Regenerative Agriculture Principles in High Value Cropping Rotation

Can a healthy soil reduce the reliance on synthetic inputs?

A report for

NUFFIELD AUSTRALIA FARMING SCHOLARS

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Executive Summary

Worldwide, soil is being degraded and lost through misguided farm practices which severely depletes the capacity of the agricultural community to feed the world.

Expanding knowledge of the complexity of soil ecosystems, is awakening farmers to the services provided by the living component of soil. The soil provides ecological services that support life on the planet, yet many farming practices do not harness these services and rely heavily on synthetic inputs. This reliance is accentuated as soil degradation progresses.

Regenerative Agriculture (RA) defines a management paradigm aimed at restoring the soil ecosystem and is gaining momentum across the globe. As the soil ecosystem gains health reliance on synthetic inputs is reduced. This paradigm involves farming with nature rather than against it, to embrace soil complexity and living biology. The five principles for healthy soil management, underpinning Regenerative Agriculture are:

1. Keep the soil covered
2. Minimise soil disturbance
3. Diversity
4. A living plant all year around
5. Livestock integration

These five principles are derived from observing how nature sustains a living soil ecosystem and are used in a farm system to maintain a highly functioning soil while producing productive crops. Through many complex interactions and synergist links these principles maintain a highly functioning soil that supports productive crops.

While the principles are universal, the implementation is varied and diverse. Every farm is different, and each farmer needs to find ways to integrate the principles onto their farm. Strategies include cover crops, companion planting, cattle, crop residues, direct seeders, strip tillage, and relaying cropping, however, there is no simple recipe.

RA requires commitment to the soil and allowing time for soil to regenerate into a self-supporting system.

Despite the high amounts of tillage required in the high value cropping rotation farmed in Tasmania, there are methods that can be used to improve soil health and reduce the reliance on synthetic inputs. This will require investment in machinery and time to trial new ways to grow high value crops.

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Foreword

From a young-age I have had a strong desire to be part of the land. This desire led me into a career in agriculture, initially in seed potato production then research, and now in my current role at Botanical Resources Australia (BRA), working with farm managers to produce pyrethrum and other crops.

BRA is a world leader in pyrethrum production, as well as running 1,000 hectares (ha) of farmland to produce crops including: pyrethrum, poppies, potatoes, carrots, onions, wheat, pulses, brassicas, hemp and others.

Producing crops is getting more difficult due to increased pressure from disease, weed resistance, chemicals being taking off the market due to safety concerns, supply issues, resistance build up, and new pests arriving into Tasmania. These issues require high synthetic input for control, with the answer seeming to be to find another chemical, which only treats the symptoms not solves the under lying problem.

This left me questioning whether there is another way of farming. Nature has been able to sustain itself for millions of years, yet farming is not. There had to be a better way of farming to solve the increasing issues and the levels of inputs required to produce crops. Being introduced to Regenerative Agriculture (RA) has opened my eyes to how a fully functional soil ecosystem can support life on this planet and produce resilient crops without the need for synthetic inputs.

My aim with my Nuffield studies on RA was to discover how to improve soil health in high value cropping rotations in order to ensure we are farming long into the future with minimal reliance on synthetic inputs.

My Nuffield journey was over 110,000 kms long; between the Global Focus Program and my personal travels. I travelled for my project through the United Kingdom (UK), France, Belgium, Netherlands, Canada, and six states of the United States of America (USA). I visited cereal producers, organic growers and a handful of vegetable growers. RA has not been widely adopted in the vegetable farming community due to the complexity of integrating this system, and because vegetables are traditionally grown in regions of fertile soil that is more forgiving.

At the start of my Nuffield journey I thought I would find the answers that would allow BRA to transform cropping systems so as to not require many synthetic inputs. To this end, I investigated seeders, cover crop mixes and soil improvements to see whether these reduce the amount of fertiliser and pesticides required to grow crops. However, as the study progressed, I realised that before making systematic changes, there must be a paradigm shift from modern agricultural thinking to an understanding of nature and the principles behind maintaining a healthy soil. I also realised how difficult it is to regenerate the soil when growing vegetables, especially root crops.

This report doesn’t contain answers about how to implement RA, but rather clues and ideas of how the principles may fit into existing farming systems. It is up to each farmer to find contextually relevant ways to implement the five principles.

As one master of soil care would say “*it’s the change in thinking on the living soil that is the most important*”. It is my hope, through this report, that agricultural stakeholders are prompted to consider how existing farm systems are managed in such a way to maintain and improve soil health – a living entity –to produce high value crops. Further, I hope my report prompts readers to think about how the farming community can understand and work with nature more effectively in order to be able to farm, long into the future. We are naive if we think can control nature and farm against it.

As a final comment, it is worth remembering that our forefathers used to speak of methods that are associated with RA and used to farm in this way. It does not have to be challenging because these are not new ideas. So, hang in there and read with an open mind!

Acknowledgments

I am incredibly grateful to Nuffield Australia and my investors Blundstone, Tasmanian Alkaloids, Bruce Wall Trust and the Robert Gatenby Memorial Trust for the experience and opportunity given to me, to grow myself and my world!

A big thank you to Botanical Resources Australia and my colleagues, who made it possible for me to have extended periods of time away from pyrethrum production. Thank you too, to all the farmers I work with who have been so understanding and supportive of my new knowledge, and who have offered so many words of encouragement and willingness to try new things.

To my family, especially my Dad, who made it possible for me to be away from home for so long – by looking after my Jack Russell, Maggie. Your love, support and belief in me got me through this life changing experience. I extend that to everyone in my life; many people supported me along this journey, kept me going in the tough times, dealt with all the tears and stress, and listened to my endless chatter and ideas, helping me to sort my thoughts. I am forever grateful for what you have done.

Thank you to all the soil carers of the world, who generously gave their time to share their passion for soil and hosted me along the way. This willingness to open your doors and farms to me, help with translation and arrange visits is what made this trip even more incredible. And to Rick Bieber, who went above and beyond what anyone could ever expect, thank you.

Figure 1: At Cereals in the UK with big boots required to take on this Nuffield journey, June 2018 (author)

Abbreviations

BRA – Botanical Resources Australia

CTF – Control/ed Traffic Farming

FAO – Food and Agricultural Organisation

Ha – Hectare

OM – Organic Matter

RA – Regenerative Agriculture

MR - Mycorrhiza

USA – United States of America

UK – United Kingdom

Objectives

To determine if a healthy soil can be a means of reducing the synthetic input requirements to produce a crop.

This objective was broken down to the following aims:

- To understand the five principles of healthy soil underpinning RA, to improve, restore and regenerate the soil in agricultural production systems.
- To investigate how the principles can be integrated into a high value, intensive cropping system in order to improve the health of the soil.
- To understand whether establishing a healthy soil in a production system is a means to reduce the synthetic inputs required to produce a profitable crop.

Introduction

The maritime climate, reliable rainfall, irrigation schemes and highly fertile red ferrosol soils of the North West coast of Tasmania makes it an ideal place for growing a diverse range of vegetable and high value crops such as poppies and pyrethrum. These natural advantages are attractive to vegetable and botanical based businesses, who contract farmers to grow their products. High land values and intensive farming systems are the norm as farmers meet contract demands and pay for the land.

The reliance on synthetic inputs, in order to produce healthy and high yielding crops, has increased over time as the fertility of the soil declines. Diseases are becoming resistant to fungicides, weed control is more complicated due to high weed pressure and resistance to the chemicals used, new diseases are affecting crops, and higher fertiliser requirements are needed to push for yield. In recent times, poppy crops have been hit with systemic mildew, which severely decreases yield, and pyrethrum diseases are building resistance to the limited fungicides that are available. Currently, the answer to these 'problems' is to reach for more and different chemicals (Wood, 2018). However, the list of chemicals available is becoming limited due to resistance build up and deregistration for human and environmental safety. Solutions need to be found to maintain high production long into the future.

The problems being solved by synthetic inputs are actually 'symptoms' of an inherit problem that is occurring at a deeper level. Degrading soil is losing its ability to provide the ecological services which support life and growth. Soil is being lost through erosion, organic matter (OM) levels are dropping, aggregate stability and structure is reducing, and falling biology diversity, is all resulting from agricultural practices. This phenomenon is not confined to the North West coast of Tasmania; it is happening across the world.

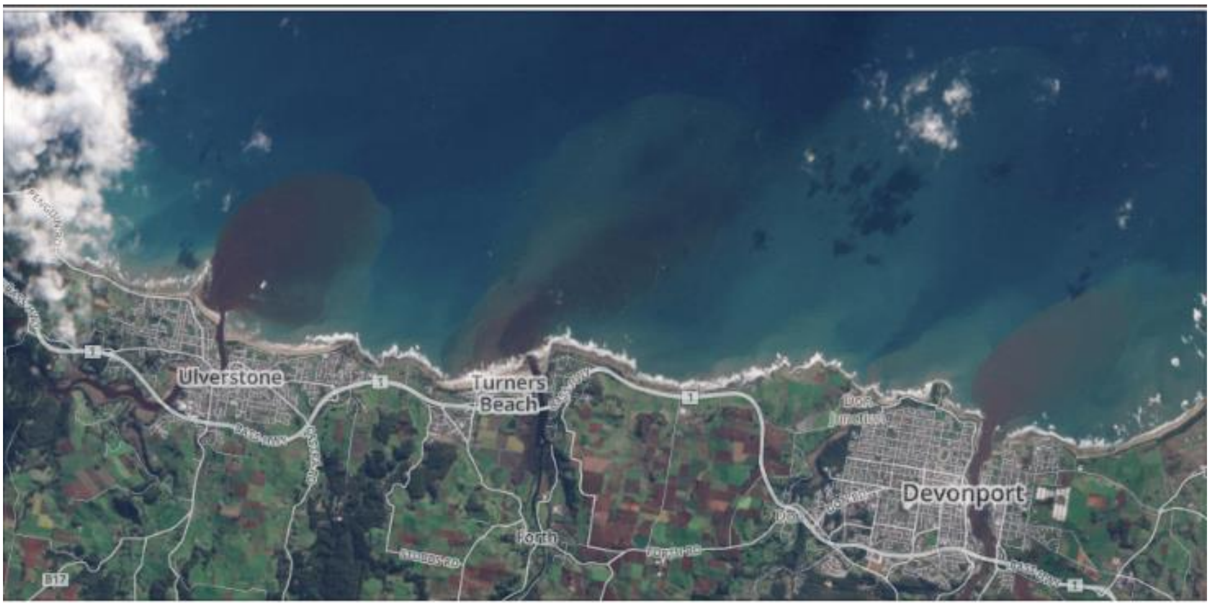

Figure 2: Aerial footage of eroded soil washing into Bass Strait from farmland on the North West of Tasmania after one rain event. July 2018. Source: John McPhee

Across the world, 75 tonnes of valuable soil is lost each day from agricultural land (Savory, 2018) and it has been quoted that there are as few as 60 seasons left in the soils of the UK and USA. This augurs an imminent crisis. The Food and Agricultural Organisation (FAO) of the United Nations is now turning to Sustainable food production systems based on sustaining soil to help reach their Sustainable Development Goals by 2030 (FAO,2011,2018).

Soil is made up of three components chemical, physical and biological, the interaction of all three determines the health of the soil. In the past emphasise has been placed mainly on the physical and chemical components however it is now emerging that Biology plays a critical role in the formation of soil from base rock and is the corner stone of forming and maintaining a healthy soil that provide a multitude of services. Plants also form a critical link in the evolution of bed rock into a complex soil ecosystem and maintaining this functioning ecosystem (Bieber (c), 2018; Willams,2018).

Figure 3: Plant community working to produce soil from parent material. Devils Tower Wyoming, USA, August 2018 (author)

The ecosystem of soil is a magnitude of life that is working together to survive, thrive and keep everything in balance/harmony. Despite the underground world of soil being treated as separate from the above ground, there are interdependent interactions between both. Plants provide the link between the two worlds. Sunlight is captured through photosynthesis and resulting carbon molecules are pumped into the soil through root exudates providing the energy source for the ecosystem. These root exudates feed the soil microbes in return for nutrients, water and complex carbohydrate molecules that are needed for plants to grow, survive and produce their own defence mechanisms, creating a positive fed back loop. A healthy plant creates a healthy soil, and vice versa (Williams (b),2018).

Modern agriculture has failed to adequately observe nature, failing to understand how the soil ecosystem has evolved and now functions. Instead, modern agriculture takes a more simplistic attitude towards soil, seeing it as a medium rather than an ecosystem, reducing the system.to monocultures, straight lines and high cultivation, with a high level of control. This system degrades the soil, leaving the biology starving and homeless resulting in death (Nichols, 2018), hence turning the soil into dirt, which requires intervention and synthetic inputs to make it function and support life. More than 0.3% of world food production capacity is lost each year through erosion and soil degradation, and great areas of land are abandoned each year (UN Global Sate of Soil Assessment, 2015 in Montgomery,2018).

Reductionist management by humans takes the system out of balance so that it can't support itself, hence requiring high levels of weed, disease and insect control. Despite our natural desire to manage the farm system in a reductionist style, there is a farmer led movement across the globe that is understanding the complex and dynamic nature of soil and the farm ecosystem, requires holistic management (Savory, 2018). And if soil is managed in this way the heavy reliance on synthetic inputs can be reduced. This style of farming is based on an understanding soil as a living entity and managed accordingly; a complete paradigm shift from modern agriculture, its polycultures and complexity and embracing what we term as 'mess'. This farming is called Regenerative Agriculture.

Chapter 1: Regenerative Agriculture

RA a farm system built around mimicking nature's management to regenerate degraded soil and restore it to a highly functioning soil ecosystem that is able it to support and sustain healthy plant growth and the long-term future and profitability of the farming business. This in turn benefits the wider landscape, the people and the local community and beyond (Emmons,2018; Massy, 2017; Thomas,2018). The primary focus of RA is a highly functioning healthy soil, which subsequently improves the quality of food produced and social aspects of farming.

Healthy soil is defined as the capacity of the soil to function, sustain life, healthy plants, animals and humans (Nichols, 2018). There are five principles of maintaining a healthy soil. These principles are based on observations of the natural ecosystem and how soil is managed in nature to maintain the balance and services required to support healthy plants. The principles are:

1. Keep the soil covered
2. Minimise soil disturbance
3. Diversity
4. A living plant all year around
5. Livestock integration

An understanding of the principles is critical to progress in RA. Only with an understanding of the 'why', that a well thought out 'how' plan can be established and implemented to improve the soil. This understanding provides the ability to critically analyse farm practices, to identify practices that degrade the soil, and to understand what could be improved to repair and achieve a highly functioning soil system (Bieber (c), 2018) that does not require synthetic inputs to produce crops.

Thoughts on the principles varied across the globe with the majority of UK and European farmers working on conservation agriculture principles utilising three principles. RA is similar to conservation agriculture, except that it has a greater level of complexity and appeared to achieve more resilience in the soil and farm business. Conservation agriculture principles, although a step above modern agriculture in terms of restoring and maintaining soil, misses key points vital to make a soil function, and appears to be driven largely by government subsidies. Farmers focus on compliance for farm subsidy payments, while few fully understood the soil and the reasons for the practices. Farmers in the USA practising RA appeared to have a better understanding of the principles of a healthy soil and were focused on implementing well thought out practices and tools that integrated all the principles.

The five principles

Keep the soil covered

Covered soil is nature's default! The cover includes deep layers of litter and/or growing plants This coverage protects the soil and keeps the environment favourable for soil biology. Wind, sunlight and raindrops negatively impact exposed soil. Wind removes small particles, taking away valuable soil as well as OM and nutrients that are adhered to the particles. It will also contribute to the evaporation of the stored soil moisture critical for the life of soil biology and any plants that may be growing. Water reserves are also depleted by direct sunlight heating the soil, also making conditions unfavourable for soil biology. The same is true when there are cold events, with the soil cooling down or even freezing. Coverage of the soil buffers these extremes to maintain stable temperatures favourable for soil biology. See Table 1 for comparisons in soil temperatures in bare and cover soil.

	Covered Soil	**Bare Soil**
South America	30C	55C
Iowa	25-32C	34-64C

Table 1: The temperatures recorded in soil covered versus bare soil in two regions of the world. Calegari, 2018; Teachout, 2018

While water is critical to the whole system, it can also damage bare soil. Water impacting uncovered soil exerts high pressure, displacing soil particles, creating disturbance and compaction to the soil structure, and initiates water erosion.

The importance of keeping soil covered is not widely recognised. In Tasmania, periods of fallow are commonly used over winter to control weeds and help with ground preparation before spring sowing. During the growing season areas of soil are exposed to sun, wind and chemical applications. Again, lack of soil coverage causes high levels of erosion, soil degradation, and an escalating war on weeds. But weeds or 'undesirable' plants are the quickest way for nature to cover and protect the soil. Plants are nature's band aid (Thompson, 2018).

Reduce soil disturbance

In nature, soil disturbance is rare, generally created through natural disasters such as weather events or localised disasters such as trees falling or over grazing. When these disturbances occur, there is immediate establishment of plants to cover the soil. In an agricultural system soil, disturbance is regular and comes in the forms of biological (overgrazing plants), synthetic applications and tillage (Fuhrer, 2012). Typically, the soil is left bare for long periods of time after the disturbance with the use of multiple applications of herbicides, further disturbing the soil biology and preventing nature's healing process - plants.

Soil disturbance is where the most damage is done to soil biology as it radically changes their environment, breaking down the soil aggregates (Lungren,2018; Nichols, 2018), destroying their modes of transport and physically killing them (Bieber (c), 2018). Regular tillage/disturbance limits the time for the biology to recover (Bieber, 2018) with pest species usually the first to recolonise and the species that control these pests the very last to return (Clapperton, 2018). Mycorrhiza (MR) fungal communities, critical for soil and plant health through mineral and water exchange, chemical signals and glue production to form aggregates, are easily killed by any forms of disturbance (Archeluta, 2018; Jones, 2018; Phillips, 2018; Williams (a), 2018).

High value crop rotations use intensive soil cultivation, such as deep ripping, powered implements and other machinery to prepare for planting and harvesting. The seed used is small and requires fine tilth for establishment, crops require uncompacted soil to grow and seeders require minimal trash to work efficiently. High levels of soil disturbance occur when harvesting root crops such as potatoes, carrots and onions. However, there are options available to reduce soil disturbance beyond current practices including direct (disc) seeders and strip tillage equipment and ideas not thought of yet.

Figure 4: Direct seeded cover crops into high levels of residue covering the soil. Dakota Lakes Research Farm, North Dakota, July 2018 (author)

Diversity

Diversity is a key component of building a highly functioning ecosystem and is one of nature's greatest tools. In a farm system diversity is required in every aspect of the farm system e.g. plant species, root structures, microbial species and populations, soil organisms, enterprises, skills, equipment, minerals, insects etc. As Brendan Rockey from Rockey Farms in Colorado says, *"we love diversity on this farm and it's all about diversity, diversity and diversity."* Diversity builds resilience, flexibility, resistance and is the ultimate insurance for an ecosystem

(Clapperton, 2018). If diversity is not present in the soil, it is not resilient when 'disasters' or extremes in weather are experienced. It is why monocultures will not survive a drought, but a diverse ecosystem will (Jones, 2018). As demonstrated in trials at Green Cover Seeds in Nebraska (Gunderson, 2018) and seen in a Tasmanian poly tunnel (Figure 5). The phenomenon occurs through 'Quorum Sensing' a new scientific discovery in diversity reaching a critical tipping point at which point collaboration occurs (Jones,2018).

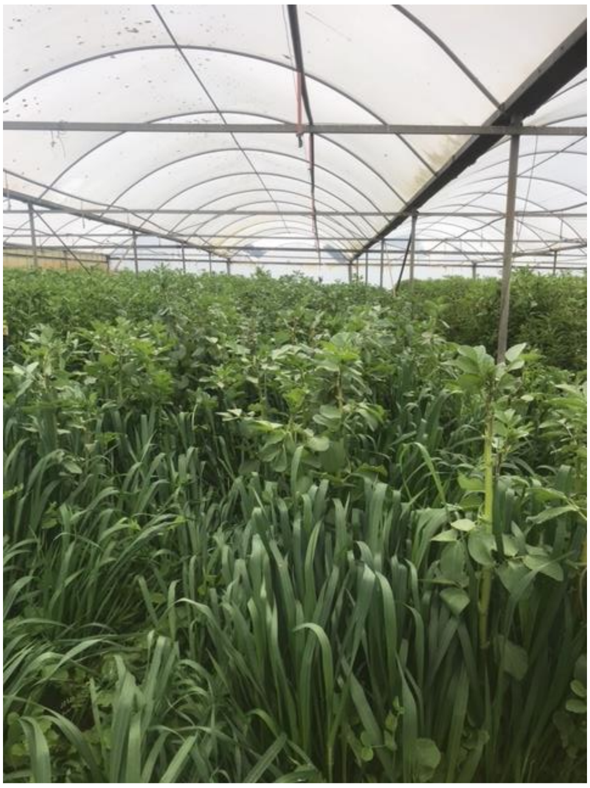

Figure 5: Diverse cover crop (eight species) grown in a polytunnel, after receiving its last irrigation 4 month earlier. North West Tasmania (author)

The soil ecosystem requires a diverse array of plants to supply a continual supply of exudates to the soil and each plant produces unique root exudates that support different microbial communities, in turn unlocking and supplying different minerals, nutrients and compounds (e.g. amino acids, amides, nitrates and plant growth regulators) all required to maintain a healthy plant (Bieber, 2018; Clapperton,2018;Jones, 2018;Williams (a), 2018).

In modern agriculture, diversity is removed from the system to bring simplicity to management however, monocultures don't work to maintain a resilient soil ecosystem (Emmons, 2018). Through recent scientific discoveries and farmer observations in diversity trials, a greater value is being placed on diversity in the farming system.

A living plant all year round

Living plants are key to a soil ecosystem as they are the means of food or energy entering the soil ecosystem and for the soil to be covered. Plants exchanges on average 30% of its captured carbon to the soil to feed the fungi and bacteria at the bottom of the food chain, which are critical to provide plant foods, help in OM formation and maintain soil structure. This relationship is a positive feedback loop whereby the plant gives carbon molecules, and the biology supplies 'food' in return to ensure the plant continues to grow and supply carbon back. If carbon is not supplied to the system, e.g. through a fallow, a starvation period will be experienced and the biology will resort to eating the stored OM in the soil, depleting the reserves (Clapperton, 2018). If there is no residual OM for the microbes they die and the soil becomes lifeless, losing structure, becomes compacted through vertical erosion and requires cultivation to achieve a suitable growing medium (Kitteridge, 2018).

In a natural system there is an array of species grown in a small area, at various stages of their life cycle. This ensures that a living plant is growing all year round, supplying carbon to the soil and covering the soil through the summer and winter periods. These plants can be categorised into warm and cool season broad leaves as well as warm and cool season grasses (Bieber (c), 2018;Davis,2017).

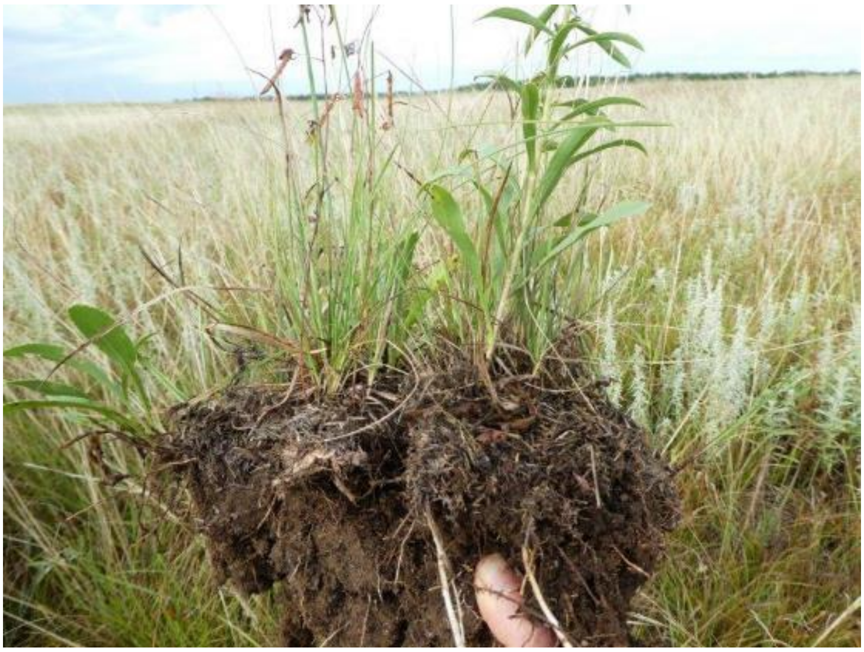

Figure 6: A diverse range of Prairie species, at various stages of life, Bieber Farms, South Dakota, July 2018 (author)

In a modern cropping rotation, there are long periods of starvation through winter fallows, and during the growing season of monocultures which only supply a narrow range of carbon molecules that only support a narrow range of biological communities. All of which leads to soil degrading and continuing need for cultivation year on year, leading to further break down of the soil ecosystem.

Integration of livestock

Plants and animals have evolved together resulting in a synergistic link between plants, animals and soil (Lungren,2018). This link between animals and soil health has only recently been recognised. Animals are now thought of as the engines of soil restoration and soil health accelerators, through spreading nutrients, providing manure (recycled carbon) and distributing microbes from their guts to the soil to help restore balance (Emmons,2018; Montgomery, 2018).

Livestock need to be managed extremely carefully, as incorrect management will lead to rapid soil degradation and the positive benefits lost. The management style must mimic the way native animals move through the landscape which is large herds continually moving through the landscape driven by predators, leaving behind large amounts of vegetation. The grazing stimulates the plants to regrow and pump more carbon into the soil to obtain the required nutrients to regrow. High stocking rates and moved often, is the best way to manage livestock to ensure soil is not damaged. If used successfully, livestock will restore the soil at a much quicker rate and help it to produce higher yields and income in cash crops.

In Tasmania, cattle have been regarded as highly destructive to the red ferrosol soils highly prized by cropping farmers. Fences have been eliminated to remove any temptation to allow cattle onto the land (Cables, 2018). Although, this perceived damage created by grazing cattle may not actually be the case, as George Hoiser experienced in the UK. Despite a high degree of pugging from winter feeding, direct seeded peas into the field, grew the highest yielding crop of peas in that field.

The integration of cattle can be the hardest of the five principles to adopt and may not be absolutely necessary. It is not widely viewed as an important part of restoring the soil throughout Europe. However, the integration of livestock is starting to be adopted in Europe as the American farmers experience filters through. The American farmers were first introduced to the idea from South American farmers (Thompson,2018).

System approach

The above five principles go hand in hand to regenerate and maintain a functioning soil that can support healthy plant growth and produce crops/plant with very little intervention. There are many interconnections and relations interwoven between all five, that must be integrated and thought of as a system. The system will function when a principle is ignored however once the number of principles being used drops the system will not function as smoothly as desired and a reliance on synthetic inputs along with cultivation will be required to produce a high yielding crop. Soil degradation, lost production and high inputs will be the result of neglecting the five principles of nature’s management (Bieber(c), 2018).

Through the conversion process there is the potential for many mistakes to be made and new issues to arise as one navigates the new frontier of farming with natures principles and restoring the soil ecosystem to balance. Initially the balance in the system is not there and more issues will be experienced when integrating the principles into a system e.g. slug infestations in newly converted fields to no till (Javis,2018) which was an issue expressed all around the world. Despite the unknown, risks and potential failures along the way, it is important to have an understanding of the system being integrated so one can evaluate why something many not have worked as planned (Harding, 2018).

This method of farming is complex, management heavy (Bailey, 2018) and challenging when considering how the thoughts and technologies of modern agriculture can be integrated, or not, in this new paradigm of farming with a living soil. It requires one to unlearn conventional wisdom, to embrace and understand the complexity of how the soil ecosystem and nature works (Bieber (c), 2018;Massy, 2017 p50-52). One must have the strength and ability to walk away from the security of conventional wisdom and the current agricultural recipe of preparing soil and growing crops. It is often difficult to start as there aren't people in the local area to learn from and tools such as seed and equipment aren't readily available (Brunault, 2018). Despite this, the growing movement of brave souls across the globe swimming against the tide of industrial agriculture are willing to share their experiences in order to prevent others having to start from ground zero and experience the hardship of failures. Although, it is up to each individual to put in place trials and determine how each of the five principles can be integrated into their system.

Chapter 2: Implementation – Tools of the Trade

While the principles of healthy soil are universal, differences in soil types, farm systems and environments mean there is no universal way to implement them. However, there are some basic starting steps. The first step in implementation is to fully understand the rotation and identify areas in the farm rotation where the principles could be used to support the soil (Berland,2018). The second step is to find methods and tools that could be used to integrate the principles into the system. Often the tools used will help integrate interrelated principles.

Keep the soil covered

Residues

Crop residue can be incorporated or retained as soil cover. Uniform spreading of residue is critical, as unevenly spread residue leads to problems arising (Jasa, 2018). In South Dakota, the clumps of residue gathered in one area had pooled water, remained wet and then caused deep tyre marks after spray application, leading to severe erosion (Bieber (c), 2018).

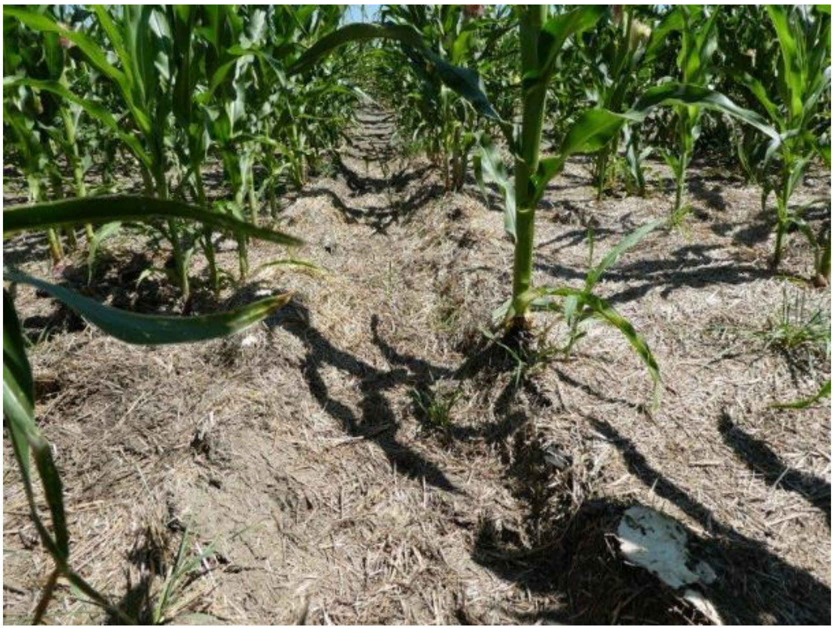

Figure 7: Residue spread unevenly resulting in water logging, compaction and erosion. South Dakota, July 2018 (author)

A high lignin or carbon-to-nitrogen ratio ensures residue remains for a long as possible (Thompson, 2018) and this needs to be managed as the system evolves and the biological activity increases (Teachout, 2018). American farmers had embraced the soil coverage principle and had the highest levels seen on regenerative farms across the world. Vegetable and organic farmers visited weren't utilising residues due to limited crop residues remaining after harvest and the high level of tillage require to prepare seed beds and control weeds. Other ways of covering the soil could be explored such as seeding straight into residue or cover cropping with plants.

Reduce disturbance

Equipment and direct seeders

Throughout the community of farmers practicing RA, the shift to reduced cultivation is the highest priority. Direct seeders are used to seed cash and cover crops directly into living or dead vegetation, and if cultivation is required every effort is made to reduce the depth of cultivation and the number of passes required to prepare the seed bed (Muratori, 2018). Cultivation is being reduced in incremental steps to ensure repair time and the gradual adjustment of the soil, and to allow production to remain viable. There is also a move away from the powered implements such as power harrows which excessively damage soil (Javis, 2018). Machinery is a big part of a farming operation and is often where farmers turn when contemplating change. However, understanding agronomy and rotation (Bailey, 2018) in conjunction with the principles are needed before making choices. Julian Herault (2018) will not advise farmers on the equipment and seeders needed for the system until they can tell him their goals, soil type and the rotation to be used.

There are many seeders available with no common machine used across the farms visited, which makes the task of choosing a seeder quite daunting. What style and brand working for one particular farm and what level of soil disturbance was tolerated, varied across farms. Throughout England and Europe, it is common for farmers to own or share two seeders, a tyne seeder and a disc seeder, due to the heavy soils being farmed and the varying conditions encountered at sowing time. The tynes create more soil disturbance and are considered a minimum tillage option, while a disc seeder is considered a no tillage option. Throughout USA and Canada, disc seeders are the seeders of choice with farmers more conscious of being no tillage farmers and creating the least amount of disturbance possible to support soil biology. They have the advantage of growing only combinable crops that respond well to a no till system. No till is currently not an option when growing root crops, however there are options to reduce soil disturbance. In France and Belgium, strip tillage is used in sugar beet and beetroot production to reduce the amount of soil cultivated. Barfoots, a large vegetable producing company in the UK with farms across the globe, acknowledged that strip tillage was the way forward for sweet corn and other vegetable crops but were not in the position to introduce it to their system in the near future (Dellicott, 2018).

Large investments in machinery are required to change to reduced disturbance yet it is important to first have proof of concept by retrofitting equipment already available on the farm before investing heavily (Teachout, 2018). Due to the emerging nature of this farming style, often the equipment is not available and needs creative thinking in the workshop to create what is required.

Control Traffic Farming (CTF)

Controlled traffic farming (CTF) is a practice where field traffic is confined to permanent wheel tracks. Control of traffic ensures that compaction is confined to defined tracks, enabling the other parts of the field to recover with minimal compaction. Reduction in wheeled traffic sees a noticeable and measurable difference in soil and the system, often observed within the first year (Hinrichson, 2018; Dellicott, 2018). See Table 2 below for benefits of CTF.

Company/Farm	Country	Crop	Results
Nathan Dellicott Barfoot,	UK	Vegetables	- Improved root systems - Balanced nutrition - High selling yield
John Huiberts	Netherlands	Tulips, Bulbs	- 10% increase in yield
Stephen Briggs, Whitehall Farm	UK	Agroforestry Apples Cereal	- Improved soil life
Matt Radford, Burwash Manor	UK	Organic Asparagus Cereal	- 8m tramlines - soil benefits
Derek Axten, Axten Farms	Canada	Mixed grains	- Means to an end - Many benefits to system
Rick Bieber Bieber Farms	USA	Mixed grains	- Doesn’t see the benefit

Table 2: Control traffic farming experiences observed across the world (author)

Despite vegetable production requiring high levels of tillage the use of CTF appears to be a tool that can be integrated to ameliorate soil damage. In the past CTF has been trialled in Tasmania’s high value cropping rotation with very good results but adoption is difficult with the variety of crops grown and equipment required for harvesting. CTF is probably best done on a seasonal basis and forgotten about come harvest time. Yet the Barfoots experience in improved yields suggest that it is something worth working towards.

Diversity

Annual cover crops

A cover crop may comprise one or more species grown between cash crops to benefit the soil. A cover crop will feed the soil, help with weed control and maintain soil moisture, add nutrition, such a nitrogen, trace minerals, and most importantly, bringing carbon molecules in to the soil during a time of usual starvation (Guy,2018;Jasa, 2018), help alleviate compaction and build soil structure. Cover crops are a means to integrate all five healthy soil principles at once.

More than three species should be used in a cover crop to maximise the benefits (Bieber (c), 2018), with trials suggesting that the best results are achieved with eight or more species (Jones,2018;Clapperton, 2018). Farmers in the USA are using mixes of up to 30 species to further increase the diversity. David Guy (2018) has found that multispecies cover crops significantly reduce weed numbers while a monoculture cover will always result in weeds. This observation is backed up by studies that show weed suppression with polycultures (Williams, 2018).

Figure 8: A handful of cover crop seed. GreenCover Seeds - Nebraska, USA. August 2018 (author)

The choice of cover crop mix depends on the end goal of the cover crop and needs to consider families, species, bacteria and fungi associations, nutrition requirements and supply, what herbicides can be used, future weed or disease risk, the method of cover crop termination, and the time frame for growth (Bieber, 2018;Calegari, 2018).

Barriers to growing cover crops in Tasmania are the extra work and increased costs. Seed can be difficult to obtain and costly, and there are difficulties in dealing with the cover crop in spring to obtain a suitable seed bed for the crops grown and equipment available. The ability to deal with cover crops in spring was something that many farmers struggled with and tried to avoid (Guy, 2018;Barol, 2018;Curtis, 2018), and in Tasmania there is the added complication of no winter frost kill or natural senescence of species. In France, cover crops are terminated using a roller before a forecast frost (Herault, 2018).

Despite the barriers seen with cover cropping there were many innovative ways cover crops and diversity where being incorporated into various systems. In France and Belgium, cover crops are being planted in autumn on prepared potato mounds to counteract soil disturbance as well as increasing the diversity of plants on what is usual bare soil (Leforestier, 2018).

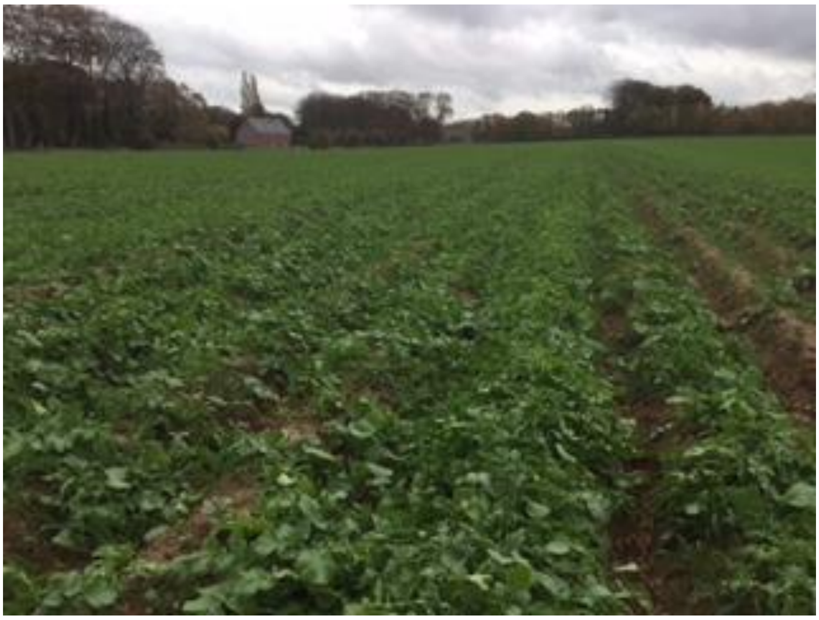

Figure 9: Potato mounds prepared in autumn and sown with cover crops for winter. November 2018, France. Source Victor Leforestier (author)

Perennial cover crops

French and English farmers have been investigating the potential of perennial cover crops under a cash crop to mitigate seed and seeding costs associated with cover cropping (Briggs, 2018;Mallard, 2018). The species being used are mainly in the legume family and include clovers and lucerne. Matt Radford (2018) is using trefoil under sown in his organic cereal crops, sowing the cereal in autumn into the dormant trefoil. This is also helping to keep the cash crop growing longer through moisture capture and other potential interactions. The use of a perennial cover can take some time to learn how to manage and some are questioning if it is worth it (Cowell, 2018; Barol, 2018).

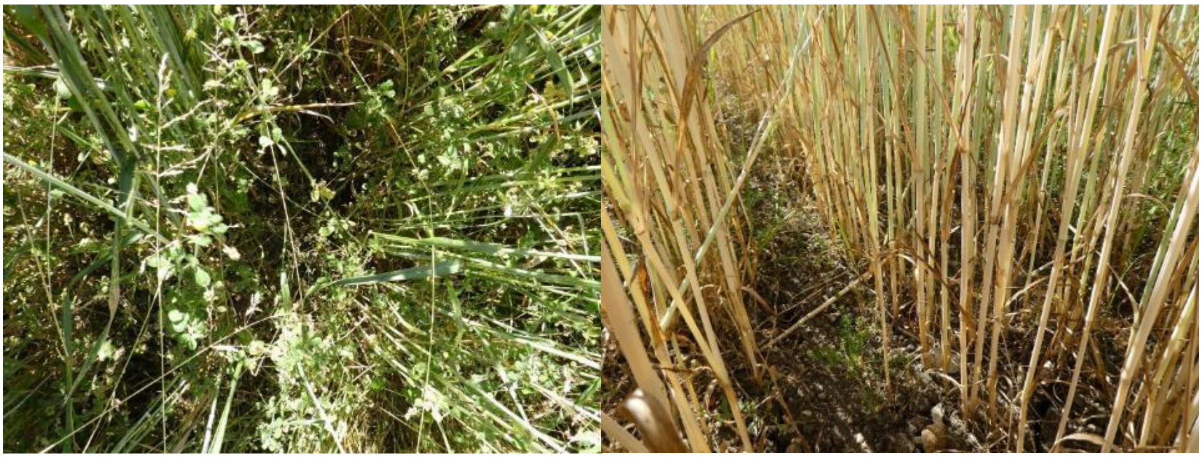

Figure 10: Organic spelt crop growing with a permanent cover of trefoil versus grown without terfoil. Burwash Manor Farm, Cambridgeshire, UK (author)

Other means of reducing the seed cost was the establishment of co-op style groups or farmer groups that can buy seed in bulk and provide mixtures (Muratori, 2018) or using the barter system to swap seeds between growers. There could be a business opportunity in providing small batches of unusual plant species in Tasmania as interest grows in cover crops.

Companion planting

Companion planting is planting different species together to obtain benefits for the cash crop production. Companion plants are used for insect control, increased yield, increased diversity, improved crop nutrition, help with crop structure and harvesting etc. Companion planting has been widely adopted in the home garden and small-scale agricultural operations but rarely in broad acre agriculture. In recent times it is being utilised on a broad acre scale with interesting results and benefits that are not yet fully understood (Axten, 2018;Guy, 2018). A trial, in France showed that wheat grown with peas in separate adjacent blocks, produced 4.7T without nitrogen compared to 6.3T with nitrogen applied, but when grown together, as a mix 6.4T was produced with no nitrogen application (Guy, 2018). This trial suggests that companion planting benefits the farm system in increased diversity and increased profitability through reduced synthetic inputs.

While most companion cropping results in all species being harvested there are incidences where some species are planted solely to aid the production, through nutrition, insect protection, support and/or harvesting ease. Derek Axten (2018) in Saskatchewan is planting linseed with lentils, to provide support to keep them standing throughout the growing season, reducing the need for fungicide and aiding in the harvest as the lentils are not flat on the ground at harvest. The linseed is a sacrificial crop. This was also being trialled by Andy Howard (2018) in the UK, and by Jeremy Wilson (2018) in North Dakota who had a whole farm trial using this method. In other companion planting both species are harvested together and separated after harvest, through a seed cleaner. Examples of these combinations included chickpeas/linseed, peas/canola, wheat/faba beans, faba beans/oats. Andy Howard (2018) obtained 15% more yield growing faba beans with oats and 0.75 tonne extra oat yield when grown with clover. John Martin (2018), did not achieve a yield increase but a decrease of 20% when trialling companion planting. However, he is interested to investigate the quality of grain produced in future, as there is a body of evidence to suggest this will be the case.

Figure 11: Chickpeas and flax companion planted - Axten Farm, Saskatchewan, Canada (author)

The use of companion planting has been successfully used to reduce and/or eliminate pest attack on crops, particularly canola. Canola is notoriously hard to establish as it is attacked by insects and birds. Winter beans were used in England to eliminate pigeon damage (Miller, 2018) and buckwheat was planted with sunflowers to supress weeds with the added benefit of reducing seed loss to birds (Guy, 2018). Growing canola with companion crops such as faba beans, lentils, fenugreek, trefoil and vetch, eliminated the need for insecticides, compared to seven insecticide applications in monoculture canola (Guy, 2018;Mallard, 2018;Walston, 2018). The farmers using this method of insect control have the benefit of the species being winter killed due to frost.

Figure 12: Sunflowers and buckwheat planted together to help with weed control and bird damage, Sky Agricultural, France, July 2018 (author)

It was not only with grain crops that companion cropping is being utilised, in the Netherlands onions are being planted with carrot crops to prevent carrot fly attack (Huiberts, 2018). Peas, chickling vetch, chickpeas and fababeans are grown in potato fields to add diversity, increase nitrogen levels and help beneficial insects colonise the crop (Leforestier, 2018; Rockey, 2018). This method has potential for Tasmania.

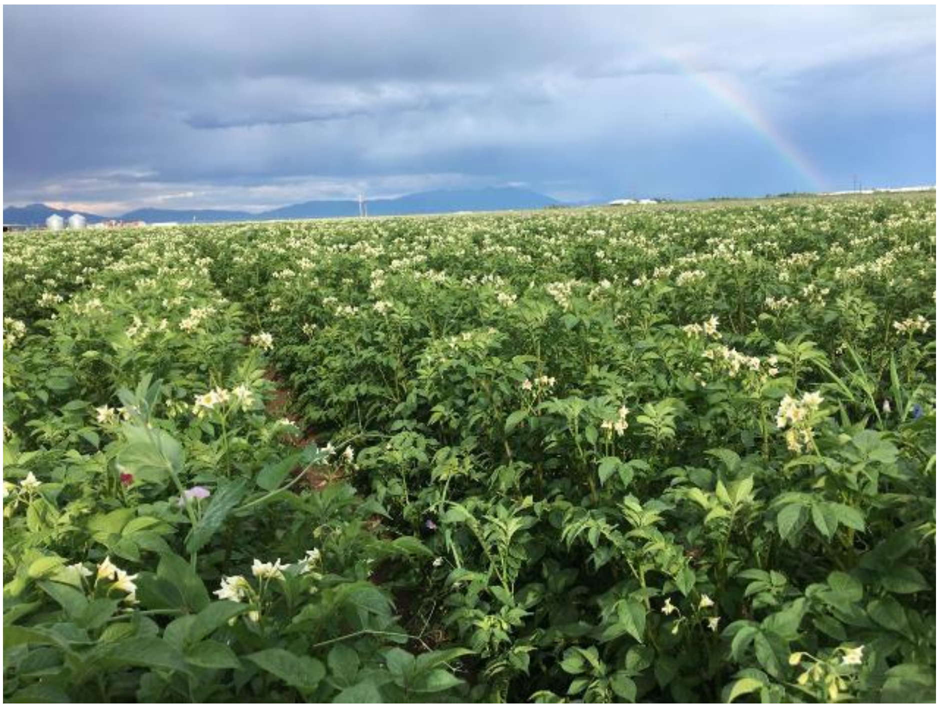

Figure 13: Peas, chickling vetch and chickpeas planted with potatoes. Rockey Farms, Colorado July 2018 (author)

Compost/OM addition

The use of compost and compost products such as teas and extracts to add OM, nutrition and diverse array of biology is widely used in the RA community to help build the soils resilience, with some believing it is not possible to farm without compost or OM additions to the system (Berland, 2018). As Nathan Free (2018) commented, "*you will be amazed at how many problems this black stuff solves!"*. The cost of compost can be prohibitive unless there is a cheap source of readymade compost or materials used to make compost. The sources of ingredients used included city waste, wood chips, manure (cow, horse, chicken, pigs), straw, animal bedding, plaster board, biodigestates, fly ash from boilers, rock meal, grass, vegetable waste, (Axten; Boral; Cowell; Free; Hawkins; Leforestier; Mallard 2018).

Varying degrees of care was observed in the making of composts depending on the outcome desired from the addition. Some farmers were not concerned about the quality and others placed great emphasis on the compost making process, ensuring the right materials were used and the biological communities were in the right proportions (Axten, 2018;Teachout,2018). Compost biological components were also being tailored to particular crop requirements, for example a daffodil crop requires a compost high in fungi, where tulips do better with a bacterium compost (Huiberts, 2018).

Compost addition was a major component to help build soil resilience at all the farms visited, producing vegetables or needing high tillage (table 4). Compost is not widely used in Tasmania in intensive cropping rotation, however it could be integrated into the system to help with OM addition and biological inoculants to help the soil ecosystem while high levels of tillage are required.

Farm	Country	Crop	OM Input
Gs,	UK	Vegetables	Composted waste from their factory Sources manure
Barfoots	UK	Vegetables	Biodigestates
Rockey Farms	USA	Potatoes	Bought compost Liquid OM
Kalfresh	Australia	Carrots, onions	Compost made on site, 4T/ha

Table 3: OM additions on farms with high tillage requirements (author)

A living root all year

Multiple crops in a year

Double cropping has been introduced in France to reduce cultivation and improve weed control and help keep a living root in the ground. Barley is harvested in July, buckwheat and winter wheat is planted straight after harvest, the buckwheat is harvested in late September and the winter wheat the following season.

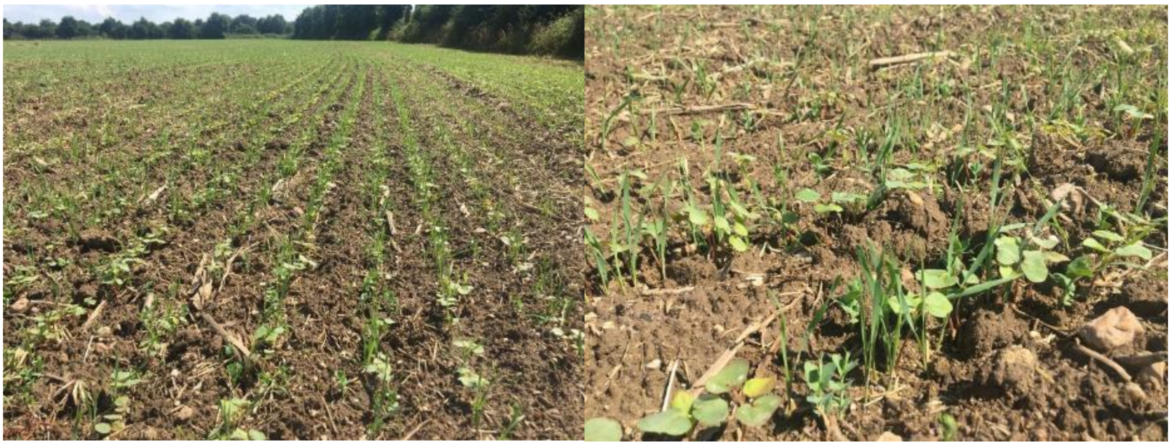

Figure 14: Buckwheat and winter wheat, 6 weeks old, planted after barley. France, July 2018 (author)

Relay cropping

Relay cropping is a version of double cropping where the second crop is planted into an already established crop. For example, cover crops are broad cast or sown into an existing crop, to have established plants at harvest. This leaves the soil continually covered with green leaves and no period of starvation for the biology. In Iowa, rows of soya beans are planted between rows of established barley and the crops are harvested at different times through modified cutter front on a combine (Steinlage, 2018).

Figure 15: Soya beans and barley relay cropped - Loran Steinlage, Iowa. August 2018 (author)

Livestock

Livestock, in particular cows, help to integrate a number of the soil principles as they utilise the biomass produced from cover crops, are a means to terminate cover crops grown (Montgomery, 2018) and provide an income stream from crops grown to improve the soil (Sims, 2017). George Hoiser (2018) suggested the addition of cows to the system is similar to spreading compost but requires a lot less work. Keith Thompson and Jay Furher (2018) have found that every field where diverse cover crops were grazed over five years, have set yield records when returned to cropping. The addition of livestock requires careful management, with a different skill set to crop production. There are many ways to bring livestock to the system, see Table 4.

Farmer	Country	Livestock Type	Source of Livestock
George Hoiser	UK	Sheep and cattle	Contracted/ grazed on pastures, cover crops
Brendon Rockey	USA	Cattle	Agisted cattle managed by the Rancher on cover crops
Tim May	UK	Sheep, dairy and beef cattle, chickens	Share farming each animal type
Jerry Doan	USA	Cow/Calf pairs	Contract grazed on cover crops
Gs (Charlotte Curtis)	UK	Sheep	Owned, used to terminate cover crop growth

Table 4: Different ways farmers have brought livestock into the farm system (author)

Barriers to livestock integration in a Tasmanian system is the perceived damage livestock cause to soil and lack of fences. However, observations of the benefits to the soil and farm business and opening the mind to further ideas, suggest that the addition of cattle may not be as hard or damaging as first thought (Furher, 2018) with options available including agistment and moveable electric fences.

Chapter 3: Benefits of Regenerative Agriculture

While RA mainly focuses on regenerating the soil, there are many other benefits that follow through taking a systematic approach to farming. As the soil improves, the land can support more, and therefore provide other business opportunities, which builds farm business resilience. This in turn provides flow on benefits to the local community as money begins to flow. There is also benefit to human health both mentally and physically as everything improves, with more profitable crops being grown with higher nutrient density. In South Dakota where no till and RA has been embraced, many new silos have been built to store the improved yields and new facilities in the towns, providing local jobs.

Reduction in synthetics

A major benefit of RA observed across the world, was the achievement of a reduction in the use of synthetic inputs over time, through soil health improvements. Although it did become apparent that there had to be an initial mindset shift in the way synthetics were used in the system. Coupled with the integration of the soil health principles, a reduction in synthetic use was initially required to kick start or speed up the recovery of the soil ecosystem. As the soil recovered, further reductions in synthetics resulted.

Methods of reducing synthetic input included; questioning if the inputs were needed in the first place, switching to biological forms of control for disease and pest, foliar applications of nutrition, using management strategies and cultural practices and looking at the application process and efficiencies. In Belgium, Regenacterre, through education programs in chemical use and application, is reducing the amount of chemicals applied by up to 30% resulting in a huge saving to the farmer and in soil improvement (Muratori, 2018). This saving on input costs freed up income that could be channelled into experimentation on methods to integrate the principles of healthy soil.

The biggest reduction and or elimination of synthetic inputs achieved by farmers visited was in insecticides and fungicides traditionally used as a preventive measure; (Axten,2018; Beck,2018;Barol,2018;Mallard,2018;Sims, 2017;Thompson 2018). Instead of applying as preventives the farmers were waiting to reach a critical threshold e.g. aphid numbers before applying the insecticide, which are often not reached. Fungicide applications were being held off until the weather conditions were favourable to disease or when levels got high (Colwell, 2018;Mallard,2018; Pontifex, 2018;Sims,2017). Although four fungicides were recommended in the UK in 2018, farmers were able to reduce the application to two through weather monitoring and improvements in the soil ecosystem (Colwell, 2018). The reduction in these synthetic inputs allows beneficial insects to build up and beneficial fungi to survive in the soil further supporting a healthy soil ecosystem which results in more reductions/elimination of insecticide and fungicide use in future as the system supports healthier plant growth.

Although fungicides have been largely dropped out of the system through improvements in soil health and questioning the actual need for them, some farmers are using alternative inputs in their place to ensure a yield is produced. Axten's in Saskatchewan, are using compost teas and extracts at times of high disease pressure to help ward off disease pathogens and a nutrition and biology addition. Nettle and comfrey teas are used in France (Leforestier, 2018) and the Netherlands (Huiberts, 2018), and essential oils in France (Mallard, 2018).

Seed dressings of fungicide and insecticides were another area where synthetics had been removed from the system. They are not used on seed planted for cash or cover crops by the majority of farmers, despite it being difficult to find untreated seed. The use of insecticide and fungicides on seed is thought to be disruptive to the soil ecosystem and may aggravate insect issues and are only required if the system is out of balance (Lungren, 2018). The use of no synthetic seed dressings has had no negative impact on yields when grown in functioning soil.

Herbicides are still widely used in RA to control weeds in cover and cash crops, although significant reductions have been made. Some weeds like black grass are effectively controlled through growing a spring barley crop for two or three consecutive years (Figure 16) (Cherry,2018) as well as improving soil health; soils where black grass grows are generally compacted, waterlogged and devoid of biology (Franklin, 2018). Simon Cowell, (2018) was able to control black grass, successfully with no herbicide applications, by growing different grass species with a lucerne crop to increase the diversity of feed produced.

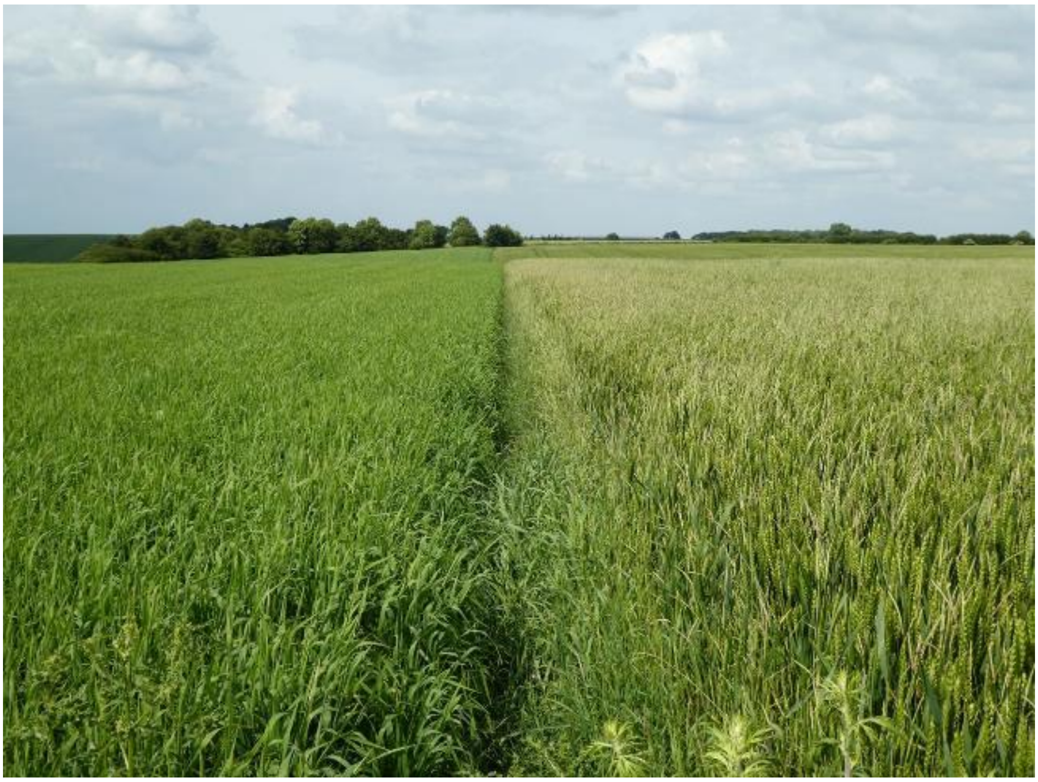

Figure 16: 2nd year of spring barley on the left with no black grass and a wheat crop on the right with black grass competing. Hertfordshire, UK June 2018 (author)

Soil ecosystem improvements have allowed reductions in fertiliser use. There is an awakening that the heavy use of fertiliser is the cause of many problems observed in modern agriculture. Granular applied fertiliser causes the biology to become redundant as the plants do not need to feed or interact with them for their nutrition requirements, hence the biology starves and soil ecosystem collapses (Clapperton, 2018). Christine Jones (2018) suggested that past research on nitrogen usage failed to recognise the importance of the soil ecosystem for nutrient uptake and in fact there is minimal need for synthetic nitrogen to grow a profitable crop. Observation of results from the hyper yielding wheat trial in Tasmania would suggest that the push to apply high rates of fertiliser may not be required to achieve a profitable yield; 11.4T/ha was achieved without nitrogen versus 12.7T/ha with nitrogen (Poole, 2018).

Despite the damage caused by fertilisers, the importance to wean the system off high fertiliser inputs to ensure profitable crops are still grown was emphasised and practiced (Jones, 2018). All the farmers visited were applying reduced amounts of fertiliser, in particular nitrogen, and still producing profitable crops, in some cases with reductions up to 100% applied in trials (Bieber,2018). Colwell (2018) has not applied phosphorus (P) and potassium (K) for 20 years and still produces good yields from a built soil. He applies liquid nitrogen with molasses to feed the biology and mitigate the negative effect of applied nitrogen.

Cultural practices were also observed as a means to reduce synthetic inputs, see examples in the previous chapter. In the UK, Belgium, France and Denmark, farmers are successfully reducing fungicides by stepping away from growing a single cultivar of wheat, rather combining a number of cultivates from different family and disease resistance lines (Colwell, 2018;Howard, 2018;Leforester,2018). This practice helps reduce fungicide resistance and aids with adding diversity to the field. At the Allerton Project in the UK, benefits of no tillage to the ecosystem were recorded in beneficial insects/predator numbers compared to tilled fields. Minimal canola pests were recorded in no tillage farm scale plots, compared to high numbers in tillage plots (Leake, 2018).

Companion planting has helped reduce insecticide applications to zero, and cover crops help reduce the number of herbicides required for weed competition and suppression. A corn study in South Dakota showed that growing a cover crop before the corn crop was as effective as an insecticide application (Lungren,2018). It became apparent that many interactions are at play in farm systems and the importance of building a healthy soil ecosystem is key to reducing synthetic inputs along with building the above ground ecosystem.

Organics

Organics seemed to be a natural progression for farmers practicing RA. Synthetic inputs have been reduced significantly and it is only a small jump to become organic, to take advantage of the market demand (Axten, 2018;Guy, 2018;Mallard, 2018). However, organics has negative features in a regenerative sense to the soil as light tillage is required to control weeds after harvesting, for crop termination and potential inter row weeding. For long time no-till farmers, this soil disturbance appeared to be a hard compromise to make and many are unwilling to make the leap. David Guy, (2018) from Sky Agricultural, had been organic for four years and hoped to get to a point where he could farm organically with no tillage. This compromise to the soil was in an attempt to be prepared for the foreseeable ban on synthetic chemicals, putting David, ahead of the game when it comes to farming without synthetic chemicals.

Lessons can be learnt from organic farming, on how to reduce synthetic inputs as there is a different mindset on crop production compared to conventional farming. In organic farming the crop requirements during growth must be considered and implemented prior to planting, unlike conventional grown crops where inputs are applied throughout the crops life. Nutritional needs are considered and met by growing cover crops high in legumes for a number of years before a paddock is turned to vegetable production (Veni, 2018), or particular cover crops that will supply the required nutrition for the following crop. However, careful balance is required to supply enough nutrition to the crop and not excess. The excess promotes weed growth which is problematic in an organic system (Free, 2018).

Alternative methods and technologies are used to control weeds and help with crop nutrition, health, pest and diseases. gas burners, comb-cut equipment (300 razor blades) to cut solid stems, inter row cultivation, camera guided equipment (Antuma;Radford;Veni, 2018). The real interest of organic farms, to my conventional mind during the study, was the physical health of the plants. The plants looked extremely healthy in spite of the lack of synthetic inputs (Figure 16).

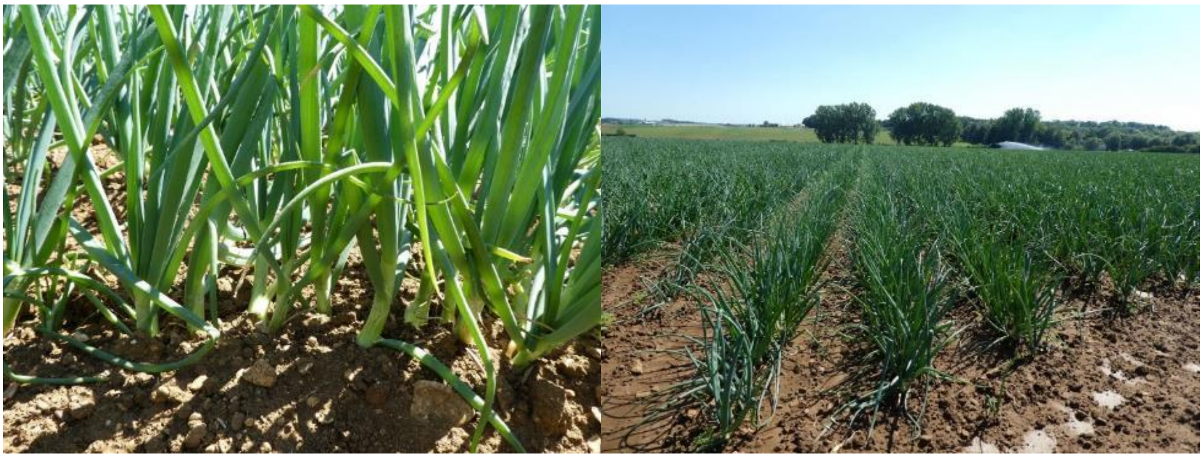

Figure 17: Organic onions at Riverford Organics, Sacrewell Farm, Peterborough, UK (author)

Stories of success – Gs

"Gs", large vegetable growers in the UK, supplying conventional and organic vegetables to European markets have recently implemented a RA plan for their Haney farm, outside Cambridge. The motivation for this comes from issues such as disease and poor soil structure; and the realisation their grandchildren will not be able to farm if the soil continues to degraded, coupled with the changing perception of food in the UK and worldwide. 1,10- and 20-year plans have been put in place to make the changes to farming practices and the young staff team are all on board with the commitment to make RA work. The transition to reduced tillage and no tillage will take many seasons with a reduction of the tillage depth each year. To help with the transition all staff have received the same training to ensure they are all in the same mind space and speaking the same language when determining how practices can be implemented.

In the first-year base line data of pH, Brix levels, potassium, boron, calcium and nitrates were collected each day. The use of this monitoring and leaf testing resulted in a 50% reduction in required crop inputs. Lowering the pH and the addition of fulvic acid to the water, when applying glyphosate has meant 2L/ha is now effective compared to the 4L/ha used in the past. To further reduce the glyphosate requirements sheep will be introduced to terminate the cover crops. To help with nutrition requirements, the amount of compost applied will be increased. Compost teas will be utilised along with brewing their own *Trichoderma* species. To make this all work, a dynamic fluid approach is being taken, mixing new technologies with old ways of farming (Curtis, 2018) as it is certainly moving into a new frontier of vegetable production.

This example shows that anything is possible given the drive from the whole team to make change happen and gives hope that RA can be successfully integrated into a vegetable rotation to reduce synthetic inputs.

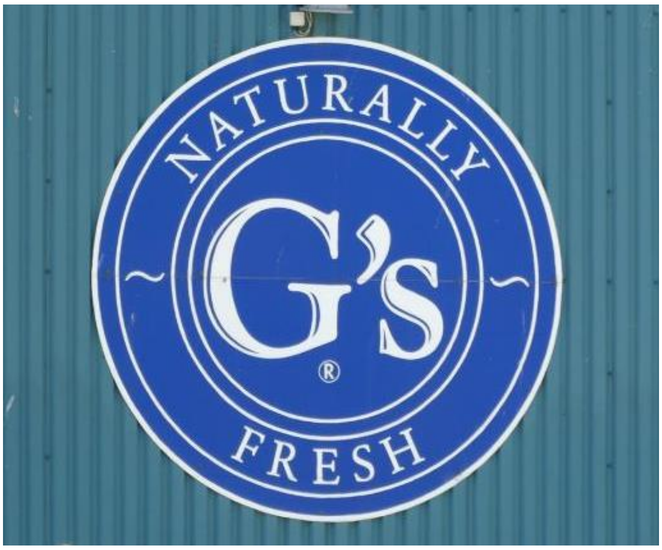

Figure 18. Gs, large vegetable growers in the UK, June 2018 (author)

Conclusion

Across the world, farmers and scientists are realising that soil is a living ecosystem providing a complexity of interwoven connections both above and below ground, which supports life on earth. This understanding has resulted in a paradigm shift in soil management to ensure soil is kept alive and thriving, allowing all the services it provides to be utilised. Farmers who have undergone this shift are producing crops that are self-sufficient with minimal input for profitable yield.

Farmers are now managing the farm as a whole system, embracing the complexity and integrating the five principles of healthy soil derived from nature to rebuild and regenerate the soil to its full capacity and build resilient farms. This requires a good understanding of the natural system and how the five principles of healthy soil work together if one is to succeed in this new frontier of farming. Improving soil health has worked to reduce inputs but it is not an overnight fix to reducing synthetics.

Years of soil degradation cannot be restored in one year. Addicted soil needs a transition to good health over a five to ten-year period, and there must be well thought out plan in place to help this journey to good health. Transition must progress in small steps to ensure a viable farm system and business. There are no recipes to follow in the transitioning process, and it requires a high level of commitment to the cause as there are unknowns, risks and inevitable mistakes. A great deal of trial and error, thinking outside the box of modern agriculture and full belief is required to make RA work.

As Lance Gunderson (2018) points out "*don't forget to believe your own eyes and ears even if you don't understand what you are seeing and hearing yet*" as the complexity of a living soil with a multitude of interactions happening is far from being fully understanding and may never be.

Currently, RA is being successfully integrated in farming systems that grow combinable crops to improve soil and reduce synthetic inputs. However, it is proving to be more difficult, and requires more creative thinking, in farming systems that produce high value crops that require high levels of tillage and grown from non-competitive seed. Despite this, with paradigm shifts, and outside the box thinking of modern agriculture, solutions can be found to integrate the five principles into a high value crop rotation. Companion cropping peas with potatoes, controlled traffic, the addition of composts, including diverse cover crops and reducing the depth of tillage used to prepare the soil for crop production where some methods used by vegetable growers across the world to improve the health of the soil. While high levels of tillage are required in a system, it becomes a much harder and slower process to regenerate the soil and get to the point where the soil is able to support healthy plant growth that is not reliant on synthetic inputs.

In Tasmania, it may be all too easy to say the task is impossible, that it's too hard to improve the soil to a point where reduced synthetics are possible. Yet with further understanding of the living soil, the determination to improve the practices, will come. It will require some out of the box thinking, and investment into equipment. There is also the option of using organic farming methods during the transition period to a self-sustaining system. The most important part of the process is to just get started and having a go, learning along the way as one sees the soil come alive!

Recommendations

In order to move forward with RA to ensure the soil continues to function ecologically and economically with fewer inputs and provide the invaluable ecological services, the following recommendations are made:

- The biological component of soil is an emerging science, and further education and learning on the services a living soil provides to a farming system should be communicated to enlighten the industry. Once soil is seen in a new light, the desire to change practices becomes greater and leads to change in individual and industry thinking.
- Find areas of undisturbed natural areas in the local region and observe the natural system before farming began in the area to help with ideas on what could be brought into the system. This, coupled with a detailed analysis of the rotation being used by the business, should be made to determine where the five principles can be integrated.
- Trial, trial and more trials over a number of years – with particular emphasis on farm scale trials rather than detailed research plot trails – when working out methods to implement the five principles.
- Research and invest into equipment that supports the five principles of soil regeneration being integrated into the system, such as direct seeders and strip tillage.
- Further research into the economic benefits and sustainability of converting a farming system to RA.
- Investigate organic principles and technologies that can be used in the early years of restoring a fully functioning soil, to aid the reduction of synthetic inputs.
- Investigate the feasibility of making and applying compost to fields in production, to mitigate the effect of high tillage through biology and OM addition.
- Do further work into crop nutrition and monitoring for plant health, to ensure synthetic inputs are only used when required. This would include monitoring nutrient levels and brix levels. Along with an emphasis on mitigating the negative effects of synthetic inputs on the biological component of soil for example the addition of carbon sources to synthetic inputs.
- The management of change is critical, as this is a new frontier of farming. Farmer groups will be needed for individual support, and aiding faster advancements, along with support from wider industry.
- Be open to new possibilities of growing crops and how the farm business runs. Through RA there are many opportunities to add further enterprises to the system and value add, reducing reliance on the dictates of companies.

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Pontifex, Grant, July 2018, personal communication, Australia

Poole, Nick, November 2018, Hyper Yields Wheat Trial Field day, Hagley, Tasmania

Radford, Matthew, 2018, personal communication, Burwash Manor Farms, UK

Rockey, Brendon, July 2018, personal communication, Center, Colorado, USA

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Teachout, Chris, August,2018, personal communication, Iowa, USA

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Veni, Nigel, June 2018, personal communications, Riverford Organics, UK

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Wilson, Jeremy, July 2018, personal communication, North Dakota, USA

Wood, Clive, June 2018, personal communication, Kings Seeds, UK

Plain English Compendium Summary

Project Title:	**Regenerative Agriculture Principles in High Value Cropping Rotation** **Can a Healthy soil reduce the reliance on synthetic inputs?**
Nuffield Australia Project No.:	1811
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Objectives	**To determine if the five principles of a healthy soil can be implemented into a high value cropping rotation to reduce synthetic inputs**
Background	High values crops are produced in Tasmania – potatoes, onions, carrots, pyrethrum, poppies, that have a high reliance on synthetic inputs for production. The system is degrading the soil, resulting in crop production becoming more challenging. The number of synthetic inputs available for use is reducing due to deregistration, weed and disease resistance and community pressure.
Research	Regenerative Agriculture (RA) and organic farmers, along with leading soil experts were interviewed across seven countries to determine how the farm system can be managed to reduce synthetic inputs and regenerate the soil ecosystem to support healthy plant growth
Outcomes	The study revealed that synthetic inputs can be reduced when the farm is managed as a system with a living soil ecosystem as the basis. The soil is to be managed using five principles of a healthy soil developed from observations of nature's system and underpin the farmer lead movement of Regenerative Agriculture. These principles are complicated to integrate into a high value cropping system with the current mindset and production model.
Implications	Farmers willing to change farming practices and place more emphasis on the soil will be able to reduce synthetic inputs and will be more prepared than others when the time comes that limited synthetic inputs are available. The farm system will be more resilient through having a living soil that provides ecological services and supports multiple
Publications	Nuffield Australia National Conference presentation, September 2019, Brisbane, Queensland