Horticulture Innovation Australia

# Final Report

## Integrating sustainable soil health practices into a commercial vegetable farming operation

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# 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 $ha^{-1}$).

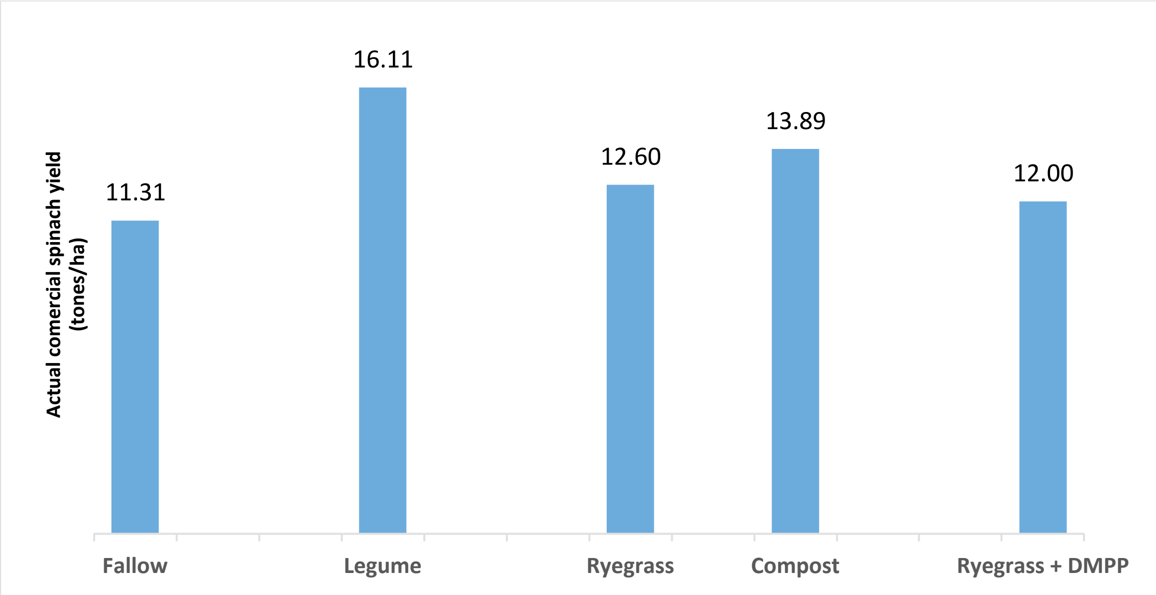



**Figure 2: Commercial baby leaf spinach yields following different cover crops or compost.**

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.

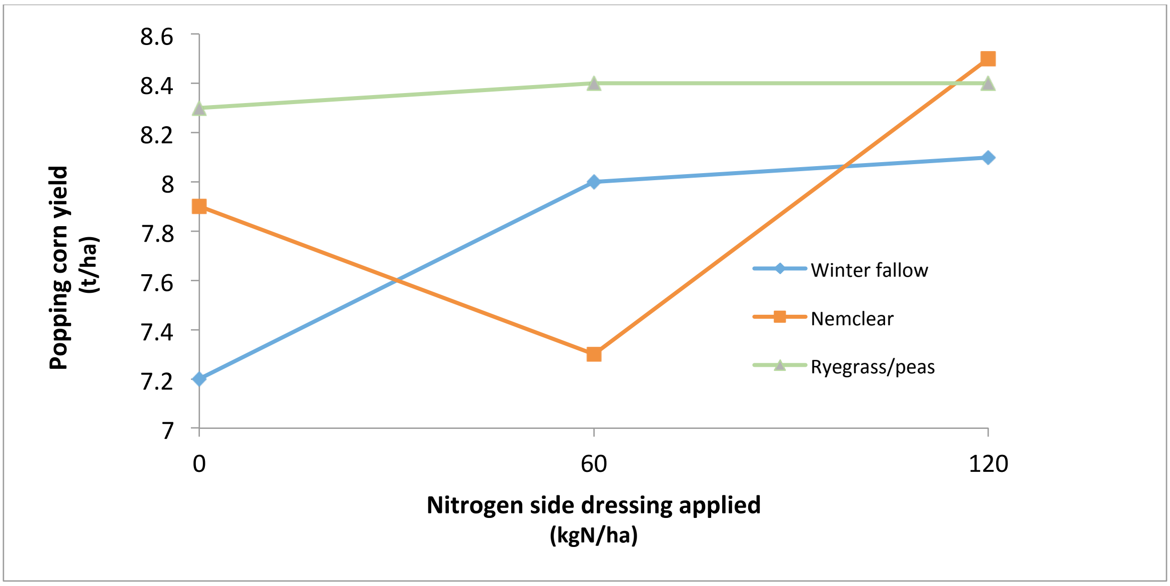



**Figure 3. Effect of differing rates of nitrogen side dressing on corn yield following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. All areas received basal fertiliser prior to sowing (174 kgN ha$^{-1}$; 20 kgP ha$^{-1}$; 56 kgK ha$^{-1}$; 32 kgS ha$^{-1}$).**

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

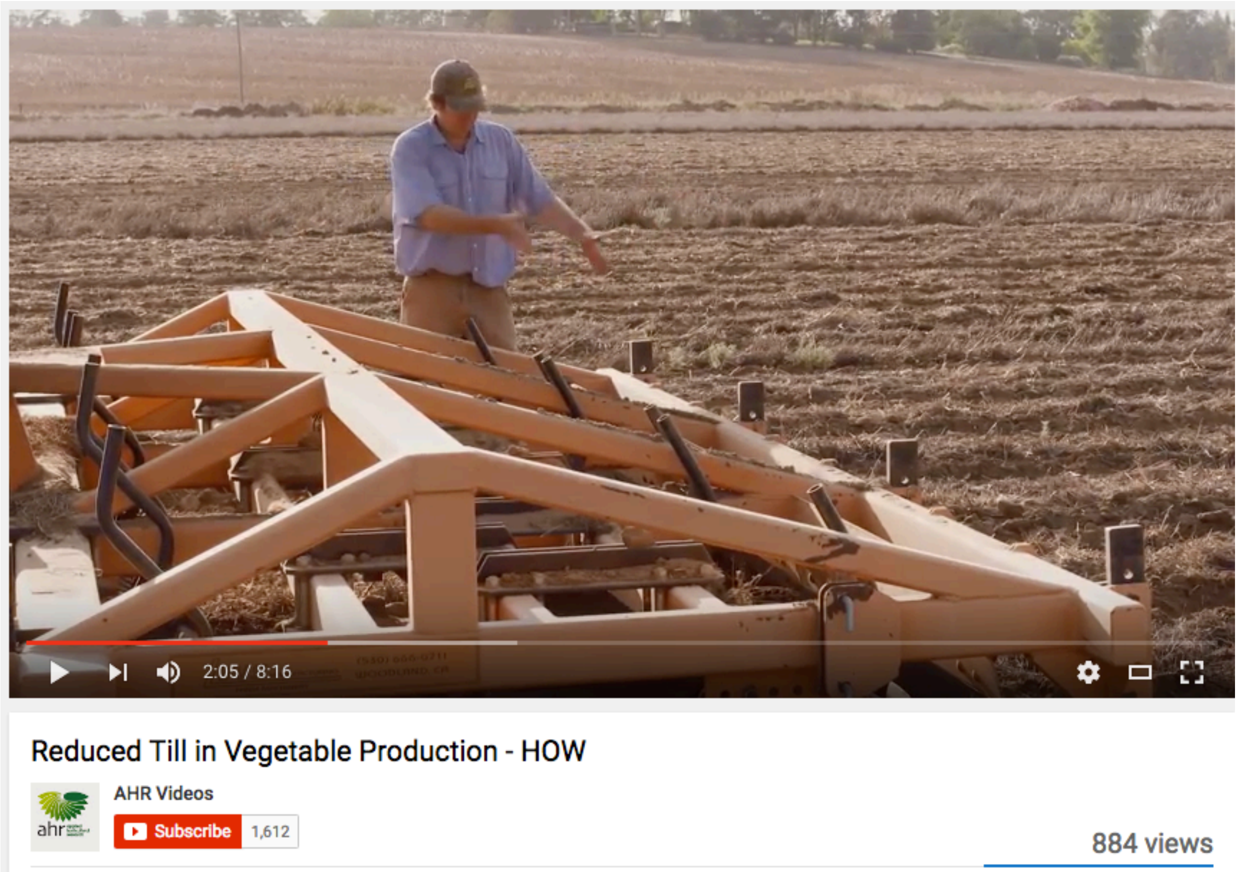
Reduced till can deliver some significant benefits to vegetable growers, including reduced input costs, better soil health and yields as good as or better than via conventional tillage. Challenges include costs of machinery modifications and new equipment, paddock rotation planning and the possibility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

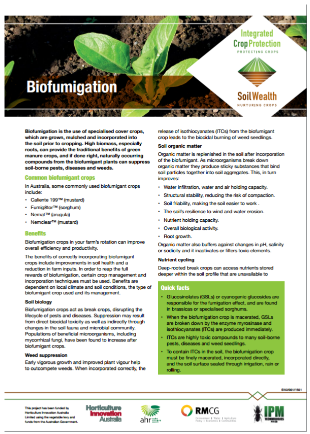
An eight-minute video feature Ed and James Fagan explaining how to implement reduced tillage and cover crops, what machinery to use, the synergies with cover cropping and timing of spraying out cover crops, incorporation and sowing of a cash crop. After 12 months the video has received 884 views.



## 5.3 Factsheets

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

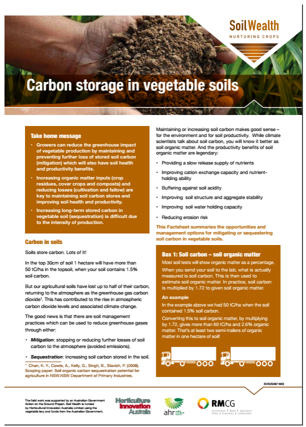
### 5.3.1 Biofumigation (Appendix 3)




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:

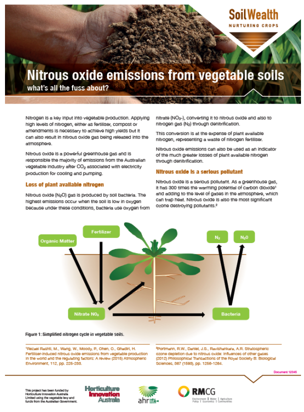



- Providing a slow release supply of nutrients
- Improving cation exchange capacity and nutrient- holding ability
- Buffering against soil acidity
- Improving soil structure and aggregate stability
- Improving soil water holding capacity
- Reducing erosion risk.

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.

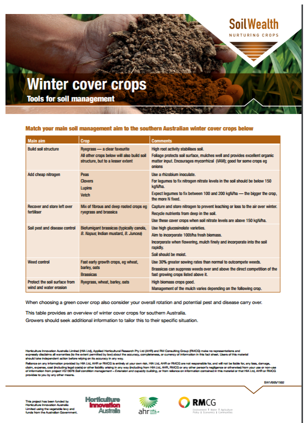



### 5.3.4 Reduced till in vegetable production (Appendix 6)

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

# Spinach yield, nitrous oxide emissions and soil carbon following cover crops and compost

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AHR Confidential Report

**Date:** January 2016

**Disclaimer**:



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## Abbreviations

DMPP: nitrogen inhibitor

UAN: urea ammonium nitrate

$CO_2$: Carbon dioxide

SOC: Soil organic carbon

ECD: Electron capture detector

GC: Gas chromatograph

FID: Flame ionisation detector

GHG: Greenhouse gases

$N_2O$: Nitrous oxide

SOM: Soil organic matter

SRI-GC: Gas chromatography

TCD: Thermal conductivity detector

**Abstract**

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 randomized 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 yield 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 $ha^{-1}$).

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).

**1. Introduction**

Agricultural activities contribute to approximately 13.5% of the total global anthropogenic greenhouse gas (GHG) emissions (Lugato et al., 2010). In Australia, agriculture is estimated to produce 85.9% of net national emissions of nitrous oxide ($N_2O$) (Browne et al., 2011). Soil and crop management practices (crop type, fallow frequency, residue management, soil amendments, cover crops, rotations, tillage, irrigation, drainage, mulching, and fertilisation) can play a major role in regulating GHG emissions such as $N_2O$ (Johnson et al., 2010). A study on the effects of the rye cover crop on $N_2O$ emissions demonstrated that additional carbon inputs may have influenced the increased $N_2O$ emissions by stimulating denitrification after N application at the rate of 135kg N/ha as 160kg to 345kg C/ha provided by the rye residues in the soil surface and may be used for microbial respiration (Mitchell, Castellano, Sawyer, & Pantoja, 2013). However, incorporating crop residues would have both positive and negative effects on greenhouse gas emissions (Abalos, Sanz-Cobena, Garcia-Torres, van Groenigen, & Vallejo, 2013). A meta-analysis study concluded that 60% of the studies demonstrated cover crop increases of $N_2O$ emissions at the soil surface, while the rest did not (Basche, Miguez, Kaspar, & Castellano, 2014).

The main GHG, carbon dioxide ($CO_2$), can be sequestered as soil carbon. The level of carbon in vegetable soil varies depending on soil properties, soil management and climate. Vegetable systems have limited opportunities to increase the long-term storage of soil carbon required for sequestration due to the intensive production system which is charaterised by frequent, aggressive tillage, low organic mater inputs from cash crops and significant fallow periods. But slowing the decrease or maintaining soil carbon levels are achieved in vegetable production systems through changes in soil management. Stabilising and maintaining soil carbon also has real soil health and productivity benefits.

Adding organic matter from plant residues of cover crops can add significant amount of carbon to the soil. The Hubbard, et al reported that soil carbon increased by 32% in just three years, when a cover crop preceded the summer cash crop, compared to a fallow. With regard to enriching SOC, a long-term study of kiwifruit in Europe found that a combination of cover crops, no-tillage and compost application for four years could result in increased soil N, P and K reserves and an addition of up to 16 tonnes of organic matter (dry weight) per ha, per year to the soil (Montanaro, Celano, Dichio, & Xiloyannis, 2010). The use of organic sources of nutrients in the form of compost and manure can contribute to soil organic matter and has significant beneficial effects on soil biology (Rahman, Holmes, McCurran, & Saunders, 2010).

Nitrification inhibitors such as 3,4 dimethylpyrazol phosphate (DMPP) can significantly reduce $NO_3^-$ leaching and $N_2O$ emissions. This offers the possibility of saving mineral fertiliser N, reducing the number of nitrogen fertiliser applications, while obtaining higher crop yields (Zerulla et al., 2001). The application of nitrogen inhibitors has been proven to be highly effective in reducing nitrogen fertiliser losses through nitrate leaching, ammonia volatilisation, $N_2O$ emissions and increasing crop yields (Cui et al., 2011; Moir, Malcolm, Cameron, & Di, 2012). However, another study on the effects of nitrification inhibitors on $N_2O$ emission reported that the $N_2O$ emissions were significantly influenced by other factors such as soil temperatures, moisture and inorganic N contents (Liu, Wang, & Zheng, 2013).

Soil management practices such as cover crops, composts and nitrogen inhibitor, can significantly affect $N_2O$ emissions, as well as influence soil organic carbon and crop growth. The aims of this study were to investigate the impacts of winter cover crops; legumes (clover or peas); ryegrass; and compost on the subsequent $N_2O$ emissions; changes in soil carbon; and yield of the spinach crop. In addition, the impact of a nitrification inhibitor (DMPP) on $N_2O$ emissions was also examined.

**2. Materials and methods**

2.1. Site characterisation

This research was carried out on a commercial vegetable farm "Mulyan Farms", located on the banks of the Lachlan River on North Logan Rd Cowra, NSW. Cowra (elevation 381 m) enjoys a Mediterranean-type climate, with an annual mild rainfall of 625mm (distributed fairly evenly year round). The area is characterised by warm to hot summer temperatures, with a mean maximum of around 30 °C while maximum winter temperatures reach 14 °C. Soils are mainly sandy loam of grey -brown colour derived from granite and sedimentary rocks (shale, mudstone) and characterised by good productivity under proper management (DPI-NSW, 2008).

The area, during the measurement time, had been characterised by progressively increasing mean monthly temperature (Table 1).

*Table 1.* Total monthly rainfall and average monthly temperature in Cowra-NSW 2015 (Source: Bureau of Meteorology)

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total monthly rainfall (mm) | 66.4 | 13.3 | 9.8 | 127.9 | 34.1 | 18.0 | 77.7 | 108.4 | 8.8 | 22.2 | 120.9 | 4.4 |
| Average monthly t (⁰C) | 30.9 | 32.7 | 29.4 | 21.9 | 17.5 | 15.1 | 12.7 | 14.7 | 18.9 | 28.1 | 28.8 | 30.4 |

The rainfall during the period of the experiment (October and November) was relatively high at 22.2120.9 mm while the temperature was at around 28 ⁰C. However, due to the uneven distribution of rainfall, overhead irrigation system was also used.

2.2. Cover Crops and Compost Trial

2.2.1. Experimental design and treatments

The experiment comprised four treatments organised in a randomised complete-block design of four replicates. Each plots was three beds wide (3.6 m) and 200 m long. The treatments were Legume (clover and peas), Ryegrass, Compost and Fallow.

Cover crops were sown on 15 May, 2014. The sowing rates for the cover crops were: balansa clover 4kg $ha^{-1}$, Morgan pea 80kg $ha^{-1}$, burst ryegrass 8 kg $ha^{-1}$. After 3 ½ months the cover crop biomass was measured on 1 October, 2014. The average fresh weight of clover, peas and ryegrass were 50.5; 85 and 56 tonnes $ha^{-1}$ equivalent to 7.58; 12.75 and 8.40 tonnes $ha^{-1}$ dry weight (D.M. Sullivan and N.D. Andrews, 2012), respectively. The cover crops were sprayed out (glyphosate at rate of 2.5 l $ha^{-}$

[1]) and the areas were left with cover crop residues over summer. On 9 February, 2015, the cover crop residues were incorporated with two passes of the bed former. Due to the lack of water the trial was delayed until the start of September, 2015. Hence the trial site remained fallow across all treatments over winter.

The compost treatment received two applications; 11 tonnes $ha^{-1}$ on 15 May, and 5 tonnes $ha^{-1}$ on 4 August, 2015. The dairy compost composition is outlined in Table 2.

*Table 2.* Composition of the dairy manure compost

| | **Nutrient** | **Compost** |
|---|---|---|
| Macro-nutrient (%) | Nitrogen | 1.47 |
| | Phosphorate | 0.18 |
| | Potassium | 0.67 |
| | Sulphur | 0.18 |
| | Carbon | 25.4 |
| | Calcium | 0.71 |
| | Magnesium | 0.32 |
| | Sodium | 0.20 |
| Micro-nutrients (mg/kg) | Copper | 20 |
| | Zinc | 87 |
| | Manganese | 116 |
| | Iron | 6,277 |
| | Boron | 17 |
| | Molybdenum | 0.9 |
| | Cobalt | 2.3 |
| | Silicon | 1,020 |
| Others | Organic matter (%) | 44.4 |
| | pH (1:5 water) | 8.5 |
| | Electrical conductivity (1:5 water) (dS/m) | 2.0 |
| | Moisture (%) | 75.6 |
| | Total organic carbon (%) | 25.4 |
| | Labile carbon (%) | 5.6 |

## 2.2. Nitrification inhibitor trial

### 2.2.1 Experimental design and treatments

The nitrification inhibitor trial comprised two treatments organised in a randomised complete block design of four replicates. The treatments were: ryegrass without DMPP and ryegrass + DMPP, where Entec fertiliser (urea ammonium nitrate [UAN]) containing 42% N, with a gradient of 3,4-

dimethylpyrazole phosphate (DMPP) at the rate of 90 L ha$^{-1}$ was mixed and applied on 5 October, 2015.

2.3. Spinach crop management

Baby spinach seeds (SV 3580 VC) were sown on 13 October, 2015 at the rate of around 300 seeds m$^{-2}$ across all treatments in both trials. Two days prior to sowing, the soil was prepared using a plantavator to reform the beds and to incorporate the base fertiliser (Nitrophoska special at a rate of 200kg ha$^{-1}$ with NPKS composition of 24-10-30-16). Eight days prior to sowing UAN 42 @ 100L ha$^{-1}$ and calcium nitrate @ 100L ha$^{-1}$ was applied. Total fertiliser nitrogen applied prior to sowing was 81.5kg N ha$^{-1}$. No additional fertiliser was applied after sowing. The amount of nitrogen in compost and legumes was 235.2kg ha$^{-1}$ and 356kg ha$^{-1}$ nitrogen, respectively (D.M. Sullivan and N.D. Andrews, 2012).

Overhead irrigation was applied at 1, 4, 8, 11, 14 and 15 days after planting additional with actual rainfall and weather listed in table below

*Table 3:* Irrigation and raining events during the spinach crop

| Date | Event | Amount of water (mm) | |
|---|---|---|---|
| 14/10/2015 | Irrigation | 24 | |
| 18/10/2015 | Irrigation | 24 | |
| 22/10/2015 | Rain | | 9 |
| 25/10/2015 | Irrigation | 24 | |
| 28/10/2015 | Irrigation | 24 | 2 |
| 29/10/2015 | Irrigation | 24 | |
| 31/10/2015 | Rain | | 9 |
| 1/11/2015 | Rain | | 10 |
| 3/11/2015 | Rain | | 12 |
| 4/11/2015 | Rain | | 6 |
| 12/11/2015 | Rain | | 6 |
| Total amount | | 120 | 54 |

The amount of water supplied in the system was estimated around 8 ml per hour. Therefore, total amount of water applied was 174 ml per whole season.

Pest and disease control were applied and managed the same way for every treatment. Spinach was harvested 28 days after sowing.

2.4. Crop measurement

2.4.1. $N_2O$ emission data

Along 350 m-long rows, experiments were separated into two areas of 16 chambers per each. In each area, two blocks or replicates were designed with eight chambers each. In each treatment, two chambers were placed randomly in the centre of a row, two on the edges of the rows and two on the furrows (six chambers per treatment, except on the legume treatments as eight chambers applied for both clover and peas). The data were observed in around areas of three chambers for each treatment in each block.

Gas samples were taken using static non-flow-through chambers (diameter 243 mm; height 205mm; installed volume of 7.3L). There are two holes in lids to allow for the insertion of a syringe needle for sampling and a thermometer to record the contemporaneous temperature. A rubber seal was also attached to the cover of head space to avoid exchange of gases between the inside and the outside of the chamber during sampling.

Chambers were inserted at 14 cm remaining above ground into the soil and remained in place throughout the trial. During the collection events, gases were taken at 14/10 (before planting), 15/10 (after planting), and 19/10; 23/10; 28/10; 30/10; 2/11 and 4/11 as they were around rainfall and/ or irrigation events.

Gas samples were taken at every 0, 30 and 45minutes in each chamber between 9 am and 2 pm after lids were sealed using a 25 mL gas-tight syringe (SGE, 25 MDR-LL-GT) and introduced into pre-evacuated 12 mL Exetainer vials with butyl rubber septa (Labco Ltd., High Wycombe, UK).

The air temperature inside the chamber and the soil temperature at a depth of 10 cm were also recorded by TP3001 portable digital thermometers at the time of sampling.

Gas analysis

Samples were analysed on an Agilent 7890A gas chromatograph (GC) fitted with a Gilson (GX 271) auto sampler. The system has 2 channels leading to $\mu$-ECD and FID detectors. $N_2O$ was analysed by $\mu$-ECD. The sample was loaded onto a 1000mL sample loop, and then injected onto a 1m Porapak Q pre column. Gases were then passed onto a 2m Porapak Q column for further separation. The pre-column was back-flushed to remove moisture after the analyses had passed onto the analytical column. Relative standard deviations (based on seven replicate injections) for $N_2O$ were <2%. For each batch of samples a range of standards, controls, and blanks were included for QC purposes (van Zwieten et al., 2010)

$N_2O$ flux calculation

The flux rate, $F_{N2O}$, was calculated using equations 1 and 2. All $N_2O$ flux rates were corrected in order of the actual air temperature during the measurement and recorded as [μg $N_2O$-N $m^2$/h]:

$$F_{N_2O} = \frac{b \times V_{CH} \times MW_{N_2O-N} \times 60 \times 10^6}{A_{CH} \times MV_{corr} \times 10^9}$$

Where: $A_{CH}$ is basal area of the measuring chamber [$m^2$]; *b* is increase in concentration [ppb/min]; $MW_{N2O-N}$ is molecular weight of $N_2O$-N [28 g/mol]; $MV_{corr}$ is temperature-corrected molecular volume [$m^3$/ mol]; $V_{CH}$ is volume of the measuring chamber [$m^3$].

$$MV_{corr} = 0.02241 \times \left(\frac{273.15 + T}{273.15}\right)$$

Where: $MV_{corr}$ is as defined; *T* is air temperature during the measurement [°C]; 0.02241$m^3$ is the molar volume of an ideal gas at 1 atm, 273.15K (Aylward & Finlay, 1974).

2.4.2. Soil data

Soil cores (7.3 cm diameter by 7.5 cm height) were taken at 0 -15 cm depths to determine soil bulk density, total porosity and air-filled porosity prior to planting and at harvest.

Soil samples for determining soil nitrate, ammonium and labile carbon concentrations were manually collected at two positions of each plot at a depth level of 0 -15 cm using a hand-operated soil auger. Forty soil samples per each experiment were collected at the start and end of experiments (5 treatments*4 replicates *2 times).

All soil samples were stored at $4^0$C before air drying at $40^0$C for 24 hours and analysed using the method (Moody, 1, & Cong, 2008) for labile carbon and nitrate ($NO_3^-$) and ammonium ($NH_4^+$)

Soil moisture probes, which were located centrally in the chambers, recorded half-hourly readings of volumetric water content at different deep levels from 0-50 cm. In addition, soil temperature (10 cm) was measured at 5 minute intervals (Sentek temperature/light data logger, Onset Computer Corporation).

2.4.3. Plant data

Plant samplings were taken at two weeks of sowing and then weekly until harvesting. A quadrant (0.33 $m^2$) was randomly placed in plot and plant density (plants $m^{-2}$), leaf fresh weight (tonnes $ha^{-1}$) and volume (ml) determined. A subsample of 30 leaves was randomly selected in order to indirectly estimate leaf nitrogen using Minolta SPAD-502 meter. In addition, 10 g of fresh leaves were used to measure leaf area. At the end, actual commercial spinach yield was determined by measuring across whole areas at harvesting.

2.5. Statistical analysis

Analysis of variance (ANOVA) was used to assess variations in soil carbon and nitrogen as well as $N_2O$ emissions according to the different treatments and time intervals with a least significant difference of 5%.

## 3. Results

3.1. Soil temperature and moisture

3.1.1. Soil temperature

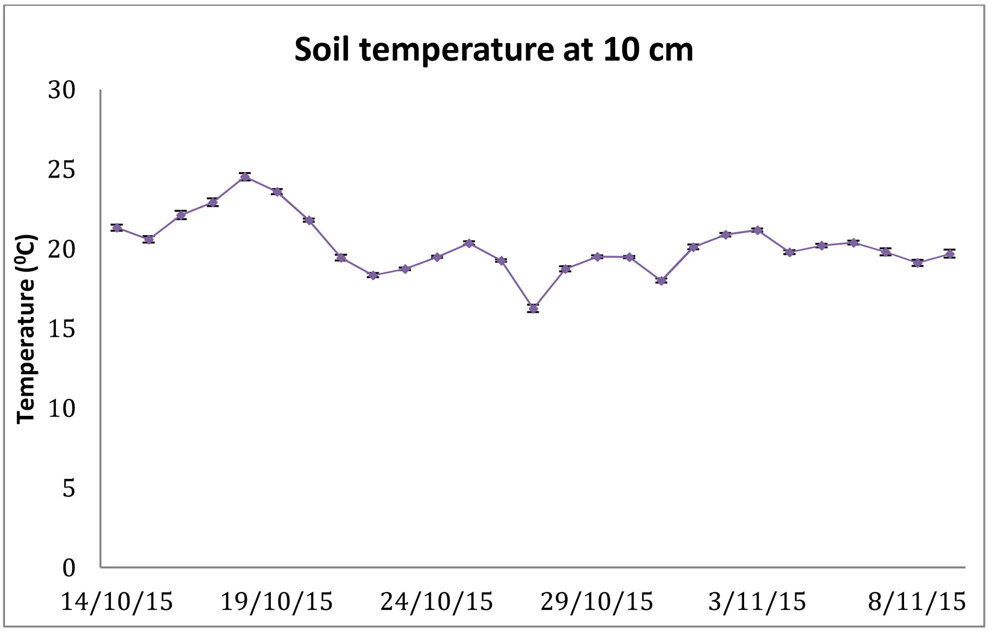


*Figure 1.* Average daily soil temperature

Overall, daily average soil temperature was slightly more than 15 $^0$C to 25 $^0$C during the whole trial period. However, temperature at sampling time varied greatly; often it was higher because it was taken in the middle of the day.

3.1.2. Soil moisture

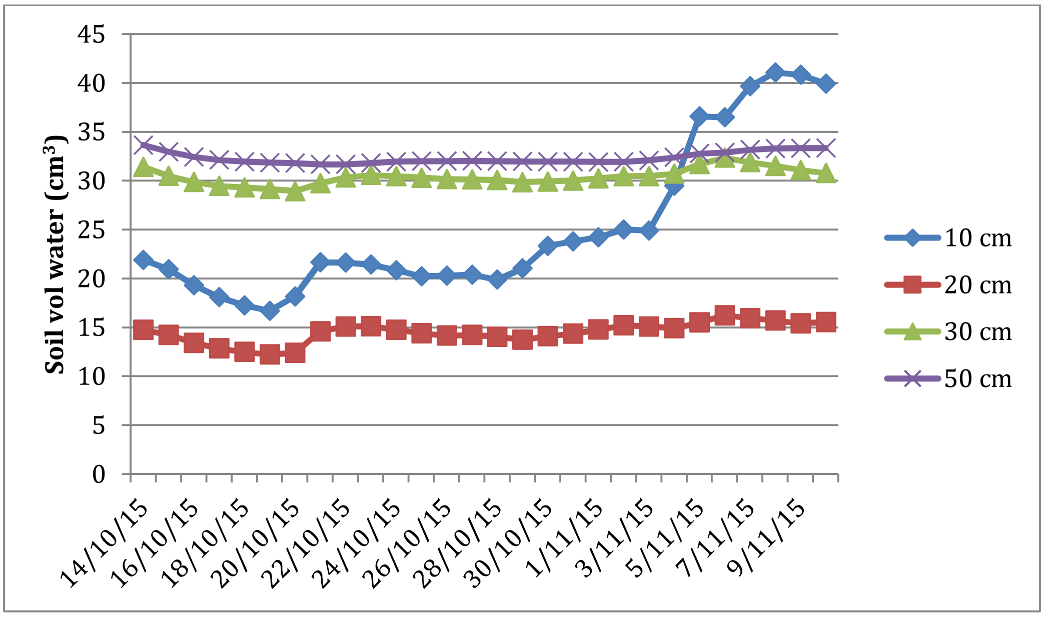


*Figure 2.* Average soil volumetric water ($cm^3$) at different soil depth levels

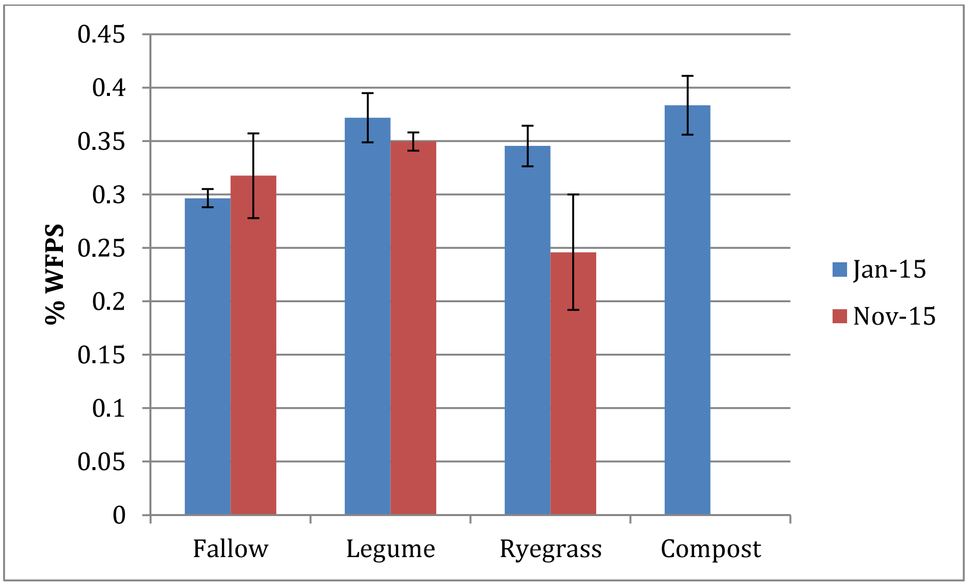


*Figure 3.* Water-filled porosity before and after the trial

Soil volumetric water and water filled porosity presented less than 40 $cm^3$ and 40 % over the whole trial period, respectively (figures 2 and 3).

3.2. Cover Crops and Compost Trial

3.2.1. Influences of cover crops and compost on $N_2O$ emissions

The average daily $N_2O$ emission was 4.41g $ha^{-1}$ $day^{-1}$ at all treatments over the spinach season. Nitrous oxide emissions were the lowest at the pre-soil cultivation on 14 October and increased sharply after a day of soil cultivation and once the first irrigation was applied. The $N_2O$ fluxes decreased after two weeks until the end of the season, with almost similar pattern at all treatments.

$N_2O$ fluxes were observed at the highest rate at the fallow and compost after soil cultivation. These fluxes were significantly higher during the first two weeks of sowing seeds and after that remained low.

Cover crops such as legume and ryegrass were observed to have lower rates of $N_2O$ emissions (accumulated 59.37 ±1.35g and 78.08 ± 1.39g $N_2O$-N $ha^{-1}$ season, respectively) compared to fallow and compost (accumulated 181.31±5.16g and 190.28±6.42g $N_2O$-N $ha^{-1}$ season, respectively) at the whole season (figure 4).

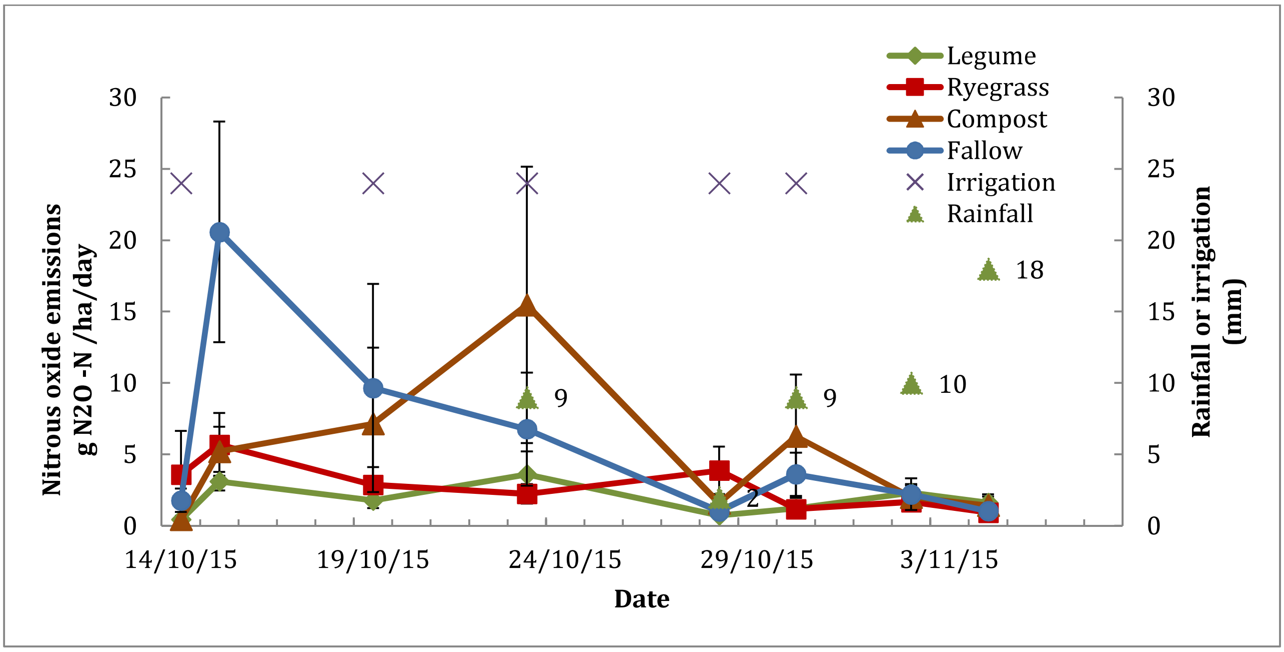


*Figure 4.* Effects of cover crops and compost on $N_2O$ emissions over a spinach season

Moreover, different positions of all treatments were observed to demonstrate $N_2O$ emissions significantly higher from wheel-track compared to centre and edge at the first two weeks after sowing but were lower than centre and edge after that (figure 5).

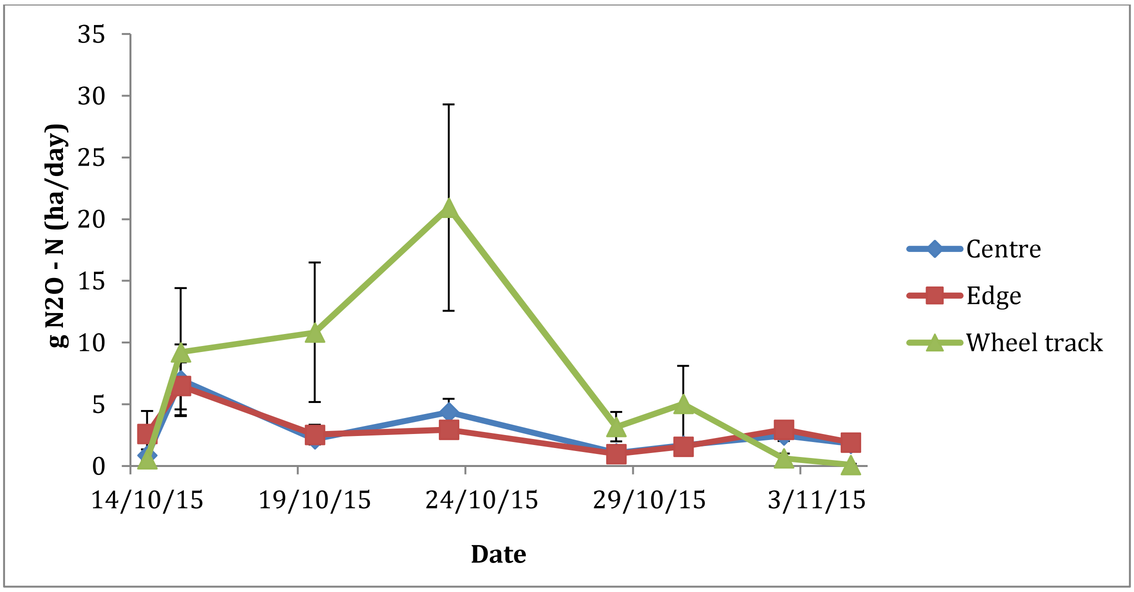


*Figure 5.* Effects of chamber positions on $N_2O$ emissions over spinach season

3.2.2. Influences of cover crops and compost on soil characteristics

3.2.2.1 Soil bulk density

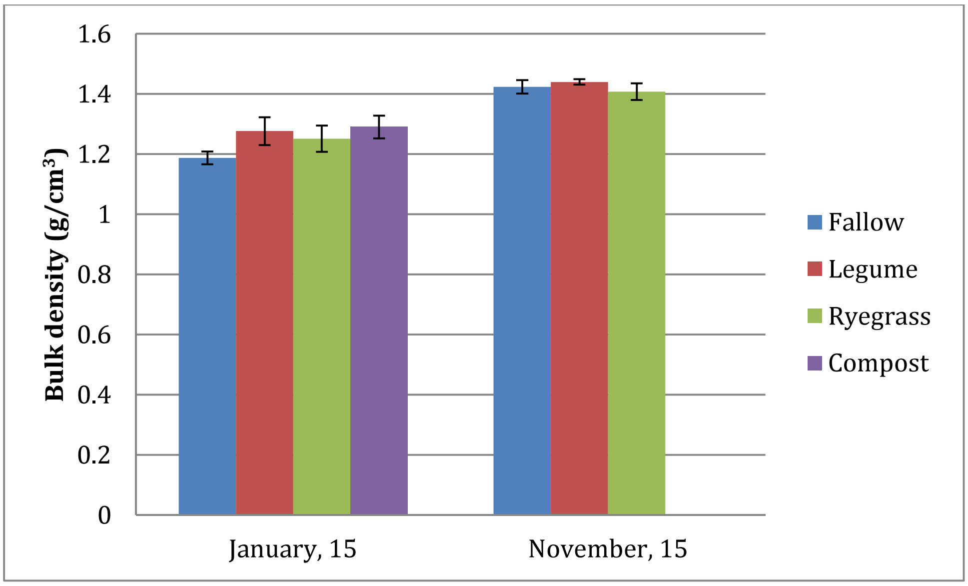


*Figure 6.* Changes of bulk density at the beginning and end of the spinach season

Bulk density increased at all treatments and there were no significant impacts from different cover crops and compost on bulk density.

3.1.2.2. Labile C

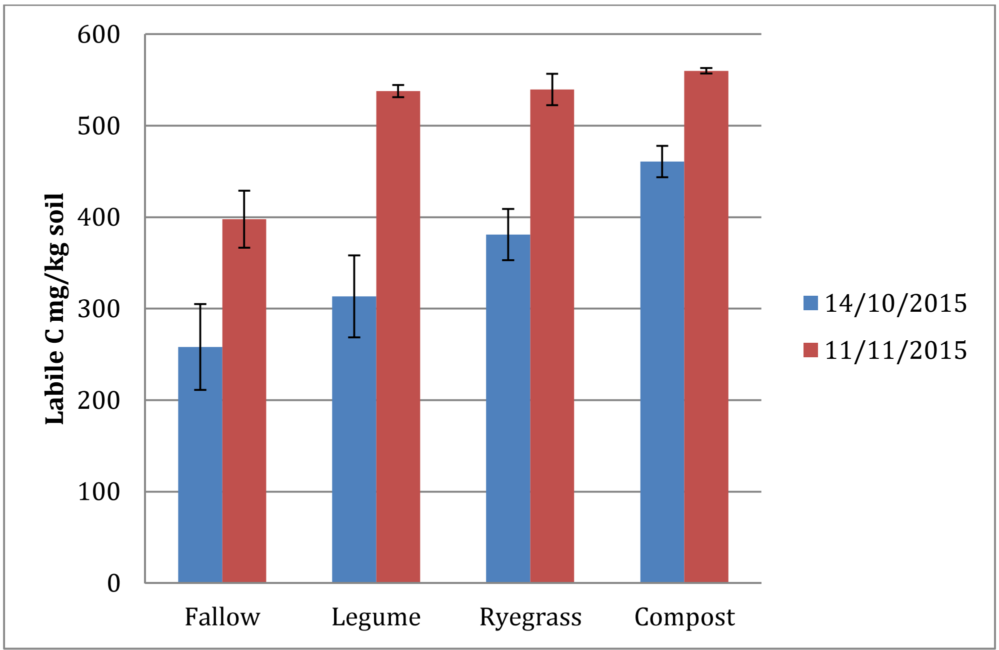


*Figure 7.* Changes of labile carbon at depth of 0-15 cm at the beginning and the end of the season

There was a consistent increase in labile carbon in all treatment over the spinach growing period (figure 7). The amount of labile carbon in fallow was observed to be significantly lower than cover crops and compost while those of legume, ryegrass and compost did not present as different. This is possibly due to the more recalcitrant nature of compost and cover crops derived C compared to fallow.

3.2.2.3. Soil nitrogen availability

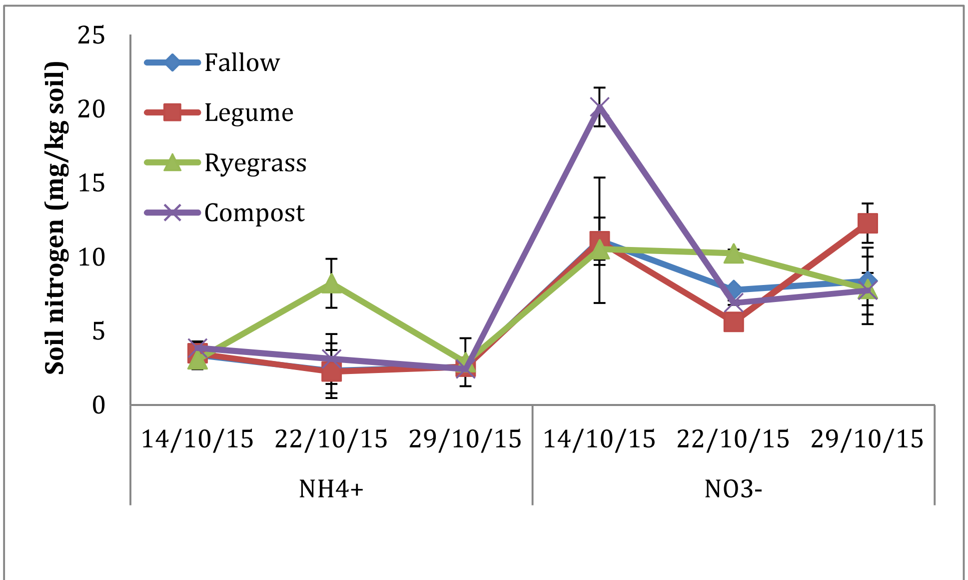


*Figure 8.* Effects of cover crops and compost on soil nitrogen availability

In general, proportion of $NH_4^+$ in the soil was lower than those of $NO_3^-$ at all treatments over the time. $NO_3^-$ concentration was observed to be the highest at beginning of the trial which were double amount compared to cover crops and fallow while the greater nitrogen at both $NH_4^+$ and $NO_3^-$ was observed in ryegrass after a week of planting. However, soil nitrate amount was likely to increase after two weeks of planting (figure 8).

3.2.3. Influence of cover crops and compost on plant growth

3.2.3.1. Plant density

The cover crop and composts had no effect on plant density and SPAD value. Interactions between different practices and weather conditions affected the growth characteristics of spinach differently. Plant density was around 100 plants per quadrant or 900 to 1000 plants per $m^2$ at the end of the season as a result of sowing seeds by machines and was kept relatively constant from germination until harvesting time. There were no significant differences among treatments (figure 9).

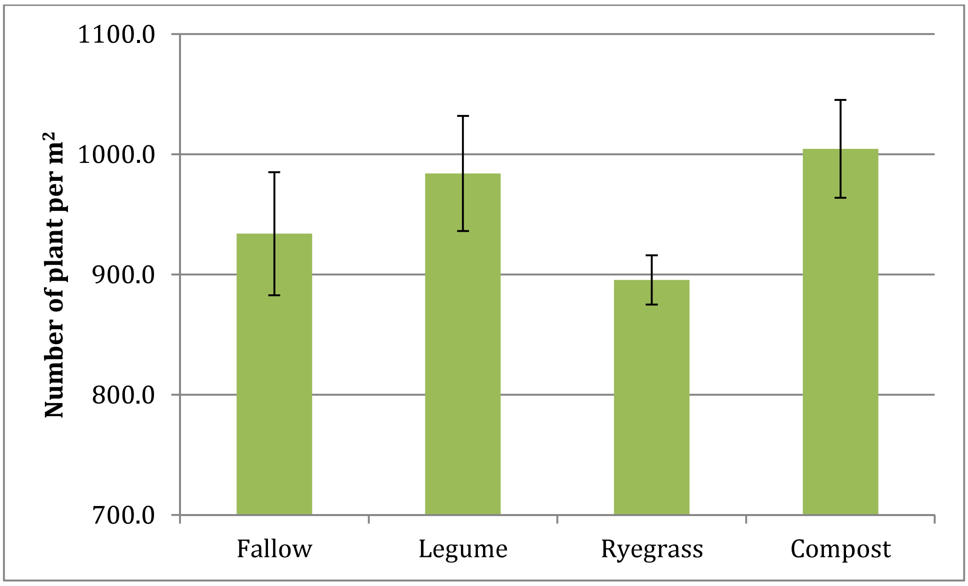


*Figure 9.* Effects of cover crops and compost on spinach density

3.2.3.2. Nitrogen level associated with SPAD value

There were slight decreases of SPAD values at all treatments over the season. The SPAD value was around 40 to 45. This indicated that different management practices did not impact on leaf foliage nitrogen.

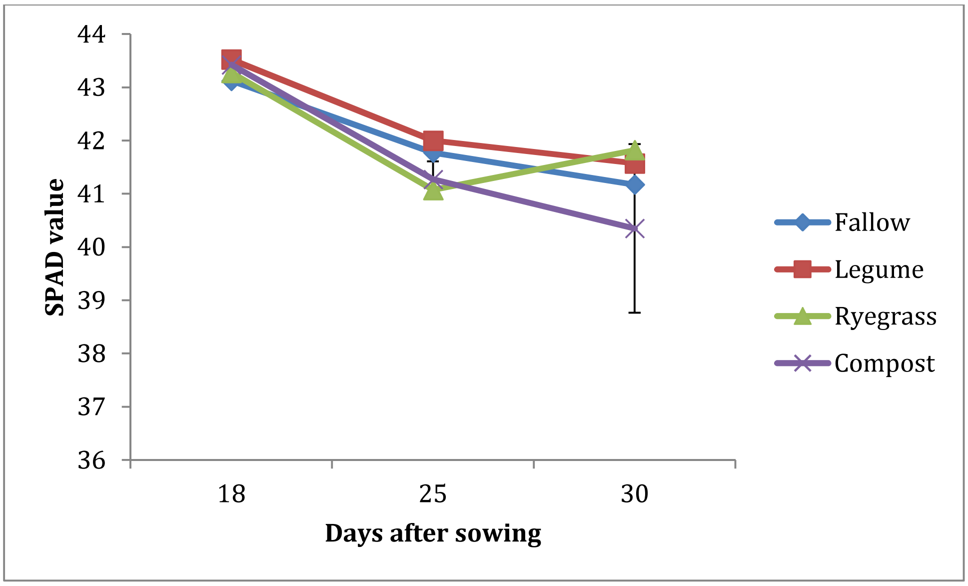


*Figure 10.* Effects of cover crops and compost on SPAD value over the spinach season

3.2.3.3 Leaf volume

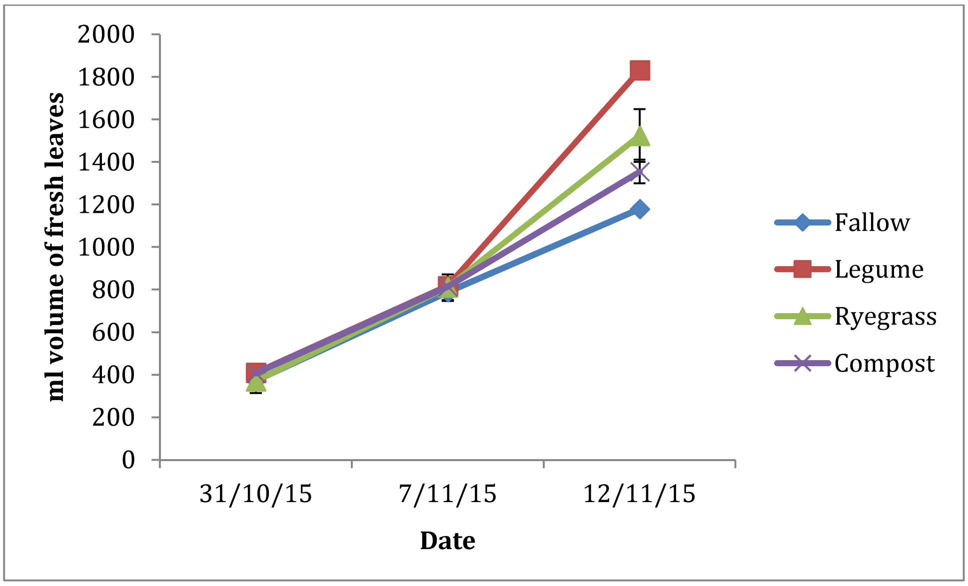


*Figure 11.* Effects of cover crops and compost on volume of fresh leaves over the spinach season

Leaf volume was the only difference in performance observed at the end of the season, of which compost demonstrated the highest leaf volume, followed by legume, ryegrass and fallow, respectively (figure 11).

3.2.3.4. Leaf area

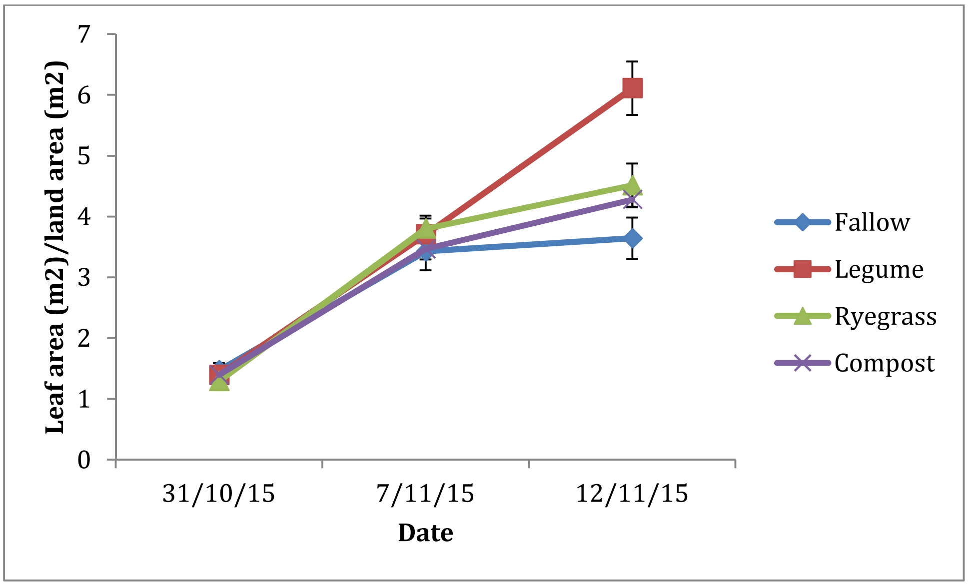


*Figure 12.* Effects of cover crops and compost on leaf area over the spinach season

Leaf areas increased over time due to natural spinach growth bearing more leaves and expanding leaf areas. Among treatments, legume showed the largest leaf areas (6 $m^2$ leaves $m^{-2}$ land areas) while compost, ryegrass and fallow were significantly lower (from 3.5 $m^2$ leaves to 4.5 $m^2$ leaves $m^{-2}$ land areas) at the end of the season. The rapid increase in leaf areas only appeared in the last week of the harvest.

3.2.3.5. Fresh yield

Fresh yields made the highest gains in legume blocks at harvesting time while compost and ryegrass treatments achieved similar yields over the spinach growing season. In contrast, fallow blocks gave the lowest fresh yields at harvest time. There appeared to be significant differences between legume and fallow but not for ryegrass and compost.

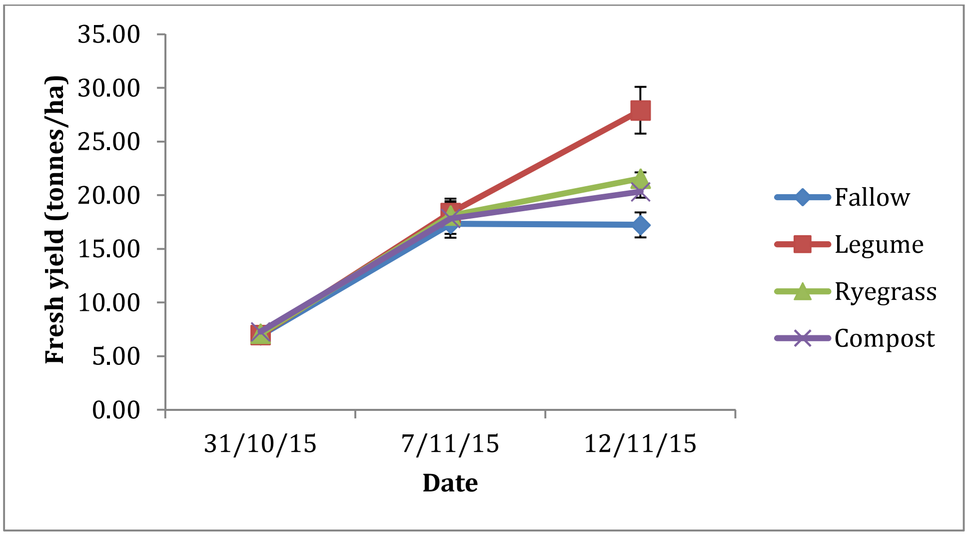


*Figure 13.* Effects of cover crops and compost on fresh yields

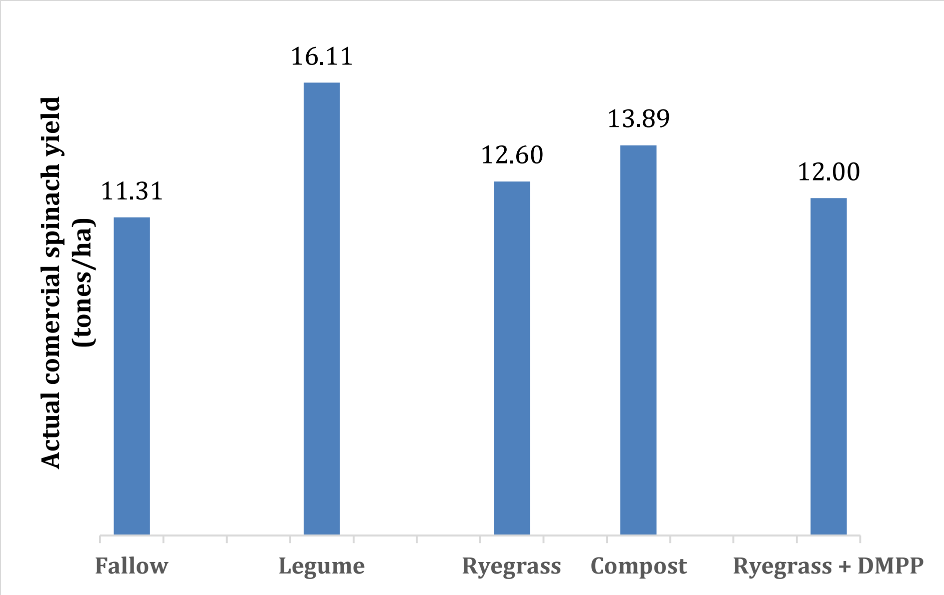


*Figure 14.* Effects of cover crops and compost on actual spinach yields

Final commercial spinach yields were collected across whole areas at harvesting by the machine after 29 days of planting. The values were consistent with fresh block yields as it was the highest at legumes, followed by compost, ryegrass and the lowest was fallow (figure 14).

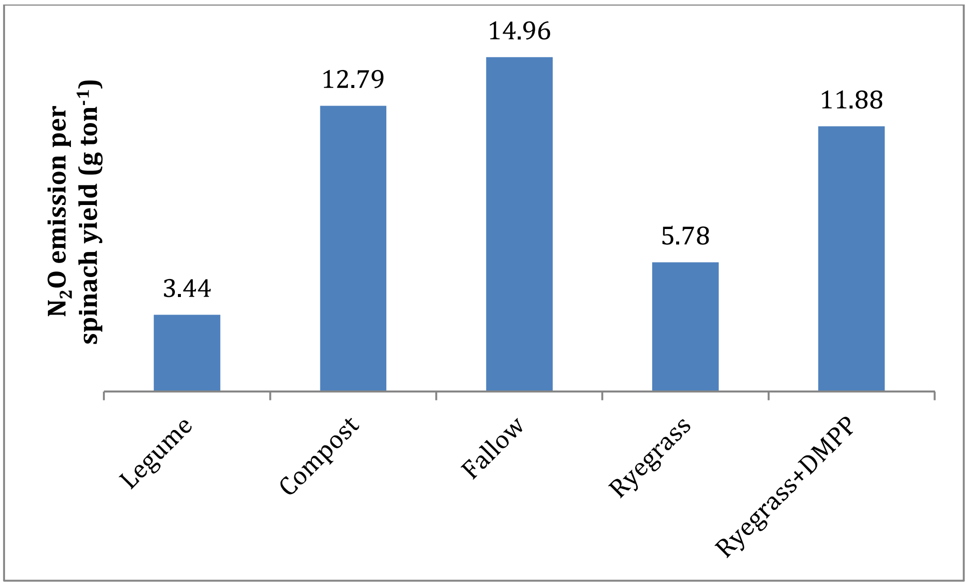


*Figure 15.* Effects of cover crops, compost and inhibitor on $N_2O$ emission intensity

N2O emission intensity was very low at legume and ryegrass but almost four times and three times higher at fallow, compost and ryegrass with inhibitor.

3.3. Nitrification inhibitor trial

3.3.1. Influences of ryegrass and nitrogen inhibitor (DMPP) on $N_2O$ emissions

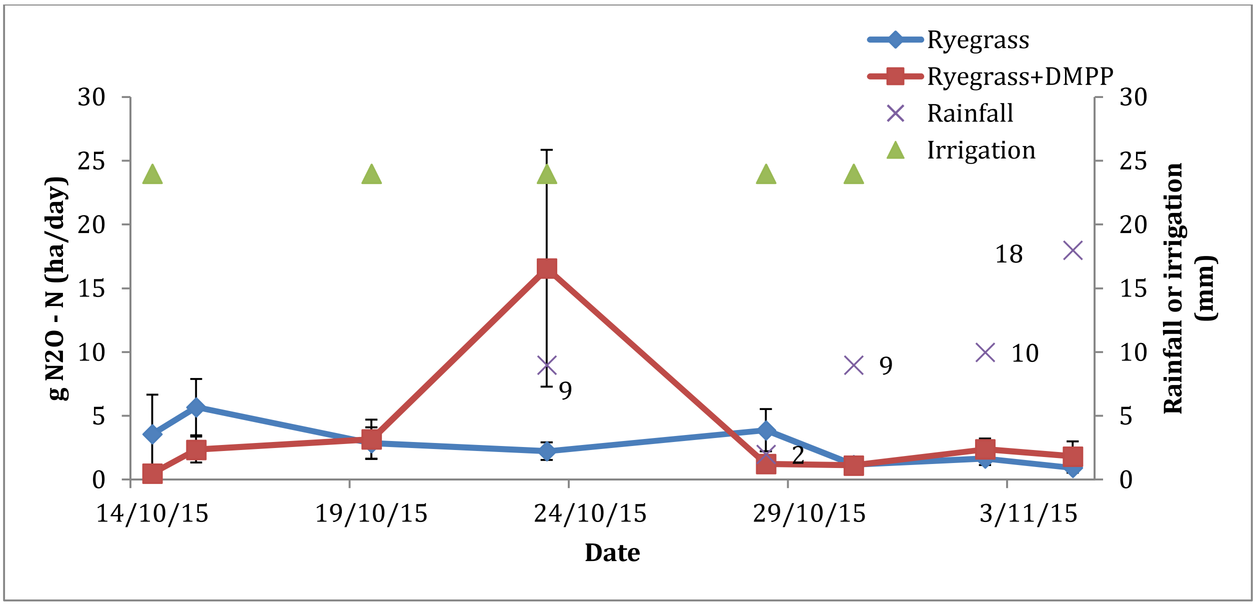


*Figure 16.* Effects of nitrogen inhibitors on $N_2O$ emissions over a spinach season

The $N_2O$ fluxes were lower in ryegrass applying DMPP than in ryegrass alone immediately after a day of cultivating and sowing. Surprisingly, on 23 October $N_2O$ emissions were elevated at ryegrass and DMPP plots. Two weeks after sowing, $N_2O$ fluxes were low and remained stable by the end of the season at both treatments.

### 3.3.2. Influences of ryegrass and nitrogen inhibitor (DMPP) on soil characteristics

#### 3.3.2.1. Labile carbon

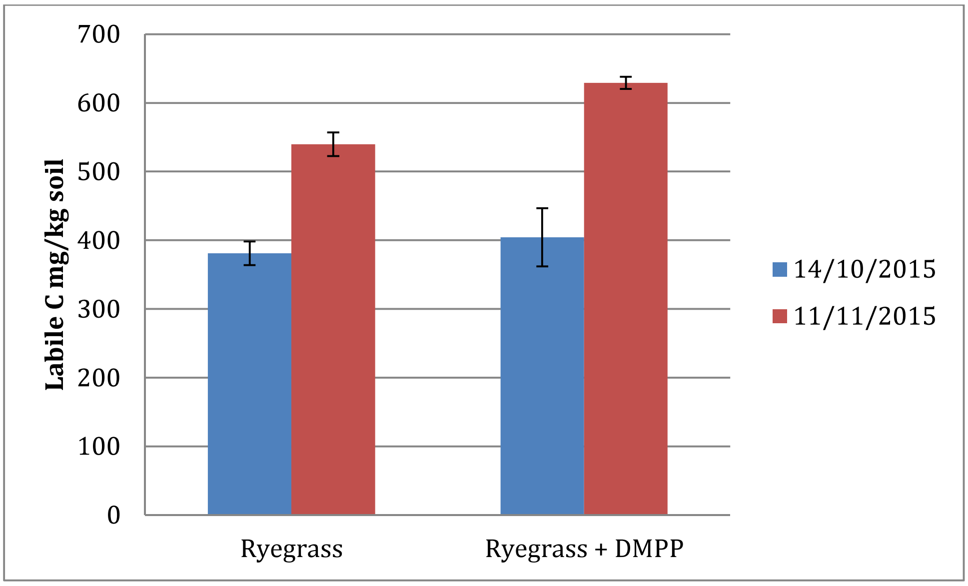


*Figure 17.* Changes of labile C at the depth of 0-15 cm at the beginning and the end of the season

The labile carbon increased with both treatments after a month of the experiment.

3.3.2.2. Soil N availability

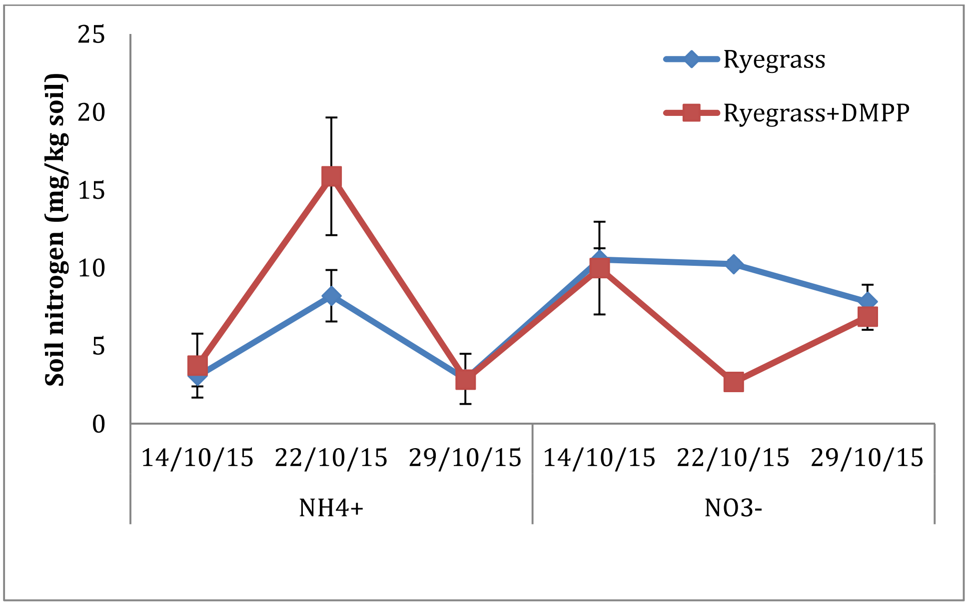


*Figure 18.* Effects of nitrogen inhibitor on soil nitrogen availability

Amount of soil $NH_4^+$ availability at ryegrass plus DMPP was observed to be higher than ryegrass alone after nine days of planting while at the same period $NO_3^-$ concentration presented as a reversed figure. Overall, the proportion of this $NO_3^-$ was higher than $NH_4^+$ at both treatments over trial time period.

3.3.3. Influences of ryegrass and nitrogen inhibitor (DMPP) on crop growth

The responses of plant density, leaf area, SPAD value, leaf volume and yields did not reveal significant differences between ryegrass and ryegrass adding DMPP (figures 19-23). This indicated that applying DMPP did not impact on crop growth and its yields.

3.2.3.1. Plant density

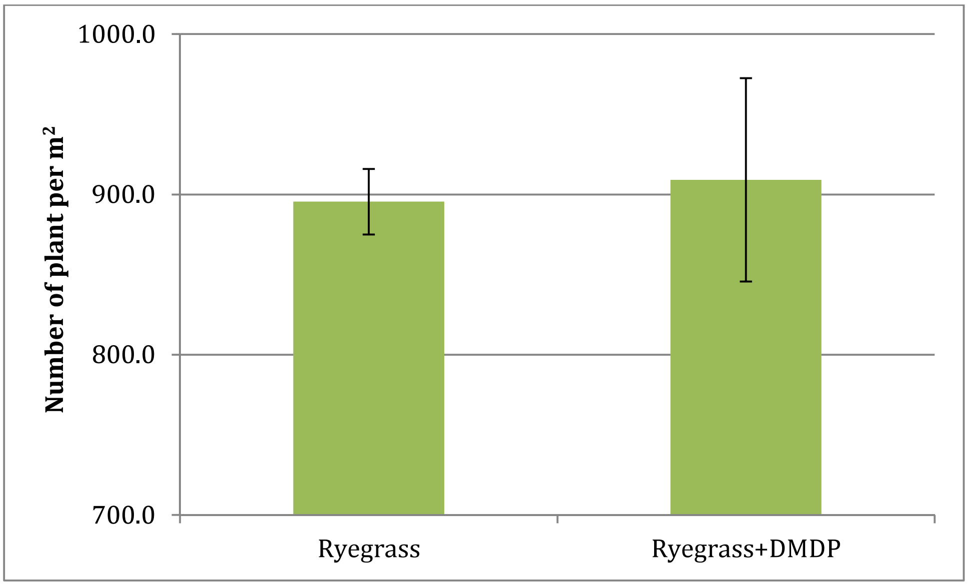

*Figure 19.* Effects of nitrogen inhibitors on spinach density

3.3.3.2. Nitrogen levels associated to SPAD value

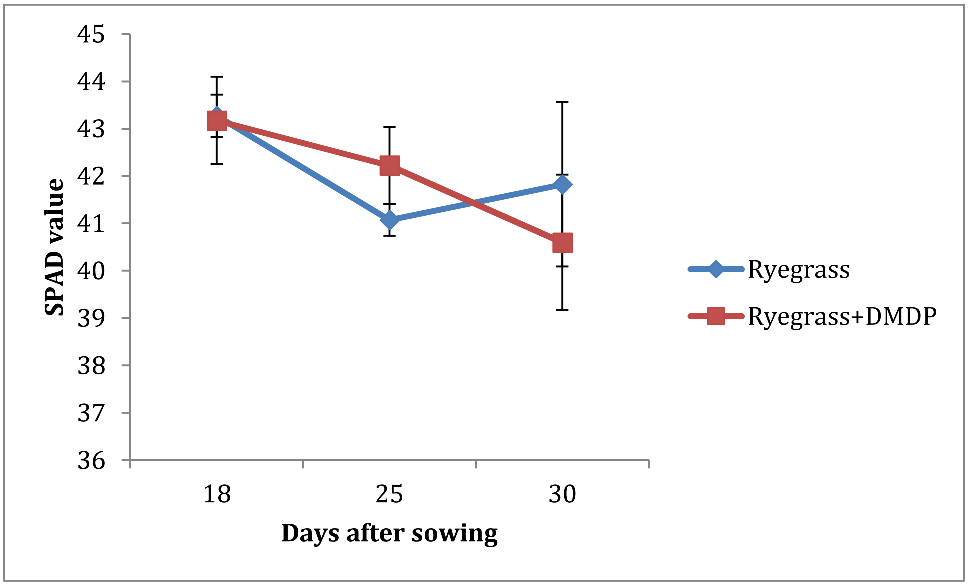


*Figure 20.* Responses of SPAD values on nitrogen inhibitor over a spinach season

3.3.3.3. Leaf volume

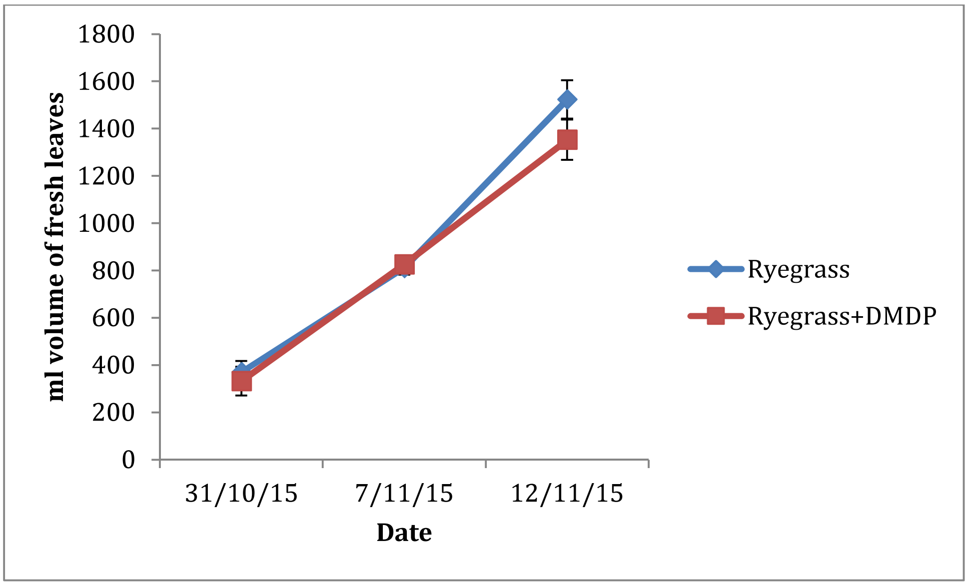


*Figure 21.* Effects of nitrogen inhibitor on volume of fresh leaves on the spinach season

3.3.3.4. Leaf area

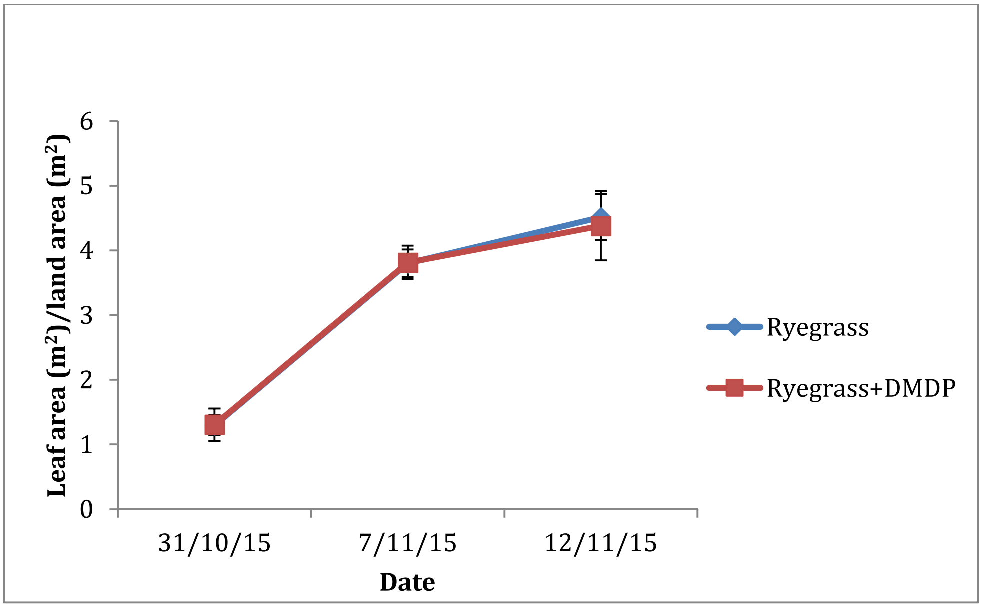


*Figure 22.* Effects of nitrogen inhibitor on leaf areas over the spinach season

3.3.3.5. Fresh yield

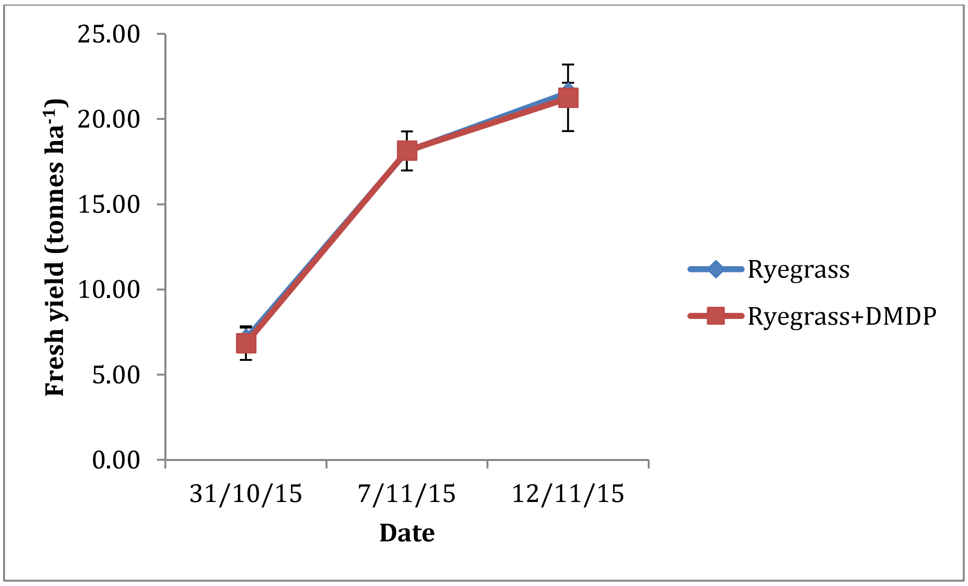


*Figure 23.* Effects of nitrogen inhibitor on fresh yields in the spinach season

**4. Discussion**

4.1. $N_2O$ emissions

The main finding demonstrated average $N_2O$ emissions over the experimental period ranged from 1.98g to 6.42g $N_2O$-N ha$^{-1}$ day$^{-1}$. This result was found similar in another study in broccoli (Scheer et al., 2014). In this study, $N_2O$ fluxes showed only low emissions as cumulative emissions over the broccoli cropping phase over five-month observation period were 298g $N_2O$ ha$^{-1}$ or 1.98g $N_2O$-N ha$^{-1}$ day$^{-1}$ with conventional fertiliser practice. However, global data from vegetable fields was reported being much higher (average emissions of 57.8g $N_2O$–N $ha^{-1}$ $day^{-1}$ (ranging from 3.3g to 703.3 g $N_2O$-N $ha^{-1}$ $day^{-1}$) and this variation was associated with nitrogen fertiliser application in open-air vegetable cropping systems (Liu, Qin, Zou, Guo, & Gao, 2013).

The key factors affecting $N_2O$ emissions from agricultural soil were soil $NO_3^-$-N content, soil WFPS, and temperature (Karen E. Dobbie & Smith, 2003). In this study, the soil temperature was not limiting $N_2O$ emissions as it was above 15 $^0$C during most of the sampling times (Yan et al., 2014). However, $N_2O$ emissions in spinach were below 10g$ha^{-1}day^{-1}$ most of the time during its short growing period. This was likely due to low N application in this spinach farm. This system received only 85 kg N/ha together with rough legume and compost-supplemented nitrogen at a limited rate. Another study reported that emissions from 9.1kg to 12.2kg $N_2O$-N $ha^{-1}$ from a broccoli crop was found in the system applying fertiliser with 130kg to 230kg-N $ha^{-1}$ in Scotland (K. E. Dobbie, McTaggart, & Smith, 1999). In addition, soil moisture was substantially low (below 40% water-filled porosity and volumetric water) that caused by frequent, small water supply via the use of an overhead sprinkler application; additionally, some little amount of rainfall also occurred. The ideal water-filled porosity for $N_2O$ emissions was >60 -70% (Pimentel, Weiler, Pedroso, & Bayer, 2015). Presence of legume and ryegrass helped to reduce $N_2O$ emissions. For instance, cumulative emissions over the spinach cropping phase of 28 day-observation period were 55g and 73g $N_2O$ $ha^{-1}$. Compost on the other hand increased three times higher as compared to cover crops. However, a reduction of emissions from cover crops from other studies was not clearly concluded. A meta-analysis study concluded that 60% of the studies demonstrated cover crop increases of $N_2O$ from the soil surface, while the rest did not (Basche et al., 2014), while higher emissions from the compost plots were probably due to greatest soil N availability in compost plots at the beginning of the experiment (double amount compared to cover crops and fallow), which could be denitrified. A study on effects of manure to emissions also concluded that composted pig slurry produced higher $N_2O$ emissions by 40% than untreated pig slurry (Vallejo et al., 2006).

Regarding the sampling position, this study has shown that the wheel tracks drove more $N_2O$ flux than bed positions. WFPS in the wheel tracks was assumed to be much higher than in the beds due to water-logging after irrigations or rain. Under these conditions, it is likely that wheel tracks were strongly denitrifying but this was far less likely in the beds. In other words, more $N_2O$ emissions were produced from wheel tracks compared to bed positions. Our results agreed with this study (Ruser, Flessa, Schilling, Beese, & Munch, 2001).

Despite the emissions shooting up on 23, October (due to high emissions on wheel tracks resulting from water logging), the DMPP applied on 5 October was generally to help reduction of $N_2O$ emissions around the initial stage as $NH_4^+$ concentration was higher and $NO_3^-$ was low at this stage with the presence of nitrogen inhibitor. These figures were reversed in absence of nitrogen inhibitor. Scheer and his colleagues (2014) concluded that $N_2O$ emissions were reduced by 75% when applying DMPP compared to the standard practice over the broccoli cropping phase (Scheer et al., 2014). However, this study did not show significant differences in the reductions of $N_2O$ fluxes between using and not using DMPP.

4.2. Crop growth

Legume produced significant higher yields compared to fallow. In fact, the crop yields showed differences at the last week before harvesting. This can be explained by the fact that the soil $NO_3^-$ content did not differ at two weeks after planting but gradually increased which then led to an increase in the final yields. Even rough soil nitrogen concentration presented in compost was high at beginning of the trial but it was reduced after two weeks and therefore, had less impact on its yield. Other yield components such as leaf area, leaf volume responded consistently with yields. Ryegrass, ryegrass adding DMPP and compost \ did not lead to any significant differences in yields. A similar study also found that DMPP and even the DMPP with lower dose and the conventional fertiliser rate did not affect broccoli yields (Scheer et al., 2014).

4.3. Soil carbon

In general, cover crops and compost initially gained more labile carbon as they were supplied from cover crop residues and manure inputs. At the end of the season, labile carbon increased at all treatments. This was because of oxidation processes of the roots, partially decayed organic matter, exudates and the activities of the soil microbes. When crops grow, more roots, exudates and microbe activity also increased, resulting in increases of labile carbon.

Although cover crops and compost received similar amount of labile carbon at the end of the season, legume had the highest rate of increase. In addition, although the cover crops had lower amount of labile carbon compared to the compost initially, by the end of the season, gradual accumulation over time resulted in a similar amount of labile carbon as compost. In fact, the cover crop in this study was harvested almost a year prior to the trial start.

## 5. Conclusions

Although cover crops such as legume and ryegrass had lower rates of $N_2O$ emissions (accumulated 55g and 73g $N_2O$-N ha season$^{-1}$, respectively) compared to fallow and compost (accumulated 169g and 178g $N_2O$-N ha season$^{-1}$, respectively) at the whole season, the low $N_2O$ emission rate was generally due to low water-filled porosity (around 40%) under low water supply via the use of an overhead sprinkler application and little rainfall and low amount of N application (82kgN ha$^{-1}$). In addition, more $N_2O$ emissions were produced from wheel tracks compared to bed positions as wheel tracks were assumed to create much higher water-logging after irrigation or rain. Moreover, DMPP application potentially reduced $N_2O$ emissions at the initial phase but a further study is needed to confirm this.

Legume gave significant higher yields and yield components compared to fallow while compost and ryegrass did not. In addition, cover crops and compost initially gained more labile carbon as they were supplied from cover crop residues and manure inputs. However, at the end of the season, legume provided the most increased labile carbon rate.

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# Potential of cover crops to reduce nitrous oxide emissions from a high nitrogen input corn crop

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# 1. 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 nitrous oxide emission, 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 emission were less than 1 g $N_2O$-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 100 g $N_2O$-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 2.8 kg $N_2O$-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.

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 1 kg 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.

# 2. Introduction

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 ($NO_3$) leaching and recover nutrients from deeper in the soil profile, reduce pest and weed pressure, and decrease soil erosion (Stivers, et al, 1999; Table 1).

**Table 1** A summary of winter cover crops suitable for vegetable production systems

| Main aim | Crop | Comments |
|---|---|---|
| Build soil structure | Ryegrass – a clear favourite | High root activity stabilises soil. |
| | All other crops below will also build soil structure, but to a lesser extent | Foliage protects soil surface, mulches well and provides excellent organic matter input. Encourages mycorrhizal (VAM); good for some crops e.g. onions |
| Add cheap nitrogen | Peas | Use a rhizobium inoculate. |
| | Clovers | For legumes to fix nitrogen, nitrate levels in the soil should be below 150 kgN/ha (≈25 mg$NO_3$/kg to 50cm). |
| | Lupins | |
| | Vetch | Expect legumes to fix between 100 and 200 kgN/ha – the bigger the crop, the more N fixed. |
| Recover and store leftover fertiliser | Mix of fibrous and deep rooted crops, e.g. ryegrass and brassica | Capture and store nitrogen to prevent leaching or loss to the air over winter.<br>Recycle nutrients from deep in the soil.<br>Use these cover crops when soil nitrate levels are above 150 kgN/ha. |
| Soil pest and disease control | Biofumigant brassicas (typically canola, *B. Napus*; Indian mustard, *B. Juncea*) | Use high glucosinolate varieties.<br>Aim to incorporate 100t/ha fresh biomass.<br>Incorporate when biomass is at a maximum; mulch finely and incorporate into the soil rapidly.<br>Soil should be moist. |
| Weed control | Fast early growth crops, e.g. wheat, barley, oats. | Use 30% greater sowing rates to out compete weeds. |
| | Brassicas | Brassicas can suppress weeds over and above the direct competition of the fast growing crops above. |
| Protect the soil surface from wind and water erosion | Ryegrass, wheat, barley, oats | High biomass crops good.<br>Management of the mulch varies depending on the crop which follows the cover crop. |

The impact of cover crops on nitrous oxide emissions from vegetable production systems is not clear. Typically, studies focus on just the cover crop or the cash crop following. A more integrated approach is required which also looks at how the whole system can be managed to improve nitrogen use while also reducing the negative environmental impacts of excess nitrogen.

Cover crops can potentially both decrease and increase nitrous oxide emissions. Decreases in nitrous oxide emissions may arise from cover crops temporarily decreasing soil $NO_3$ pools and by supplying more nitrogen through mineralisation of organic nitrogen stores during the growing season. Increases in nitrous oxide emissions may arise where carbon sources are limiting soil microbial activity. In these situations, a cover crop's contribution to the labile carbon pool can enhance nitrous oxide emissions from the soil surface (Mitchell et al. 2013).

A greater understanding of the impact of cover crops on nitrous oxide emissions from vegetable production is required, and importantly how the system can be managed to improve nitrogen productivity and reduce the negative environmental impacts.

Cover crops introduce more complexity and cost into vegetable production systems. If widespread use of cover crops is to occur there need to be clearly defined benefits that outweigh the direct and indirect costs. While some benefits occur immediately (e.g. reduced weed or disease pressure), benefits such as improved soil structure and general soil health take time to be realised in both the soil and the bottom line. Understanding how cover crops impact on nitrous oxide emissions will allow the greenhouse impacts to be added to this cost–benefit equation.

## 1.1 Objective

What impacts will winter cover crops (Nemclear mustard or ryegrass/peas) have on the summer cash crop of corn in relationship to:

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

Furthermore, have the organic matter and nitrogen added by the cover crop improved the soils' ability to buffer the nitrogen supply during crop growth? These benefits may be observed only if nitrogen fertiliser is sub-optimal or if there are extreme weather events, e.g. heavy rain, a run of hot weather.

## 1.2 N rate demo

To determine the nitrogen "value" of the cover crops, i.e. to determine if the cover crops reduced the amount of nitrogen fertiliser required to achieve a similar yield, a side dressing of nitrogen (Anhydrous ammonia was applied at commercial rates (120 kgN $ha^{-1}$) with strips of 0% and 50% of the commercial rate applied.

# 3. Commercial Scale Demonstration Area

## 2.1 Overview of Mulyan, Cowra, NSW

The trial was located 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.

## 2.2 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 2).

**Table 2.** 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 |

## 2.3 Location and farm map

The cover crops in the conventional tillage demonstration trial took place in the 12 ha Block 1 (Figure 1). Prior to the establishment of the cover crops a lettuce crop was grown which was harvested in December 2013. Summer weeds were controlled with herbicides with the winter cover crops sown on 15 May 2014.


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

## 2.4 Cover and cash crop details

### 2.4.1 Cover crops

The cover crops were sown on 15 May 2014 with fertiliser added at sowing (Table 3). The winter fallow received no fertiliser and weeds were not controlled during the winter. Volunteer ryegrass established in the fallow area during this period (Figure 2).

**Table 3.** Summary of winter cover crops sown and fertiliser applied on 15 May 2014.

| Cover crop | Area (ha) | Seeding rate (kg $ha^{-1}$) | Fertiliser (kg $ha^{-1}$) |
|---|---|---|---|
| Nemclear mustard | 5.5 | 6 | 6 kg N + 13 kg P (banded with seed) |
| | | | 41 kg N anhydrous ammonia |
| Burst annual ryegrass and | 5.5 | 10 | 6 kg N + 13 kg P (banded with seed) |
| Morgan field peas | | 40 | |
| Winter fallow – weeds: ryegrass, shepherd's purse, deadnettle | 1 | 0 | No fertiliser applied |


**Figure 2.** Winter cover crops prior to cultivation 5 September 2014.

### 2.4.2 Corn cash crop

Corn (Zea mays L) was sown at 85 kg $ha^{-1}$ on 11 November 2014.

Prior to sowing, all areas were sprayed with glyphosate and 2,4-D and five days later disced twice followed by one pass with a supercolter. On 29 October beds were pulled up and furrow irrigation applied. Immediately prior to planting, a plantavator was used to reform the beds and incorporate the compound fertiliser.

*N fertiliser*

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.

A side dressing of anhydrous ammonia (120 kgN $ha^{-1}$; Big N 82% N) was applied 22 days after planting. Within each of the three areas (Nemclear mustard, ryegrass/peas or winter fallow) strips were created with either 0, 60 or 120 kgN $ha^{-1}$.

*Water*

The corn crop received an estimated 6.2 mL of water over the season. This was made up of nine furrow irrigation events (4.5 ML) and in season rainfall of 1.7 ML.

# 4. Monitoring

## 4.1. Soils

There were moderate soil nitrate levels immediately prior to the cover crops being sown which equated to 105 kgN $ha^{-1}$. The two cover crops received a further 6 and 47 kgN $ha^{-1}$ for Nemclear mustard and ryegrass/peas, respectively (Table 3).

By the end of the cover crop soil nitrate levels differed considerably between the three areas. In the cover cropped areas soil nitrate levels had declined to the equivalent of only 8 kgN $ha^{-1}$ while the winter fallow control still recorded 95 kgN $ha^{-1}$. Under the winter fallow, soil nitrate levels had increased in the subsoil and decreased in the topsoil.

By the end of the cover crop, prior to incorporating, no differences were observed in the soil organic matter content.

**Table 4.** Soil nitrate and organic matter concentration at the beginning and end of the cover crop.

| Depth (cm) | Prior to cover crop | End of cover crop | | |
|---|---|---|---|---|
| | | Winter fallow | Nemclear mustard | Ryegrass/peas |
| | | *Soil nitrate (ppm)* | | |
| 0-15 | 31.5 | 19.4 | 2.6 | 1.9 |
| 15-30 | 23.0 | 29.1 | 1.6 | 2.2 |
| | | *Soil organic matter (%)* | | |
| 0-15 | 2.6 | 2.9 | 2.7 | 2.5 |
| 15-30 | 2.1 | 2.4 | 2.4 | 2.4 |

## 4.2. Cash crop

### 3.2.1 Early crop growth

In each treatment three plots were established and corn plant height, leaf collar number and SPAD measured.

Plant height was measured from the soil surface to the top of the plant. Leaf collar—which determines leaf stage in corn—was counted at each measurement interval. An indirect estimate of leaf nitrogen was obtained using a Minolta SPAD-502 meter. Values from the SPAD meter are closely related to the N status of crops such as corn (Zea mays L.) (Fox et al., 2001)

SPAD measurements and heights were undertaken on the same plants. Before tassel emergence (VT growth stage) readings were taken from the uppermost leaf which had fully collared. After the VT growth stage readings were taken from the leaf at the uppermost ear shoot.

### 3.2.2 Yield

Immediately prior to harvest the plots were hand harvested and yield determined.

## 4.3. Greenhouse gas measurements

### 4.3.1. Field sampling

*Cover crops*

Five static non-flow-through chambers (diameter 243 mm; height 205 mm; installed volume of 7.3L) were installed randomly in each of the three areas (ryegrass/peas, Nemclear and fallow). $N_20$ sampling was conducted approximately every two weeks, and more frequently around major rainfall events (>25mm). Chamber head air samples were collected from the static chambers at 0, 30 and 45 minutes after lids were sealed, using a 25 mL gas-tight syringe (SGE, 25MDR-LL-GT), and introduced into pre-evacuated 12 mL Exetainer vials with grey silicon septa (Labco, UK). Chamber temperature was measured during sampling using a TP3001 digital thermometer.

*Corn crop*

Initially, five chambers were located in each of the three areas (ryegrass/peas, Nemclear and fallow) for the first irrigation cycle prior to planting.

From planting, eight chambers (four in the furrow, four on the rows) were located in the ryegrass/peas and winter fallow areas only. A series of measurements were taken around the first irrigation after basal fertiliser (Nitrophoska fertiliser broadcast @ 200 kg/ha) was applied and then around other irrigation events. Generally, the series included a pre-irrigation (-1 day) and then 1, 2, 5, 9 days after irrigation.

### 4.3.2. Sample analysis

Samples were analysed on an Agilent 7890A gas chromatograph (GC) fitted with a Gilson (GX 271) auto sampler. The system has two channels leading to μ-ECD and FID detectors. $N_2O$ was analysed by μ-ECD. The sample was loaded onto a 1000 mL sample loop, and then injected onto a 1 m Porapak Q pre column. Gases were then passed onto a 2 m Porapak Q column for further separation. The pre-column was back-flushed to remove moisture after the analytes had passed onto the analytical column. $CO_2$ and $CH_4$ were analysed by FID. Sample was loaded onto a 500 mL sample loop, and then injected onto a 1 m Porapak Q pre column, a 2 m Porapak Q column, then a 1 m molecular sieve column to achieve further separation of gases. $CO_2$ was bypassed around the molecular sieve column. Both $CO_2$ and $CH_4$ were passed through a catalytic methaniser before detection. RSDs (based on seven replicate injections) for $N_2O$ and $CO_2$ were <2%. For each batch of samples, a range of standards, controls, and blanks were included for QC purposes (van Zwieten *et al.* 2010).

The flux rate, $F_{N2O}$, was calculated using Eqns 1 and 2. All $N_2O$ flux rates were corrected for the actual air temperature during the measurement and recorded as:

[$\mu gN_2O\text{-}N\ m^2/h$]:

$$\mathrm{F_{N_20}} \; = \; b \,\square\, \mathrm{V_{CH}} \,\square\, \mathrm{MW_{N_20-N}} \,\square\, 60 \,\square\, 10^6 \mathrm{A_{CH}} \,\square\, \mathrm{MV_{corr}} \,\square\, 10^9$$

where $A_{CH}$ is basal area of the measuring chamber [$m^2$]; $b$ is increase in concentration [ppb/min]; $MW_{N2O\text{-}N}$ is molecular weight of $N_2O$-N [28 g/mol]; $MV_{corr}$ is temperature-corrected molecular volume [$m^3$/ mol]; $V_{CH}$ is volume of the measuring chamber [$m^3$].

$$\mathrm{MV_{corr}} = 0.02241 \,\square\, \left(\frac{273.15 \; + T}{273.15}\right)$$

where $MV_{corr}$ is as defined; $T$ is air temperature during the measurement [$^oC$]; $0.02241m^3$ is the molar volume of an ideal gas at 1 atm, 273.15K (Aylward and Finlay, 1974).

# 5. Results

## 5.1. Cover crop biomass

Prior to incorporation the cover crop shoot biomass was 11.3 and 6.7 t $ha^{-1}$, for Nemclear and ryegrass/peas respectively, while the winter fallow had a shoot biomass of 2.2 t $ha^{-1}$ of volunteer ryegrass and other weeds.

## 5.2. Early corn growth

The cover crops had no effect on the early growth of the corn plants, with plant height and collar number the same across the three areas. (Figure 3 and Figure 4).

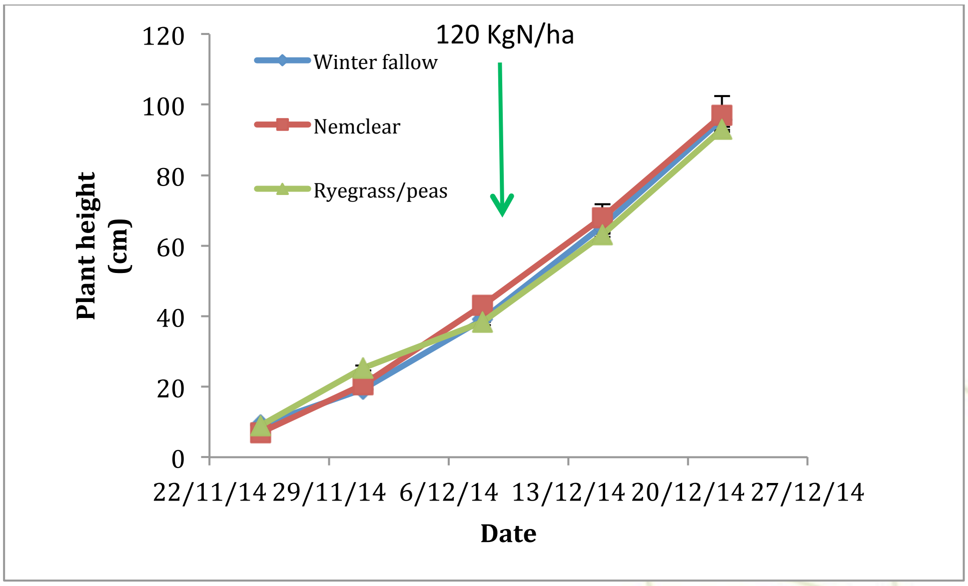


**Figure 3.** The early growth of the corn plants following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. The arrow indicates the timing of a 120kgN $ha^{-1}$ side dressing. All areas received basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$). Error bars indicate the standard error of the mean.

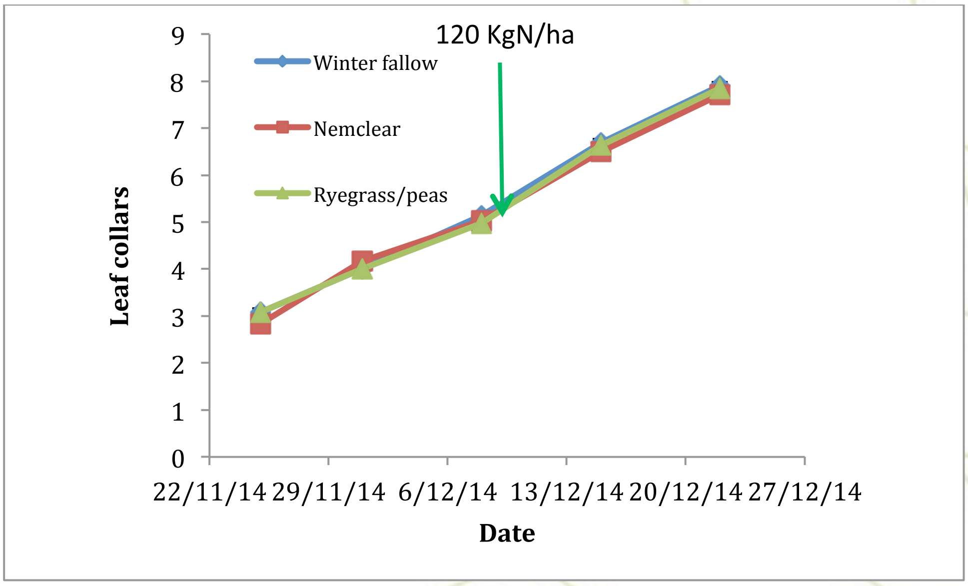

**Figure 4**. The early development of the corn plants following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. The arrow indicates the timing of a 120kgN/ha side dressing. All areas received basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$). Error bars indicate the standard error of the mean.

The nitrogen status of the corn plants varied over time with very high SPAD values when plants reached their maximum height. No consistent difference could be observed between the three treatments (Figure 5).

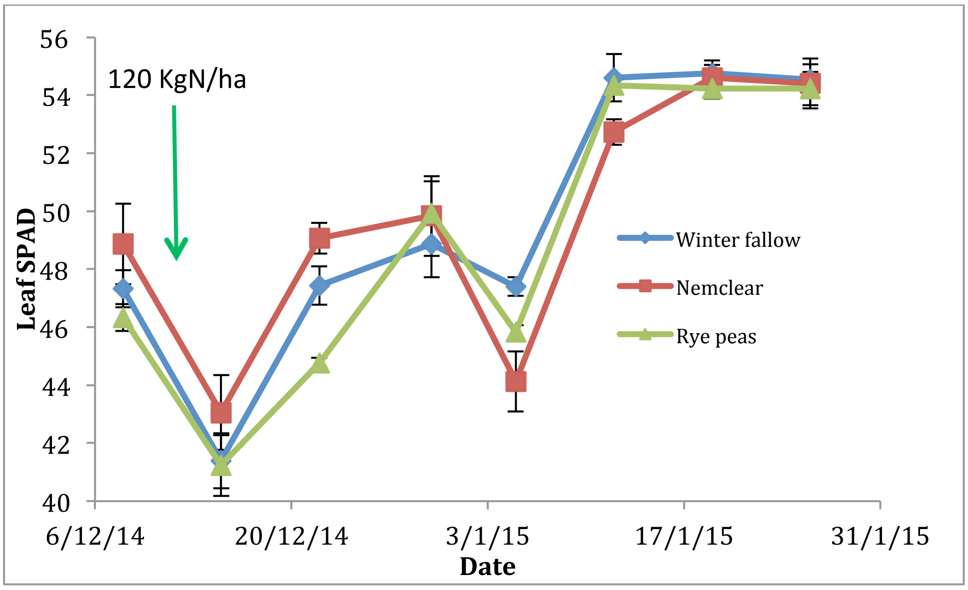


**Figure 5**. Changes in leaf SPAD values—an indicator of foliage nitrogen—during the rapidly growing phase of the corn crop. The crop was established following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. The arrow indicates the timing of a 120kgN/ha side dressing. All areas received basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$). Error bars indicate the standard error of the mean.

Surprisingly, there was only a very small response to the varying rates of nitrogen fertiliser applied as a side dressing (Figure 6).

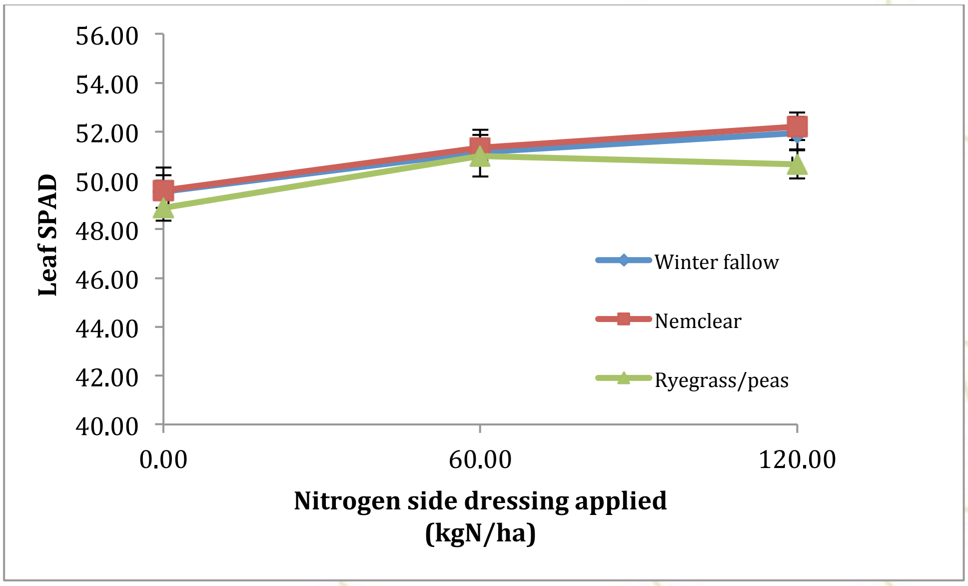


**Figure 6**. Response of leaf SPAD values – an indicator of foliage nitrogen – to varying rates of nitrogen fertiliser side dressing (0, 60 or 120 kgN $ha^{-1}$. The crop was established following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. All areas received basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$). Error bars indicate the standard error of the mean.

At silking – one of the most critical stages in determining yield potential – no differences in the number of cobs per plant could be observed due to either nitrogen fertiliser rates or cover crops (Table 5).

Table 5. Effect of differing rates of nitrogen side dressing on corn cob numbers measured at R1 silking. The crop was established 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 $ha^{-1}$). Values are the means and (standard error of the mean).

| | Nitrogen fertiliser side dressing (kgN $ha^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Cover crop | 0 | | 60 | | 120 | |
| | *Average corn cobs per plant* | | | | | |
| Winter fallow | 1.40 | (0.21) | 1.33 | (0.15) | 1.20 | (0.06) |
| Nemclear mustard | 1.33 | (0.03) | 1.43 | (0.03) | 1.37 | (0.09) |
| Ryegrass/peas | 1.27 | (0.12) | 1.40 | (0.10) | 1.40 | (0.06) |

## 5.3. Crop yield

Corn grown after cover crops produced higher yields but only when no side dressing of nitrogen was applied. The yield from the ryegrass/peas and Nemclear cover crop areas was 15% and 10% greater, respectively, than the winter fallow when no nitrogen side dressing was applied. When nitrogen fertiliser was applied, the different cover crops produced similar yields, apart from the Nemclear with 60 kgN $ha^{-1}$.

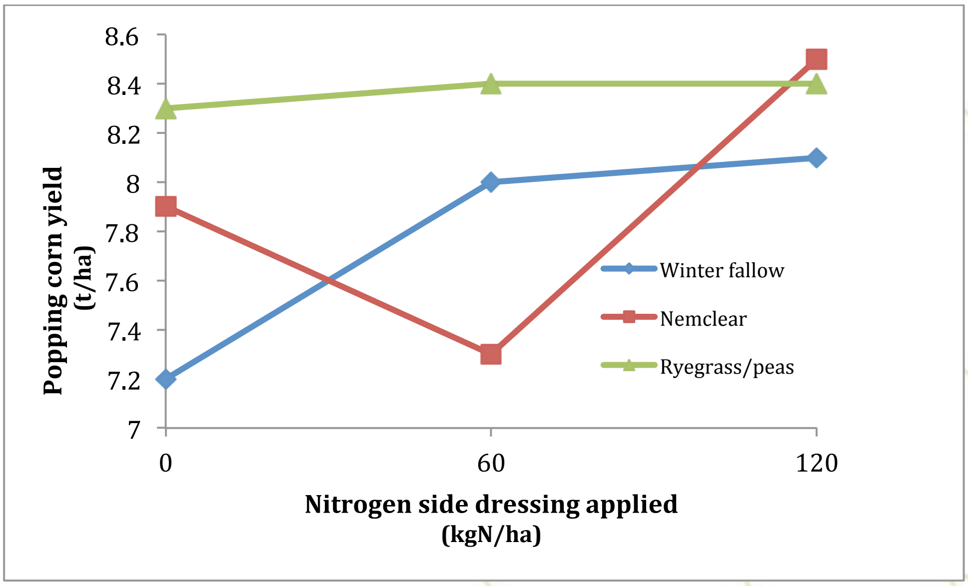


**Figure 7**. Effect of differing rates of nitrogen side dressing on corn yield. The crop was established following either a winter cover crop of Nemclear mustard or ryegrass/peas, or a winter fallow. All areas received basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$). Values are the means and (standard error of the mean).

## 5.4. Nitrous oxide emissions

### 5.4.1. Cover crop emissions

Nitrous oxide emissions from the soil were very low both prior to the autumn establishment of the cover crop (0.24 g $N_2O$-N $ha^{-1}$ $day^{-1}$), and during the growth of the cover crops. The winter fallow averaged 0.82 g $N_2O$-N $ha^{-1}$ $day^{-1}$, while the ryegrass and pea, and Nemclear, both averaged 0.96 g $N_2O$-N $ha^{-1}$ $day^{-1}$. No increase in emissions was observed following significant rainfall events.

### 5.4.2. Corn crop emissions

Large nitrous oxide emissions from the soil were observed during the corn growing season. Peak emissions were in excess of 100 g $N_2O$-N $ha^{-1}$ $day^{-1}$ (Figure 8). The very high emissions were associated with the furrow irrigation events immediately after either the 175 kgN $ha^{-1}$ basal application, or the 120 kgN $ha^{-1}$ applied as a side dressing. By the end of the growing season furrow irrigation events were no longer associated with increased nitrous oxide emissions.

Early in the growing season the ryegrass/pea cover crop treatment produced nitrous oxide emissions more than twice those of the winter fallow treatment. However, following the 120 kgN $ha^{-1}$ side dressing, when the largest emissions were observed, the ryegrass/pea cover crop treatment emissions were 30% lower than that observed in the ryegrass/pea cover crop. As a result, seasonal emissions were similar between the two treatments.

Over the corn growing season there was no differences in nitrous oxide emissions from the corn crop grown following the ryegrass/pea cover crop or a winter fallow. Growing season emissions were estimated to be 2.80 and 2.77 kg $N_2O$-N $ha^{-1}$ for the ryegrass/pea cover crop or winter fallow, respectively.

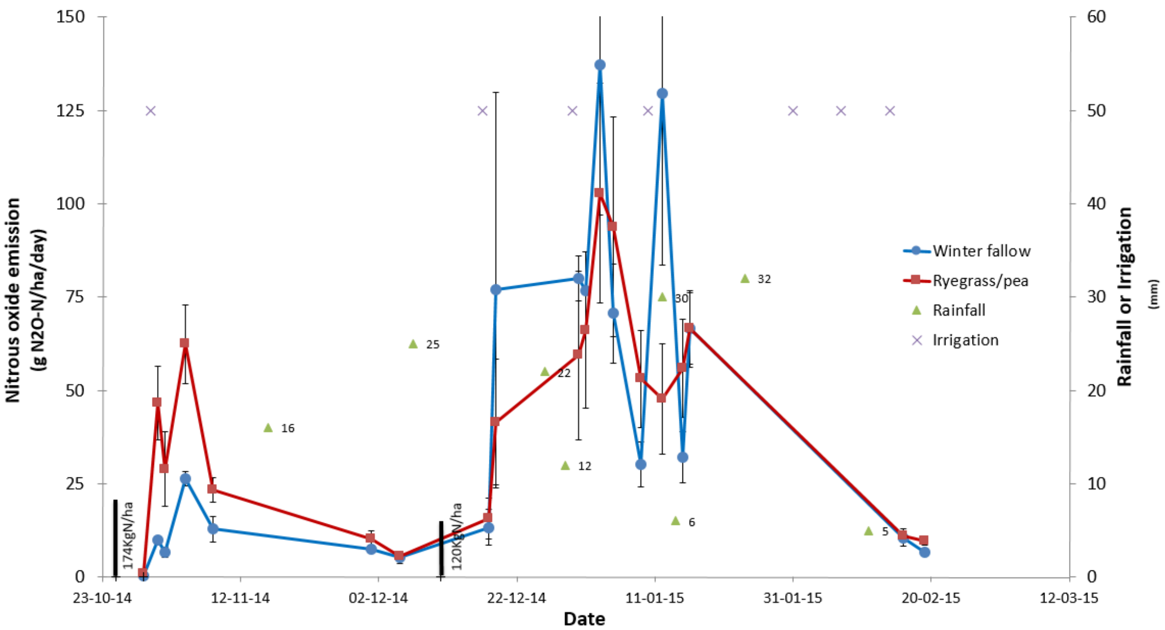


**Figure 8**. Nitrous oxide emissions from a furrow irrigated corn crop. The crop was established following either a ryegrass/peas cover crop of a winter fallow. The black bars indicate the timing of the basal fertiliser prior to sowing (174 kgN $ha^{-1}$; 20 kgP $ha^{-1}$; 56 kgK $ha^{-1}$; 32 kgS $ha^{-1}$) and the 120 kgN/ha side dressing as anhydrous ammonia. The X indicate irrigation events (50mm/event) with rainfall shown by the green triangles. Error bars indicate the standard error of the mean.

# 6. Discussion

## 6.1. Impact of a cover crop on corn crop nitrous oxide emissions

The impact of cover crops on the nitrous oxide emissions from the following cash crop is not clear cut. In a recent meta-analysis, cover crops were found to have decreased $N_2O$ emissions in 40% of studies, while 60% reported that cover crops increased $N_2O$ emissions from the following cash crop (Basche et al 2014). The meta-analysis also emphasised the importance of monitoring over both the cover and cash crop growth cycle.

Very low nitrous oxide emissions were observed during the growth of the cover crop. Daily emission was less than 1 g $N_2O$-N $ha^{-1}$ $day^{-1}$, even following high rainfall events which would have induced soil anaerobic conditions, in all the cover crop and winter fallow areas. This confirms that winter cover crops produce low emissions during their growth in part due to the low soil temperatures. By contrast, very high nitrous oxide emissions were observed during the corn crop.

In this corn production system, nitrous oxide emissions in excess of 100 g $N_2O$-N $ha^{-1}$ $day^{-1}$ were observed (Figure 8). The high nitrogen fertiliser rates and use of furrow irrigation were the dominant determinants of 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 was measured after the nitrogen side dressing application. As a result, corn crop nitrous oxide emissions were similar between both cover crop and fallow areas over the whole season. This was despite the different emission patterns, discussed below. In both the ryegrass/pea cover crop and winter fallow area approximately 2.8 kg $N_2O$-N $ha^{-1}$ was emitted during the growth of the corn crop. This represents 0.95% of the applied nitrogen and is in line with the IPCC default value of 1.25% of fertiliser nitrogen being emitted as nitrous oxide.

Cover crops can affect nitrous oxide emissions indirectly through changing either the amount of carbon or nitrogen available to microbes, both of which are major determinates of nitrous oxide losses (Mitchell et al. 2013).

The main driver of initial difference in nitrous oxide emissions from the corn crop appeared to be the large input of fresh organic matter into the soil. Between 43–65 t $ha^{-1}$ of fresh organic matter was incorporated into the soil in the ryegrass/pea and Nemclear cover crops, respectively, compared to 15 t $ha^{-1}$ in the winter fallow area. This fresh food source, combined with 174 kgN $ha^{-1}$ of nitrogen fertiliser and furrow irrigated, stimulated the soil microbial population. The soil respiration rate was more than double in the ryegrass/pea area compare to the winter fallow. The higher soil microbial activity would have made anaerobic conditions more likely during the first furrow irrigation. This would explain the higher nitrous oxide emissions observed in both cover crops compared to the winter fallow, immediately following the first irrigation event. Due to the large input of nitrogen fertiliser it is unlikely that the 88% lower soil nitrate levels at the end of the cover crops had a major effect on nitrous oxide emissions (Table 4).

It may be possible to reduce the early season emissions by allowing the cover crop to breakdown before the basal nitrogen fertiliser is applied. In practice this could be achieved by cultivation the cover crop in and irrigating prior to applying nitrogen fertiliser. This would allow the cover crop biomass to decompose without high soil nitrogen levels. As this would push the fertiliser application closer to sowing, care would need to the placement and timing to avoid ammonia/ammonium toxicity problems, although maize seedlings are reasonably tolerant to ammonia.

Thirty per cent less nitrous oxide emissions were produced by the cover crop area following the second irrigation and application of 120 kgN $ha^{-1}$ (Figure 8). This was also the peak period for nitrous oxide emissions with daily rates in excess of 125 g $N_2O$-N $ha^{-1}$ $day^{-1}$ for the winter fallow area. During this period the initial stimulation of the soil microbial population from the incorporation of the fresh biomass had subsided with soil respiration now lower in the cover crop area. The initial decomposition of the cover crop would have drawn down soil nitrogen. This may account for the reduced nitrous oxide emissions in the cover crop area after. However, no measurement of soil nitrate levels was made to confirm this.

## 6.2. Impact of cover crop on corn growth

The cover crops had no effect on corn growth and yield under the commercial practices where 294 kgN ha-1 was applied. This luxury rate of nitrogen fertiliser applied ensured that early corn growth was not nitrogen-limited. Hence any nitrogen effect of the cover crop was not expressed and early growth measurements could not distinguish between cover cropping and winter fallowed areas (Figure 3,Figure 4 and Figure 5).

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 (Figure 7). From this fertiliser response curve it appears that the ryegrass/pea cover crop contributed approximately 60 kgN ha-1 of nitrogen, with the Nemclear cover crop a little less.

## 6.3. Implications for managing vegetable soil to reduce nitrous oxide emissions with cover crops

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.

Nitrogen fertiliser rates can be reduced to account for the nitrogen conserved or added by the cover crop. In this case study the nitrogen value of the ryegrass/pea cover crop was estimated to be 60 kgN $ha^{-1}$. Reducing the side dressing by 50% to 60 kgN $ha^{-1}$ in the ryegrass/pea area could reduce the potential for nitrous oxide emissions during the peak emission period, while having no impact on yield.

Nitrous oxide emission could be reduced by applying the basal nitrogen fertiliser closer to planting. This would allow the bulk of the cover crop to be decomposed, with associated high microbial activity and enhance anaerobic conditions, before any fertiliser is applied. Care would

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 1 kg 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 during the corn crop. This would be more than a third of the applied nitrogen fertiliser and represents a considerable cost to the grower.

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. Managing cover crops and nitrogen fertiliser to reduce nitrous oxides is a win for the environment, your health and farm productivity.

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# Biofumigation

**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 soilborne pests, diseases and weeds.**

## Benefits

Biofumigation crops in your farm's rotation can improve overall efficiency and productivity.

The benefits of correctly incorporating biofumigant crops include improvements in soil health and a reduction in farm inputs. In order to reap the full rewards of biofumigation, certain crop management and incorporation techniques must be used. Benefits are dependent on local climate and soil conditions, the type of biofumigant crop used and its management.

## Common biofumigant crops

Some commonly used biofumigant crops used in Australia include:

- Caliente 199™
- Fumig8tor™
- Nemat™
- Nemclear™ (mustard)

### Soil biology

Biofumigation crops act as break crops, disrupting the lifecycle of pests and diseases. Suppression may result from direct biocidal toxicity as well as indirectly through changes in the soil fauna and microbial community. Populations of beneficial microorganisms, including mycorrhizal fungi, have been found to increase after biofumigant crops.

### Weed suppression

Early vigorous growth and improved plant vigour help to outcompete weeds. When incorporated correctly, the release of isothiocyanates (ITCs) from the biofumigant crop leads to the biocidal burning of weed seedlings.

### Soil organic matter

Organic matter is replenished in the soil after incorporation of the biofumigant. As microorganisms break down organic matter they produce sticky substances that bind soil particles together into soil aggregates. This, in turn improves:

- Water infiltration, water and air holding capacity
- Structural stability, reducing the risk of compaction
- Soil friability, making the soil easier to work
- The soil's resilience to wind and water erosion
- Nutrient holding capacity
- Overall biological activity
- Root growth

Organic matter also buffers against changes in pH, salinity or sodicity and it inactivates or filters toxic elements.

### Nutrient cycling

Deep-rooted break crops can access nutrients stored deeper within the soil profile that are unavailable to shallow rooted crops. Better biological activity can lead

## Quick facts

- When biofumigation crops are macerated, active compounds  are released that are highly toxic to many soil-borne pests, diseases and weed seedlings.
- To contain the active compound in the soil for as long as possible, the biofumigation crop must be finely macerated, incorporated directly (within 20-30 minutes, and the soil surface sealed through irrigation, rain or rolling.
- Brassicas can be grown in cool conditions, sorghum needs warmth to thrive.
- An interval of at about four weeks is recommended before planting the commercial crop.

SW2/001/1501

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

to improved nutrient cycling and crop nutrient uptake. The nutrients become available to the next cash crop. Increased rates of nitrogen mineralisation following brassica and other break crops have been recorded.

## Managing a biofumigant crop

Growing a biofumigation crop requires good management and attention to detail similar to a vegetable crop. Unlike many of the low input, low management green manure crops, biofumigation crops may need some fertiliser and irrigation.

To get the most out of biofumigant crops you need to consider:

- Choose the most suitable type and right variety; each has specific requirements and benefits.
- Having the necessary equipment to manage the crop correctly.
- Plant at the best time within your rotation and time of year.
- Test soils to ensure appropriate nutrient management for the biofumigant crop as well as subsequent crops in your rotation. Make sure soil sulphur levels are adequate for brassicas.
- Timing of biofumigant crop growth to maximise production of the active compound. GSL levels e.g. are highest at 20-25% flowering.
- Seed at the rate recommended by the seed supplier.
- Maceration and incorporation should only be done when soil moisture levels are not too high, otherwise soil structure will be damaged.
- Incorporate the well-macerated biofumigant straight away to release the active compound. Soil temperatures >12 degrees e.g. improve ITC formation.

Benefits of biofumigants will not always happen after the first crop.

Biofumigants cannot be grazed.

*All agronomy management practices should be discussed with your production advisor*

## More information

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*Adapted with permission from the Tas Farming Futures project, which is supported by funding from the Australian Government*

## Case study: one grower's experience

David East, a lettuce grower from the Manjimup region, WA, became hooked on the benefits of biofumigation during his long participation in the WA Department of Agriculture's brassica projects.

He uses biofumigants (caliente mustard) and other green crops extensively on his three properties growing direct seeded iceberg, cos and babyleaf lettuces.

David is using biofumigants to control Sclerotinia in iceberg and cos as well as weeds in babyleaf. As a further disease break measure, he'll sometimes use perennial pastures for a long rotation. He found that using different green crops helps release phosphorus (P) from his high P fixing soils and improve organic matter levels. He now is involved in the Soil Wealth project to be able to quantify why he's getting big results with caliente mustard and the economic benefits.

David is keen for fresh vegetables to be a highly profitable industry in Manjimup. The aim for him and his three sons is to be the best, sustainable producers of high quality, summer, autumn and early spring vegetables.

Lettuce after biofumigation

Lettuce without biofumigation affected by Sclerotinia

SW2/001/1501


# Carbon storage in vegetable soils

## Take home message

- **Growers can reduce the greenhouse impact of vegetable production by maintaining and preventing further loss of stored soil carbon (mitigation) which will also have soil health and productivity benefits.**
- **Increasing organic matter inputs (crop residues, cover crops and composts) and reducing losses (cultivation and fallow) are key to maintaining soil carbon stores and improving soil health and productivity.**
- **Increasing long-term stored carbon in vegetable soil (sequestration) is difficult due to the intensity of production.**

## Carbon in soils

Soils store carbon. Lots of it!

In the top 30cm of soil 1 hectare will have more than 50 tC/ha in the topsoil, when your soil contains 1.5% soil carbon.

But our agricultural soils have lost up to half of their carbon, returning to the atmosphere as the greenhouse gas carbon dioxide[1]. This has contributed to the rise in atmospheric carbon dioxide levels and associated climate change.

The good news is that there are soil management practices which can be used to reduce greenhouse gases through either:

- ***Mitigation***: stopping or reducing further losses of soil carbon to the atmosphere (avoided emissions).
- ***Sequestration***: increasing soil carbon stored in the soil.

[1] Chan, K. Y., Cowie, A., Kelly, G., Singh, B., Slavich, P. (2008). Scoping paper: Soil organic carbon sequestration potential for agriculture in NSW.NSW Department of Primary Industries.

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 Factsheet summaries the opportunities and management options for mitigating or sequestering soil carbon in vegetable soils.**

### Box 1: Soil carbon – soil organic matter

Most soil tests will show organic matter as a percentage.

When you send your soil to the lab, what is actually measured is soil carbon. This is then used to estimate soil organic matter. In practice, soil carbon is multiplied by 1.72 to given soil organic matter.

**An example**

In the example above we had 50 tC/ha when the soil contained 1.5% soil carbon.

Converting this to soil organic matter, by multiplying by 1.72, gives more than 80 tC/ha and 2.6% organic matter. That's at least two semi-trailers of organic matter in one hectare of soil!

SW5/028/1603

The field work was supported by an Australian Government Action on the Ground Project. Soil Wealth is funded by Horticultural Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

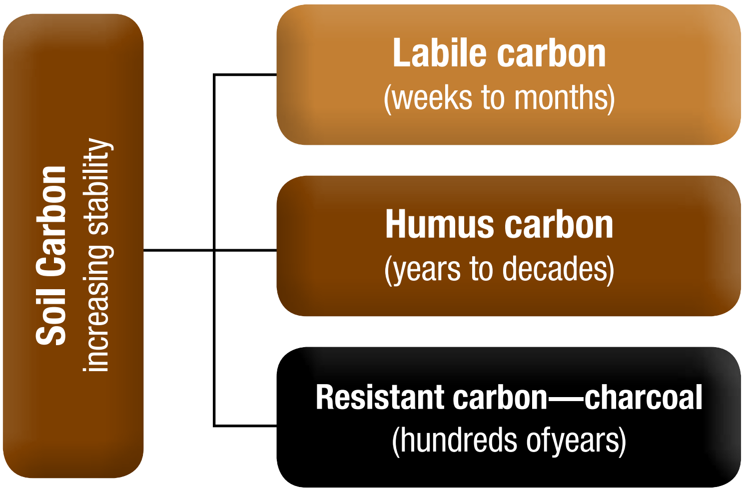



**Diagram 1** The commonly recognised forms of soil carbon and their stability in soil.

## Types of soil carbon

There are different types of soil carbon which vary in their properties, decomposition rates and influence on soil health, fertility and function[2].

The three types of soil carbon commonly recognised are shown in Figure 1. Understanding the types of soil carbon and how they respond to management will help you understand the potential for mitigation or sequestration of carbon in your soil.

**Labile carbon** is made up of partially decomposed organic matter and soil microbes. It is sensitive to the amount of fresh organic matter inputs, such as cash-crop residues, cover crops and compost, and is typically short-lived. Labile carbon lasts only weeks to months before being broken down to more complex stable forms of soil carbon (humus) by soil microbes.

Decomposition can be rapid under warm, moist nutrient-rich condition, as typically found in vegetable soils.

Labile carbon is the major food source for soil microbes and as a result influences many soil functions. Labile carbon is important in maintaining and developing soil structure, particularly in sandy and loam soils. The rapid decomposition makes labile carbon an active source of nutrition for soil microbes and plants.

As the most dynamic of the soil carbon types, labile carbon is a good early indicator of how management practices may be changing soil carbon.

In the field, labile carbon is most visible as the "glue" binding the aggregates around plant roots.

**Humus carbon** is relatively stable, lasting for years to decades due to the organic compounds in humus being more complicated or physically protected by clays. Both of these slow microbial decomposition.

Humus carbon plays a role in all key soil functions, such as soil structure and moisture retention, storing and releasing nutrients, and general soil health.

In the field this gives soil the dark colour of the topsoil and the "sweet" smell of a healthy soil.

**Resistant carbon** is dominated by charcoal. The type of carbon is very stable and may last for hundreds of years. Resistant charcoal changes little over time and while being a carbon store it contributes little to the key soil functions.

In vegetable soils it is most likely in alluvial soil along rivers, where charcoal has been deposited after fires. As charcoal can persist for hundreds of years these soils can be located a long way from the current river channel.

In the field, charcoal may be seen as dark flecks through the soil profile.

[2] This Factsheet doesn't cover inorganic soil carbon such as carbonate. If your soil contains significant amounts of inorganic carbon, e.g. soils containing limestone, specialist information should be sought.

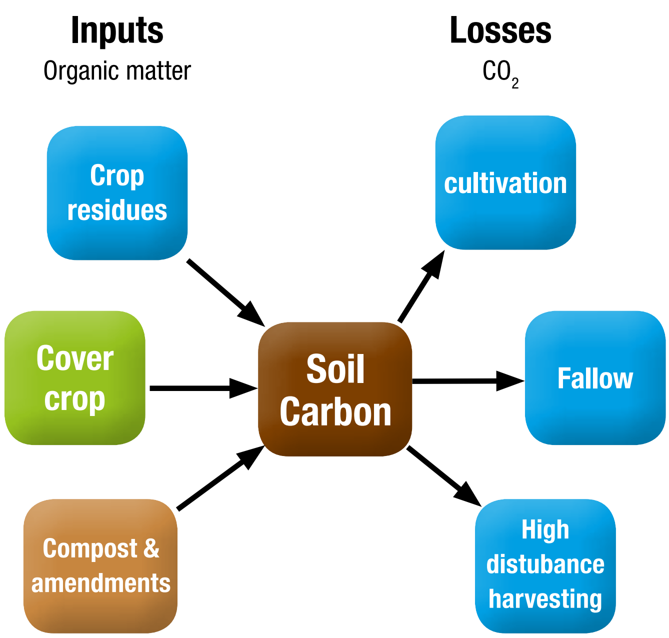



**Diagram 2.** Changes in soil carbon is mainly determined by how management affects the inputs of organic matter and their losses

## Soil tests and the types of soil carbon

Commercial soil test will give total soil carbon (or soil organic matter – box 1), which measured all three types of soil carbon outlined in diagram 1.

Most commercial labs can also measure labile carbon separately (sometimes called active carbon). The ratio of labile-to-total-soil-carbon can be a good way to track how your soil is responding to changes in soil management.

High levels of resistant carbon in your soil can make soil test results difficult to interpret as they mask any change in soil carbon due to management. Specialist soil advice is required if high levels of resistant carbon are suspected in your soil.

## Soil carbon and vegetable soils

The intensity of vegetable production systems makes it difficult to sequester carbon in the soil in the long-term. However, it is possible to mitigate further loss of soil carbon, as shown in the case study.

The main motivation for growers to maintain or build soil carbon will be to improve soil health and productivity. Any climate change mitigation benefits will be a bonus on top of these productivity benefits.

## What determines how much soil carbon is in the soil?

The soil carbon you have today is a balance of the inputs of organic matter and the losses[3] through microbial decomposition, as summarised in diagram 2. While the principles are nice and simple, the management of these inputs and losses in intensive vegetable productions systems is anything but simple.

Intensive vegetable production is characterised by low inputs of organic matter and practices which promote high losses. Specific practices are required to address this imbalance to maintain or build soil carbon.

The intensity of vegetable production limits inputs of organic matter into the soil from crop residues. Multiple, short growing season crops, (e.g. baby leaf) result in the soil being fallow or with young, low biomass crops for most of the time, limiting the input of organic matter into the soil from the shoots, roots and root exudates. When crops are grown for longer the harvesting of much of the crop for sale (e.g. lettuce and cabbage) restricts organic

[3] Erosional losses of soil and associated soil carbon can be large but are not considered here. For ways of protecting your soil refer to the *Erosion—How to Protect Your Soil* Factsheet. However, these losses are not considered in this Factsheet.

matter input into the soil to largely the root systems. Disease pressure can sometimes mean crop residues are removed to reduce disease carry-over.

Intensive vegetable production systems are also characterised by high levels of soil disturbance, which promote soil carbon loss through exposing soil carbon to the soil microbes and ensure soils are well aerated. At the end of some crops there is a high level of disturbance during harvest (e.g. carrots and leeks), further promoting the loss of soil carbon.

Vegetable production also creates ideal conditions for soil microbial activity through irrigation and fertiliser application during the summer, creating warm, moist and usually well-aerated soil.

Practices with the greatest potential to mitigate soil carbon loses involve both increasing organic matter input and reducing losses.

## Increasing organic matter input

### Composts and amendments – importing organic matter

In intensity vegetable cropping, importing organic matter in the form of composts and amendments is a viable option. Depending on the maturity of the products composts will be a mix of fresh organic matter and labile and humus carbon. Regular additions of compost or amendments can help maintain or build soil carbon.

There are restrictions on the use of composts and other amendments due to food safety requirements. This can restrict the use of composts in some vegetable production systems. Also, composts and amendments can be expensive to buy and spread, while the increase in soil carbon can be short-lived[4]. Biochar is another option being considered to increase soil carbon. As biochar is similar to charcoal, it tends to be more resistant to decomposition. To date, trials have produced varying results with respect to increasing soil carbon and improving soil productivity[5].

### Cover crops – growing your own organic matter.

Cover crops can be used strategically to boast organic matter input to the soil. Cover crops can produce bulk organic matter where it is need and through the action of the roots and root exudates can have a bigger impact on the soil than just the amount of organic matter produced. When a cover crop replaces a fallow period the benefits can be considerable. Improvements in the levels of labile carbon can be seen quite quickly.

In managing cover crops in vegetable production systems, the following need to be considered: identifying cropping windows, matching cover crops to the window, having sufficient water to grow the cover crop, managing the transition from cover to cash crop, any specialised benefits, and pest and disease considerations.

### Changing rotation – adding higher biomass cash crops.

Organic matter input can also be increased by changing the crop rotation to either include a higher biomass cash crop where less is harvested, e.g. beans or corn, or rotating through a pasture phase for grazing or hay. This option requires more land area and is ideally suited to more extensive mixed farming enterprises.

## Reducing losses

### Reducing losses through less aggressive tillage.

Reduced till and permanent beds can reduce the amount of soil disturbance and help maintain soil carbon levels. The use of reduced till systems typically involves a system change to permanent beds[6]. It is usually necessary to rebuild the soil carbon, and associated soil structure before using “softer” tillage practices.

### Fallow.

Minimising fallow period will help reduce losses of soil carbon. When a soil is fallow decomposition of soil carbon continues but there are no ongoing inputs from cash or cover crops.

[4] Favoino, E., Hogg, D. (2008). The potential role of compost in reducing greenhouse gases. Waste Management & Research, 26(1), 61–69

[5] Kuppusamy, S., Thavamani, P., Megharaj, M., Venkateswarlu, K., and Naidu, R. (2016). Agronomic and remedial benefits and risks of applying biochar to soil: Current knowledge and future research directions. Environment international, 87, 1–12.

[6] Reduced till in vegetable production – Cultivate less and improve your profits. Soil Wealth Factsheet http://www.soilwealth.com.au/imagesDB/news/RedtillSW12150203.pdf

## Case study: Managing to stop soil carbon loses and improve soil productivity

Ed and James Fagan are third-generation growers on the family farm which has been producing vegetables since 1943, and broad acre crops since 1886.

The intensity of traditional vegetable production was taking its toll, with the soil requiring more cultivation and fertiliser, while yields continued to struggle.

The soil was in decline. Soil carbon had declined from 2.7% in uncropped soil to 0.7% after more than 50 years of intensive vegetable cropping. That's a loss of 75 tC/ha!

Ed and James needed to try something different to improve their soil. They introduced reduced-till, permanent beds to reduce further losses of soil carbon. But after 50 years of vegetable cropping they need to put more organic matter back into the soil and build their soil carbon. Especially now that they were growing babyleaf spinach, with the associated low organic matter input and frequent cultivation.

In conjunction with AHR, Ed and James tried ryegrass cover crops or compost to add some more organic matter and build soil carbon in their permanent beds system. A ryegrass cover crop was grown in the beds for eight months adding more than 4t/ha of organic matter*, but, importantly, additional organic matter would have been added through the roots and root exudates. Over the same period 10t/ha of compost* was applied in two applications.

The good news is that the ryegrass cover crop and compost has stopped the decline in soil carbon, showing that cover crops and compost can mitigate carbon loss. Because much of this increase was in labile carbon, soil management will need to continue adding organic matter to sustain those improvements in soil carbon. While it will not be possible to get the soil back to the levels of 50 years ago, before cropping began, it is important both for greenhouse impacts and soil productivity to stem further losses of soil carbon.

Growing the ryegrass cover crop has not only mitigated soil carbon loss, but, importantly, it has helped to transform troubled paddocks into more productive soils. Soil structure has improved, input costs are down and crop yields are on the improve.

Adding compost also helped to mitigate soil carbon loss. But the cost of composts, together with handling and food safety make it a second-best option for Ed and James. In other vegetable farms, where land is at a premium, reducing the time to grow cover crops, compost may be the most suitable option.

Ed and James see cover crops, combined with reduced tillage and permanent beds, as the way forward to improve the productivity of their soil and make sure the family is still growing vegetable in another 50 years.

Ryegrass cover crop at the Fagan family farm.

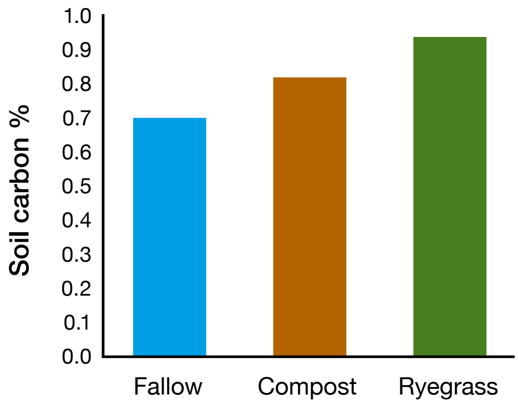



**Figure 1.** The ryegrass cover crop and compost were able to stop further soil carbon loses.

*Ryegrass and compost rates are in dry weights.


# Nitrous oxide emissions from vegetable soils

## what's all the fuss about?

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.

Nitrous oxide is a powerful greenhouse gas and is responsible the majority of emissions from the Australian vegetable industry after $CO_2$ associated with electricity production for cooling and pumping.

### Loss of plant available nitrogen

Nitrous oxide ($N_2O$) gas is produced by soil bacteria. The highest emissions occur when the soil is low in oxygen because under these conditions, bacteria use oxygen from nitrate ($NO_3$-), converting it to nitrous oxide and also to nitrogen gas ($N_2$) through denitrification.

This conversion is at the expense of plant available nitrogen, representing a waste of nitrogen fertiliser.

Nitrous oxide emissions can also be used as an indicator of the much greater losses of plant available nitrogen through denitrification.

### Nitrous oxide is a serious pollutant

Nitrous oxide is a serious pollutant. As a greenhouse gas, it has 300 times the warming potential of carbon dioxide[1] and adding to the level of gases in the atmosphere, which can trap heat. Nitrous oxide is also the most significant ozone destroying pollutants.[2]

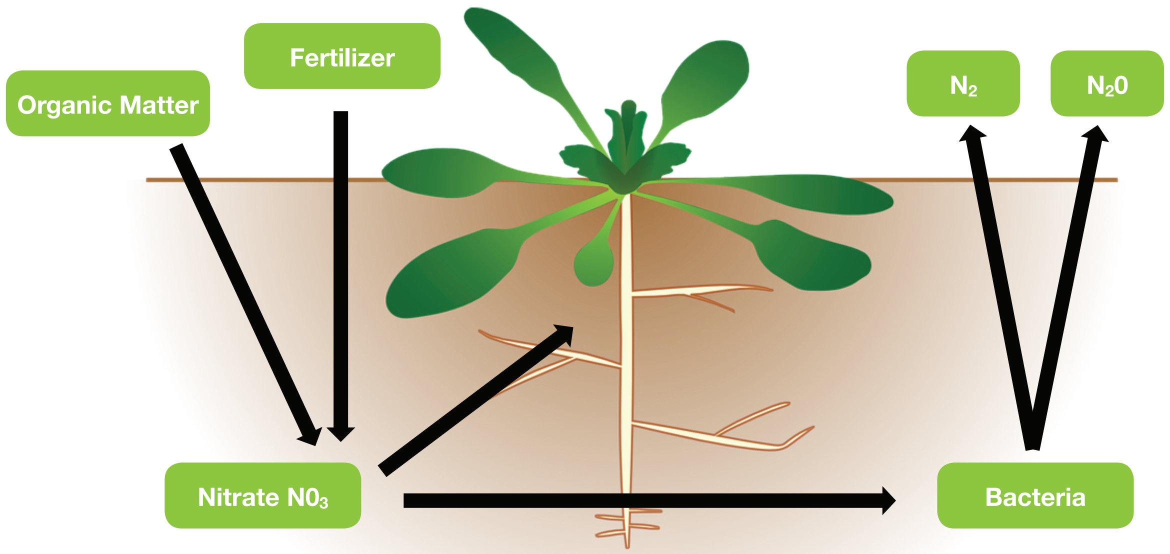



**Figure 1: Simplified nitrogen cycle in vegetable soils.**


[1]Rezaei Rashti, M., Wang, W., Moody, P., Chen, C., Ghadiri, H. Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review (2015) Atmospheric Environment, 112, pp. 225-233.

[2]Portmann, R.W., Daniel, J.S., Ravishankara, A.R. Stratospheric ozone depletion due to nitrous oxide: Influences of other gases (2012) Philosophical Transactions of the Royal Society B: Biological Sciences, 367 (1593), pp. 1256-1264.


Document 12345


This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

## How to reduce $N_2O$ emissions from vegetable soils

### It's a summer issue

Soil temperature has a major impact on the activity of soil bacteria, which produce nitrous oxide emissions. As a "rule of thumb", nitrous oxide emissions are low when the soil temperature is below 15°C.

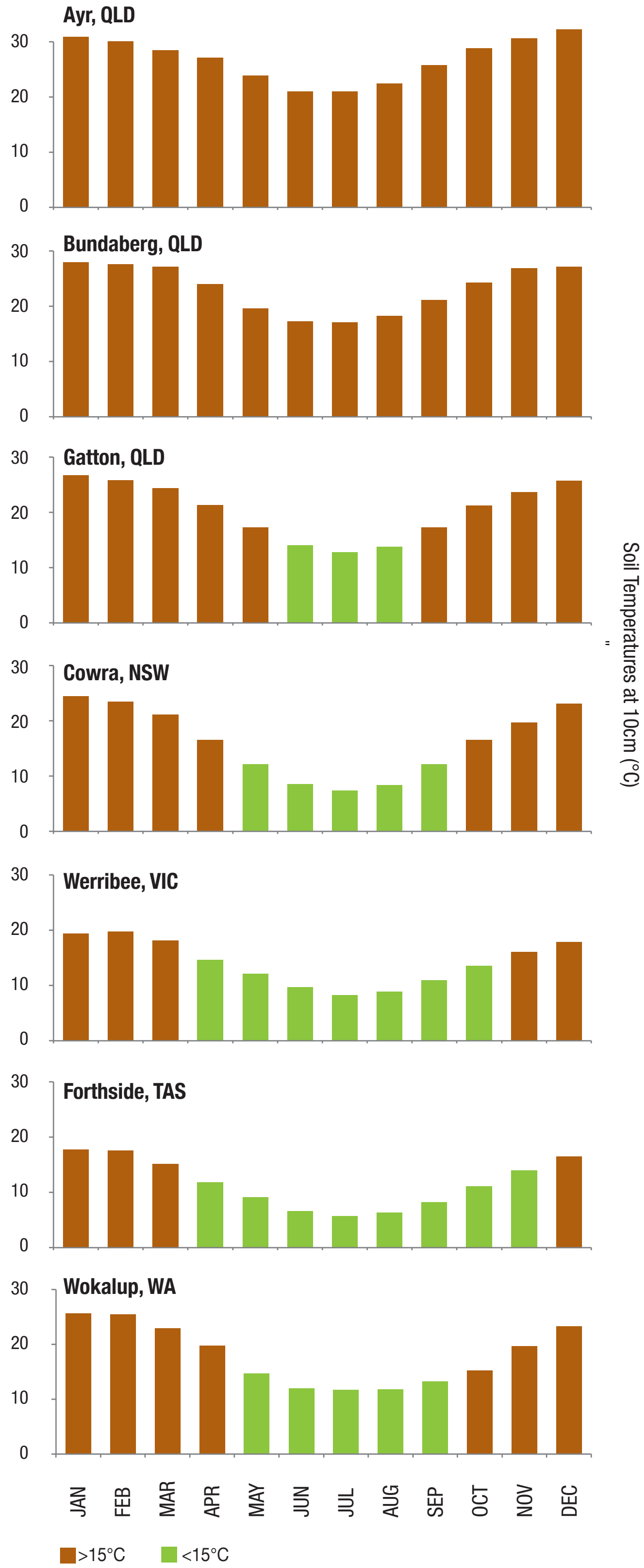
For most vegetable growing areas this reduces the risk of emissions to over late spring-summer-early autumn. Figure 2 shows typical soil temperatures in your region over the year. The orange bars represent the danger times.

## Water – the key to managing emissions

Water the key driver in vegetable farms – get your irrigation management right to reduce N losses through both $N_2O$ emissions and nitrate leaching. $N_2O$ emissions increase when the soil is wet, either through rainfall or heavy irrigations.

To reduce the risk of $N_2O$ emissions nitrogen fertilisers should be applied at least a week after rainfall or irrigation. Tillage under wet conditions should also be avoided.

**Figure 2: Soil temperatures in major vegetable growing areas**



## Nitrogen management: The 4 R's[3]

Fertiliser is a cost to production; the more efficiently it is applied and used by the crop the better for production, profitability and the environment.

1. **Right Product –** Under wet soil conditions, nitrate in the soil is converted to oxides of N and $N_2$. It follows that $N_2O$ emissions are less where ammonium ($NH_4$+) is the dominant form of N and its rate of conversion to $NO_3$- in the soil is slowed. Nitrification inhibitors can slow the conversion of $NH_4$+ to $NO_3$- but the price and logistics need to be considered.
2. **Right Rate –** The optimum N fertiliser rate depends on the crop and the system in which it is growing. Nitrous oxide emissions may only be small component of overall N losses from wet soils. It makes sense to consider the other sources of N supply, type of fertiliser, logistics, cost, crop requirements and N emissions when deciding on the appropriate fertiliser application rate. $N_2O$ emissions are more likely when the supply of nitrate in the soil is greater than required by a crop.
3. **Right Time –** Matching fertiliser application to crop demand makes best use of this resource. Limit pre-planting N and add N during the crop if possible or use slow release fertilisers – know your crops N uptake pattern.
4. **Right Place –** Placing the fertiliser in the active root zone is optimal.

**Add organic matter to the soil but don't apply nitrogen fertiliser at the same time.**

Adding organic matter is great for the soil but is does increase the risk of nitrous oxide emissions. Soil bacteria feed on soil organic matter, and they need oxygen to process this food, just like we do. When large amounts of organic matter are added, the heightened bacteria activity can use up all the available oxygen and force soil bacteria to look for alternative sources of oxygen. One source is the oxygen associated with nitrate, resulting in nitrous oxide emissions and nitrogen losses through denitrification.

[3] Best Management Practices to Reduce Nitrous Oxide Emissions for Annual Vegetable Production. Gerard Fullerton, Chris Dowling, Jeff Kraak, George Rayment, Julio Vargas, Ash Wallace & Charlie Walker.

### Take home messages

- **Nitrous oxide losses can be controlled with good management**
- **Water logged soil will have higher $N_2O$ emissions (and greater nitrate leaching)**
- **$N_2O$ emissions are lower when soil temperature is below 15°C**
- **High soil carbon/organic matter mixed with soil nitrogen cause $N_2O$ emissions**
- **Ammonia based and slow release fertilisers reduce $N_2O$ emissions**
- **Take soil samples to see where your nitrogen is going**

On vegetable farms, organic matter is usually added as composts and amendments, or as cover crops or crop residues. High N organic amendments, such as lucerne mulch and compost, increase the risk of $N_2O$ losses.

## Soil testing can help you

Taking soil samples down to 30cm and having them analysed is an efficient way to manage soil nitrogen. Sampling before a planting will tell you how much N is already available – you might be able to reduce your fertiliser. Proper analysis will also show your limiting nutrients – stops you wasting N. Sampling after a crop will show your residual N.  A deep-rooted cash or cover crop can recover it.

## Sequester carbon in the soil, or mitigate nitrous oxide emissions?

Soil carbon content is a driver of nitrous oxide emissions so doing things that increase soil carbon can work against nitrous oxide abatement. Conversely, pursuing nitrous oxide abatement can work against soil carbon sequestration. The whole system must be considered to ensure that its total carbon footprint is lowered, not just one aspect of it.

The effect of soil management on nitrous oxide emission can clearly be seen here in figure 3.

Farm 1 recorded higher soil organic matter, higher nitrate and used more fertiliser than Farm 2. Basal fertiliser was applied approximately 30 days prior to planting and the soil was saturated just after planting at both sites. As a result Farm 1 experienced a greater loss of N to the atmosphere.

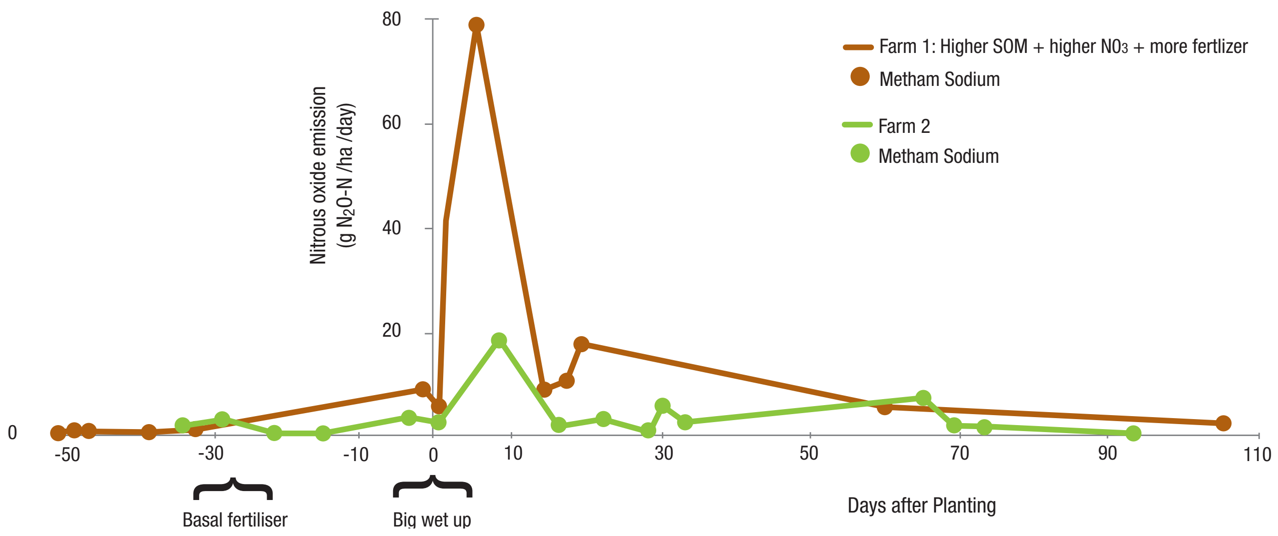



**Figure 3: Results of a study monitoring nitrous oxide emissions from tomatoes.** Source: K. Montagu, S. Moore, L. Southam-Rogers, N. Phi Hung, L. Mann and G. Rogers, Low nitrous oxide emissions from Australian processing tomato crops – a win for the environment, our health and farm productivity.


# Reduced till in vegetable production

## Cultivate less and improve your profits

### Watch the new reduced till video

Cowra vegetable grower Ed Fagan explains how reduced till vegetable farming techniques improve his bottom line in a new soil wealth video available on YouTube.

Click this link to play the video:
***Reduced till vegetable production — Why?***

In the late 1990s a small number of progressive growers in Australia started experimenting with reduced till (or minimum till) for vegetable production. 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.

### Benefits

Reduced till can deliver some significant benefits to growers. These include:

- Reduction in input costs save money and time.
- Fewer tractor passes are needed, saving labour, machinery and fuel cost.
- Less fertiliser is required because of improved root development.
- Fewer irrigations are needed because more water can be stored in the soil.
- Major improvements in soil health.
- Better soil biology leading to a reduction in soil-borne disease pressure.
- Better soil structure and stability leading to less compaction.
- More stable soil aggregates which improve air and water movement and can also results in less erosion.

Flowing from the above, growers can benefit from:

- A wider timeframe for completing farm activities.
- Marketable yields as good or better than via conventional tillage.
- Revenue as good or usually better than via conventional tillage.
- Ability to harvest or prepare soils sooner after rain events.
- Less time and horsepower needed for cultivation activities.

Ed Fagan, Mulyan Farms, Cowra.

### Challenges

There can also be some major challenges in implementing reduced tillage practices into vegetable cropping systems. These include:

- Capital costs of machinery modifications and new equipment.
- Harvesting systems may need to change.
- Possibility of new pest species (slugs, snails, earwigs due to more organic matter) and the need for integrated control.
- Possible changes to the crop protection system.

### Background to reduced till

Reduced till has been used extensively in broadacre agriculture since the mid 1980s, with benefits including reduced input costs (especially tractor related), good soil moisture retention through retention of stubble, good water infiltration and better yields. The benefits over conventional tillage have been particularly clear in drought years.

Cropping soils that have been heavily worked with conventional tillage often become degraded, with poor structure, high bulk density, low water infiltration rates and rapid runoff. In summer, even heavy watering does not always allow sufficient water to soak in, and yields suffer.

Degraded soils require even more cultivation such as deep ripping to counteract these negative effects.

It's a vicious cycle!

SW1/002/1501

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

# Reduced till in vegetable production

- Decreased soil temperature which can lead to slower crop development and longer planting to harvest times.
- Paddock rotation planning needed.

## Case study: Mulyan Farms, Cowra NSW

Ed and James Fagan began using permanent bedding, composting and cover cropping on their least productive vegetable block in 2008. The block was requiring high inputs— tillage, fertiliser and time and was still returning poor yields and low financial returns.

The Fagans set up permanent beds and sowed ryegrass. They killed off the ryegrass in the spring, incorporated the residue in the latter part of summer and prepared the beds for sowing onions in the autumn.

Within one year of implementing reduced till, the extra returns were outweighing the cost of the cover cropping and the compost. While input costs remained roughly the same, the yield was greater and returns improved.

Ed reported the resulting onion crop was phenomenal.

Spraying for weeds over summer wasn't required because the ryegrass left a thatch on top—a big saving. There was a good establishment of onions, nutrition was even, and roots were massive and vigorous.

Four years later, the brothers have seen a complete turnaround in the block. Onion crops are now as good as they could possibly be, and input costs are less—on a paddock that traditionally would have been a no-go for onions.

Economically, the extra margin, the extra yield and the slightly lower cost of growing the crop outweighed the margin that would have accrued by having a second cash crop in that block for the year.

Plus, there was a huge soil health benefit—improved structure, improved water infiltration, and improved uptake—largely due to the profusion of worms. A lot of the tillage that used to be required under conventional methods to break up compaction layers was now done by the worms and microbes in the soil.

The infiltration rate of water increased from 2 ml per hour to 10 ml per hour.

The more activity there is in the soil, the quicker the residue from the previous crop breaks down. So a lot of the breakdown of the cover crops is done by the soil itself.

Annual rye cover crop on permanent vegetable beds.


Implement to incorporate crop and cover crop residues with minimal soil disturbance.


James Fagan with planter designed to sow cover crops through crop residues without cultivation.

## For more information

Watch the video: *Reduced till in vegetable production. Why?* On YouTube

Follow the Cowra Soil Wealth trial on facebook: www.facebook.com/SoilWealthCowra

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SW1/002/1501

Soil Wealth

NURTURING CROPS

# Winter cover crops

## Tools for soil management

### Match your main soil management aim to the southern Australian winter cover crops below

| Main aim | Crop | Comments |
|---|---|---|
| Build soil structure | Ryegrass — a clear favourite<br>All other crops below will also build soil structure, but to a lesser extent | High root activity stabilises soil.<br>Foliage protects soil surface, mulches well and provides excellent organic matter input. Encourages mycorrhizal (VAM); good for some crops eg onions |
| Add cheap nitrogen | Peas<br>Clovers<br>Lupins<br>Vetch | Use a rhizobium inoculate.<br>For legumes to fix nitrogen nitrate levels in the soil should be below 150 kgN/ha.<br>Expect legumes to fix between 100 and 200 kgN/ha — the bigger the crop, the more N fixed. |
| Recover and store left over fertiliser | Mix of fibrous and deep rooted crops eg ryegrass and brassica | Capture and store nitrogen to prevent leaching or loss to the air over winter.<br>Recycle nutrients from deep in the soil.<br>Use these cover crops when soil nitrate levels are above 150 kgN/ha. |
| Soil pest and disease control | Biofumigant brassicas (typically canola, *B. Napus*; Indian mustard, *B. Juncea*) | Use high glucosinolate varieties.<br>Aim to incorporate 100t/ha fresh biomass.<br>Incorporate when flowering, mulch finely and incorporate into the soil rapidly.<br>Soil should be moist. |
| Weed control | Fast early growth crops, eg wheat, barley, oats<br>Brassicas | Use 30% greater sowing rates than normal to outcompete weeds.<br>Brassicas can suppress weeds over and above the direct competition of the fast growing crops listed above it. |
| Protect the soil surface from wind and water erosion | Ryegrass, wheat, barley, oats | High biomass crops good.<br>Management of the mulch varies depending on the following crop. |

When choosing a green cover crop also consider your overall rotation and potential pest and disease carry over.

This table provides an overview of winter cover crops for southern Australia.
Growers should seek additional information to tailor this to their specific situation.



SW1/005/1502

This project has been funded by Horticulture Innovation Australia Limited using the vegetable levy and funds from the Australian Government.

Horticulture Innovation Australia

ahr applied horticultural research

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## Field Day – Farm Walk 11 September 2014

A farm walk field day was held on Mulyan Farm in Cowra, NSW on the afternoon of 11 September 2014 to demonstrate the different cover crops in action, show the benefits of permanent beds, allow the Fagan brothers to explain the equipment they have purchased and allow local industry the opportunity to interact with and ask questions about the research. The event was publicised via the AusVeg weekly update, a local radio presentation and word of mouth, which all contributed to the turnout of 29 participants.

The farm walk commenced with introductions and a tour of the different cover crops led by Marc Hinderager explaining the properties of each to the group and it was very effective showing the different crops side by side and up close. Trenches were dug amongst each of the treatments to expose the root structure and soil condition in each plot, showing attendees the differing abilities of the cover crops (Figure 2).

**Figure 1: Ryegrass, Balansa Clover and Morgan Field Peas shown side by side at the field day site. Additional crops of Caliente-199 and Nemclear can be seen across the track.**

Dr Kelvin Montagu and the Fagan brothers proceeded to systematically outline the several pieces of equipment that had been purchased by Mulyan Farms to incorporate cover crops into soil, mulch waste produce and form beds, seen in Figure 2. The group was very interested in the capabilities of each piece of machinery and appreciated the first-hand experience discussed by the Fagan brothers. This was evidenced by the high level of attendee participation in this segment of the field day.


**Figure 2: James Fagan explaining and demonstrating their specialised equipment to the field day group. Biosecurity was highlighted at the farm walk with participants required to disinfect before entering the cropping area.**

In last segment of the field day Gordon led the group to an area that had not been managed with a regime of cover crops on the edge of the paddock, and they were able to see how degraded the soil condition was before this project was applied to the land.

Refreshments were served over a question and answer session and the field day was brought to a close with a survey handed out to the participants to gain some insight as to their motivations in attending, and assessment of the performance of the field day (shown in the Appendix).

The major motivations were interest in green crops, biofumigant crops, soil biology and reduction of input costs. The majority of attendees were farmers and industry advisors and overall the group was very satisfied with the field day performance. A survey was undertaken of participants with the results presented in Figures 4–6.

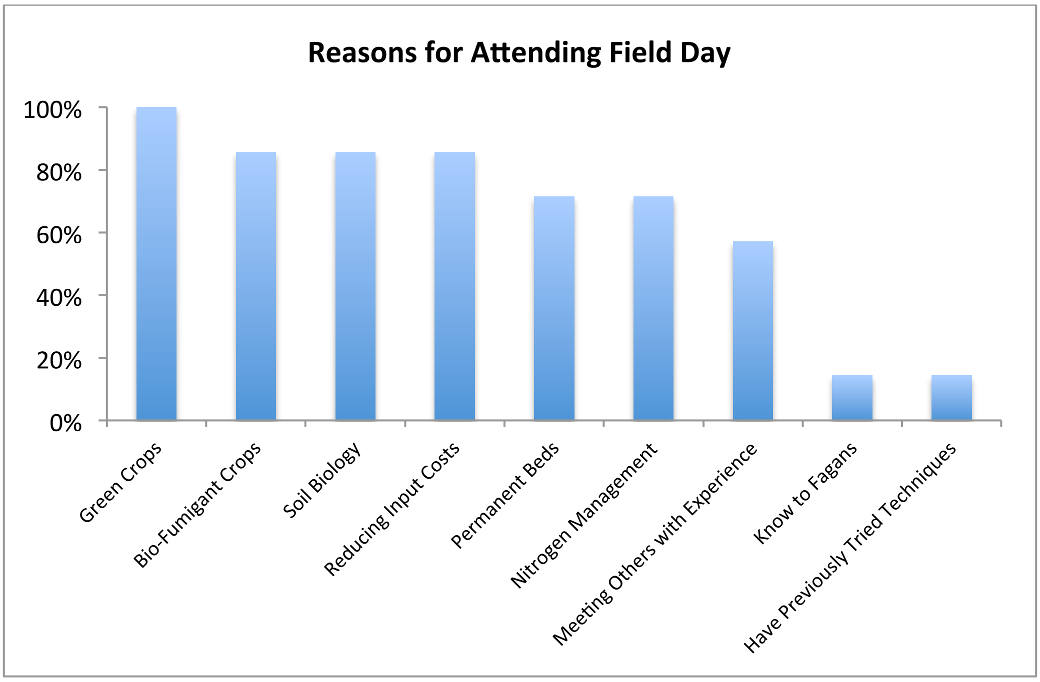


**Figure 3: Survey results of participant's motivations for attending the field day.**

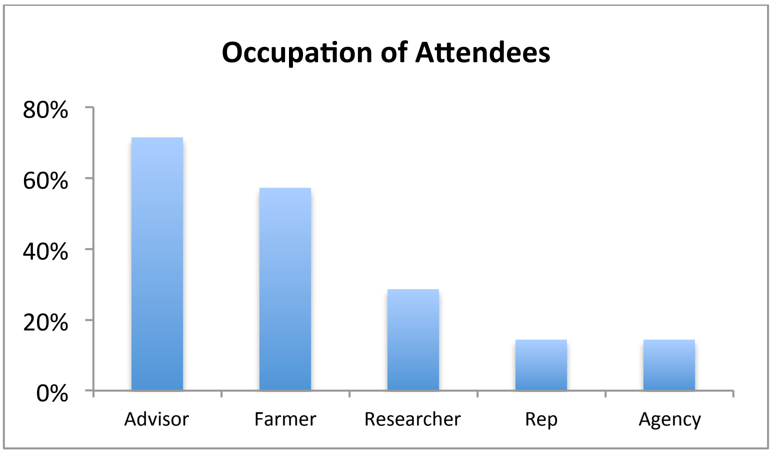


**Figure 4: Survey results of participant's occupations. More than one answer was permitted.**

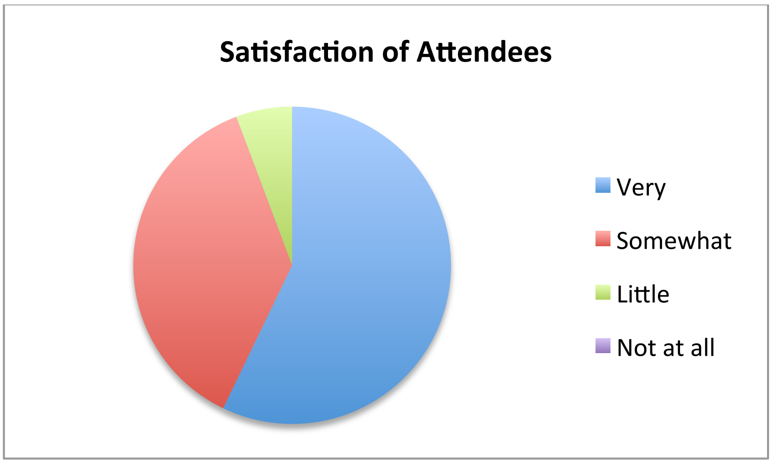


**Figure 5: Survey results of overall participant satisfaction of the field day.**

## Integrating sustainable soil health practices into a commercial vegetable farming operation (VG12115)

## 2016 Field Days Report

## Cowra Field Day

A field day was held at Cowra on the 28th of Aril 2016. A presentation on cover crops, nitrogen management and non-chemical pest protection was given at the DPI Agricultural Research Station before a farm walk at Mulyan Farms demonstrating the cover crop planted in the field. Local Land Services also presented information on new technologies in irrigation. There were at total 17 local growers and advisors in attendance.

There was a keen interest in the different types of cover crops, the properties and benefits of each variety and how to integrate them with cash crop rotations.


Figure 1: Cowra field day workshop.

Figure 2: Cowra field day farm walk

## Bathurst Field Day

A field day was held for the Bathurst site on the 27th of April 2016 at Michael Willot's property, nearby to Michael Camezulli's property, which was unsuitable do to a clubroot infection. The field day was held in conjunction with Central Tablelands Local Land Services, who presented information on irrigation technologies and management, and a workshop was conducted on reduced tillage techniques and cover crops. There was a strong interest in cover crops, 67% of respondents to feedback sheets listed cover crops as the most interesting topic of the field day. There were 15 people in attendance.

Figure 3: Bathurst field day

## Gippsland Field Day

A Gippsland field day was held on the 6th of March 2016 in at Schreurs and Sons property. The field day was hosted in conjunction with AGF Seeds, Southern Farming Systems and The West Gippsland Catchment Management Authority and featuring Steve Groff, the founder of Tillage Radish. The day was focused on cover cropping information and there were approximately 25 people in attendance.


Figure 4: Gippsland field day