applied horticultural research

Demonstrating the benefits of reduced-till vegetable production

FINAL REPORT

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AHR Confidential Report

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Kalfresh
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Industry partners

AUSVEG
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The contributions by agronomists Stuart Grigg, Marc Hinderager and Glenn Geitz were key to making the system work at farm scale and for helping to spread the word across the regions.

AUSVEG has provided assistance to communicate with growers, which has allowed a truly national exposure for project outputs and events. Netafirm contributed its irrigation expertise to the Gippsland demonstration site.

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Executive Summary

Intensive vegetable cultivation involving repeated rotary hoeing and deep ripping have been identified as major causes of declining soil physical and biological health, yield loss and disease proliferation. But reducing tillage in vegetable production involves changes in attitude, as well as upskilling of, and expanding knowledge among growers, advisors and related support industries. This project achieved all those, using demonstration sites and by communicating the benefits and challenges using a mix of traditional communication methods, plus online postings and social media.

The project created two demonstration sites at Bathurst, NSW, and East Gippsland, Vic, to demonstrate how reduced tillage practices can be integrated into commercial vegetable production. Three showcase sites were also created to highlight the changes in tillage by vegetable growers. Those sites were at Kalbar, Qld; Cowra, NSW and Werribee, Vic. They highlighted the fact that similar yields can be obtained with reduced tillage, while improving soil conditions. The project has been upfront about the challenges and the need to work through problems with growers and agronomists. For example, at the Bathurst site the no-till practice resulted in an outbreak of the pest symphilids (*Hanseniella ivorensis*), which affected putting in the pumpkin crop. Meanwhile, at the Gippsland site, modifications were needed to the transplanter to enable crop establishment under reduced tillage.

These benefits and challenges of reduced tillage were communicated to growers and advisors through:

- Two videos, which have been viewed more than 2,870 times since December 2014
- Six farm walks attended by more than 200 people
- Three factsheets delivered to the vegetable industry via AUSVEG and SoilWealth websites, and email
- Five Facebook pages followed by 770 people
- Five articles in grower publications.

The project has benefited from the communications channels of AUSVEG – the vegetable industries' peak body – and at Soil Wealth (www.soilwealth.com.au). This has allowed the project to spread the word across the industry outside of areas not directly covered by the project. As a result, interstate growers and advisors have attended events held by the project.

The demonstration sites have proven very popular with the industry. With the support for these sites, which were due to expire in 2016, the industry has agreed to fund them through to 2017. This is a good result for the project and will create a strong legacy. In addition, outputs from the project will continue to be promoted through Soil Wealth.

The project has influenced the soil management practices on 2,100ha of the five demonstration and showcase sites and more than 400 growers and advisors have been reached through a range of traditional and electronic communications methods. The key reduced tillage messages and knowledge delivered will have a lasting influence helping to achieve soil management practices on at least another 5,000ha by 2018.

Contents

Background

This project aims to improve the adoption of reduced-till production practices among vegetable growers. Only around 15% of growers currently use reduced till/ controlled traffic methods, resulting in loss of soil carbon, poor soil structure and build-up of soil-borne diseases. The project will encourage adoption by showcasing where farmers have already implemented reduced till.

Three natural resource issues that will be dealt with by this project are:

1. Declining soil health due to intensive vegetable production
2. Direct on-farm greenhouse gas emissions
3. On-farm energy use

Intensive cultivation, rotary hoeing and deep ripping have been identified as major causes of declining soil physical and biological health, yield loss and disease proliferation (Montagu 1995; Pattison 2009; Porter 2012). Rogers (HAL project VG11034) found rotary hoeing and deep ripping are practiced by 70% of growers, while only 15% of growers use some form of minimum tillage.

Most soil tillage operations aim to correct problems caused by other tillage operations. For example, deep ripping to relieve compaction caused by tractor wheels; plough pans caused by disc ploughs; and scarifying to break up surface crusting caused by rotary hoeing, which destroys soil structure. This remedial tillage is unnecessary in a no-till production system, and saves the cost of diesel and capital expenditure on tractors and equipment.

Vegetable growers in Australia are still mainly using conventional cultivation methods including pre-plant ripping (74%) and rotary hoes (70%) to cultivate 125,000ha of highest quality arable soils in Australia. These practices are expensive and damaging to soils (Rogers, 2012). Growers repeatedly plant the same crops year after year, with cultivation used as the main tool used to bury crop resides, relieve compaction, control weeds and prepare seed beds. Practices such as deep ripping, disc ploughing, rotary hoeing, and using tines between the crop rows to break up surface crusting and control weeds are common. It is an endless cycle and much of the cultivation is really just attempting to repair damage that previous cultivation has caused.

These aggressive, energy-intensive cultivation practices result in:

- 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.

This decline was extensively reviewed by Rogers (2012). Conservation tillage practices can fully reverse the negative impacts on soil health caused by long-term intensive vegetable production in only three years (Carter et al. 2009), as well as significantly reducing the incidence of soil borne disease (Stirling et al. 2008).

No-till systems have already been adopted by a number of growers in North Queensland and Tasmania. Although only 15% of Australian vegetable farmers use reduced tillage there is strong evidence that many farmers are concerned about soil health. There is considerable (and growing) interest in cover crops, compost and soil testing. However, lack of information and knowledge is hindering other improvements in soil management.

Controlled traffic, and reduced tillage production to reduce input costs and improve soils, were identified as a key RD&E issue by vegetable growers (Rogers 2012). This demonstrates to vegetable growers the benefits of reduced tillage under commercial conditions.

There are approximately 5,700 vegetable-growing businesses in Australia using 125,000ha of arable land. We aim to reduce usage of intensive soil cultivation methods from 70% to 50% of the industry by 2018. This equates to approximately 25,000ha of land. This target may be achieved by focusing on medium to large operations, who are most concerned about input costs as well as able to invest in the equipment required. It is expected that soil carbon levels will increase by 50% within five years among growers adopting no-till methods. Adoption will continue to increase in the next 5–10 years, as the economic benefits of this innovation become more widely appreciated and information is commonly available.

Methodology

Communications

Communication was a major focus of the project, with farm walks, workshops, media coverage, factsheets, video and social media used to communicate with the wider vegetable industry.

The most effective and trusted communications occur when respected, innovative growers speak directly to other growers. The project has used this approach to develop many ways of sending the message about the implementation of current and new technologies for managing soil health – from farm walks and workshops to videos, print and by using social media.

Demonstartion sites

On-farm demonstration sites were developed in two vegetable growing areas (NSW and Vic). Four to five crops will be grown at each demonstration site using no-till, reduced-till and conventional systems. Cover crops were also incorporated into the rotations.

Gippsland Demonstartion site

Bill and Bernadette Bulmer started with a small 30ha dairy farm in the 1970s and have grown this into today's 500ha intensive vegetable growing operation. The business, now run by Andrew and Kaine Bulmer, is one of the largest vegetable growing enterprises in the Mitchell River Valley in East Gippsland, Vic.

With more than 40 years of farming expertise, Bulmer Farms is a leader in the growing of lettuce, baby spinach, baby salad leaf and baby broccoli varieties across nine farms in the region.

Soils cropped vary from sandy clay loams, to loams and medium silty clays, depending on proximity to the Mitchell River and location within the river valley. The intensive cultivation used to grow the vegetable crops, and the market requirements to harvest when soil conditions are sometimes not suitable, have taken a toll on the soil.

If soils are not managed correctly they can crust and become very cloddy, the incidence of various soil-borne diseases can increase, and during flooding the soils are prone to erosion. The Bulmers and their cropping team see management of soil – their most important asset – as a major focus, as they continue to grow and expand the business. The Bulmers have a long history of using cover crops to manage their soils.

The Bulmers, together with the project team, are now trialling a range of soil cultivation practices which reduced the amount of tillage required and enhance the soil health benefits of cover crops. Partnership with the project is allowing the Bulmers' production team to trial and refine "softer" approaches to tillage before committing to their use across the business.

Figure 1. Gippsland demonstration site showing the three cultivation practices.

The tillage practices demonstrated at the Gippsland site (Figure 1):

- Conventional cultivation: For each crop the Bulmers' standard cultivation practices of deep ripping, two passes with the discs, rotary hoe and bed former
- Reduced tillage: This practice formed beds in two passes involving just the rotary hoe and bed former, leaving out the deep ripping and discing
- No-till (permanent beds): After the initial establishment of the beds (using conventional cultivation) no further broadscale cultivation was undertaken.

Across the three tillage practices five crops have been grown (baby leaf spinach → lettuce → baby broccoli → cover crop → baby leaf spinach → lettuce, Figure 2). Details of the site progress are available at http://www.facebook.com/soilwealthgippsland

Figure 2. Gippsland demonstration site with the winter baby broccoli crop, the third crop grown under the different cultivation practices.

A practical challenge was the direct transplanting into the uncultivated soil with crop residues. This has been addressed by the modification of the transplanter by the site agronomist (Figure 3).

Figure 3. Gippsland demonstration site agronomist Stuart Grigg outlining the challenges in modifying the planter to operate in no-till.

Bathurst Demonstration site

Michael and Karen Camenzuli started growing cabbages on a 10ha farm in 1989 and have expanded to more than 60ha on the Macquarie River south of Bathurst, NSW. Their three children have plenty of work to do when they are not in school, helping with growing and harvesting cabbage, sweet corn, and making lucerne or oaten hay.

Michael is passionate about soil health. Like many vegetable growers, a big challenge for Michael is harvesting and delivering produce when soil conditions are too wet. The wet, cold conditions when harvesting cabbage in winter can result in considerable soil damage. In summer, harvesting of the corn crop requires heavy machinery, also potentially damaging the soil.

Typically, post-harvest tillage needed to be multiple, deep and aggressive to fill in ruts and wheel tracks and loosen the compacted soil. Such tillage takes a toll on the soil and also pushes up costs.

Michael is working with the project team to look at permanent beds, cover crops and reduced tillage within his rotation of cabbage and corn or pumpkins. The objective is to give the soil biology a chance to build structure and reduce the amount of tillage, and hence, costs, while also building soil health.

The tillage practices demonstrated at the Bathurst site were (Figure 4):

- Tilled: After each crop the beds are disced flat and left fallow over winter; prior to establishing the crop, the site is disced and then rotary-hoed and bed-formed
- Tilled with cover crop: After each crop the beds are disced flat and an oats/vetch cover crop grown over winter; prior to crop establishment the site is disced and then rotary-hoed and bed-formed
- No-till: Winter cover crop of oats/vetch sown into the 2014 cabbage crop; no further cultivation of the beds has occurred.

Figure 4. Bathurst demonstration showing the three soil management practices.

Across the three tillage practices an oat/vetch cover crop was grown during the 2014 and 2015 winter. A pumpkin crop was grown over the 2014/15 summer (Figure 5) and cabbage over the 2015/16 summer. Details of the site progress are at http://www.facebook.com/pages/Soil-Wealth-Bathurst/1457060841220457

Figure 5. Pumpkins growing on the reduced-till permanent beds with the winter cover crop reducing weed competition and conserving moisture.

The soil-dwelling symphilid insect was problematic in the no-till practice requiring the pumpkins to be re-sown (Figure 6).

Figure 6. Symphilids appeared in high numbers, especially on the reduced till permanent beds with cover crop mulched. Pumpkins seedlings were attached and had to be replanted.

Showcase sites

Three showcase sites were established to highlight reduced till and cover crop practices, which improve soil health. These were established in three locations:

Kalbar, Queensland

Kalfresh was started in 1992 by father and son team Barry and Robert Hinrichsen at Kalbar in the Fassifern Valley south-west of Brisbane. Kalfresh has now expanded to properties across the Fassifern and Lockyer Valleys and Wallaville near Bundaberg, growing more than 600ha of carrots, beans, onions and pumpkins.

Kalfresh farming operations are managed by Robert Hinrichsen, who has a commitment to good farming techniques. Rob could see soil structure and biology declining under the standard intensive vegetable production practices. This was leading to increased production costs and problems with soil disease and an over-reliance on soil fumigants such as metham sodium.

Six years ago, Rob and his team decided to focus on and adopt four key practices to improve the health of his soil and business:

1. Controlled traffic farming (permanent beds)
2. Compost and biological fertilisers
3. Cover crops
4. Integrated pest management (IPM)

Rob and the team are now working together on the challenges of soil compaction, surface sealing and the soil-borne disease pythium. At the Kalbar site demonstrations are being conducted on the potential benefits of variable rates of compost, cover cropping and a Plant Growth promoting rhizobacteria (*Bacillus subtilis*).

Details of the site progress are available at
http://www.soilwealth.com.au/demo-sites/kalbar-qld/

Cowra, New South Wales

Ed and James Fagan are third generation vegetable growers having taken over from their father Peter, the running of the 1,400ha farm on the banks of the Lachlan River near Cowra, NSW.

Mulyan Farms has been growing broadacre crops since 1886 and in 1943 ventured into vegetables with the opening of the local cannery.

Today Peter enjoys retirement, and while the cannery is now closed the boys have diversified into babyleaf spinach, lettuce and popping corn, while continuing to grow beetroot, onions, asparagus, as well as dryland wheat and canola.

During the 1950s, 60s and 70s vegetable soil management practices were quite hard on the soil, but at the time it wasn't evident what we were doing, long-term to the soil. The light soils along the river lost their organic matter and structure. More cultivation was required and nutrients were easily leached below the shallow crop root zones, adding cost and acidifying the soil.

Ed and James have taken a whole-farm approach to rebuilding the soils on Mulyan Farms after more than 60 years of intensive cultivation and vegetable cropping. Carefully planned crop rotations, reduced tillage and cover crops have all been used to revitalise the soil and enhance its productivity.

Ed and James have made great progress and are now working with the team to further refine their use of cover crops to build soil organic matter and structure, cycle nutrients, optimise nitrogen use and control weeds. Caliente and Nemclear mustards, ryegrass, field peas, clover and compost are all being trialled in reduced-till permanent beds system.

Details of the site progress are available at
http://www.soilwealth.com.au/demo-sites/cowra-nsw/

Werribee, Vic

Fragapane Farms together with the project team are now trialling a range of soil cultivation practices which reduced the amount of tillage required and also the addition of compost.

Soil management in the Werribee area is complicated by intensive rotations, high salinity irrigation water and sodic soils.

Details of the site progress are available at
http://www.soilwealth.com.au/demo-sites/werribee-vic/

Results & Discussion

Gippsland

Crop growth

In November 2014, iceberg seedlings were transplanted into the conventional till and half of the reduced till practice using an unmodified lettuce transplanter. Following this, the machine was fitted with temporary brackets to house discs (assembled on freewheeling hubs) that would be used to cut through plant trash remaining through the no-till practice. This principle is similar to that used by broad acre farmers practicing reduced tillage with cereal crops. Once these modifications were installed, the iceberg seedlings were transplanted into the remaining section of the reduced till and the no-till practice. It was in the no-till practice where the machine had to cut through trash that some issues were encountered:

- As transplanting commenced in the no-till practice, where the machine had to move through brassica cover crop trash, blockages and skips in plant drop (through transplanter) were frequent. We had the idea to start transplanting slowly to allow the discs to cut through and push the trash out of the plant lines, as it turns out this only added to the issue. Once a bit more speed was achieved the machine did a very reasonable job of cutting through trash without blocking and seedling skips were considerably fewer.
- The discs on the transplanter had to be set slightly off-centre to the plant lines of the transplanter to dislodge the relatively stocky root systems of the brassica cover crop
- Time needs to be taken to experiment with the levelling of the transplanter, i.e. setting the machine to bite in a little at the front, while creating a good furrow for transplants, as it tends to lead to increase blockages when transplanting. Similarly, adjusting the machine so that the discs are angled back does not create an adequate transplant furrow. We found that having the transplanter level and increasing the depth that the discs were allowed to cut in yielded better results
- When creating brackets for temporary cutting discs, allow room for adjustments as this saves a lot of time when moving between trashy cover cropped and non-cover cropped areas.

Generally, there were very few growth differences between practices following transplant. Around 3–4 weeks after transplant holes started appearing in the leaves of the crop transplanted into the cover-cropped area (no-till and reduced-till practices). Some of these had been caused by slugs, others were perforations in the leaf caused by wind and the trash that remained in this practice. Whilst slugs can easily be baited for, leaf perforations caused by trash may only be avoided by mulching remaining material on the bed prior to transplant, which may not be practical. Some seedlings in the cover-cropped practice were planted too deep, which led to coning of plants and a loss of yield. It is likely that this would have been caused by running the planter slowly and a lack of experience on the transplanter's behalf when transplanting – seedlings set too deep could have been manually corrected but may have been missed under trash build ups. No other noticeable differences were observed until the heads were harvested.

Lettuces were harvested on 8 January, 2015. The yield data was calculated based on the weight of 100 heads, randomly cut across the replicates and trimmed for processing. This data has then been used to calculate the effective yield per hectare based on the weight per head (Table 1).

Table 1. Average head size and crop yield of iceberg lettuce grown under three soil management practices.

	No- Till	Reduced Till	Conventional Till
Average Head Weight (grams)	685	590	545
Yield (T/Ha)	35.5	30.6	28.3

Heads in the conventionally tilled practice were noticeably less firm than those heads in the other bays and appeared to have been at least 5–7 days behind the heads grown in the no-till bay.

A baby broccoli crop was planted in February 2015 and grown through to September 2015. There were lodging issues in the plants transplanted into the no-till area because of issues at transplant. Press wheels (or similar) at transplant may have prevented this from happening by ensuring the seedling was firmly in place. When harvesting commenced in early May these plants had recovered.

Due to the continuous harvest of baby broccoli side shoots over months it was not possible to collect yield data under commercial conditions.

A baby leaf spinach crop was grown from February to April 2016. Prior to this a summer cover crop had been grown across the site. The mulched cover crop was incorporated into the soil with decreasing amounts of tillage; conventional tillage area was disced twice, ripped and rotary hoed and bed formed, Reduced till area ripped and rotary hoed and bed formed, no-till area was rotary hoed and bed formed. Final spinach yields are shown in Table 2.

Table 2. Yield of baby leaf spinach grown following the establishment of three soil management practices. Over the last 20 months four previous crops had been grown and the conventional, reduced- and no-till practices were cultivated 25, 15 and 7 times. Values are the fresh weight at harvest.

	No- Till	Reduced Till	Conventional Till
Yield (t/ha)	18.0	17.9	16.1

Soil conditions

Soil conditions were assessed 10 months from the start of the soil practices. In this time the conventional till, reduced till and no-till practice had 15, 9 and 5 cultivations, respectively. For the no-till practice no additional tillage had occurred after the initial establishment of the beds. During this period three crops had been grown with yields in the no-till similar or better than the other soil management practices (Table 1).

Across all three practices soil organic matter was high in both the topsoil and subsoil. Labile or active carbon was at moderate levels with an early trend showing increasing levels as tillage reduced (Table 3). However, across all practices the proportion of soil carbon as labile carbon was low at 1.3–1.5%, well below the 5% ideal level. On inspection of the soil, considerable charcoal was observed in the soil. This form of carbon is not active and will obscure all but very large changes in soil organic matter. Thus the measure of labile carbon will be important in highlighting changes in soil carbon under the different practices.

Table 3. Soil properties at the Gippsland demonstration site 10 months after commencing the tillage practices.

	No-till	Reduced-till	Conventional till	No-till	Reduced-till	Conventional till
	0 - 15 cm			*15 - 30 cm*		
Organic Matter (%)	3.6	3.7	3.8	1.6	2.0	2.2
Labile C (mgC/kg soil)	307	303	297	141	178	172
$pH_{(CaCl)}$	7.2	7.1	7.3	6.7	6.6	6.7
Nitrate (ppm)	1.4	1	3.9	1.1	0.5	1.3
Phosphorus (ppm)	191	180	148	58	60	58
Water stable aggregates (%)	14	10	12	10	11	9
Bulk Density (g/cm^3)	1.31	1.32	1.26	1.60	1.46	1.38

A remarkable feature of the soil after 10 months was the similarity in bulk density across practices (Figure 7). Despite the marked differences in the amount of cultivation in the three practices the topsoils were of similar bulk density. Furthermore, the no-till practice had grown three crops in 10 months since cultivation.

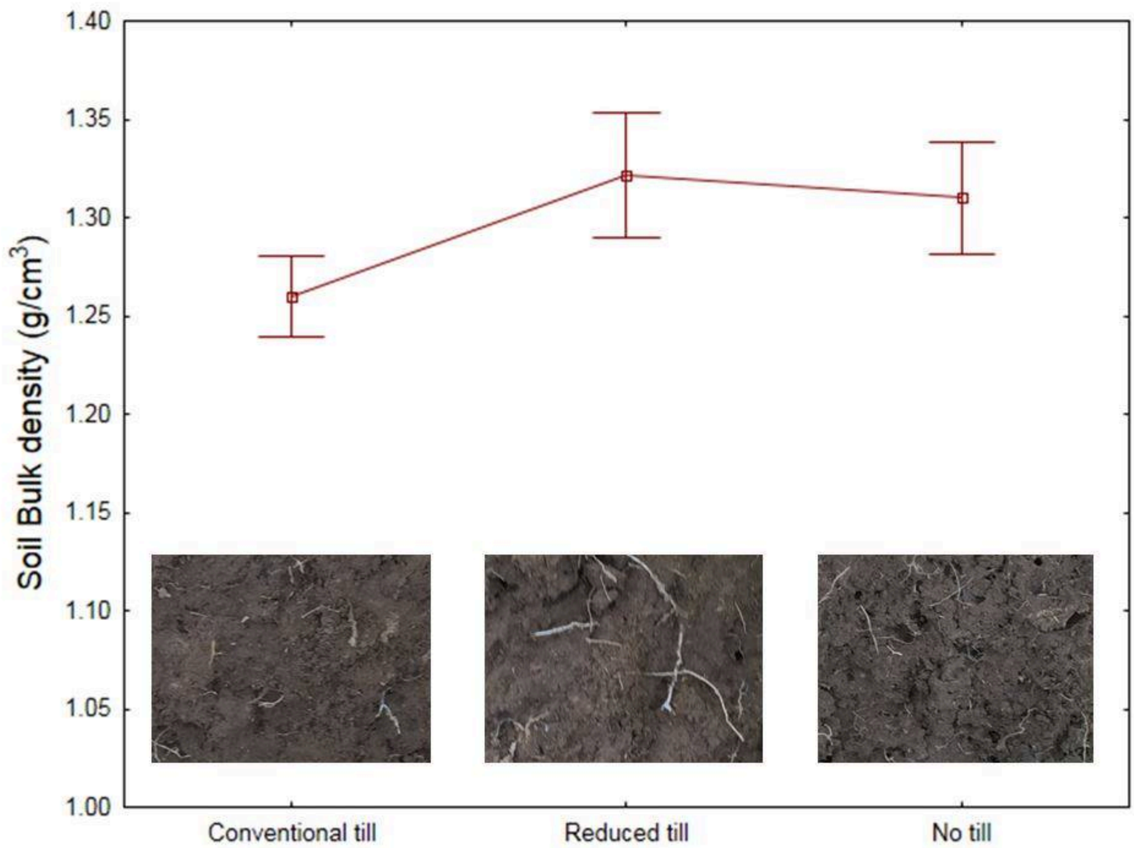


Figure 7. Topsoil bulk density and soil appearance after 10 months of the three soil management practices in which the conventional, reduced- and no-till practices were cultivated 15, 9 and 5 times.

Inspection of the soil at the farm walk showed how the same bulk density could be achieved in different ways. In the conventional till practice repeated cultivation recreated the topsoil for each crop with the soil structure inherently unstable and characterised by few macropores. By contrast, the no-till practice had allowed soil biology to build a stable soil structure with aggregate stability increasing over this period. Thus the two practices highlight the different ways a similar suitable soil structure can be created, by encouraging soil biology to build soil structure or by using aggressive tillage practices for each crop.

The soil sampling and farm walk soil pits did highlight an issue with the subsoil of the no-till. The no-till practice had a high subsoil bulk density, which appeared related to gradients across the site rather than the practice. A deep ripping treatment together with a cover crop to stabilise the subsoil was implemented across the site over the 2015–16 summer.

Further soil sampling took place in February 2016, 20 months after soil management practiced had started. In this time the conventional till, reduced till and no-till practice had 25, 15 and 7 cultivations, respectively.

Soil sampling had revealed a subsoil compaction issue. This was managed across the site through deep ripping followed by a cover crop. Four months after ripping the bulk density of the 15–30cm layer had successfully been reduced across all areas (Table 3 v Figure 8).

Again the striking result is the similarity of bulk density across the three areas despite considerable differences in tillage. After five crops the soil bulk density was similar despite the large differences in the amount of tillage.

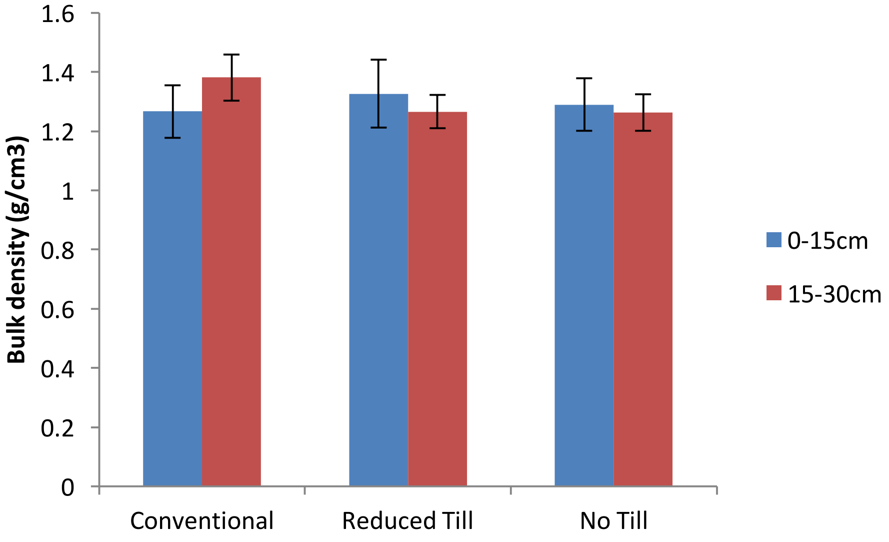


Figure 8. Soil bulk density after 20 months of the three soil management practices in which the conventional, reduced and no-till practices were cultivated 25, 15 and 7 times.

Bathurst

In November 2015, pumpkins were sown into the three soil management practices. Early establishment of the pumpkins was a problem in the no-till permanent beds due to soil insect attack by symphilids causing seedlings to die (Figure 6). Cultivation is an effect control measure for symphilids and hence damage was low in the tilled practices. It was considered that the cover crop was not sprayed out early enough and hence provided a “green bridge” through to the crop. Thus for the next cabbage crop the cover crop will be sprayed out earlier.

Once the pumpkins were established in the no-till practice growth was good and weed control excellent (Figure 9).

Figure 9. Weed control in the no-till practice following a winter cover crop of oats and vetch.

Once the pumpkin crop was established, the pumpkin crop in the no-till practice out preformed the tilled treatments with respect to crop yield due to bigger pumpkins. This may have been related to the better conservation of moisture by the *insitu* mulched no-till practice.

Table 4. Yield of pumpkins grown under three soil management practices. No-till practice had not been cultivated since early 2014, Till with cover crop had been cultivated 10 times and the Till no cover crop cultivated 8 times.

	No-Till	Tilled Cover crop	Till No cover crop
Number of pumpkins per plant	2.2	2.6	2.2
Average Weight (kg)	7.9	5.0	6.8
Yield (t/ha)	46	35	40

At the commencement of the demonstration site the topsoil organic matter averaged 2.2% across the site. The soil management practices appear not to have been able to increase or maintain this level of organic matter with the organic matter 14 months latter lower in all practices, but the decline was greater in the tilled no cover crop practice.

There was more labile or active carbon under the reduced-till cover crop in both the top- and subsoil. This may indicate that this practice will stabilise and slowly build soil organic matter over time. There are indications that this is occurring with the bulk density lower in the no-till practice. This is despite there being no cultivation since the cabbage crop was established in early 2014. By contrast the tilled practice has had 10 cultivation events. This indicates that the soil structure can be built and stabilised using soil biology. However, this can bring new challenges as was the case with the pumpkin crop where symphilids soil insects attacked the germinating pumpkins resulting in them having to be replanted (Figure 6).

Table 5. Soil properties at the Bathurst demonstration site 14 months after commencing the tillage practices.

	No-till	Tilled	Tilled	No-till	Tilled	Tilled
	Cover crop	Cover crop	No cover crop	Cover crop	Cover crop	No cover crop
		0 - 15 cm			*15 - 30 cm*	
Organic Matter (%)	1.8	1.8	1.5	1.3	1.8	1.3
Labile C (mgC/kg soil)	390	333	320	270	182	177
$pH_{(CaCl)}$	6.4	6.5	6.8	6.3	6.3	6.4
Nitrate (ppm)	6.3	5.8	7.2	2	2	6
Phosphorus (ppm)	56	55	48	41	32	27
Bulk Density (g/cm^3)	1.39	1.47	1.46	1.56	1.56	1.63

The three soil management areas were planted to cabbage, the growers primary cash crop, and grown over the summer. Near the end of the cabbage crop further soil sampling was undertaken (Table 6). The largest change in soil organic matter observed in the no-till soil at 15-10cm. Here the soil organic matter increased from 1.3 to 2.0%. We attribute this to the high level of earthworm activity (Figure 10) in the no-till area, where earthworms were more than 40 times more abundant then in the conventional tilled area. The earthworms would have incorporated significant amounts of the winter cover crop increasing soil organic matter in the 15-30cm. Under conventional tillage the additional of a winter cover crop increased earthworm numbers by more than 8 fold.

Table 6. Soil properties at the Bathurst demonstration site 14 months after commencing the tillage practices.

	No-till	Tilled	Tilled	No-till	Tilled	Tilled
	Cover crop	Cover crop	No cover crop	Cover crop	Cover crop	No cover crop
		0 - 15 cm			*15 - 30 cm*	
Organic Matter (%)	1.8	2.1	1.9	2.0	1.7	1.7
Labile C (mgC/kg soil)	366	407	324	260	293	234
$pH_{(CaCl)}$	6.3	6.6	6.8	6.1	6.2	6.2
Phosphorus (ppm)	53	50	51	48	40	37
Bulk Density (g/cm^3)	1.45	1.25	1.22	1.57	1.61	1.48

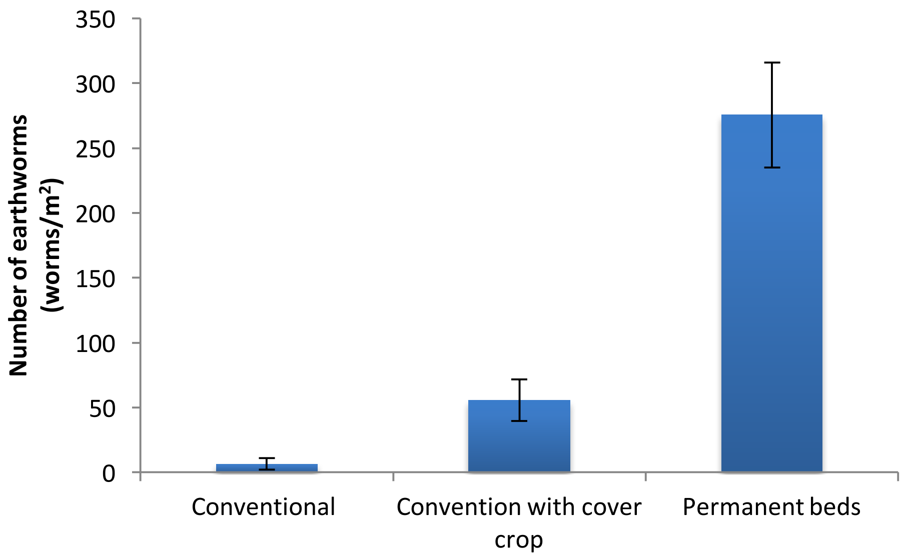


Figure 10. Earthworm number following the growth of 2 summer cash crops and 2 winter cover crops under three tillage and cover crop practices.

Showcase sites

The showcase sites at Kalbar, Qld, Cowra, NSW and Werribee, Vic were commenced after the demonstration sites. Learning's from these three sites will be incorporated into the final report in March 2016.

Communications

Videos

Two videos were made by the project outlining why and how reduced till can be used in vegetable production. The videos have been viewed more than 2,870 times since posting in December 2014.

Reduced Till in Vegetable Production WHY?

https://youtu.be/RfbhOxnULyI

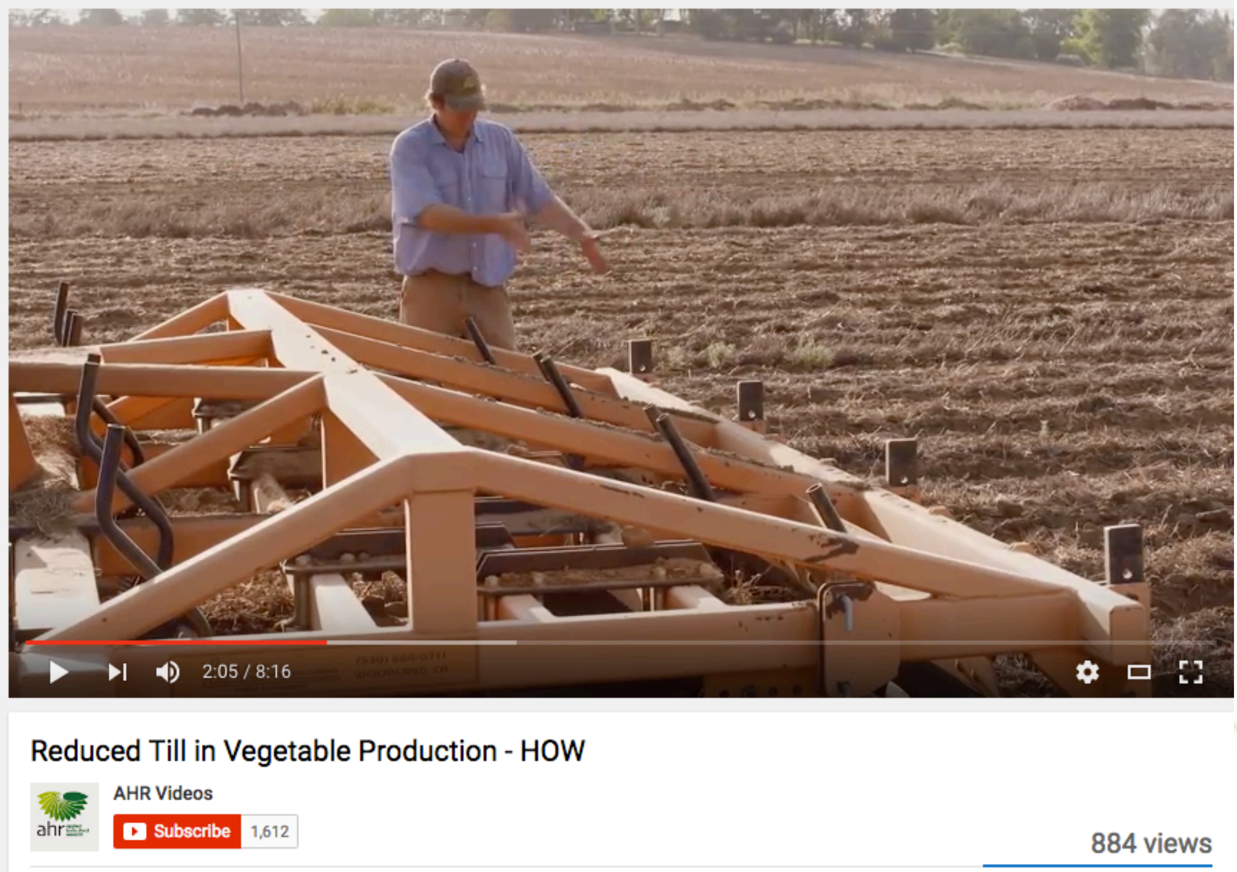
Reduced till can deliver some significant benefits to vegetable growers, including reduced input costs, better soil health and yields as good as or better than via conventional tillage. Challenges include costs of machinery modifications and new equipment, paddock rotation planning and the possibility 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 1951 views.

Reduced Till in Vegetable Production HOW?

https://youtu.be/5rH3CFh7yvU

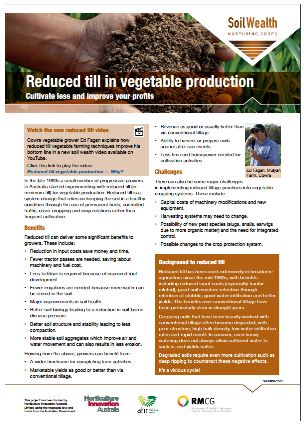
An eight-minute video feature Ed and James Fagan explaining how to implement reduced tillage and cover crops, what machinery to use, the synergies with cover cropping and timing of spraying out cover crops, incorporation and sowing of a cash crop. After 12 months the video has received 916 views.



Factsheets

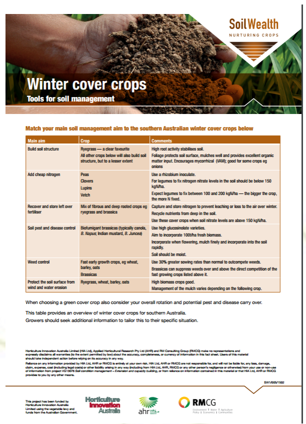
The project contributed to the following Factsheets. These were delivered to the vegetable industry as hard copy at farm walks and field days and electronically through the AUSVEG weekly email, the SoilWealth fortnightly Bulletin, via the @SoilWealth twitter, and on Facebook pages.

Reduced till in vegetable production (Appendix 1)


SoilWealth
Reduced till in vegetable production
Cultivate less and improve your profits

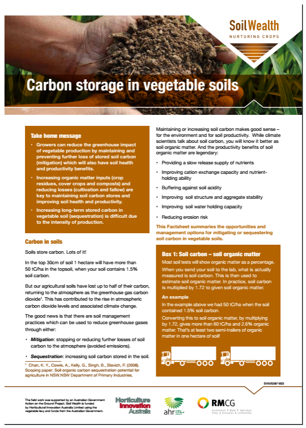
Reduced till is a system change that relies on keeping the soil in a healthy condition through the use of permanent beds, controlled traffic, cover cropping and crop rotations rather than frequent cultivation.

Winter cover crops (Appendix 2)


SoilWealth
Winter cover crops
Tools for soil management

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.

Carbon storage in vegetable soils (Error! Reference source not found.)


SoilWealth

Carbon storage in vegetable soils

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.

Facebook pages

A Facebook pages provide a near real-time record of the developments at the Gippsland, Bathurst Cowra, Kalbar and Werribee demonstration sites. By the end of the project the five Facebook pages were being followed by 770 people.

The Facebook sites show a sequential log of the soil management practices applied and their performances over time. The sites also help AHR to communicate with growers and advisors. They are also used to advise site followers of upcoming events.

The Facebook pages add value to field days with information also disseminated online before and after farm walks.

The Gippsland, Victoria Facebook page has been liked and followed by 207 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 Bathurst, New South Wales 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 Cowra, New South Wales Facebook page has been liked and followed by 256 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 Werribee, Victoria Facebook page has been liked and followed by 153 people and can viewed at www.facebook.com/SoilWealthWerribee/.

The Kalbar, Queensland Facebook page has been liked and followed by 79 people and can viewed at www.facebook.com/Soil-Wealth-Kalbar-1680554925499949/?fref=ts.

Media article

Bugs in the system at Bulmer Farms at Lindenow
http://www.weeklytimesnow.com.au/agribusiness/on-farm/bugs-in-the-system-at-bulmer-farms-at-lindenow/story-fnker6cv-1227411142312

Tillage key in veg growth trial
http://www.goodfruitandvegetables.com.au/news/magazine/farm-business/education-and-training/tillage-key-in-veg-growth-trial/2739145.aspx

Reduced tillage options in vegetables. Jeanette Servers of Good Fruit & Vegetable
http://www.soilwealth.com.au/resources/videos-and-apps/bulmer-farm-walk-may-2015/

Soil guru shows how it's done at National Horticulture Convention
http://www.weeklytimesnow.com.au/agribusiness/horticulture/soil-guru-shows-how-its-done-at-national-horticulture-convention/story-fnker6g8-1227422212518

Rob Hinrichsen Soil Wealth Grower Success Stories, AUSVEG 6 Jan 2016

Field days

Cowra, NSW 11 September 2014 – 28 participants

Gippsland, Vic 21 May 2015- 60 participants

Kalbar, Qld 28 June 2015- 45 participants
Kalbar, Q 30 August 2015 – 30 participants
Bathurst, NSW 27 April 2016 – 24 participants
Cowra, NSW 28 April 2016 – 22 participants

Outcomes

The project outcomes were:

- By 2018, 125 farming entities, covering 7,500ha, will have trialled the innovative practice
- 400 farming entities have improved their knowledge and skills.

The project has through the demonstration sites, farm walks, videos, factsheets and Facebook sites provided information on reduced tillage practices in vegetable production. Directly the project has influenced the soil management practices on 2,100 ha of the five demonstration sites growers. The project has also provided new information on combining cover crops with reduced tillage to improve soil productivity and health.

Through the 200 grower and advisors who have attended farm walks soil tillage practices will be influenced on at last another 5,000 ha by 2018. For example, an agronomist at Simplot is looking to help growers incorporate cover crops and reduced tillage into corn production systems to address issues such as low infiltration rates under centre pivots. This is a direct result of attended field days at Cowra.

More than the 400 growers and advisors have been reached through the project. Information on the 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). In addition to the more than 200 growers and advisors who have attended farm walks, there have been more than 2,800 viewings of the two videos, more than 770 people following the five Facebook sites, and more than 2,000 receiving the factsheets via either the AUSVEG weekly update or the Soil Wealth fortnightly Bulletin. The use of a range of traditional and electronic communications methods has allowed the project to deliver the key reduced tillage messages to a wide audience beyond the demonstration sites and specific events.

The project has successfully demonstrated and communicated that combining reduced tillage with 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.

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.

Longer term Outcomes

The project has contributed to the longer term improvement in soil management in the vegetable industry. The demonstration sites have proven very popular with the vegetable industry. The sites established under this project will continue to be supported by industry through the Soil Wealth project. This is a great long term outcome for the project and ensures a strong legacy.

The project has contributed to a transformation of the vegetable industry. Leading Tasmanian vegetable grower Colin Houston has recently recognised the Fagan's important 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 videos and electronic and social media to give Ed and James a wider audience.

The factsheets, videos and Facebook pages detailed in the outputs section provide a permanent resource. These resources will help the Australian vegetable industry improve soil productivity and health in the longer term.

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 vegetable production system.

Economics

The sustainable practices demonstrated in this study can have a positive economic impact. Differences in gross margins at selected sites were calculated based on the measured marketable yield and the costs of implementing the various practices on farm. Leguminous cover crops such as clover and field peas (Figure 11) show an ability to improve yield and a potential to reduce nitrogen fertiliser demand. Reduced and minimum tillage (Figure 12) show the ability to maintain and exceed yields when compared to conventional tillage. Serenade and composting (Figure 13) also demonstrate that yields can be sustainably increased without nitrogen fertiliser.

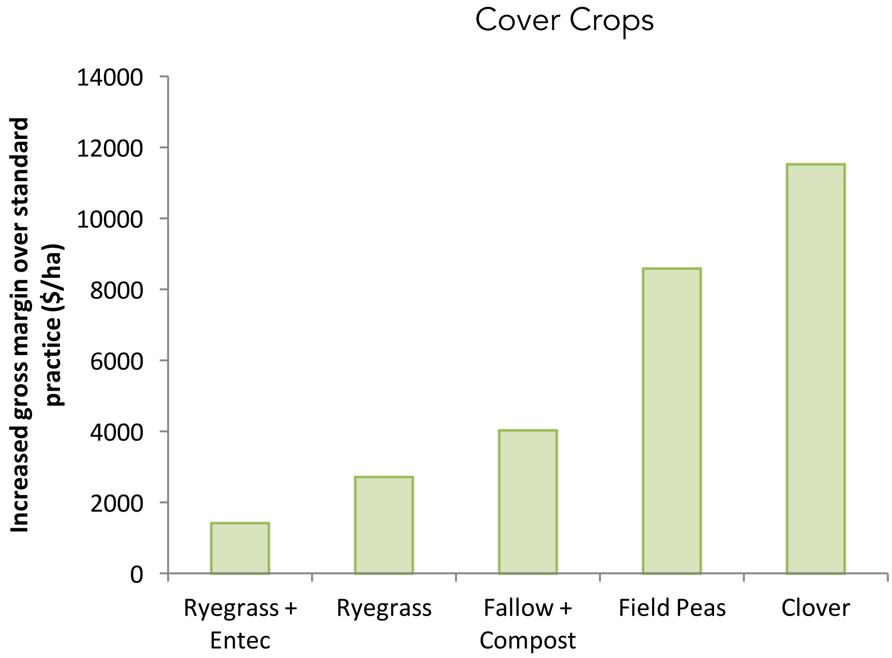


Figure 11. Increased gross margin per hectare due to various cover crops over the standard practice of fallowing, based on measured yields and a price of spinach at $3.00 per kilogram.

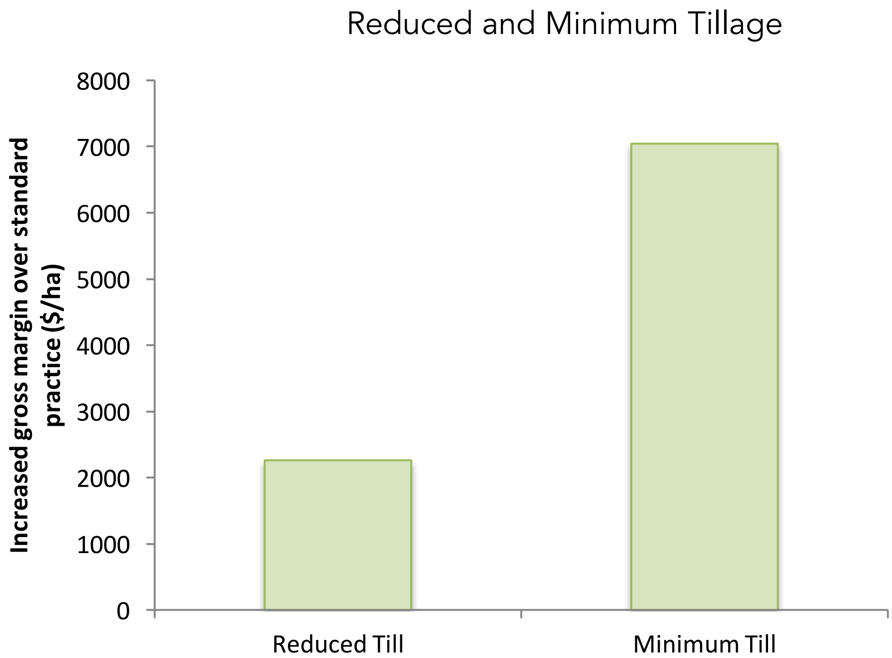


Figure 12. Increased gross margin per hectare due to reduced and minimum tillage over conventional tillage, based on measured yields and a price of lettuce at $0.97 per kilogram.

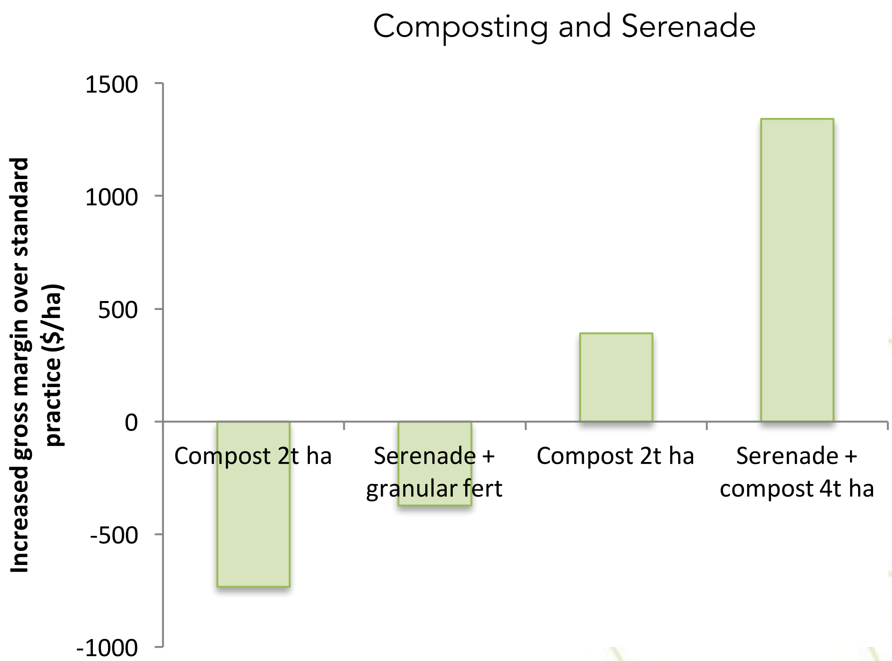


Figure 13. Increased gross margin per hectare due to soil amendments over the standard practice of granular fertiliser, based on measured yields and a price of carrots at $0.40 per kilogram.

Evaluation and Discussion

Overall 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 learned experiences from practices used on the demonstration sites 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.

Effectiveness of activities

The 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 AUSVEG and Soil Wealth to deliver the key messages to a wide vegetable industry audience has significantly increased the effectiveness of the project.

The project has broadened the original geographic focus on NSW and Victoria 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 2,800 since being released and are now a permanent resource available to the industry.

Learned experiences

The key lessons 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.

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.

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.

Future needs for uptake of innovation

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.

Implementing system change requires perseverance, as practical issues will need to be addressed on each farm. The project has been upfront with the challenges and the need to work through such issues with the growers and agronomists. For example, at the Bathurst site the no-till resulted in an outbreak of symphilids, which affected the establishment of the pumpkin crop. While at the Gippsland site modifications were required to the transplanter to enable crop establishment under reduced-tillage practices. Despite these issues, yields were demonstrated to be similar or higher to the conventional tillage practice. Such learned experiences are similar to the reduction in tillage in broadacre cropping. Building trust and strong linkages with growers and their agronomists has been the key to working through these issues.

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. Reducing tillage in vegetable production involves changes in growers, advisors and support industries attitude, knowledge and skills. To make this work involves more than just reducing tillage with changes needed at a farming systems level. For example, reducing tillage is part of a system change involving permanent wheel tracks, cover crops and compost to help build the stable soil structure rather than the rotary hoe and ripper creating it for each crop.

A key to working at the farming system level is for future projects to be partnerships between leading growers and researchers. Such a 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.

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 can be implemented within the vegetable industry.

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 cover crop practices based on a greater understanding of cover crop agronomy and root "signatures" which promote beneficial soil biology.

Appendices

Appendix 1: Reduced till in vegetable production

Appendix 2: Winter cover crops

Appendix 3: Carbon storage in vegetable soils

Soil Wealth
NURTURING CROPS

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 Farm, 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.

Horticulture Innovation Australia

ahr applied horticultural research

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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 Farm, 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

Contact

Gordon Rogers gordon@ahr.com.au 0418 517 777 or
Doris Blaesing dorisb@rmcg.com.au 0438 546 487

SW1/002/1501

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 All other crops below will also build soil structure, but to a lesser extent	High root activity stabilises soil. 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 Clovers Lupins Vetch	Use a rhizobium inoculate. For legumes to fix nitrogen nitrate levels in the soil should be below 150 kgN/ha. 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. Recycle nutrients from deep in the soil. 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. Aim to incorporate 100t/ha fresh biomass. Incorporate when flowering, mulch finely and incorporate into the soil rapidly. Soil should be moist.
Weed control	Fast early growth crops, eg wheat, barley, oats Brassicas	Use 30% greater sowing rates than normal to outcompete weeds. 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. 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.

Soil Wealth
NURTURING CROPS

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.

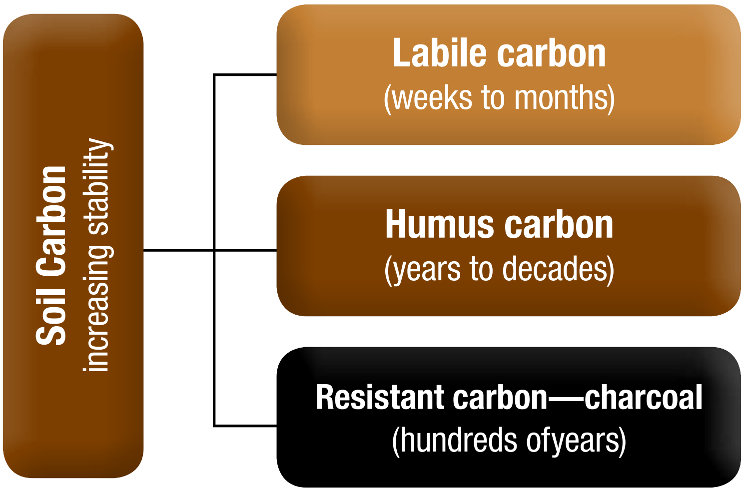

Diagram 1 The commonly recognised forms of soil carbon and their stability in soil.

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.

Carbon storage in vegetable soils

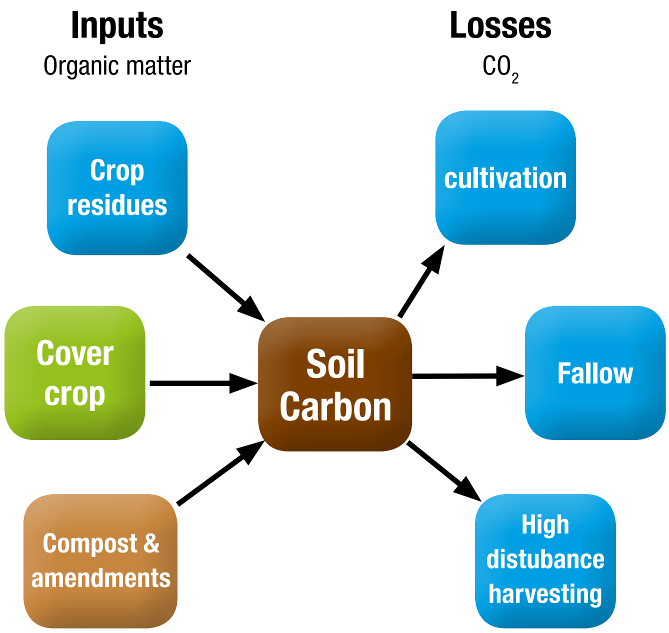

Diagram 2. Changes in soil carbon is mainly determined by how management affects the inputs of organic matter and their losses

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.

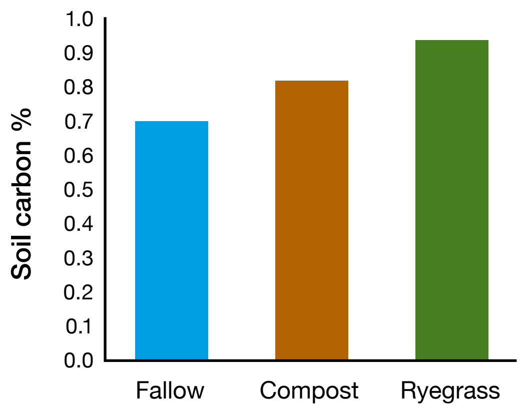

Figure 1. The ryegrass cover crop and compost were able to stop further soil carbon loses.

*Ryegrass and compost rates are in dry weights.