsoil decompaction) is needed since some negative effects such as compaction are a major risk on some types of soils.
  - Growers have been warned against possible 'negative effects' such as lowering SOM if the treatments are continued over more years.
  - Most participating growers have become more aware of the risk of 'simple' unique solutions and have started to discuss options of 'staged' soil management, making it possible to react to simple indicators (such as SPAD meter readings) and adapt management based on observations (such as yield evolution over time or sward vigour).

- The (limited) participative research approach used in this project has shown a clear advantage for the (bidirectional) transfer of knowledge as recommended by White (2010) that led to the addition of some measurements and research questions (such as water efficiency).
  - The collaboration and exchanges with the growers and consultants also helped to identify the major risk and services they are concerned with, which added some observations such as canopy temperature measurements.

- The duration of this pilot experiment is not sufficient to look for longer lasting effects.
  - The treatments Tillage and Herbicide, even when not repeated, will have an effect on grape growth (e.g. leaf growth, flower induction) for the coming season (White 2010). Unfortunately we will not be able to observe these expected effects since we are not able to continue the project in the coming season. We did suggest the growers to be aware of this possible after-effect.
  - Continuing the treatments on the same plots for several years would also allow determination of their effects on some ecosystem services over a longer term. This could for example show that continued tillage increases the risk of SOM decline, giving the inverse effect of what was observed in one year. It would also allow small differences in ecosystem services, such as seed predation and entomopathogens to evolve and we would be able to show more differences between treatments.

- In a new experiment, a number of improvements should be made. Some have been highlighted in the discussion.
  - The option of 'green manure' (autumn sown winter crops destroyed in early spring) seems very interesting to consider in future experiments, since it could be a technique that combines more advantages than risks, especially for maintaining soil fertility and avoiding compaction.
  - In addition, we think it would be very worthwhile to include in a possible follow-up experiment a study on the presence of Mycorrhiza (Arbuscular Mycorrhizal Fungi AMF) since these organisms can increase the efficiency of root uptake (White 2010) and these organisms can also be shared between ground cover and vines. Molecular and more classic techniques are available to study this interaction.
  - More knowledge needs to be acquired on the diversity of soil microbes and this should be related to measurements of their activity (for instance in different steps of the mineralization of SOM).
  - The nutritional status of the vine should be measured on the plants directly. For this standard petiole/leaf blade analysis should be performed at several growth stages during the year (Flowering, Veraison and Yield).
  - Impact on wine quality could be investigated through micro-vinification.
  - Furthermore, the role of different ecosystem service providers could be assessed experimentally, for example by using 'exclusion techniques' (such as the cages tested in the seed predation experiments). It is important for growers to know this, as it allows the recognition of a healthy soil.

- In this context it is important to also approach vineyard ground cover as an (agro-) ecological system:
  - Grassy Sward, either sown or 'volunteer' in a vineyard inter-row is in ecological terms a rather 'juvenile' herbaceous plant community that would evolve over time through natural processes (succession) into woody vegetation if no management is done.
  - Therefore human management (mowing or grazing) is needed to maintain this cover and to optimise the services provided by the sward and more generally to manage the vineyard agro-system, but these 'disturbances' will not just allow a sward to maintain its 'juvenile' stage, but also have other impacts on the soil and vine growth (such as compaction by machinery).
  - Therefore a 'permanent sward' should not be maintained 'at all costs'. It seems more realistic to observe and, if needed, adapt the soil management over time.
  - While it is impossible to avoid some long term negative aspects of agricultural management (such as compaction) an intervention such as tillage, subsoiling or green manure can be used to remediate soils, but growers should be aware of the possible negative effects that can arise.
- Therefore a better 'formalisation' of a set of decision rules seems needed. The data do not yet permit establishment of such a set of rules since the effect of changes can be slow (SOM build-up or degradation) and will also depend on climatic conditions (rainfall, ….), soil type and management practices. The European project PromESSinG is therefore lasting three years and repeated in different areas of central Europe.

9. RECOMMENDATIONS

This experiment has highlighted that the existing practice of 'permanent sward' adopted in most McLaren Vale vineyard blocks has a number of advantages but also risks that were not always well recognized by growers and consultants.

Changing soil management (in this case sward suppression) can have clear (short term) beneficial effects, remediating some of these problems, while degrading other ecosystem services.

Measurement techniques for ecosystem functions/services have been optimised for most data, but more focus on water efficiency and plant physiology is needed in future experiments. .

This one year experiment is not sufficient to observe longer term effects of soil management practices, especially on the biological indicators (soil biota, seed predation, insect pathogens).

Because of limited resources, the existing management diversity, linked to soil and climate conditions, but also cropping systems (e.g. irrigation intensity, under-row management) as occurring in Australian viticulture, could not be covered either.

The multidisciplinary approach of agro-ecology and the many scientists involved in the project have permitted creation of a real synergy to reach a more holistic and comprehensive approach to a real practical management question for the growers and industry.

All participating researchers have expressed their interest in continuing to participate in this project. The partners of the European PromESSinG project have also expressed their interest to associate with an Australian Viticulture project and exchange methods and results.

We therefore recommend initiating more formal long term collaboration with the European PromESSinG project through a 3 year / 3 management options / 3 viticultural regions project in Australia. Already the PromESSinG project has been able to adjust its experimental setup, set of measurements and timing of observations based on the experience obtained in this Australian R&D project. Comparing data from outside Australia will clearly have added value (White 2010)

We will submit such a project to the oncoming AGWA call. An Australian project should take into account a number of aspects that are of particular interest to Australian viticulture.

- Pedo-Climatic variation (in and between regions).
- Irrigation practices (from limited to abundant irrigation) associated with stem water stress measurements. As an example : McLaren Vale and Riverland
- Plant nutrient situation should be assessed regularly through petiole analysis
- Consider the option of micro-vinification to look for the influence on wine quality
- Include in the project variation ofthe management of the under-vine area: either mechanical or chemical management, as a 'nested' design (half the plots in each region). This would also substantially increase the interested for organic and bio-dynamic growers
- Increase the precision on soil meso-fauna and include other functional groups such as earthworms.
- Test other techniques to study the diversity of soil microbes, tempting to establish relationships between biomass and diversity to activity and function (e.g. nutrient release and improving SOM)

10. APPENDICES

Appendix 1: Communication

During the project we have been communicating with the participating growers and consultancy on the following occasions:

- General presentation to select candidate blocks and growers on August 22nd (McLaren Vale)
- Participation in a vineyard field day on soil management in Langhorne creek (October 24th)
- Individual encounters with each participating growers for collection of information on their block (December 2014, January 2015)
- Presentation of intermediate results to participating growers on (January 30th Samuels Gorge Winery)
- Presentation of the results to all McLaren Vale growers on April 21st 2015 (Willunga)
- Presentation of the results to Barossa growers technical committee on June 18th 2015 (Tanunda)
- Individual encounters with all participating growers and consultants and discussion of results and implications for their block (First week of June 2015)

Scientific communications:

- Presentation of the project during the Australian Entomological Society annual meeting (Canberra October 1st 2014)
- Presentation of the project for WAITE campus staff on November 26th 2014
- International Research Seminar Waite campus June 25th 2015

No communications have been submitted to technical journals yet, but we will be preparing a communication for the 'Wine and Viticulture Journal' shortly.

Appendix 2: Intellectual Property

Intellectual property has been agreed on in Article 8 of the Host agreement between AFW and Bordeaux Sciences Agro concerning Maarten van Helden's stay at Adelaide University:

CITATION
'Article 8: Intellectual Property and the Protection of Results
Each party shall remain the owner of the respective scientific and technical knowledge, know-how, rights and intellectual and industrial property titles in its possession on the date the present agreement enters into effect.
Intellectual property created by Mr. Maarten VAN HELDEN during his time as visiting research fellow at the University of Adelaide, that has been created using any pre-existing intellectual property of the University of Adelaide shall be owned by the University of Adelaide.
Other intellectual property created by Mr. Maarten VAN HELDEN during his time as visiting research fellow at the University of Adelaide shall be co-owned by both Parties in proportion to their respective overall contributions (intellectual and financial) to the execution of the corresponding research.
Where intellectual property is co-owned, the Parties shall determine together how such intellectual property shall be protected through intellectual property law, patenting or trade secret (know-how).In the case that the co-owned intellectual property shall be likely to be exploited, whether commercially or non-commercially, the Parties shall consult each other to agree in writing which Party shall be responsible for said exploitation, acting as agent for both Parties. Profits from any commercialisation of co-owned intellectual property shall be shared between the Parties on a pro rata basis in proportion to their intellectual and financial contributions to the research leading to the invention concerned'
END CITATION

The results of this project are freely available through this report and upcoming publications.
All data have been shared with the participating growers and consultants.
As planned the data have also been shared with the other partners of the PromESSinG project.

Appendix 3: References

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Appendix 4: Staff

The actual experimental work in the project was done almost exclusively by the main investigator (Maarten van Helden, Bordeaux Sciences Agro; Main Investigator s part of his sabbatical year) but help, advice and equipment loan by the following people made the project possible:

- Mike Keller (School AFW; coordinator)
- Maryam Yazdani (AFW; Experimental setup, Field and lab work assistance)
- Cassandra Collins (AFW; Viticulture)
- Annette James (AFW; Berry analysis)
- Tim Cavagnaro (AFW; Soil ecology and physics)
- Rebecca Stoner (AFW; Technical laboratory assistance)
- Cameron Grant (AFW; Soil physics, Soil chemistry)
- Katja Hogendoorn (AFW; Insect identifications and cultural integration)
- Roberta De Bei (AFW; Analysis of images for LAI measurement)
- Chris Penfold (AFW; Ground Cover Trails)
- Greg Walker (SARDI; Technical assistance)
- Michael Nash (SARDI; Collembola identification)
- Peter Crisp (SARDI ; Mite identification)
- Victor Sadras (SARDI; SPAD meter measurements, experimental setup)
- Dilhani Perera (SARDI : Insect sorting)
- Martin Moran (SARDI; SPAD meter measurements)
- Helen Degraaf (SARDI; Insect identification, lab assistance)
- Alan McKay (SARDI; Soil PCR analysis)
- Katherine Linsell (SARDI: Soil PCR analysis)
- Stephen Tyermann (Univ. of Adelaide; Infrared Canopy temperature measurements)
- Wendy Sullivan (Univ. of Adelaide Canopy, technical assistance)
- James Hook (AFW, DJ Growers Consultancy: Practical aspects with Growers)
- Peter Bolte (Pekabo Pty Ltd Consultancy: Practical aspects with Growers)

Experimental blocks used for this experiment

Nr	Name	Clone	Planting Dist. (m)	Planting year	Hoeing date	Spraying date	X Coord	Y Coord	Rows	HERBICIDE Poles	SWARD Poles	TILLAGE Poles	Remarks
1	Chalk Hill	R6W	3 x 2	2007	12/9	13/9	35°10'07.61"S	138°34'03.00"E	21-24	15-20	10-15	5-10	
2	Coriole	1654	3 x 1.5	1998	4/9	5/9	35°10'58.82"S	138°33'06.32"E	34-37	14-19	9-14	4-9	
3	Craig Camm	1654	3 x 1.5	1994	2/10	13/9	35°12'03.24"S	138°30'55.96"E	25-28	14-19	9-14	4-9	
4	Hawthorn Ridge	1654	3 x 1.5	2000	25/9	13/9	35°15'08.93"S	138°30'19.65"E	244-247	14-19	9-14	4-9	
5	James Cooter	1654	3 x 1.5	1998	2/10	13/9	35°16'48.76"S	138°31'06.35"E	45-48	14-19	9-14	4-9	
6	Kay brothers	Local	3 x 1.8	1993	9/9	13/9	35°10'55.84"S	138°33'49.59"E	3-6	13-18	9-13	3-8	
7	Kirwin	1654	3 x 1.8	1997	2/10	13/9	35°17'58.05"S	138°30'54.88"E	6-9	23-28	18-23	13-18	
8	Leconfield 1	1654	2.5 x 1.5	1999	11/9	12/9	35°13'49.60"S	138°32'55.40"E	100-103	14-19	9-14	4-9	
9	Leconfield 2	1654	3 x 1.5	1996	11/9	12/9	35°13'50.61"S	138°32'42.52"E	12-15	15-20	10-15	5-10	
10	Manjalda	1654	3 x 3	2002	2/10	11/9	35°14'27.15"S	138°34'09.56"E	50-53	14-19	9-14	4-9	
11	Redwind	1654	3 x 1.6	1996	24/9	11/9	35°16'04.32"S	138°30'33.98"E	64-67	8(22)-10(28)	6(16)-8(22)	4(10)-6(16)	Wooden poles as limits
12	Reedy Creek	1654	3 x 1.5	1996	25/9	13/9	35°14'45.17"S	138°31'09.29"E	4-9	137-140	140-145	146-149	Plots not in same rows
13	Samuels Gorge 1 (N)	1654	3 x 2.5	2001	9/9	13/9	35°10'03.45"S	138°32'32.99"E	87-90	21-26	17-20	11-16	
14	Samuels Gorge 2 (S)	1654	3 x 2.5	1998	9/9	13/9	35°10'11.50"S	138°32'28.39"E	16-19	17-22	12-17	7-12	

Table 2 : Description of the blocks (exact location, age, density, clone, treatment dates) used in the experiment
Colour codes : Blue = Herbicide, Brown = Sward, Green = Tillage).
Note : Only in Reedy Creek Block the plots were not in the same row, to avoid variation in plant vigour.

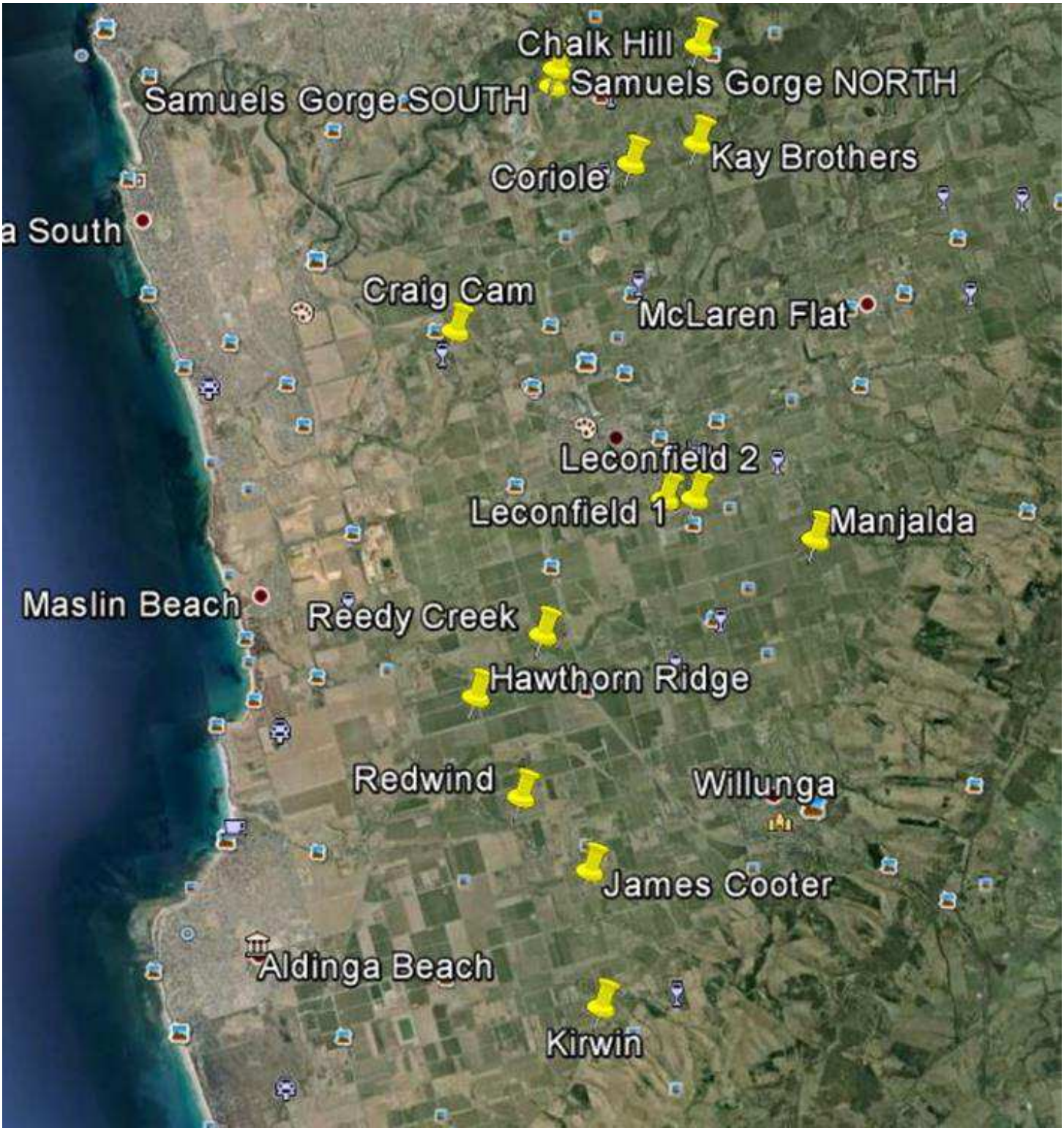


Figure 35: Localisation of the 14 blocks in the McLaren Vale area. The whole area of the McLaren Vale region is covered, but climatic differences are very limited.

Appendix 6: Budget reconciliation

The End of Project Financial Statement completed online in CIMS.