Trialling compost and green manure crops on an organic vegetable farm

Cockatoo 2017

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Comparing the use of compost and green manure crop on an organic vegetable farm at Cockatoo, Victoria

Introduction

The aim of this three-year sustainable agriculture project was to understand how compost and/or green manure crops, as a source of organic matter could improve the physical structure and hence the fertility of a raised bed vegetable cropping system on a certified organic farm.


Andrew Morris (r) with consultant Chris Alenson

The trial site is situated on a 25ha certified organic horticulture farm at Cockatoo. The farm is on a west facing slope that has previously been subjected to considerable erosional forces with substantial soil being eroded and deposited across the trial site. The grey silty loam duplex soils are derived from Silurian/Devonian sediments and have poor structure with minimal A horizon development. Approximately 10 hectares of the farm are rotationally cropped with a wide range of vegetables on an annual basis.

The trial site, due to extensive soil movement and position in the landscape has resulted in an area that has low fertility and low production levels.

Organic horticulture practiced on this farm relies on the development of healthy fertile soils through the use of soil building activities, such as using legume crops, green manures, sound rotations, additions of compost and mineral fertilisers where appropriate (Knight, 2008).

Soil assessment of the trial site indicated that soil compaction appeared to be a major constraint to production. It was assessed that the soil required the additions of organic matter through either compost and/or green manure crops, leading to improved structure and allowing crop roots to access increased moisture, oxygen and nutrients (Termorshuizen, A.J. et al, 2004).

Trial Design

The 0.1-hectare trial site was divided into 4 treatments (with 4 replications per treatment). Each replication was a 100m long x 1.5m wide trial bed. There were 16 beds in total.

The cultivated area was prepared using a chisel plough to loosen soil to a depth of 400mm and then a rotary hoe and bed-former was used to establish the 1.5m wide beds (the bed former reduced the beds to 1m width.


Forming the beds

The A horizon depth in the uncultivated soil was 150-200mm and was defined as a grey silty loam. This was incorporated into the silty loam B-horizon. Observation of the vegetable beds indicate that the cropping beds were comprised of both A and B horizons.

The beds were established as set out below:

A. Mineral fertiliser (700kg/ha) + 5t/ha compost (both products applied Oct/Nov each year)

B. Mineral fertiliser (700kg/ha) + Green manure crop (both products applied Oct/Nov each year)

C. Mineral fertiliser (700kg/ha) + 5t/ha Compost + 10t/ha rock dust (compost & mineral fertiliser applied Oct/Nov each year & 1 initial application of rock dust)

D. Mineral f fertiliser (700kg/ha) + Control (no additional amendments) (product applied Oct/Nov each year)

(The certified organic mineral fertiliser was applied over all plots and the application was based on the initial benchmark soil analysis. The mineral fertiliser had an analysis of N 2.2%, P 4.95%, and K 5.46%. It was applied at the rate of 700kg/ha. This equates to an annual application rate of; N 15.4kg/ha, P 34.65kg/ha, K 38.2kg/ha)

Layout of the trial site

	Trial Site Layout																
									→North								
Treatments	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	
	5t/ha compost (annually)	Green manure crop (annually)	5t/ha Compost + 10t/ha rock dust (compost annually & initial application of rock dust)	Control (no additional amendments)	5t/ha compost (annually)	Green manure crop (annually)	5t/ha Compost + 10t/ha rock dust (compost annually & initial application of rock dust)	Control (no additional amendments)	5t/ha compost (annually)	Green manure crop (annually)	5t/ha Compost + 10t/ha rock dust (compost annually & initial application of rock dust)	Control (no additional amendments)	5t/ha compost (annually)	Green manure crop (annually)	5t/ha Compost + 10t/ha rock dust (compost annually & initial application of rock dust)	Control (no additional amendments)	**100m Length**
1.5m centres with 1m beds			Mineral fertiliser (700kg/ha) was also applied to all beds on an annual basis														

Treatment A - Mineral fertiliser + 5t/ha compost (annually)

The commercial mineral fertiliser was applied annually at the rate of 700kg/ha along with annual applications of compost at the rate of 5t/ha.

Treatment B - Mineral fertiliser + Green manure crop (annually) - Due to very wet conditions the sowing of a green manure crop by machinery could not be undertaken so organic Lucerne hay was spread annually across the appropriate trial beds after application of the mineral fertiliser. This was then incorporated into the soil. The organic Lucerne hay was spread at a quantity consistent with a sown green manure crop that is grown and then incorporated into the soil. (7500kg/DM/Ha). The commercial mineral fertiliser was applied annually at the rate of 700kg/ha.

Treatment C - Mineral fertiliser + 5t/ha Compost + 10t/ha rock dust (compost annually & initial application of rock dust) - The intention behind the treatments utilising compost + rock dust was to investigate the use of a rock dust (RIRDC, 2001, Van Straaten, 2006) as a source of additional elements allowable under National Organic Standards (2016). Applied with compost, which potentially provided the opportunity for Humic acids in the compost to assist in mobilising otherwise tightly bound elements in the rock dust. The commercial mineral fertiliser was applied annually at the rate of 700kg/ha

Treatment D - Mineral fertiliser + Control

The 4 replicated control beds had annual applications of 700kg/ha of the mineral fertiliser, which was the same as

the other treatments. No other amendments were added.

The Lucerne was spread manually on the correct beds and then incorporated into the soil with a rotary hoe.

Comment on the analysis of the compost used

Compost from a commercial composter is one of the allowable inputs (after confirmation of an acceptable analysis by the certification agency), that can be utilised in organic agriculture. The compost analysis from the three (annual) deliveries varied significantly which is not uncommon as ingredients can change from batch to batch and the composting process itself can vary according to production conditions at the time.

The Carbon to Nitrogen (C:N) ratio is one of the important indicators of the quality of a compost. A mature compost should have a C:N ratio of less than 15:1. As the C:N ratio becomes wider the availability of N reduces significantly. Analysis of key nutrients in the 3 annual deliveries is tabulated below and the variation is evident. The first delivery of compost had an analysis of 0.62% N which equates to 6.2kg of N per tonne, but with a C:N ratio of 36:1 research has indicated that no N will be released from the compost in the first year and it is likely that N will be drawn from the soil in an effort to stabilise the high carbon levels (Prasad, 2009).

Compost analysis

	2014	2015	2016
Nitrogen	0.62%	1.11%	0.84%
Phosphorus	0.15%	0.60%	0.27%
Potassium	0.33%	0.59%	0.65%
Sulphur	0.15%	0.10%	0.15%
Carbon	22.40%	26.10%	23.70%
Calcium	0.90%	2.03%	1.30%
Magnesium	0.22%	0.47%	0.33%
Sodium	0.08%	0.10%	0.15%
pH	7.5	7.3	6.1
Carbon: Nitrogen ratio (desirable 14:1)	36:1	24:1	28:1

Compost was spread manually to ensure accuracy of placement and rate. It was then incorporated with the bed former.

Rock dust

Basalt rock dust was obtained from the Jindivick quarry, which is a basaltic dust from Tertiary volcanics (20-40million years in age). Basalt being a basic igneous rock contains in its mineral assemblage a wide range of elements that offer potential for remineralising the soil (Chesworth, 1983). The finer the particle size the more surface area that can be exposed to biological activity and soil acids that might mobilise nutrients from the material. Sizing of the dust indicated that more than 45% was less than 250 microns and suitable for the intended trial. A number of the trace elements listed in the table below have now demonstrated their essentiality to healthy plant physiology and development (Pendias, 1984). Some of the major silicates analysed are listed in the table below:

Silicate analysis of the basaltic rock dust

Na_2O	MgO	Al_2O_3	SiO_2	K_2O	P_2O_5	CaO	TiO_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	SO_3	CO_3O_4
2.78%	4.79%	13.66%	51.71%	1.45%	0.37%	7.76%	1.99%	0.02%	0.04%	0.17%	11.94%	0.04%	0.06%

Testing Protocols

Benchmark testing and monitoring criteria was based on 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 further full soil analysis were undertaken on an annual basis. Monthly analysis of Nitrogen, Phosphorus and Potassium was undertaken to understand how these nutrients might be mobilised during the seasons due to the various treatment protocols. As the cycling of nutrients is critical in organic farm management, both temperature and moisture readings were reported on a monthly basis as these are key drivers of soil biology responses which drives nutrient availability.

In year two labile carbon was analysed as part of the annual full soil analysis. 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 easily 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 (the soluble fraction) in the organic matter can be reduced.

Analysis of Results

Physical observations

The Benchmark soil assessment indicated poor soil physical characteristics with most prominent soil constraints being identified as a lack of soil structure with poor water infiltration and minimal worm activity. Vegetable root depth was limited and the reduced pore space indicated possible anaerobic conditions not conducive to microorganisms responsible for nutrient cycling (Pengthamkeerati et al, 2011).

At the conclusion of the trial there was an improvement in soil granulation, water infiltration and root growth in the green manure treatment and slight improvement in the compost treatment and compost + rock dust treatment.

Soil Moisture Retention

Each month moisture readings were taken to a depth of 150mm with a digital moisture meter, and over the life of the project, the soils in the green manure treatment held more moisture than the other 3 treatments. However, this was not consistent over every season. The winter months showed no difference in soil moisture between the treatments. The green manure crop treatment showed an increase in soil moisture of 34%, in summer an increase of 48%, and in autumn an increase of 44%. This increased moisture was a key factor in providing an environment that is suitable for microorganisms involved in N cycling. This was illustrated by higher levels of Nitrate N in the green manure treatments throughout the season.

Soil Temperature

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

Soil moisture meter

Soil Test Key Points

Nutrient	Benchmark 03/06/2014	Compost 05/06/2017	Green manure 05/06/2017	Compost/Rock dust 05/06/2017	Control 05/06/2017
pH (1:5 water)	6.1	5.67	5.93	6.2	5.85
Olsen P mg/kg	26	31	38	31	20
Colwell P mg/kg	60	74	86	54	68
Morgan K ng/kg	29	76	87	52	43
Total Nitrogen %	0.23	0.25	0.24	0.24	0.24
Organic matter %OM	5.1	5.8	5.6	5.7	5.4
Total Carbon %	2.93	3.34	3.22	3.26	3.11
Labile carbon %		0.69 (Nov15)	0.56 (Nov15)	0.68 (Nov15)	0.65 (Nov15)
		0.65 (Aprl16)	0.63 (Aprl16)	0.66 (Aprl16)	0.63 (Aprl16)
		0.69 (May17)	0.39 (May17)	0.36 (May17)	0.47 (May17)
Effective Cation Exchange Capacity (ECEC) cmol+/Kg	6.87	7.17	6.61	7.4	6.33
Ca/Mg ratio	5.7	3.7	4	4.4	4.8
CEC Calcium %	80.6	71.2	72.0	76.0	75.7
CEC Magnesium %	14.1	19.2	18.0	17.4	15.6
CEC Potassium %	2.1	4.3	5.3	2.7	2.8
CEC Sodium - ESP %	2.1	2.5	1.7	2.0	3.0
Solvita (1 to 5)	2	2.5	3	2.5	2.5

Soil analysis

The soil pH did not vary significantly between the treatments, and although moderately acid, is not considered sufficient to impact nutrient availability.

Phosphorus Olsen P (available P) levels in the control were 20mg/kg (desirable 20mg/kg) and Colwell P (which measures the potentially available P) was 68mg/kg (desirable 45mg/kg). At the end of the trial an increase in the Olsen P of more than 50% was seen across all treatments compared to the control. Available potassium was 43mg/kg in the Control and 86mg/kg in the green manure bed. Nitrate nitrogen levels monitored on a monthly basis are discussed below. Total nitrogen did not vary between the controls and treatments.

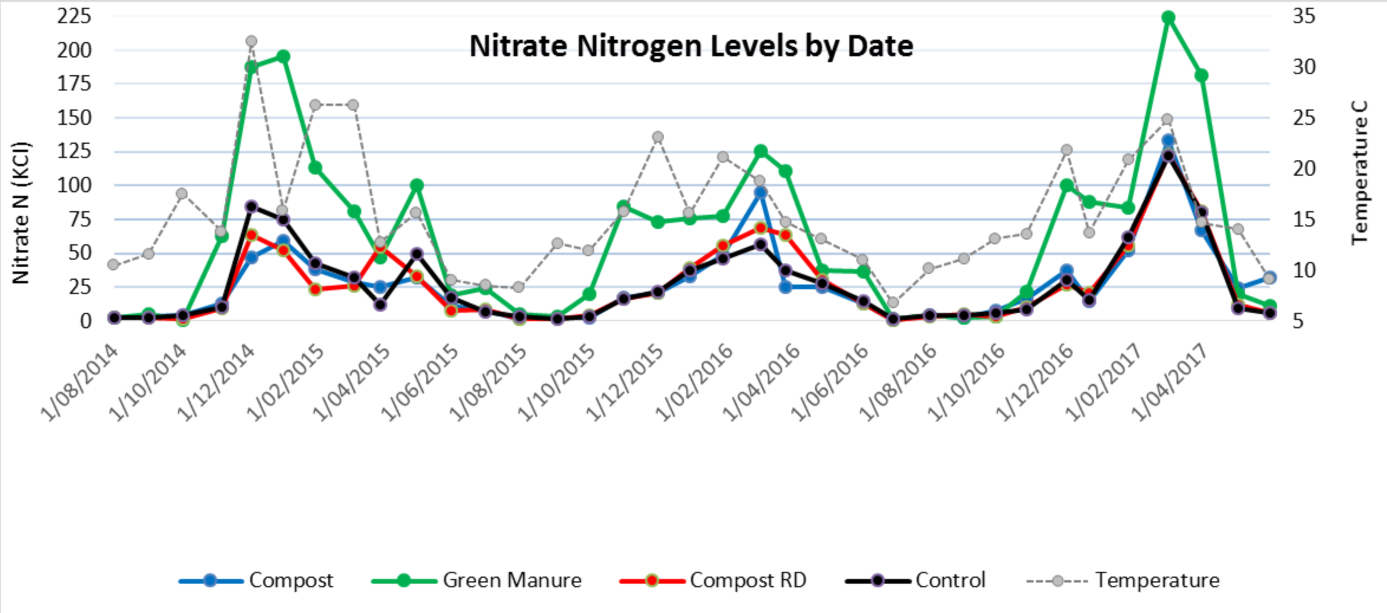
Organic matter increased across all treatments, with the beds where compost was applied registering the highest levels. The compost treatments also registered the highest Effective Cation Exchange Capacity (ECEC) levels.

Labile carbon decreased in the Control treatment over the period of the trial indicating that this easily decomposable fraction of organic matter was cycling but not being replaced. Interestingly in the compost treatment, labile carbon remained constant, indicating labile carbon that may have been oxidised during cultivation and production, had possibly been replaced by the addition of the compost. In the green manure treatment, labile carbon increased from 2015-2016 but decreased markedly at the conclusion of the trial. In both the green manure treatment and the compost+ rock dust treatment, over-cultivation and exposure to the atmosphere over a period of weeks may have impacted organic matter, thereby oxidising and lowering the labile carbon fraction. The labile carbon in the compost treatment did not show the same decline. This is hard to explain but could relate to cultivation practices and timing of cultivation in the specific beds.

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 perhaps demonstrate how the nutrients N, P & K might be released due to biological activity during seasonal changes in 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



Results for nitrate nitrogen correlated well with soil temperature (seasonal conditions) and moisture. The highest levels of nitrate nitrogen were seen in the treatments with the green manure crop (Lucerne). The movement of nitrate nitrogen is a clear illustration of the operation of the nitrogen cycle which is optimised when temperature, moisture and oxygen along with an organic food source is available to soil microbial life.

The increased soil nitrate nitrogen levels in the green manure treatment over the most productive part of the season (October-March) has demonstrated that there would be potential to reduce the applications of nitrogen fertiliser under some vegetable crops, as the levels required were more than adequately supplied by the addition of the green manure crop. This is displayed below.

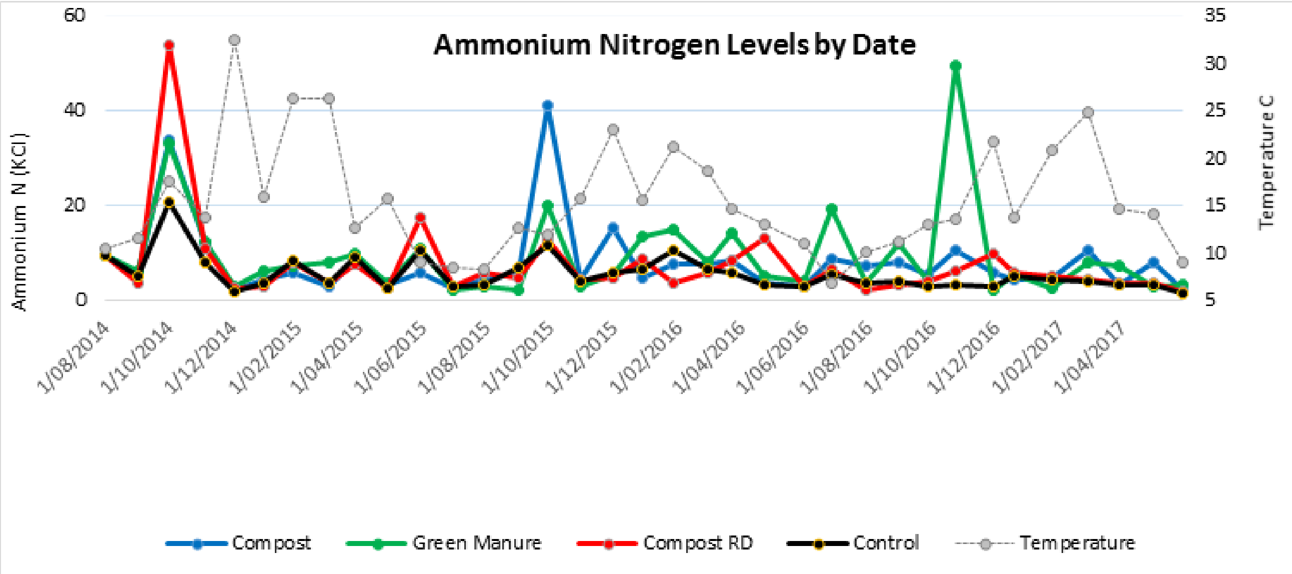
Nitrate Nitrogen levels in Treatment 2 (green manure) and nitrogen removal from two vegetable crops

	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Ave Oct-Mar
Nitrate Nitrogen mg/kg	22	100	88	84	224	181	**116**
Nitrogen Kg/hectare*	31	140	123	118	314	253	**163**
Cauliflower nutrient N removal kg/ha	109	109	109	109	109	109	**109**
Lettuce nutrient removal N kg/ha	120	120	120	120	120	120	**120**

Source: Understanding nitrogen fertilisers for vegetable production on sands, Sustainable Agriculture Fact Sheet No 4.

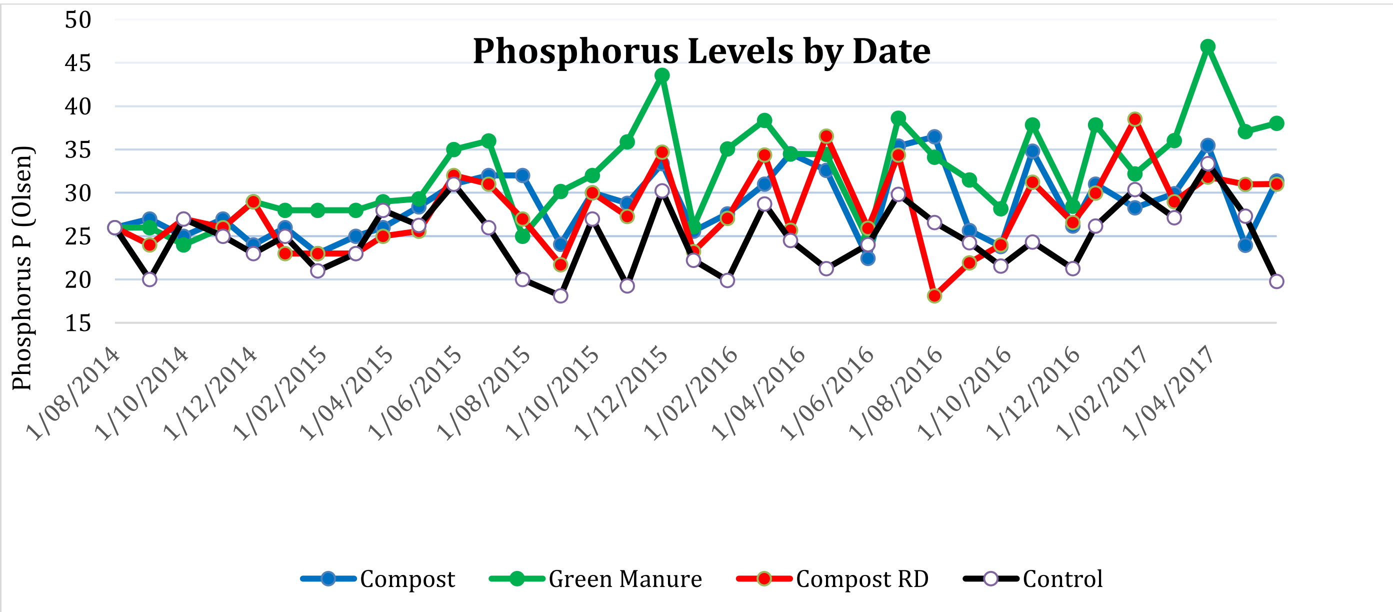
*Note: calculation is based on mass of soil in 1ha = 10,000m^2 x soil depth of 100mm = 10,000 x 0.1m = 1000m^3
Mass by the bulk density 1000 cubic metres x 1.4 ton/m^3 (bulk density) = 1400tons x mg/kg nitrate nitrogen

Ammonium N



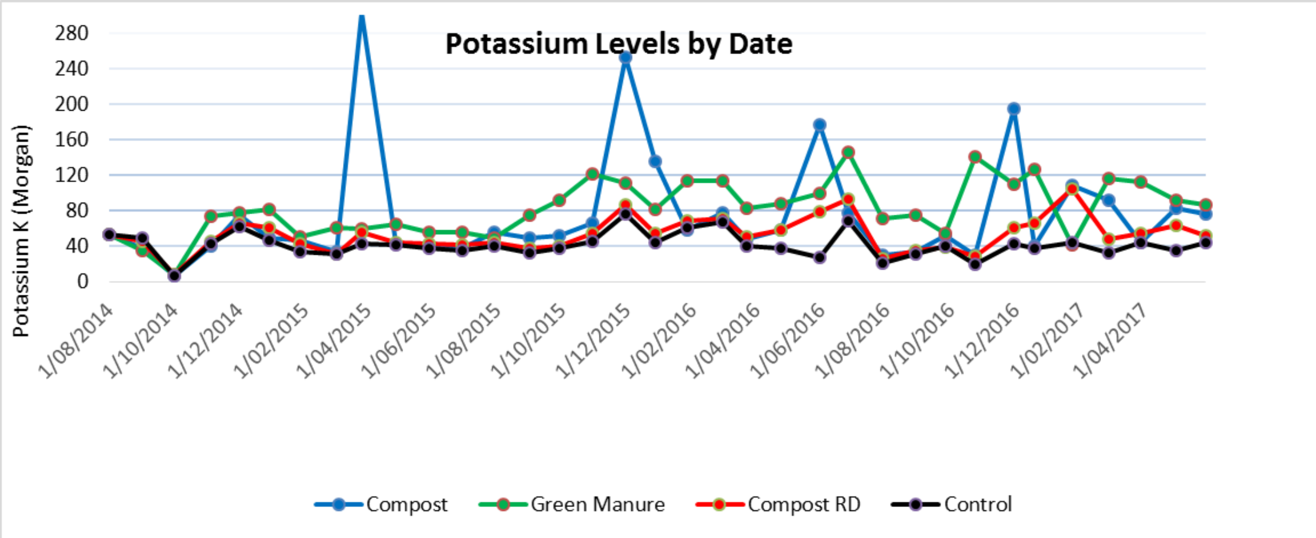
Ammonium nitrogen is an indication of the progress of decomposition. Organic matter is initially consumed by microorganisms and is converted to ammonium nitrogen and as temperature continues to increase, the ammonium nitrogen produced through biological activity is converted to nitrate nitrogen. The graph shows the movement of ammonium nitrogen through the year according to inputs and seasonal variability.

Phosphorus



The graph illustrating phosphorus levels over the trial period indicate an increase from a base of 25mg/kg to 38mg/kg in the green manure treatment and 30mg/kg in the compost treatments. There was an increasing trend in the levels of P for all treatments compared to the control.

Potassium



The graph illustrating potassium indicates peaks in the compost treatments where incorporation into the soil and subsequent decomposition has released bound potassium. As an essential major plant nutrient it is readily released and available from compost. These silty loam soils are relatively low in potassium so additional supplies from compost are very beneficial. The graph also illustrates that the green manure crop (Lucerne) is also undergoing decomposition and releasing potassium.

Solvita soil health test (CO_2 respiration)

At the conclusion of the trial Solvita tests were undertaken on all treatments. The control, compost and compost + rock dust all indicated 2.5 out of a possible 5. The green manure treatment indicated 3. A score of 2.5-3 is classed as having medium soil activity. It should be noted that soil temperatures at the time of sampling would impact heavily on microbial activity in the soil thus influencing these Solvita tests.

Vegetable yield and quality

The beds containing the green manure crops had the highest production and were higher quality than other treatments. The colour of the leaves of silver beet were more intense green with a gloss not exhibited on other treatments. Andrew Morris (farm owner) commented that, “The broccoli plants were healthier; their heads now coming through in the green manure beds are bigger, far and away bigger than any others. Beans cropped heavier, silver beet leaves were glossy and all vegetables grown looked healthier”.

Compost beds exhibited the next best production and quality.


Treatment A


Treatment B


Treatment C


Treatment D

Treatment B (Green Manure) is exhibiting larger, glossier and deeper green leaves when compared to the other treatments. There is slight yellow colouring in Treatments A, C and D

Financial analysis

As a result of improved soil fertility in the green manure bed it is anticipated that 75% less commercial fertiliser could be used saving at least $475. As plant requirements for Nitrogen are easily being met, there may only be the need to apply some minor and trace elements to ensure optimum production.

Andrew Morris (Farm owner) said "the improvement in soil fertility resulted in an extra 30 boxes of broccoli being produced providing an additional return of $900/ha. Broccoli heads that normally weigh in at 150-200grams were reported in the green manure strips to be at least 250 grams. In addition, the workability of the beds have improved resulting in energy efficiencies in terms of fuel used.

Annual Costs & Returns				
	Treatment A	Treatment B	Treatment C	Treatment D
Commercial Fertiliser 700kg/ha + spread est. $40t	$664	$664	$664	$664
Compost 5t/ha = 10m^3/ha @ est. $60m^3 spread	$600		$600	
Rock Dust 10t/ha (initial application) est. $75t spread			$750	
Green Manure seed & sowing est. $230ha		$230		
TOTAL	**$1264**	**$894**	**$2214**	**$664**
Potential fertiliser saving		$475		
Or profit from additional yield if status quo continued		$900		

The 2 treatments with compost applications did not show a significant increase in yield or quality. However, there will be some benefits from the addition of mineral elements contained in the compost. There are also residual benefits that may have accrued due to the increases in organic matter and organic carbon.

The cost of supply, delivery and spreading of the compost @ 5t/Ha (calculated at 10m^3/ha) was estimated at $60m^3. The value of the nutrients contained in the compost are displayed in the table below.

$ Value of Nutrients in 1t of Compost								
Nutrient	**kg/tonne compost (2014)**	**kg/tonne compost (2015)**	**kg/tonne compost (2016)**	**$/kg ***	**$/tonne compost (2014)**	**$/tonne compost (2015)**	**$/tonne compost (2016)**	**Total $/tonne compost 3 years)**
Nitrogen	6.2	11.1	8.4	$ 1.27	$ 7.87	$ 14.10	$ 10.67	$ 32.64
Phosphorus	1.5	6	2.7	$ 4.40	$ 6.60	$ 26.40	$ 11.88	$ 44.88
Potassium	3.3	5.9	6.5	$ 1.68	$ 5.54	$ 9.91	$ 10.92	$ 26.38
Calcium	9	20.3	13	$ 0.50	$ 4.50	$ 10.15	$ 6.50	$ 21.15
Sulphur	1.5	1	1.5	$ 0.70	$ 1.05	$ 0.70	$ 1.05	$ 2.80
				TOTAL	**$ 25.57**	**$ 61.26**	**$ 41.02**	**$ 127.85**

* based on March 2010 fertiliser prices, calculating the $/tonne by the % nutrient/tonne.

Value of nutrients in Compost spread at 5t/ha annually over 3 years (15t x $127.85 = $1917.75)

Cost of spreading Lucerne

Due to very wet conditions the sowing of a green manure crop by machinery could not be undertaken so organic Lucerne hay was spread annually across the appropriate trial beds. This was then incorporated into the soil. The organic Lucerne hay was spread at a quantity consistent with a sown green manure crop that is grown and then incorporated into the soil at 7,500kg/DM/Ha. The value of the nutrients are displayed in the table on the following page and are consistent with the level of nutrients returned to the soil through growing and then incorporating a green manure crop.

$ Value of Nutrients in 1t of Lucerne								
Nutrient	kg/tonne lucerne (2014)	kg/tonne lucerne (2015) ave of 2014 & 2016	kg/tonne lucerne (2016)	$/kg *	$/tonne lucerne (2014)	$/tonne lucerne (2015) ave of 2014 & 2016	$/tonne lucerne (2016)	Total $/tonne lucerne 3 years)
Nitrogen	20.3	21.3	22.3	$ 1.27	$ 25.78	$ 27.05	$ 28.32	$ 81.15
Phosphorus	2.3	2.45	2.6	$ 4.40	$ 10.12	$ 10.78	$ 11.44	$ 32.34
Potassium	9	13.2	17.4	$ 1.68	$ 15.12	$ 22.18	$ 29.23	$ 66.53
Calcium	18.1	12.6	7.1	$ 0.50	$ 9.05	$ 6.30	$ 3.55	$ 18.90
Sulphur	2.5	1.8	1.1	$ 0.70	$ 1.75	$ 1.26	$ 0.77	$ 3.78
				TOTAL	**$ 61.82**	**$ 67.57**	**$ 73.31**	**$ 202.70**
* based on March 2010 fertiliser prices, calculating the $/tonne by the % nutrient/tonne.								

Value of nutrients in Lucerne - spread at 7.5t/ha annually over 3 years (22.5t x $202.70 = $4560.75)

Cost of purchasing the Lucerne hay - $250t x 7.5t/ha annually over 3 years ($250 x 22.5t = $5625)

Summary

The benchmark soil assessment, including the physical, biological and chemical parameters indicated that the soil base had constraints that were reflected in the reduced production of vegetables from the trial area. Soil chemistry indicated that one of the major constraints could be low nitrogen levels required to drive production. The soil physical characteristic that was seen as the major constraint to production was the compacted soil impacting soil oxygen and moisture penetration. This is partly due to the fine silty loam texture and the cultivation (and incorporation) of the B profile which is lower in organic matter and biological life. This has created an environment not conducive to microbial life, which is responsible for the cycling of organic matter.

The trial strategy to overcome these constraints through the addition of compost and/or a green manure crop was demonstrated to be successful in creating soil conditions suitable for the soil biological life. The green manure crop in particular with the use of Lucerne increased the soil organic matter and the labile carbon levels. It also stimulated the cycling of organic matter resulting in consistently higher nitrate nitrogen levels. It was noted that long after the incorporation of this green manure the levels of nitrogen continued to be at a high level. Levels achieved were well above desirable levels required for a single vegetable crop in a rotation.

Interestingly the labile carbon decreased in both the green manure and the compost + rock dust treatments over the last few months of the trial despite an overall increase in organic matter. It is considered that this may be a result of cultivation of these beds with soil being exposed for some time prior to planting.

The use of compost was the next most successful trial treatment with increased organic matter and stable labile carbon levels. Increased production was evident.

The treatments with the compost + rock dust demonstrated improved physical characteristics with an increase in organic matter but decreased labile carbon. This possible anomaly has been discussed above as a result of production strategies that left the soil surface exposed for some time. There did not appear to be any benefit in increased plant nutrients released from the rock dust. No increase in production was noted over the control treatment. The decrease in labile carbon is an important observation indicating the benefit of the analysis in demonstrating the movement as a component of organic matter due to management practices.

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

The use of Lucerne as a green manure was a most successful input into the system and reinforces the importance of this strategy in an organic farming system in not only adding organic matter and nutrients to the soil system but stimulating the soil biology to an extent where nitrogen levels suggest that inputs of commercial nitrogen fertilisers can be reduced or even replaced.

Key learnings from demonstration

- Benchmark visual soil assessment identified a lack of soil structure as a major constraint to production
- The Lucerne green manure beds improved the soils physical characteristics (structure and moisture holding capacity)
- The Lucerne green manure beds improved the soils chemical characteristics
- The vegetables grown in the Lucerne beds yielded higher production and displayed a deeper green colour
- The Lucerne green manure initiated a greater response in terms of mobilising nitrate nitrogen
- Labile carbon decreased where trial strips had lengthy periods of exposed soil
- Monthly monitoring of N,P, K indicated a strong correlation between high nitrate levels, temperature, moisture, oxygen and a microbial food source
- The 3 year trial demonstrated how the nitrogen cycle responded positively to management and organic inputs

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