Integrating sustainable soil health practices into a commercial vegetable farming operation

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Contents

1 Summary

Integrating sustainable soil health practices into commercial vegetable production is required to reverse declines in soil health and maintain or improve the productivity and profitability of vegetable enterprisers. The project looked at "softer" soil management practices, such as reduced tillage, cover crops, compost and controlled traffic, at Mulyan Farms, Cowra NSW with leading vegetable growers Ed and James Fagan.

Over the three years the project has contributed to two videos, two Technical Report, four farm walks, five factsheets and contributed content to three Facebook pages.

The trials at Mulyan Farms have provided commercial scale validation that "softer" soil management practices can be integrated into large-scale vegetable production. For example, all cover crops produced a more profitable spinach crop, compared to a traditional fallowed system. Increases in profitably of 36 and 48% were obtained following the legume cover crops of Morgan Field peas or Balansa clover, respectively.

The project has successfully demonstrated and communicated that combining cover cropping with controlled traffic and reduced tillage will allow for sustainable improvement to the soil condition which can maintain or improve yields, and reduce input costs.

A key feature of the project has been the use of farmer-to-farmer communication, for example, in the videos and farm walks. The project team has helped Ed and James to document their soil management practices, and trial new ones, and then communicate the learnings to other growers. This has been the key to achieving the outcomes for the vegetable industry.

2 Keywords

Cover crop, mulch, legume, no-till, minimum till, sustainability, soil, biofumigation

3 Introduction

Vegetable growers in Australia mainly use conventional cultivation methods including pre-plant ripping (74%) and rotary hoeing (70%). Aggressive cultivation is expensive and damaging to soils (VG11034). Cultivation is typically used to bury crop residues, relieve compaction, control weeds and prepare seed beds.

These energy-intensive cultivation practices result in a:

- Decline in soil organic matter levels
- Decline in soil physical structure, aggregate stability and increased compaction
- Reduction in soil microbial activity and diversity with consequent build-up of soil-borne diseases such as *Fusarium, Sclerotinia, Pythium* and *Rhizoctonia*.
- Extra cost through larger tractors, increased fuel consumption and a greater labour requirement

This general decline in the soil condition leads to reduced yield, and reduced eating and keeping quality of leafy vegetable crops such as lettuce and baby leaf salad lines.

The decline in soil microbial levels generally, in combination with repeated crops of the same species, or even the same family, can lead to a build-up of plant pathogenic organisms. Repeated crops of the same species allow pathogenic organisms to multiply without sufficient competition from other non-pathogenic soil organisms. Organic matter is critical in soils to provide a source of food for non-pathogenic soil micro-organisms; it has positive effects on soil nutrient-holding capacity and on soil structure (Bailey and Lazarovits 2003; Carter, Noronha et al. 2009).

Cover crops are non-income producing crops grown primarily to protect and improve the soil. The benefits of using cover crops in rotations are well documented and include their potential to build and stabilise soil structure, add soil nitrogen, reduce nitrate leaching and recover nutrients from deeper in the soil profile, reduce pest and weed pressure, and decrease soil erosion (Stivers, et al, 1999).

While not new, the use of legumes to nitrogen to soils is gaining fresh attention. Leguminous cover crops such as lucerne, vetch and clover with and without grasses in the inter-row have great potential (Sanchez, Cichon et al. 2006; St. Laurent, Merwin et al. 2008; Teravest, Smith et al. 2010). Also of interest are mustard cover crops with biofumigating properties, which research has shown to control *verticillium wilt* (Larkin, Honeycutt et al. 2011) and *rhizoctonia solani* (Larkin and Griffin 2007) in the field.

This project studied the effect of a range of cover crops on paddocks that have been in a reduced till and controlled traffic regime since 2009. The soil quality of these paddocks had been heavily degraded from decades of intensive cultivation, and the farm owners were intent on restoring the soil quality of the land. Management practices such as reduced tillage and residue mulching, where the soil is always covered, growing plants and not regularly cultivated, can increase soil organic matter levels and restore soils to a healthy condition very rapidly (Rogers, Little et al. 2004; Kumar, Abdul-Baki et al. 2005; Wang, Klassen et al. 2005; Carrera, Buyer et al. 2007; Stirling and Eden 2008).

The project worked with vegetable growers Ed and James Fagan to document their soil management practices, trial new ones and then communicate learnings with other growers.

4 Methodology

4.1 Overview of Mulyan, Cowra, NSW

The project undertook a series of trials on the 1,400 hectare Mulyan Farms, 5 km west of Cowra NSW. Approximately 50% of the farm is irrigated from either the Lachlan River or bore water. Dryland crops include wheat, canola, lucerne and perennial pastures. Irrigated crops include beetroot, spinach, onions, lettuce, popping corn and asparagus.

4.2 Climate

The climate of Cowra is characterised by a summer average temperature exceeding 30°C, and cool winters. Cowra has an annual rainfall of 598 mm, which falls evenly throughout the year (Table 1).

Table 1. Long-term (1966 – 2011) average climate data for Cowra.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean rainfall (mm)	59.6	52.9	40.4	42.8	46.3	40.5	52.5	47.8	52.5	56.3	53.3	53.3
					Temperature (^{0}C)							
Mean maximum	32.2	31.4	28.1	23.6	18.6	14.7	13.7	15.5	18.6	22.7	26.7	30.2
Mean minimum	15.6	15.6	12.5	8.3	5.1	3.1	2.1	2.8	4.5	7.0	10.2	13.1

4.3 Location and farm map

The cover crops and nitrogen in the conventional tilled corn demonstration trial took place in the 12 ha Block 1. The biofumigant trial was undertaken on block 8b. The reduced tillage, cover crop and compost trial was undertaken on block 8a. (Figure 1)

Figure 1. Aerial photo of Mulyan farms showing the location of the trial and demo sites.

4.4 Cover crops and compost under reduced tillage trial (Block 8a)

Details of the methodologies used in this trial are provided in Hung, et. al. 2016 (**Appendix 1**). A short summary is provided below.

The trial aimed to determine the best soil management practices to improve soil health, decrease nitrous oxide emissions and improve crop productivity. A range of soil management treatments were applied to rebuild soil organic matter following almost 40 years of intensive cultivation.

Soil improvement practices included legume cover crops (Morgan Field peas and clovers), ryegrass, biofumigant cover crops (Nemclear and Caliente mustards), compost and a fallow control. All areas were managed under a reduced till, controlled traffic system.

The cover crops were grown from May to October 2014 and sprayed off with glyphosphate and left as surface residues through the summer of 2014–15. Soil samples were taken from each treatment before the residues were incorporated into the soil with two passes of a bed former in February 2015.

An additional treatment of a nitrification inhibitor (ENTEC), was applied to the ryegrass treatment to study its effects on soil nitrogen retention and nitrous oxide emissions. Nitrous oxide emissions were monitored during the growth of the cover crop and subsequently during the spinach cash crop.

A spinach crop was sown across all treatments in Spring 2015, having been delayed by dry condition in autumn. The spinach crop performance was monitored with regular measurements of plant density, leaf colour, weed counts and ultimately yield. Soil condition was assessed through nitrate, labile carbon, total carbon, bulk density and full nutrient analyses. Soil temperature was recorded at 10cm and moisture to 50cm. The crop was commercially harvested in November 2015 and final soil samples were collected the following day.

Detailed methodology is provided in **Appendix 1**.

4.5 Cover crops and nitrogen fertiliser trial with corn

Details of the methodologies used in this trial are provided in Montagu et al 2015 (**Appendix 2**). A brief summary is provided below.

The trial aimed to determine the impact of two winter cover crops, either Nemclear mustard or ryegrass/peas on the summer cash crop of corn in relationship to:

- Crop growth and yield
- Nitrogen use
- Impact on nitrous oxide emissions

The cover crops were sown on 15 May 2014 with fertiliser added at sowing. The winter fallow received no fertiliser and weeds were not controlled during the winter. In early September the cover crops were sprayed with glyphosate and 2,4-D and five days later cultivated in. Corn (Zea mays L) was sown at 85 kg ha^{-1} on 11 November 2014. A total of 294 kgN ha^{-1} was applied to the corn crop over the growing season. A basal application of anhydrous ammonia (150 kgN ha^{-1}, Big N 82% N) and a compound fertiliser (24 kgN ha^{-1}; 10 kgP ha^{-1}; 28 kgK ha^{-1}; 16 kgS ha^{-1}, Nitrophoska Special 12% N), was applied twelve and two days prior to planting.

It was expected that the nitrogen fixing capabilities of the ryegrass/peas combination and the biofumigation properties of Nemclear mustard should be able to perform with lower nitrogen input than the control. Three rates of 0, 60 and 120 kgN ha^{-1} anhydrous ammonia were applied in strips as side dressings to each of the cover crop treatments and the control.

Five static non-flow-through chambers were installed in the soil to measure the nitrous oxide emissions from each of the treatments throughout both the cover crops and cash crop, with a focus on irrigation events which expect higher soil emissions. In each treatment three plots were established and plant height, leaf collar number and SPAD measured regularly and yield was determined by a hand harvest immediately prior to the commercial harvest.

Detailed methodology is provided in **Appendix 2**.

4.6 Field days

Field days were organised to disseminate knowledge gained through the trial and to demonstrate cover crops in situ to local growers and advisors. Throughout the trial period there were a total of four field days, two at the trial site in Cowra, one in Bathurst, NSW and one in Gippsland, VIC. The events involved a technical briefing on the benefits and challenges of cover cropping, the equipment and processes required to successfully farm with cover crops and a farm walk through the different varieties.

4.7 Factsheets

Factsheets are a very efficient method to inform the wider horticultural industry of innovative sustainable practices. A range of professional and succinct soil management factsheets were developed.

4.8 Electronic and Social Media

The project used electronic and social media to extend the reach of the project. This included placing electronic resources, such as factsheets on the AHR website and later on soilwealth.com.au.

The Cowra site was one of the first attempts to use social media platforms for vegetable research trials. A Facebook page facebook.com/SoilWealthCowra was used to update interested parties on the developments and results of the trial site. Similar pages were established for the two ancillary sites in the project and are listed in the outputs of this report.

The project has also contributed content to the @Soilwealth Twitter feed.

5 Outputs

5.1 Reports

The project has produced two substantive reports on the trials undertaken at Mulyan farms.

5.1.1 Spinach yield, nitrous oxide emissions and soil carbon following cover crops and compost (Appendix 1)

Summary

Agriculture is a major contributor to nitrous oxide emissions, with emissions being affected by cropping practices such as cover crops, nitrogen fertiliser rates, soil tillage and irrigation methods. The aims of this study were to investigate the impacts of winter cover crops (legume and ryegrass) compared to compost or fallow on spinach growth and yields and N_2O emissions.

Five treatments (legumes (peas and clover), compost, fallow, ryegrass and nitrogen inhibitor (DMPP) were arranged in a randomised complete block design with four replicates in Cowra, NSW. Cover crops were sown in May, 2014, grown over winter/summer, and then sprayed out before incorporating into soil. Compost was applied twice to the fallow treatment; 11 tonnes ha^{-1} on the 15 May, 2014, and 5 tonnes ha^{-1} on August 2015. A commercial spinach crop was sown across all areas on 13 October, 2015 and harvested on 12 November, 2015. A total of 82kg N ha^{-1} was applied as a basal nitrogen fertiliser prior to sowing of the spinach. Soil samples, crop data were collected weekly with nitrous oxides sampled more frequently using static chambers.

Spinach grown following a legume cover crop yielded over 60% more compared to the fallow area, while ryegrass and compost were 25 and 18% more than the fallow. The nitrous oxide emission from spinach grown following either the legume or ryegrass cover crops were very low (55g and 73g N_2O-N ha^{-1} $season^{-1}$, respectively). Spikes in emissions were observed when spinach was grown after fallow or compost addition resulting in greater over all nitrous oxide emissions (169g and 178g N_2O-N ha^{-1} $season^{-1}$, respectively). Despite these spikes in emissions, the generally low nitrous oxide emissions were attributed to the frequent and small irrigation using overhead sprinklers resulting in a low water-filled porosity (around 40%) and the low nitrogen fertiliser rate used (82kg N ha^{-1}).

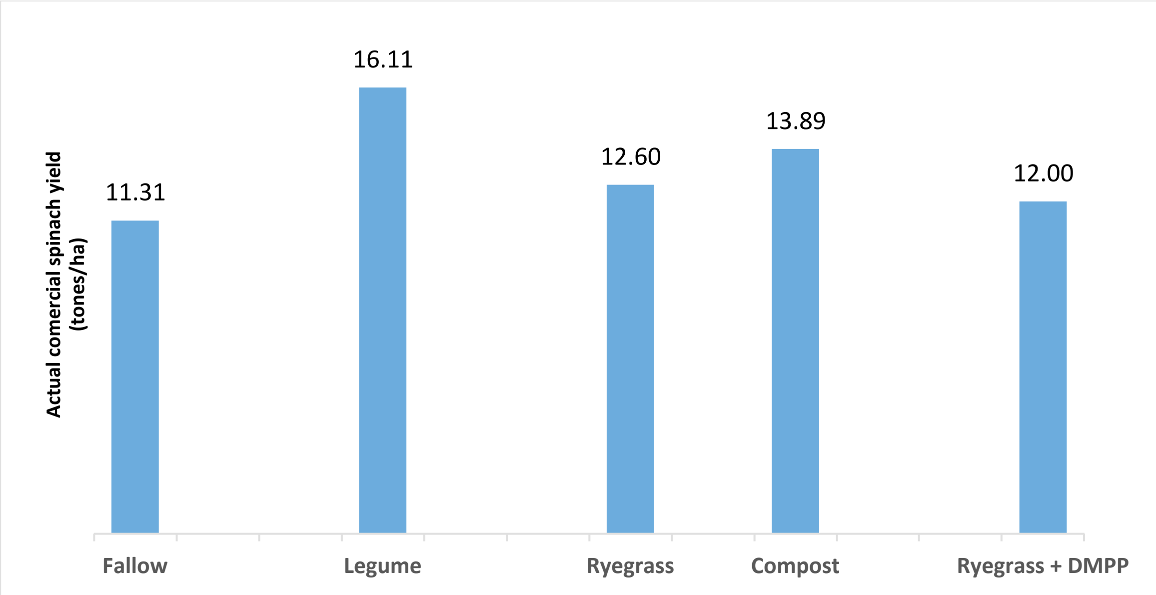


Figure 2: Commercial baby leaf spinach yields following different cover crops or compost.

The higher spinach yields and lower nitrous oxide emissions following a legume cover crop resulted in substantially lower nitrous oxide emission intensity than spinach grown following a winter fallow (2.0g vs 9.8g N_2O-N ton spinach^{-1}, respectively).

5.1.2 Potential of cover crops to reduce nitrous oxide emissions from a high nitrogen input corn crop (Appendix 2)

Summary

Cover crops are a practical soil management tool. Understanding the range of benefits is important as cover crops add more complexity and cost into vegetable production systems. The potential for cover crops to reduce the emission of nitrous oxide – a serious greenhouse gas – is one benefit not widely considered. This report looks at the impact of winter cover crops (Nemclear mustard or ryegrass/peas) on the yield and nitrous oxide emissions of the summer cash crop of popcorn at Cowra, NSW.

Very low nitrous oxide emissions were observed during the growth of the cover crop. Daily emissions were less than 1g N_2O-N ha^{-1} day^{-1} in all the cover crop and winter fallow areas. This confirms that winter cover crops produce low emissions during their growth. By contrast, very high nitrous oxide emissions were observed during the growth of corn crop. In this corn production system, nitrous oxide emissions in excess of 100g N_2O-N ha^{-1} day^{-1} were observed. The high nitrogen fertiliser rates and use of furrow irrigation were the main reasons for the high nitrous oxide emissions.

The effect of the cover crop varied during the season, initially being higher than the fallow area immediately following incorporation but lower when maximum emissions were measured after the nitrogen side dressing application. As a result, corn crop nitrous oxide emissions were similar across the cover crop and fallow areas over the whole season with 2.8kg N_2O-N ha^{-1} emitted during the growth of the corn crop.

The cover crops had no effect on corn growth and yield under the commercial practices where 294 kgN ha^{-1} was applied with yields similar at 8.1-8.5 t ha^{-1} of popcorn. When the amount of nitrogen fertiliser applied was reduced, the potential benefits of the cover crops were observed with the final yield of corn 10% and 15% less in the fallow area, compared to the Nemclear and ryegrass/pea areas, respectively. This indicates that the ryegrass/pea cover crop contributed approximately 60 kgN ha^{-1} of nitrogen, with the Nemclear cover crop a little less.

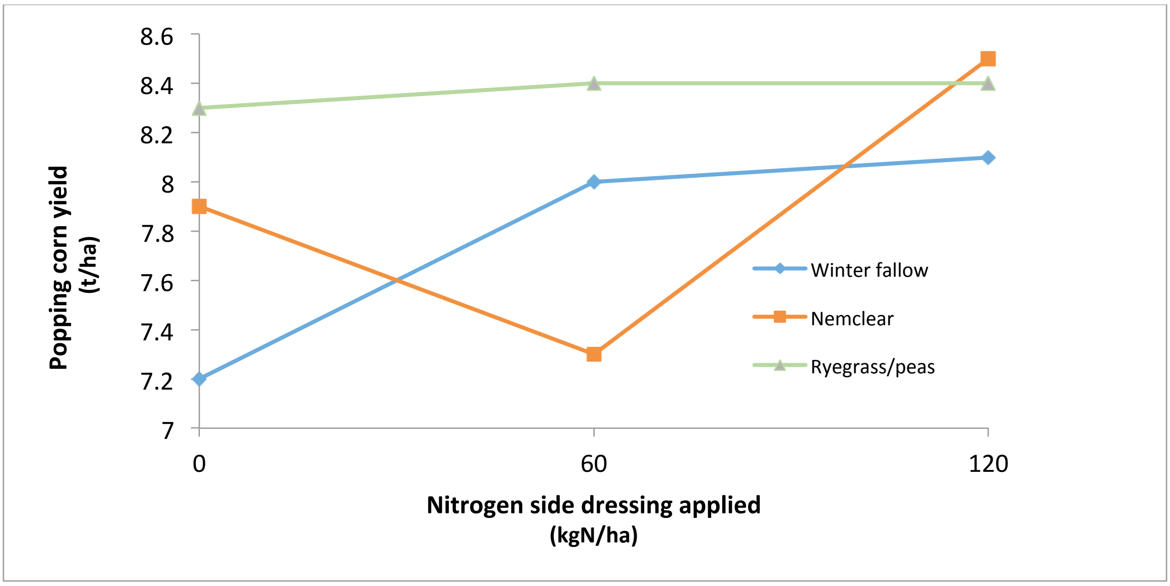


Figure 3. Effect of differing rates of nitrogen side dressing on corn yield following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. All areas received basal fertiliser prior to sowing (174 kgN ha^{-1}; 20 kgP ha^{-1}; 56 kgK ha^{-1}; 32 kgS ha^{-1}).

Cover crops have the potential to reduce nitrous oxide emissions, but changes to the current production system will be required. In this case study, key changes would include reducing the nitrogen side dressing rate during peak emission period to account for the nitrogen added by the cover crop, and incorporating cover crops before nitrogen basal fertiliser is applied. We estimate that this could have reduced the nitrous oxide emissions during the corn crop by 25–30% while decreasing costs and maintaining yields.

The loss of 2.8 kg N_2O-N ha^{-1} through nitrous oxide emissions is agronomically insignificant, representing less than 1% of the applied fertiliser. However, the anaerobic conditions which favour nitrous oxide emissions also favour loss of nitrogen as N_2 back to the atmosphere. From recent studies it has been estimated that for every 1kg of nitrogen lost as nitrous oxide, a further 40 kgN may be lost as N_2 (Peter Grace, pers. com). This would suggest that more than 100 kgN ha^{-1} was lost to the atmosphere during the corn crop. This would be more than a third of the applied nitrogen fertiliser and represents a considerable cost.

Cover crops have the potential to reduce nitrous oxide by 25–30% but changes in the amount and timing of nitrogen fertiliser applied are required to realise this potential. This would deliver environmental and farm profitability benefits as nitrous oxide emissions are a potent greenhouse gas, increase ultraviolent radiation and skin cancer by depleting the ozone layer, and waste applied nitrogen fertilisers.

5.2 Videos

5.2.1 Reduced Till in Vegetable Production WHY?

https://youtu.be/RfbhOxnULyI

Reduced till can deliver some significant benefits to vegetable growers, including reduced input costs, better soil health and yields as good as or better than via conventional tillage. Challenges include costs of machinery modifications and new equipment, paddock rotation planning and the possibility of new pest species.

In this five-minute video, Ed Fagan explains why he is using reduced till and some of the great results he's getting—while saving money. After 18 months the video has received 1909 views.

5.2.2 Reduced Till in Vegetable Production HOW?

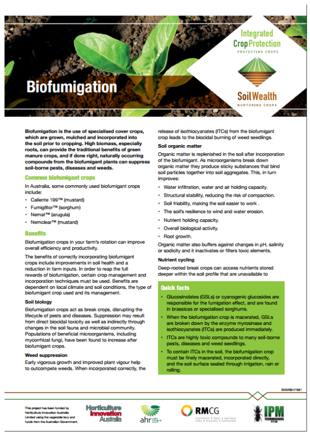
https://youtu.be/5rH3CFh7yvU

An eight-minute video feature Ed and James Fagan explaining how to implement reduced tillage and cover crops, what machinery to use, the synergies with cover cropping and timing of spraying out cover crops, incorporation and sowing of a cash crop. After 12 months the video has received 884 views.

5.3 Factsheets

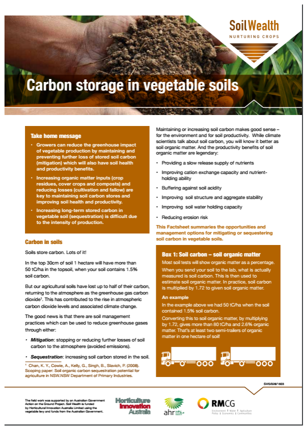
There were a total of five factsheets produced as part of this project:

5.3.1 Biofumigation (Appendix 3)



Biofumigation is the use of specialised cover crops, which are grown, mulched and incorporated into the soil prior to cropping. High biomass, especially roots, can provide the traditional benefits of green manure crops, and if done right, naturally occurring compounds from the biofumigant plants can suppress soil-borne pests, diseases and weeds.

5.3.2 Carbon storage in vegetable (Appendix 4)

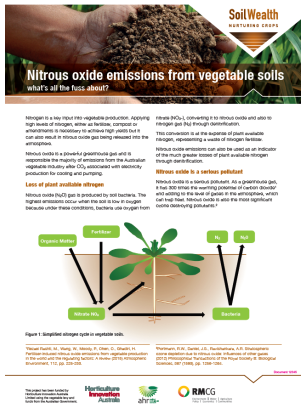


Maintaining or increasing soil carbon makes good sense – for the environment and for soil productivity. While climate scientists talk about soil carbon, you will know it better as soil organic matter. And the productivity benefits of soil organic matter are legendary:

- Providing a slow release supply of nutrients
- Improving cation exchange capacity and nutrient- holding ability
- Buffering against soil acidity
- Improving soil structure and aggregate stability
- Improving soil water holding capacity
- Reducing erosion risk.

This fact sheet summaries the opportunities and management options for mitigating or sequestering soil carbon in vegetable soils.

5.3.3 Nitrous oxide emissions in vegetables (Appendix 5)

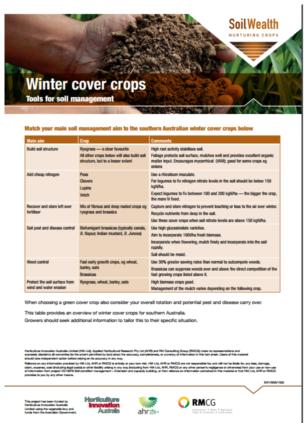


Nitrogen is a key input into vegetable production. Applying high levels of nitrogen, either as fertiliser, compost or amendments is necessary to achieve high yields but it can also result in nitrous oxide gas being released into the atmosphere. The factsheet outlines the risks of nitrous oxide emissions, methods to control emissions such as irrigation timing and fertiliser applications, lists risky periods for vegetable growing regions and compares to soil carbon sequestration options.

5.3.4 Reduced till in vegetable production (Appendix 6)

Reduced till is a system change that relies on keeping the soil in a healthy condition through the use of permanent beds, controlled traffic, cover cropping and crop rotations rather than frequent cultivation.

5.3.5 Winter cover crops (Appendix 7)



Provides a clear summary of the different properties of the cover crops used in the project and outlines how to build soil structure, add cheap nitrogen, recover and store left over fertiliser, soil pest and disease control, weed control and protect the soil from wind and water erosion.

5.4 Facebook pages

A Facebook page was developed to record the developments at the Cowra, Bathurst and Gippsland trial sites and to provide frequent updates on developments at each site.

The Facebook sites show a sequential log of the treatments applied and their performances over time. The sites also help AHR to communicate with growers and advisors and part of the Soil Wealth extension framework. They are also used to advise site followers of upcoming events.

The Facebook pages add value to field days with information also disseminated online.

The Cowra Facebook page has been liked and followed by 252 people and can viewed at www.facebook.com/SoilWealthCowra. The page includes details of the recent spinach crop that was harvested in November 2015, and also the field day help on 28 April, 2016.

The Bathurst Facebook page now been liked and followed by 76 people and can be viewed at www.facebook.com/Soil-Wealth-Bathurst-1457060841220457. The page is currently following a recent cabbage crop, and also features the field day held on 27 April, 2016

The Gippsland Facebook page has been liked and followed by 205 people and can viewed at www.facebook.com/soilwealthgippsland. The page includes details of the current cover crops in preparation for a baby leaf crop this year. It also reports on the recent field day held at Koo-Wee-Rup.

The pages can be found by searching *Soil Wealth Cowra*, *Soil Wealth Bathurst* or *Soil Wealth Gippsland*.

5.5 Field days

There was a field day held at Mulyan Farms, Cowra in September 2014, and a report is attached as (**Appendix 8**).

There were three field days held in 2016; Gippsland in March, Bathurst in April and second field day at Cowra. A report is attached (**Appendix 9**).

6 Outcomes

Were all intended outcomes achieved?

The project outcomes were:

- a commercially validated and sustainable leafy vegetable production system for Australian conditions resulting in high productivity and soil restored to a sustainable condition,
- improved profitability and sustainability for the vegetable industry in Australia, and
- an objective assessment of impacts of minimum tillage involving mulches, legumes and controlled traffic on productivity, soil health and carbon sequestration.

The project has contributed to the knowledge base which will allow the vegetable industry to achieve the outcomes listed above. In particular, the project has provided solid evidence for the use of cover crops and reduced tillage in the vegetable production systems of western NSW, the target region for the project.

Information on the trials and practices which improve soil conditions and yield have been communicated through a mix of traditional pathways (farm walks, factsheets and articles) and though electronic and social media (videos, Facebook and Twitter). This has allowed the project to deliver the key findings of the project to a wide audience outside the target region.

The trials at Mulyan Farms, Cowra NSW, have provided commercial scale validation that "softer" soil management practices can be integrated into large-scale vegetable production. For example, all varieties of cover crops produced a more profitable spinach crop, compared to a traditional fallowed system. Increases in profitably of 36 and 48% were obtained following the legume cover crops of Morgan Field peas or Balansa clover, respectively.

The project has successfully demonstrated and communicated that combining cover cropping with controlled traffic and reduced tillage will allow for sustainable improvement to the soil condition and which can maintain or improve yields, and reduce input costs.

Assessments of the impacts of reduced tillage combined with cover crops at Mulyan Farms were undertaken (**Appendix 1** and **Appendix 2**).

A key feature of the project has been the use of farmer-to-farmer communication, for example, in the videos and farm walks. The project team has helped growers to document their practices, trial new ones, and then communicate the results to other growers. This has been the key to achieving the outcomes for the vegetable industry.

Did the project achieve additional benefits?

The project has broadened the geographical reach of the project and delivered information to areas outside the target region in central NSW. In particular, the linkages with Soil Wealth (VG13076) has allowed outputs such as the videos, factsheets and trial sites to have a national profile. This has seen growers and advisors attend farm walks from outside the region. On the flip side the project trials at Cowra, Bathurst and Gippsland have proven a useful resource for Soil Wealth.

Linkages with the Federal-funded Action of the Ground project have allowed the impacts of cover crops on nitrous oxide emissions to be evaluated. Without the commercial scale trials established in this project this would not have been possible.

Are there any outcomes that are likely to be achieved in the longer term as a result of the project?

The trial reports, fact sheets, videos and Facebook pages detailed in the outputs section provide a permanent resource. These resources will help the Australian vegetable industry improve long term profitability and sustainability. The Soil Wealth project is continuing to promote these resources to help the industry to recognise the benefits of improved soil management and options such as cover cropping and reduced tillage.

Furthermore, the growers and advisors who have attended the farm walks have taken away new practices, tools and thinking on sustainable soil management in intensive vegetable production. This upskilling of growers and advisors will help achieve the longer term sustainability of leafy vegetable production system.

Detail all economic, social and environmental impacts (benefits/risks to industry, community and the environment) that have resulted from the project.

The projects economic impact has been achieved through adding, refining and documenting the sustainable soil management practices of leading vegetable growers Ed and James Fagan. Their experience and impact on profitability has been shared with the vegetable industry encouraging other growers nationally to incorporate more sustainable soil management practices into their businesses.

Tasmanian vegetable grower Colin Houston has recently recognised the Fagan's leading role in opening up communication about growing practices across the vegetable industry. "Ed and James have shown an openness to share information which was not there five years ago. They have changed the way growers think about sharing information". The project has contributed to this by facilitating field days and through the use of electronic and social media to give Ed and James a wider audience.

7 Evaluation and Discussion

Discuss project evaluation and overall project performance

The project, along with other soil management projects delivered by AHR, has made an important contribution to increasing the interest and use of more sustainable soil practices in Australian vegetable production systems.

The project has contributed to the increased use of electronic and social media to communicate and link vegetable growers across Australia. This has allowed the learnings and experiences from practices in the central west of NSW to be more widely available contributing to the overall success of the project.

This project has built on other industry activities, such as the Bayer group of leading growers, of which Ed Fagan is a member, and more recent projects such as Soil Wealth. The overall project performance is interwoven with these other activities to encourage and promote more sustainable soil management practices in the vegetable industry.

The effectiveness of project activities in delivering project outputs and achieving the intended outcomes.

Project has used a mix of traditional field days and printed materials, together with electronic and online media to deliver outputs to the widest range of growers as possible. Farm walks are very effective for the attending audience, but are very narrowly focused, and the ability to use the Soil Wealth framework has significantly increased the effectiveness of the project.

The project has broadened the original geographic focus on Western NSW to a wider audience of growers through Facebook pages, YouTube videos, websites and fact sheets.

The project has contributed to videos on why and how to use reduced tillage and cover crops and promoted these through the Soil Wealth framework. The two videos are presented by growers Ed and James Fagan and give an in depth review of the benefits and challenges to both productivity and profitability that they have experienced. This farmer-to-farmer communication is a very effective communication method with additional credibility added by Ed Fagan's award of 2015 NSW Farmer of the Year by the NSW Farmers Association. The videos have been viewed more than 2,700 since being released and are now a permanent resource available to the industry.

The Facebook page SoilWealthCowra has been used to convey information about this project with 256 followers. The site was regularly updated as the trials progress, such as when cover crops are sown, sprayed or incorporated, when harvests occur and when any relevant information arose. The site was successful because much of the target audience is familiar with the Facebook interface and regularly access the service. There was positive feedback, both verbally and on the site, that the medium is very user friendly, allows interested people to keep updated outside of their business hours and that information can easily be shared amongst peers. The format also provided an excellent transcript of the project progress.

The project took advantage of alignment with cover crops and reduced till mix at the Gippsland and Bathurst sites, to provide a wider industry spread. Two additional Facebook pages were created to promote the benefits of sustainable soil management. These pages, SoilWealthGippsland and SoilWealthBathurst, increased the reach of the project with experiences gained from working with the Fagan's at Mulyan being used at the Bathurst and Gippsland sites.

Feedback on activities and the quality and usefulness of project outputs. Detail how and when feedback was sought and how this feedback was incorporated into the project.

There were written surveys following the field days, as well as ongoing discussions with participating growers and positive feedback on the three Facebook pages. A summary of the feedback from field days is included as **Appendix 8** and **Appendix 9**. Feedback was used to identify key areas of interest that required more information.

Demonstrate and quantify changes resulting from the project (e.g. productivity, practice, attitudinal). These changes should be in the form of performance against established benchmarks, intended outcomes and key result areas that were established at the beginning of the project. The monitoring of these changes would ideally have started early in the project to provide before and after comparisons.

After three years the project team is starting to see a shift in grower behaviour and growers considering cover crops and/or reduced tillage. For example, an agronomist at Simplot is looking to help growers incorporate cover crops into production systems to address issues such as low infiltration rates under centre pivots growing corn. They attended both field days at Cowra and followed up on more information. Field days and communications have targeted this area.

The learning from the project and overall relevance to industry.

The key learnings from the project are:

The vegetable industry is recognising the effect of healthy soil on profitability and productivity, and this project has contributed to that increased focus. The use and relevance of cover crops is growing for managing soil borne diseases, nutrient retrieval and weed management. There is also an increased interest in the use of biofumigants to reduced agricultural chemical use

Soil management is a whole-farm approach requiring dedicated management of both reduced till and cover crops. Growers need to be willing to accept that the income benefits of rejuvenating the soil may not be realised immediately, but instead is an investment in future productivity.

Strict no-till regimes are often not suitable for vegetable production. Instead strategic tillage can be required to reduce the risks of disease from crop residues and to provide suitable soil conditions for the mechanical harvesting of crops such as spinach.

8 Recommendations

This project has contributed new information and understanding of how "softer" soil management practices can be integrated into commercial vegetable production to ensure soil health and productivity is improved. While many of the practices, such as cover crops, reduced tillage, controlled traffic and compost, have been used in other industries their integration into vegetable production system in a profitable way remains a challenge.

Further work is required at a farming system levels to determine the best mix of soil management practices to suit the different vegetable production systems. A key to working at the farming system level is for future projects to be partnerships between leading growers and researchers. Such partnership combines the practical and commercial experience of the grower with the monitoring and measuring expertise of researchers to develop commercially validated and objectively assess soil management practices. Furthermore, farmer-to-farmer communication, facilitated and supported by project teams, is the most effective communication approach to achieve industry change.

New information is required to help vegetable growers to manage cover crops to deliver soil productivity and health benefits. In the short term this will require information, optimised under Australian conditions, on the most appropriate cover crop species, cropping sequences, sowing windows and transition practices. In the longer term exciting opportunities exist to develop and test new practical cover crop practices based on a greater understanding of cover crop agronomy and root "signatures" which promote beneficial soil biology.

Tillage and controlled traffic are important practices to help improve soil conditions. There is a need to summarise the different tillage implements used and what impacts they have on the soil. This could take the form of a series of videos showing different tillage equipment used in vegetable production, what they are best used for and their impact on the soil. This also applies to controlled traffic systems, where documenting the practices of leading growers would help demonstrate why and how controlled traffic systems can be used in vegetable production.

9 Scientific Refereed Publications

n/a

10 Intellectual Property/Commercialisation

None to report

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13 Appendices

Appendix 1: Spinach yield, nitrous oxide emissions and soil carbon following cover crops and compost.

Appendix 2: Potential of cover crops to reduce nitrous oxide emissions from a high nitrogen input corn crop.

Appendix 3: Biofumigation factsheet.

Appendix 4: Carbon storage in vegetable.

Appendix 5: Nitrous oxide emissions in vegetables.

Appendix 6: Reduced till in vegetable production.

Appendix 7: Winter cover crops.

Appendix 8: 2014 Cowra Field Day

Appendix 9: 2016 field day Reports