Trialling green manure crops for nutrient cycling in intensive organic horticulture

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Introduction

The aim of this project was to understand how the use of a range of different green manure crops could reduce the reliance on purchased inputs and increase nutrient cycling thus improving the soils physical, biological and chemical characteristics on a certified organic horticulture farm.

Figure 1 Green manure trial strips

Figure 2 Green manure crop with control in foreground

Organic horticulture practiced on this farm relies on the development of healthy fertile soils through the use of soil building crops of legumes, green manures, sound rotations and additions of compost and mineral fertilisers where appropriate. One of the major challenges facing organic growers is the limited research and extension available to support their enterprises and this approach to production horticulture, particularly in Australia.

In any intensive horticulture enterprise, over-cultivation and the compaction by agricultural machinery can cause a decline in soil quality parameters including; soil structure, organic matter, soil carbon, soil biology and nutrient availability (Cotching 2002).

The demonstration trialed and compared 6 different green manure crops each year for 3 years against a control. The control was immediately adjacent to the other strips and no green manure crops were sown into the control area. The intention was to demonstrate that soil quality characteristics would either be enhanced, or at least maintained, through the use of green manure crops.

The use of green manures is an ancient strategy practiced by the early Greeks, Romans and Chinese cultures. Its definition covers the enrichment of soil by the addition of undecomposed plant material either in situ or brought in to the site. Depending on its maturity it can be used to increase soil organic matter, nutrient availability, biological activity, soil structure, suppress weeds and reduce nutrient loss. (Chatter & Gasser, 1970, Elm Farm Research Centre, 1982).

The trial site of 0.056ha is situated on a farm at Piedmont managed by the owner Liz Clay in partnership with Wally Brown.

Liz has a long history in the organic agricultural industry and is an experienced horticultural producer and sustainable agriculture activist.

The vegetable crops are marketed directly to consumers through farmer's markets. The farm has been certified organic for 26 years and has over this time pioneered organic vegetable farming and marketing.

The farm is on a North-facing slope on a gradational Ferrosol soil derived from Tertiary basalts (20-40my).

Ferrosol soils are generally strongly acidic, high in iron oxides with an ability to tie-up phosphorus. Although they are free draining, when wet they can be compacted due to their higher clay content. Soil assessment of the trial site indicated a deep (>300mm) well-structured red to brown soil with good aggregation, deep root activity and abundant earthworms.

Figure 3 Aggregated soil from trial area

Trial design

The 0.056ha trial site was divided into 7 treatments with each bed measuring 10m in length x 8m wide.

The cultivated area was prepared using an agro plough to loosen soil and then rotary hoed to a depth of 100mm. The green manure seed was then broadcast at a rate of 1.5kg per 80sm strip. The green manure crops were mulched before being incorporated into the soil with a rotary hoe in early to middle October.

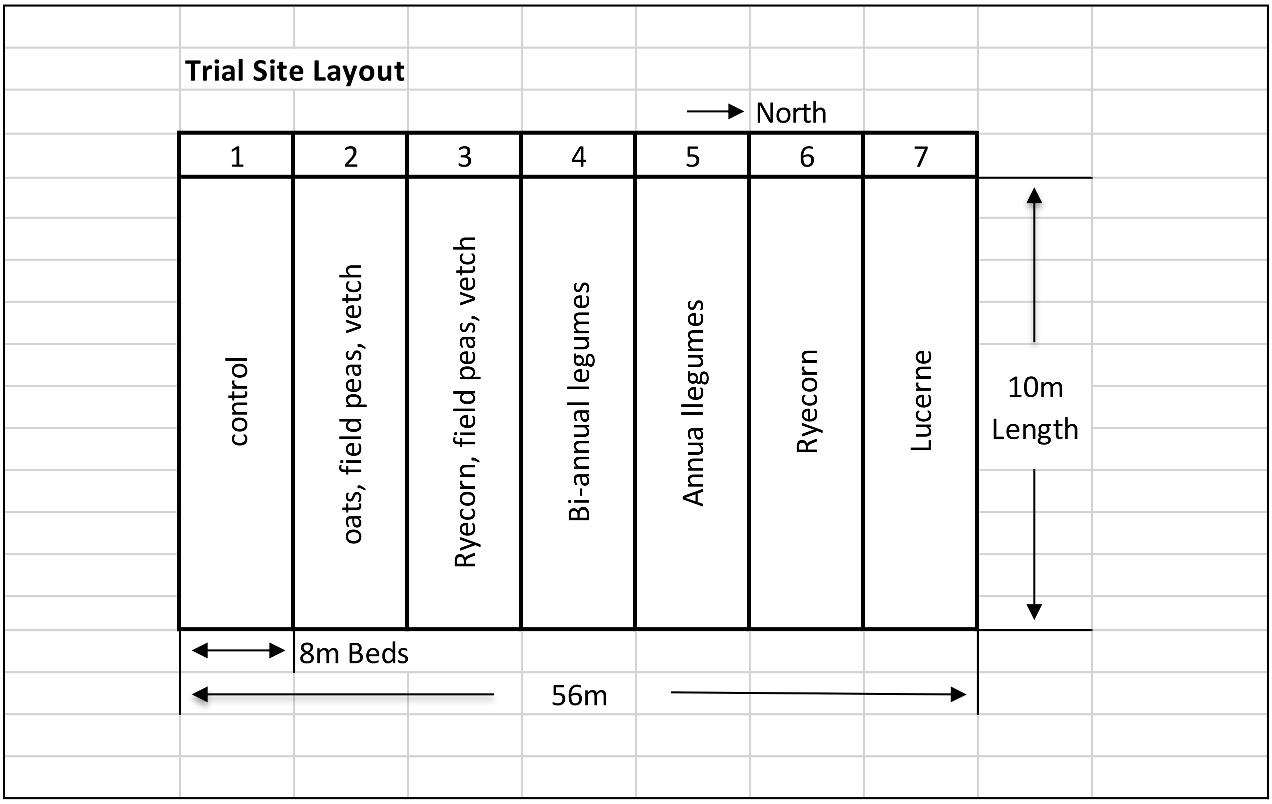


Figure 4 Site Layout

Due to the difficulty of sowing and establishing the lucerne in Bed 7, the lucerne hay was manually spread across the strip after application of the mineral fertiliser. It was spread over the strip at a quantity consistent with a typical green manure crop that is sown and then incorporated into the soil (7500kg/DM/Ha). Given this was material added to the strip, it needs to be recognised as a different treatment to the green manure crops.

Figure 5 Green manure crop being mulched prior to incorporation into soil

Organically certified commercial mineral fertiliser (Terra Firma – Organic Life) was applied annually over all beds at the rate of 700kg/ha. The nutrient analysis of the commercial fertiliser was 3.6% nitrogen, 3.1% phosphorus, and 4.0% potassium. This equates to an annual application rate of 25.2kg/ha nitrogen, 21.7kg/ha phosphorus and 28.0kg/ha potassium.

The lucerne hay had an analysis of 2.23% nitrogen, 0.26% phosphorus, 1.74% potassium and 0.71% calcium.

Testing protocols

Benchmark testing and monitoring criteria was based on an assessment of the soil's physical, biological and chemical characteristics. A full soil analysis was taken at the start of the trial as a benchmark and at the end of the demonstration. Monthly analysis of nitrogen, phosphorus and potassium was undertaken to understand how these nutrients might be mobilised during the seasons under the various green manure crops. As the cycling of nutrients is critical in organic farm management, both temperature and moisture readings were measured on a monthly basis as these are key drivers of soil biological responses.

Figure 6 Flowering field peas

Labile carbon was analysed on an annual basis. Labile carbon is the readily decomposable fraction of organic matter and is a better indicator of soil quality status than organic matter, as it responds more quickly (either negatively or positively), to management practices (Bending et al, 2000).

In any form of agriculture when soil is cultivated, organic matter can be oxidised, and if soil-building practices such as the use of legumes, green manure crops or compost are not used in the rotation, labile carbon can be reduced. In an organic farming system where the sustainability and enhancement of soil fertility is seen as essential, this monitoring provided the data necessary to help understand this critical soil aspect.

The Solvita soil test is a technology and method that allows the soil CO2 respiration of microorganisms to be measured in the field. As biological activity increases and organic matter cycles, CO2 is released. The rate of release is regarded as an indicator of soil health.

As an additional semi-qualitative measure of microbial activity, 50mm square pieces of filter paper were placed in a nylon mesh bag and buried at a depth of 100mm and removed 3 months later and the decomposition measured and photographed. This also provides an indication of the level of biological activity between the treatments.

Analysis of results

Physical observations

The benchmark soil assessment indicated a soil with a high level of fertility based on its physical characteristics of excellent structure, good water infiltration and extensive worm activity (Doran and Parkin, 1994). The pleasant smell indicated aerobic conditions and a habitat suitable for microorganisms. Extensive nodulation was observed on the roots of the green manure legumes. Initially on dissection young nodules are white or grey but as the legume matures they demonstrate a pink to red colour indicating active rhizobia bacteria. The red colour is caused by leghemoglobin that controls oxygen to the bacteria in the nodule.

Figure 7 Nodules on the roots of a legume

At the conclusion of the trial the physical soil characteristics (structure and water infiltration) had not changed.

Moisture readings were taken each month to a depth of 150mm with a digital moisture meter. Over the life of the project, and across the seasons, the moisture in the strips varied considerably, however the green manure and lucerne strips consistently contained more moisture (lucerne indicated 38% increase compared with the control strip in 2017/8).

This increase in moisture would result in less stress for plant roots, less need for irrigation, and an environment more conducive to microbial activity. The table below illustrates the trends observed.

Figure 8 Moisture meter

Figure 9 Moisture comparisons between treatments at specific points of time

Average Moisture over 4 months period	Nov-March 2015/16	Nov-March 2016/17	Nov-March 2017/18
Control	11.8	12.5	10.7
Ave of the 5 Green manure crops*	13.8	12.8	13.0
Lucerne	16.7	11.8	15.0

***Note:** Average of the 5 Green Manure crops did not include the Lucerne treatment

Soil temperature

There was no discernible difference in soil temperature between any of the treatments over the life of the project.

Soil analyses

The table below presents the results of the control and green manure strips.

Figure 10 Soil Analysis								
Nutrient mg/kg	1 Control 2015	1 Control 2018	2 Oats, Peas, Vetch 2018	3 Ryecorn, Peas, Vetch 2018	4 Legumes Bi-annual 2018	5 Legumes Annual 2018	6 Ryecorn 2018	7 Lucerne 2018
pH (1:5) water)	5.92	6.1	6.12	6.09	6.08	5.6	5.8	5.78
Available Ca mg/kg	1026	991	1030	1028	1128	848	932	927
Morgan K mg/kg	213	352	319	335	342	188	208	420
Olsen P mg/kg	30	25	29	31	30	23	21	21
Colwell P mg/kg	75	100	113	103	104	77	80	80
Total Nitrogen %	0.37	0.28	0.31	0.36	0.37	0.39	0.39	0.41
Organic matter %	9.3	7.4	8.3	8.6	9.2	9.7	9.9	10.2
Total Carbon %	5.32	4.24	4.73	4.92	5.24	5.56	5.66	5.83
Labile carbon %	Nov-15	0.80	0.84	0.90	0.91	0.83	0.95	0.97
	Jun-17	1.06	1.03	1.14	1.37	0.94	1.04	1.23
	Nov-17	0.61	0.92	1.02	0.93	1.03	1.07	1.04
	May-18	0.92	0.86	0.99	0.96	0.62	1	0.92
Effective Cation Exchange Capacity (ECEC) cmol +/kg	14.04	13.59	13.58	13.85	14.63	11.42	12.37	13.15
CEC Calcium %	70.3	69.7	72.00%	72.4	71.7	71.8.0%	72.9	67%
CEC Magnesium %	16.2	16.1	18.00%	14.4	15.6	15.80%	15.7	15.50%
CEC Potassium %	9.1	12.7	5.30%	12	12	8.80%	8.8	15.40%
CEC Sodium %	1.1	0.9	0.7	0.5	0.6	1.2	0.6	0.7

Soil analyses summary points – Green manure strips and Control 2018

- Organic matter decreased between the 2015 and 2018 controls demonstrating that without the addition of green manure crops, soil organic matter declines substantially.
- Organic matter increased across all strips relative to the 2018 control.
- Total carbon increased across all strips except the control, which decreased from 2015 to 2018
- Total nitrogen increased across all strips compared with the control (2018).
- The measured difference in Phosphorus (both Olsen & Colwell) was attributed to the historic location of an old dairy closest to strip 1 (control) which would explain the decrease in P measured across the site.
- Although there was some variation in labile carbon over the course of the trial almost all strips indicated an increase or remained constant.

- An increase in the available potassium in the lucerne strip can be attributed to up to 3.2% potassium contained in the material incorporated. This is due to the lucerne being an input and not grown in situ.

Soil analysis: comparing the control strip 2015 with the control strip 2018

The results in this comparison are extremely informative. The control strip from 2015 over the course of the trial was managed the same as all the green manure strips, but without the sowing of a green manure crop. The same quantity of 'Terra Firma - organic life' fertiliser was applied on all beds.

The results demonstrate clearly that there has been a decline in total nitrogen, organic matter and carbon in the control bed, indicating that soil quality has decreased over this period.

Monthly soil analysis

The monthly monitoring of nitrogen, phosphorus and potassium provided particularly interesting results. The concept behind the monthly monitoring was to understand and demonstrate how the nutrients N, P and K might be released due to biological activity (nutrient cycling) during seasonal conditions of temperature, moisture and soil oxygen, indicating an environment suitable for these aerobic microorganisms.

Prior to the planting of vegetables each season, the commercial mineral fertiliser was applied to all beds. This should be considered when interpreting the results.

Nitrate N

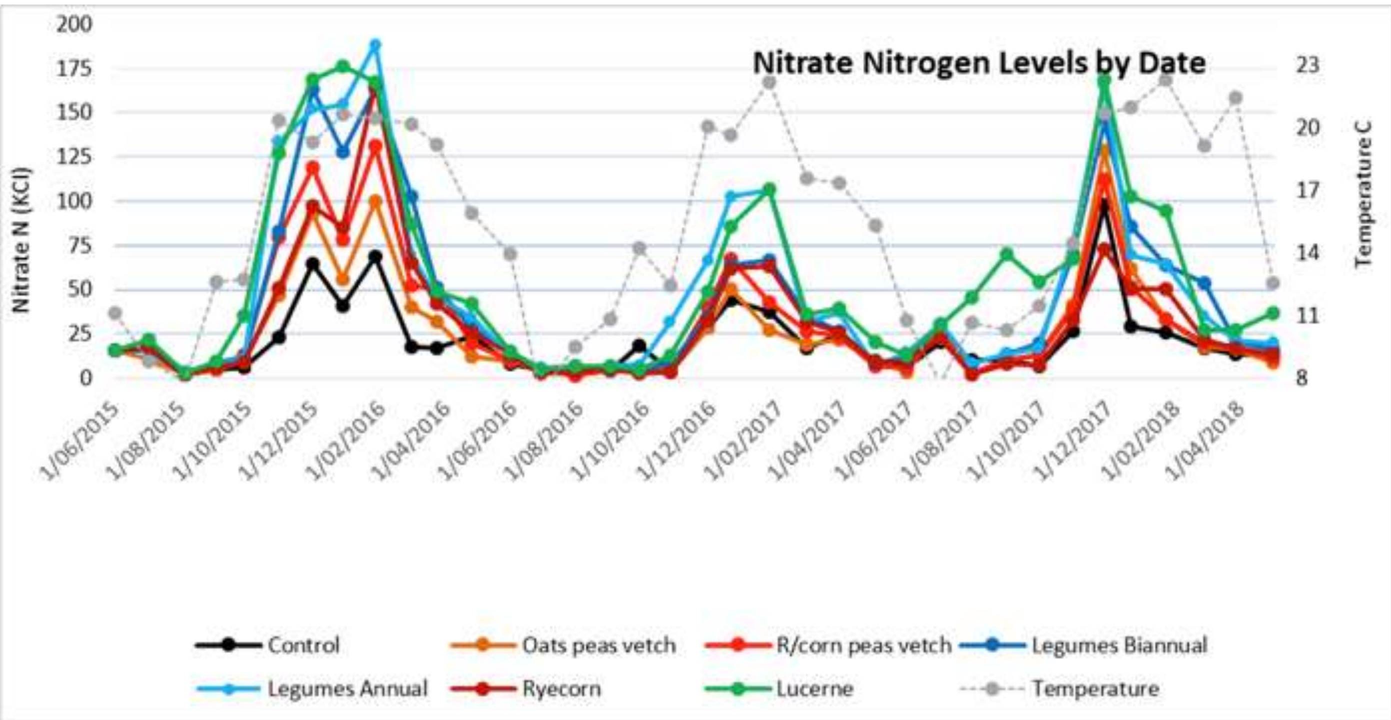


Figure 11 Nitrate nitrogen levels over the course of the trial period

Results for nitrate nitrogen correlated well with soil temperature (seasonal conditions) and moisture. The highest levels of nitrate nitrogen (Table above) were seen in the lucerne strip followed by the annual legumes and the bi-annual legumes. The movement of nitrate nitrogen is a clear illustration of the operation of the nitrogen cycle which is optimised when temperature, moisture and oxygen, together with an organic food source, is available to soil microbial life.

The increased soil nitrate nitrogen levels in the green manure strip over the most productive part of the season (November-March) has demonstrated that there is potential to reduce the applications of nitrogen containing organic fertiliser under some vegetable crops, as the levels required are adequately supplied by the addition of the green manure crops.

Figure 12 Nitrate Nitrogen levels (mg/kg) from Nov – Mar over 3 vegetable growing seasons

Nitrate Nitrogen mg/kg	Nov/March 2015/16	Nov/March 2016/17	Nov/March 2017/18
Average Control	41.9	30	37
*Average of the 5 Green manure crops	97.1	45	57
Average Lucerne	129.7	64	84

***Note:** Average of the 5 Green Manure crops did not include the Lucerne treatment

Ammonium N

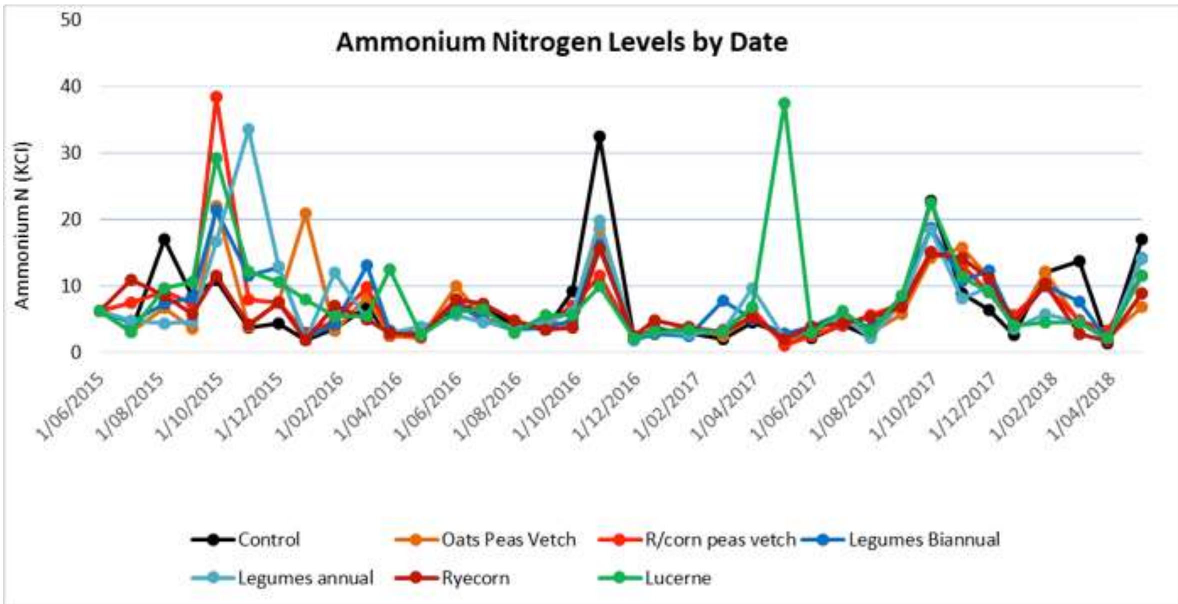


Figure 13 Ammonium nitrogen levels over the course of the trial period

Ammonium nitrogen is an indication of the progress in the nutrient cycling process. Organic matter is initially consumed by microorganisms and is converted to ammonium nitrogen and, with further microbial action, is converted to nitrate nitrogen. The graph shows the movement of ammonium nitrogen through the year according to inputs and seasonal variability.

Phosphorus

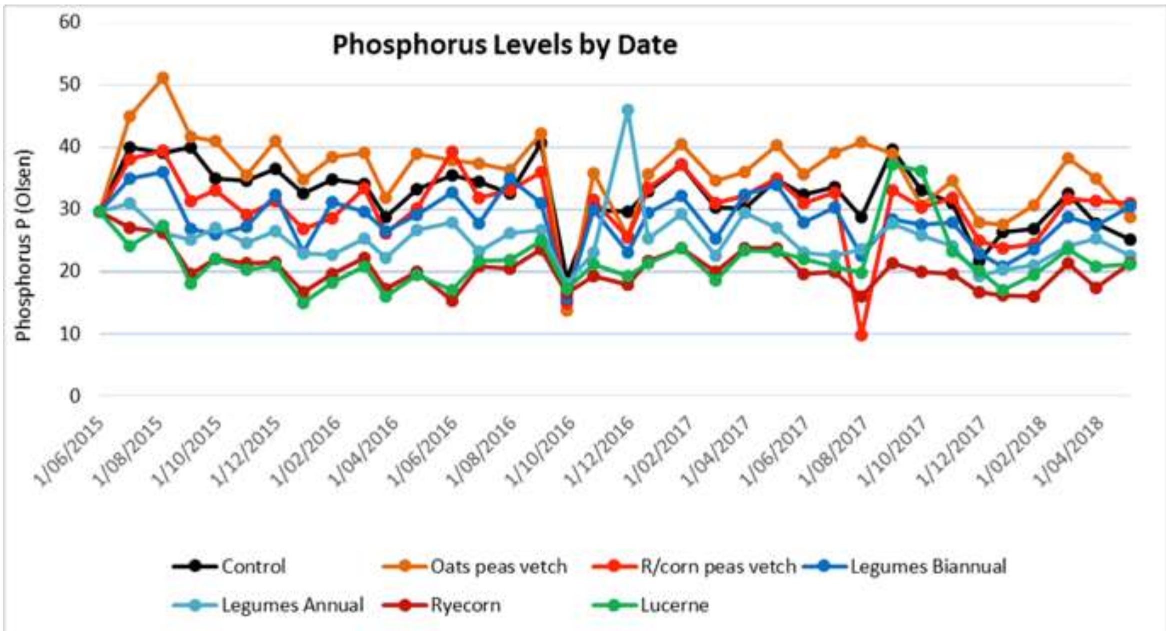


Figure 14 Phosphorus levels over the course of the trial period

The graph illustrating phosphorus levels over the trial period indicates very little variation over the course of the trial. There is a slight increase after the input of the organic based fertiliser and incorporation of the green manures. Phosphorus adheres strongly to soil particles so other than its removal through crop production, it remains more stable.

Potassium

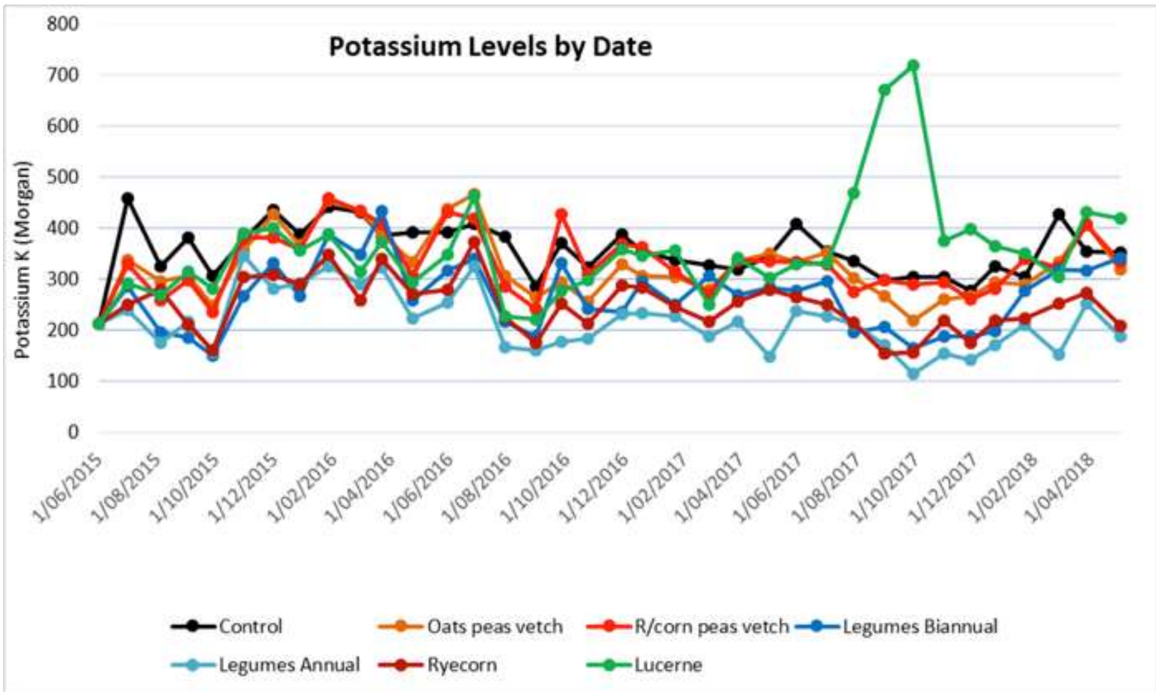


Figure 15 Potassium levels over the course of the trial period

After incorporation of the green manures, and with the increase in soil temperature, all trial strips indicated an increase in potassium. This is a reflection of both potassium contained in the green manures and a release from soil mineral particles due to the action of organic acids released by soil microorganisms. (Masood & Bano, 2016, Boyle & Voigt, 1973).

Soil biology - a snapshot

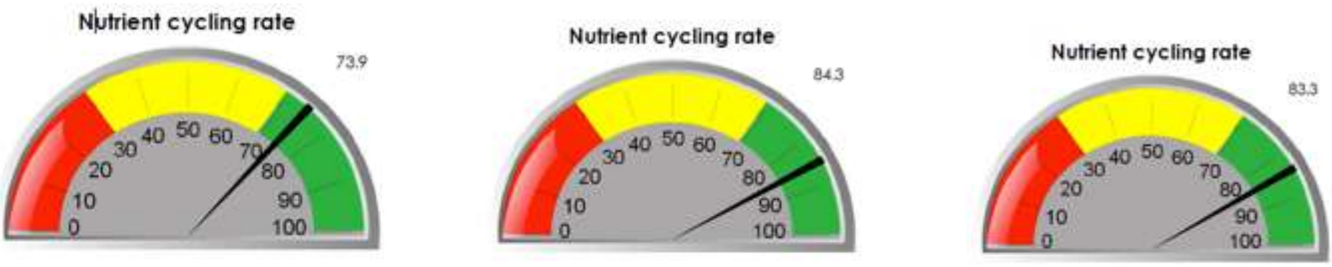
Soil samples from all strips were sampled in early May 2018 and submitted to Microbiology Laboratories Australia for profiling. Results for three of the strips are illustrated below.

Table 16 Soil biology under different treatments (May 2018)

	Moisture	Temperature	Nitrate nitrogen	Microbiology balance	Nutrient cycling
Strip 1 Control	8.7	12.6	13	70.7	73.9
Strip 4 Bi-annual legumes	7.5	12.5	16	79.3	84.3
Strip 7 Lucerne	9.2	12.5	37	77.9	83.3

Moisture and temperature data are tabulated as they play a critical role in optimising microbial populations. Although soil moisture is sufficient, soil temperatures in May are below optimum (25-30 degrees) and hence nutrient cycling resulting in nitrate nitrogen are lower than in the warmer months when the soil temperature is higher. It is clear however that the lucerne (Strip 7) is still releasing its nitrogen. The control strip which did not have a green manure input has a lower microbiology balance, nutrient cycling and as a consequence lower nitrate nitrogen.

The laboratories use indicator diagrams to visually illustrate results and these are seen below.



Strip 1 Control **Strip 4 Bi-annual legumes** **Strip 7 lucerne**

Figure 17 Soil biology indicator diagrams indicating nutrient cycling rate

Solvita soil health test (CO_2 respiration)

During the trial Solvita tests were taken to gauge biological activity. The photo below indicates the soil health based on the activity of the soil microorganisms on a scale from 1-5. The test (photo on the left) taken in September 2017 when soil temperatures were low (11 degrees) understandably indicated only moderate biological activity. The photo on the right taken in December (21 degrees) from soil in the lucerne strip indicates a moderate to high biological activity. Soil biological activity is optimised between 25-30 degrees (Pietikainen, J., 2005).

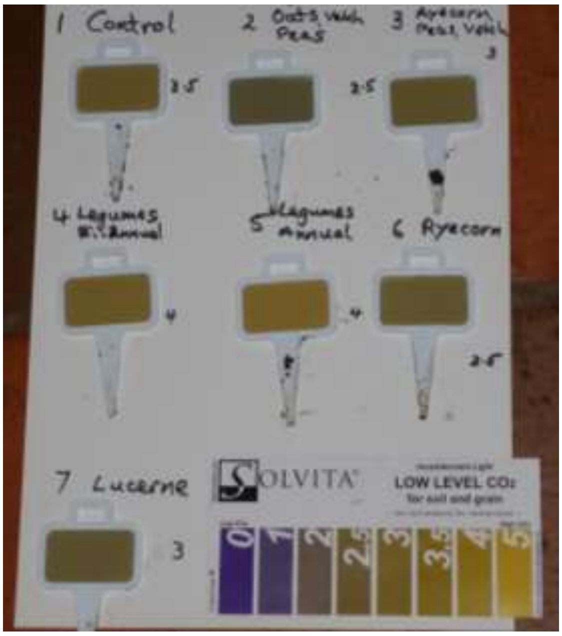


Figure 18 Solvita Tests September 2017

Figure 19 Solvita Tests December 2017

Paper decomposition soil tests

Soil scientists often use cotton fabric (100% cellulose) buried in the soil to assess microbial activity based on the decomposition of the fabric (Latter & Walton 1988). In this trial 50mm square pieces of filter paper were placed in an onion bag and buried to a depth of 100mm in the soil. The bags were uncovered after 3 months, examined and photographed. The photo below illustrates the state of decomposition of the papers under the different green manure soils. The lucerne strip illustrated the most extensive state of decomposition indicating a higher level of biological activity than adjacent beds.

Figure 20 Onion bag with paper ready for burial

Figure 21 Decomposition of cellulose paper under the green manure strips. A 20c coin provides a reference for scale

Vegetable yield and quality

The quality of produce across all beds, including the control, was generally of high quality. Variations in crops were observed with the highest production in the lucerne strip with a similar rise in quality.

Figure 21 Healthy zucchinis

Figure 22 Wally with a wheelbarrow full of cabbages

Producers observations

"Crops varied in terms of their production and quality across the different strips with tomatoes producing more heavily in the ryecorn and lucerne strips.

Beans were less productive and appeared less healthy following legume crops

Zucchinis were more prolific in the legume crops but appeared to fruit less.

Eggplants were a lot bigger and more productive in the lucerne than in the Ryecorn strip.

Capsicums looked healthier, had deeper green and glossier leaves in the legume strips.

Zucchinis had less powdery mildew in the lucerne and the oats and legume strips while the control had extensive powdery mildew problems.

Producer has noted that the legume green manure crops nitrate nitrogen levels were available soon after incorporation into the soil. Whereas, the Ryecorn nitrate nitrogen levels were more delayed in their availability. This is important from a producer perspective for planning crop rotations and planting times".

Financial analysis

It has been indicated that the increase in soil nitrogen and mobilisation as nitrate nitrogen is sufficient for a season's production from the cropped area.
As plant requirements for nitrogen are easily being met, there may only be the need to apply strategic minor and trace elements to ensure optimum production.

Figure 23 Annual Costs & Returns			
	Control Strip $/ha (annual cost)	5x Green Manure Strips $/ha (annual cost)	Lucerne Strip $/ha (annual cost)
Commercial Fertiliser 700kg/ha @ $800t	$560	$560	$560
Green Manure seed 150kg/ha @ $2200t		$330	
Lucerne hay spread $150bale = $300t x7.5t/ha			$2250
TOTAL	**$560**	**$890**	**$2810**

Figure 23 Financial summary

The use of green manure crops has increased both the total nitrogen and available nitrogen in this trial to levels where there may not be any advantage in the supply of nitrogen as an organic input (Terra Firma – Organic life fertiliser). Regular soil analyses would indicate whether deficiencies in other major elements need addressing in the future.

Summary

The benchmark soil assessment, including the physical, biological and chemical parameters indicated that the soil was of a high quality. Chemical analysis indicated a moderately acid soil with good levels of total nitrogen, phosphorus, potassium, organic matter and organic carbon.

It has been well documented that over-cultivation of the soil can lead to a decrease in organic matter and organic carbon and a related decline in biological activity. The cultivation and preparation of vegetable beds in horticulture is difficult to avoid. Organic agriculture through well designed rotations, including soil-building crops such as legumes, compost and green manures, attempts to avoid the decrease in soil quality. In organic agriculture in Australia, there hasn't been extensive research establishing the benefits of green manure crops and its effects on key soil parameters.

The objective of the trial, to investigate whether a range of green manures would enhance soil fertility, provided an opportunity to assess whether strategic green manure cropping could enhance or at least maintain the soil quality required for an intensive horticultural operation.

The trial, utilising a range of green manure crops, successfully demonstrated an increase in soil total nitrogen, organic matter and either enhancement or maintenance of labile carbon. The most successful green manure mixes in building soil nitrogen levels were lucerne, annual legumes and bi-annual legumes.

The green manure crops that built the highest soil organic matter levels, in order, were ryecorn, annual legumes and bi-annual legumes.

Adding Lucerne resulted in an even higher soil organic, soil carbon and total nitrogen level. Although the Lucerne was applied as an input (rather than grown in situ) in this demonstration, it still is regarded technically as a green manure.

The increase in soil organic matter was reflected in the maintenance of the soil physical characteristics that were noted in the initial trial benchmarking. This visual assessment, in conjunction with the increase in the chemistry of organic carbon, demonstrated soil quality had improved as a result of utilising green manure crops as a management strategy.

The soil analysis of the 2018 control compared with the initial 2015 control indicated a decline in organic matter, total nitrogen and total carbon. This indicates that the cultivation and cropping of the control without the addition of organic matter provided by a green manure crop has led to deterioration in some of the major soil quality characteristics.

The green manure crops increased the soil organic matter and stimulated the cycling of organic matter resulting in consistently high nitrate nitrogen levels. Levels achieved were well above desirable levels required for a single vegetable crop in a rotation.

Although not new to science, the demonstration of the importance of temperature moisture and oxygen in nutrient cycling and the operation of the nitrogen cycle cannot be underestimated.

The use of a green manure crop as part of the rotation in a vegetable production system is seen as a cost effective strategy, which minimises the use of outside inputs.

Key learnings from demonstration

- Cultivation and cropping in the control strip over the trial period without the additions of organic matter supplied by a green manure crop led to a decrease in organic matter, total nitrogen and total carbon.
- The green manure crops increased total soil nitrogen, organic matter and total carbon relative to the 2018 control.
- The green manure crops have maintained existing soil nutrient and organic matter levels demonstrating the importance of growing green manure crops as part of a continual horticultural cropping program.
- The green manures that built the highest soil organic matter levels were ryecorn, annual legumes and bi-annual legumes. Lucerne was even more effective in increasing soil organic matter when applied and incorporated.
- The monitoring of labile carbon is an effective measuring tool to indicate either positive or negative responses to soil management.
- The lucerne and annual legume green manures were responsible for the highest nitrate nitrogen levels across the trial period.

- Levels of nitrogen across all strips were sufficient to support the crops grown during the season.
- Seed bed preparation and incorporation of the green manure material did not decrease soil organic matter or organic carbon levels in the soil.
- Monthly monitoring of nitrogen, and potassium indicated a strong correlation between nutrient levels, soil temperature, moisture, oxygen and a microbial food source.
- There is potential to reduce or eliminate Nitrogen fertiliser inputs under a green manure cropping regime (depending on the crop grown).

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