Integrating Livestock into a Continuous Cropping System in a High Rainfall Environment

Turning rainfall into revenue

A report for

By Stuart McDonald

2018 Nuffield Scholar

August 2020

Nuffield Australia Project No 1817

Supported by:

Scholar Contact Details

Stuart McDonald
Belcan Partnership
Belmont Canowindra NSW 2804
Phone: +61 263 640 200
Email: stuartmc1@me.com

NUFFIELD AUSTRALIA Contact Details

Nuffield Australia
Telephone: 0402 453 299
Email: enquiries@nuffield.com.au
Address: PO Box 495, KYOGLE, NSW 2474

Executive Summary

The desire to more efficiently utilise every drop of rain that falls lead to the exploration of the integration of livestock into a continuous cropping system in a high rainfall environment.

The addition of livestock to a continuous cropping system has the potential to generate extra income, improve water utilisation, promote nutrient cycling and lower risks for high upfront cost enterprises.

Soil health improvement was one of the more unexpected benefits associated with livestock introduction to a continuous cropping enterprise. It was the sole reason for adopting livestock into a cropping system for many of the farms visited as part of the research.

Management of the five soil health principles underpins any improvement of soil properties including water retention.

Grazing offers opportunity to grow a more diverse rotation. A grazing 'crop' allows versatility in planting times and harvest. Extending what can be the busiest times of year on farm and spreading the workload into more manageable pieces. Grazing crops can add fertility, organic matter, and rotation options in terms of weed control for a paddock.

Extra management, infrastructure, expertise and labour is involved in introducing animals into a cropping system. Livestock can quickly turn plant growth, generated at any time of the year, into money. Higher rainfall provides greater opportunity to generate income. With better utilisation of rainfall as it falls there is scope to increase the returns generated per 100mm of rainfall received, minimise salinity (leakage from the system), stop erosion, and improve the dynamic properties of soil within every land managers control.

Rotational crop diversity has more options for income generation than grain only systems. Diversity in crop rotation can give a more robust and resilient farming system.

Table of Contents

Table of Figures

Foreword

My desire to more efficiently utilise every drop of rain that falls onto our property lead me to explore the integration of livestock into a continuous cropping system in a high rainfall environment. Our property, “Belmont”, is in a 650mm average rainfall area that is non-seasonally distributed. Our current practices see us planting spring crops on our best arable land, largely in a wheat, wheat, canola three-year rotation.

Our remaining country is improved pasture that carries sheep and cattle. Livestock currently only access cropping land when grazing cereals or canola are grown – either for limited periods within the growing crop, or residue post-harvest (short duration, high density graze over the summer fallow months). Wheat stubble is generally burnt when crop yields are average or above. Our average yields over the last ten years have been 3.9t/ha for wheat and 1.8t/ha for canola.

The cropping system is one of high inputs, medium risk and good profitability. Our water use efficiency declines with above average rainfall. For example, in 2016 we had a water use efficiency (WUE) of 12 with 830mm annual rainfall, whilst in 2015, with a 590mm annual rainfall, resulted in a WUE of 17.

Continuous cropping has been adopted following financial benchmarking assessment on individual paddock performance. The transition between cropping and pasture phases and back to cropping were identified as underperforming parts of the rotation. By focusing on a continuous cropping rotation with higher returning crops grown with greater intensity over the rotation, financial returns were made more consistent across paddocks.

We found that crops that incorporated livestock grazing were consistently higher returning than grain only crops within our business. To achieve a higher level of return across the whole rotation I wanted to identify the degree to which livestock grazing could be applied. I would like to build a system on our property that improves soil carbon and associated soil properties (higher fertility, higher water holding capacity, higher water infiltration, improved soil structure, increased biological activity), that has less risk, has equal or greater profitability, and utilises and captures rain more efficiently.

This report reviews the opportunities for more efficient use of available rainfall through the livestock integration within cropping systems. Through my study I have learnt how management of the five soil health principles underpins any improvement of soil properties including water retention. This report will explore these principles and the management practices which influence them.

Acknowledgments

I would like to thank Nuffield Australia for giving me the opportunity to complete a scholarship. It is a life changing experience that has pushed and excited me.

Thank you also to the Grains Research and Development Corporation (GRDC) who supported my scholarship. Their ongoing support of Nuffield is a credit to the return they provide to the Australian grain industry.

Thank you to the Foundation for Arable Research New Zealand (FAR NZ) and Sustainable Agricultural Research and Education, United States of America (SARE USA) for their assistance while travelling through their respective countries.

My wife is the single most important person in making my Nuffield experience possible. From encouragement to apply, polishing me into a presentable applicant, motivating me and supporting us during my farm absences. Her love and support has lasted the three years this process has taken.

Thank you to our agronomist Peter Wilson whose positive attitude and professional knowledge assisted me gaining this scholarship and helped deal with farm decisions during my farm absences.

Thanks to all the people that have hosted me on their farms or place of business. I have appreciated the candor and fullness of our discussions.

Thanks to the following researchers and producers who I have spoken with personally and are mentioned throughout this report. All visits I undertook were valuable and greatly appreciated, especially for the welcome and hospitality that I received. Amongst them were Jay Fuhrer, Thibault Presles, Todd McPeak, Alan Mindemann, Jimmy Kinder, Craig Whiteside, Jacob Miller, Lane Meyer, Bart Ruth, Rocky Bateman, Jimmy Emmons, Craige McKenzie, Guillaume Milard, Phil Jarvis, Nicolas Duboust, and Henderson Farms-Alabama.

To my children Florence, Ivy, and Bede – your warm embrace upon returning to you from overseas made every trip home eagerly anticipated.

Abbreviations

AU: Animal Unit (450kg animal)

CSIRO: Commonwealth Scientific and Industrial Research Organisation

DSE: Dry Sheep Equivalent (60kg merino wether)

FAR: Foundation for Arable Research (New Zealand)

GRDC: Grains Research and Development Corporation

mm: Millimetre unit of measure for rainfall (25mm = 1 inch)

NDVI: Normalised Difference Vegetation Index

NRCS: Natural Resources Conservation Service

NSW: New South Wales

t/ha: tonnes per hectare

UK: United Kingdom

USA: United States of America

USDA: United States Department of Agriculture

WUE: Water Use Efficiency (kilograms of grain/hectare/millimeter of rain)

Objectives

The author was interested to see how farmers around the world deal with:

1. Utilising every drop of rain on a dryland farm.

2. What livestock options can be employed to improve return from plant growth including:
   - breeding versus trading livestock
   - single or multi species
   - applying intensive animal manures
   - graze to harvest or dual-purpose graze and grain

3. Rotation diversity.
   - cash crop versus grazed crop
   - timing of planting to suit moisture availability not necessarily grain fill

4. “Tools in the toolbox”:
   - full cultivation compared to zero till and the range between
   - high density grazing compared to set stocking and the range between these
   - range of cool and warm season grasses and broadleaves
   - good crop and grazing management as compared to less effective management

5. Profitability and risk: weighing up returns from a change to system, transition times, how much return is needed?

While the motive for pursuing livestock integration started out as a means to extract greater income and reduce risk in a business, the ‘movement’ to greater livestock integration has taken root in soil health advocates worldwide. The benefits to soil health are a bonus that is explored in this report.

Introduction

A continuous cropping system that relies on rainfall has, at its core, the efficient use of that rainfall. Storing summer rain in a chemical fallow that can last five months is currently seen as best practice. In dry years it can be the difference between producing a crop and not, and in better years can provide the reserve for a crop to produce above the level previously achievable with in crop rain alone.

The efficiency of soil to store rainfall for use by a crop ten months after it has fallen will vary according to how well it captures rain in the first place, and then on how it holds moisture within the root zone of the plants that hope to use it. This report reviews techniques farmers around the world are employing to improve water capture and retention.

Livestock have the unique ability to turn plant cellulose into high value protein and can as a result, generate income from a resource that otherwise has little monetary value. Livestock can be a tool that is used to achieve a goal. Like any tool, a good understanding of the effects on the landscape of grazing livestock is essential to successful integration into an existing system. This report places an emphasis on correct integration of livestock only when discussing the introduction of livestock into an existing cropping system as to do any other way would be counterproductive.

The many ways that livestock can be integrated into cropping systems are discussed in order to highlight ways that animals can have an impact on land that has had little or no livestock presence for many years. The financial viability of introducing livestock will be left for individual managers to evaluate and determine how appropriate it can be in their circumstances. This is a relatively simple exercise and best done with local knowledge to truly gauge how integration of livestock can occur. If in doubt start small! This report aims to discuss the system benefits that correct integration of livestock can provide, as this can be hard to quantify in dollar terms alone. Benefits can accrue over years and are influenced by many different factors.

The importance of the five soil health principles was an unexpected finding from this study. The principles are:

- Minimise the disturbance of the soil
- Protect the surface of the soil

- Introduce plant diversity
- Introduce livestock
- Have a living root in the soil for as long as possible

When livestock are integrated with soil health in mind there is an opportunity to build a system that allows soil to function as a vital living ecosystem that sustains plants, animals and people and generate extra returns. Each of the five principles will lead to enhanced soil properties and the combination of all five properties is the most ideal.

The information around soil health referred to in this document is not new. The principles are old and widely applicable. David Montgomery discusses techniques from 1650 in his book, 'Dirt: An erosion of civilizations', that are being revisited now and adapted successfully into modern farming. The term soil health can have more than one meaning. One definition of soil health provided on the United States Department of Agriculture – Natural Resource Consulting Service (USDA-NRCS) website, is "*the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans*" (NCRS, 2019).

Chapter 1: Utilising Every Drop that Falls

The ability of a soil to absorb and retain water for plant growth in Australia's variable climate could be its most important quality. Climate change is seeing the advent of more intense and erratic rainfall events, and in the Australian environment, more prolonged periods of dry (Press, 2019). Most dryland farms would cite moisture as their most yield limiting input. Absorbing and retaining water will be set by a combination of inherent and dynamic qualities of the soil. A 'healthy' soil compared to a degraded soil of the same soil type will store very different amounts of moisture. Management practices undertaken on a paddock influence the dynamic qualities in the soil either positively or negatively.

Dynamic qualities of a soil that can be influenced by management include:

- organic matter present (above and below the ground)
- the presence of living plants in a soil
- wheeling by heavy machinery that impacts on soil structure and compaction
- biological activity and macrofauna abundance that rely on a suitable environment being present to live.

Soil organic matter is capable of holding several times its own weight in water, effectively increasing a soil's bucket for holding water when high levels of soil organic matter are present. High levels of soil organic matter can create and stabilise soil structure, improve water infiltration and reduce evaporation (Hoyle, 2013). The Noble Institute in Oklahoma, USA, is working with clients that have increased their water infiltration rate into their soil from 12.5mm/hr to 162.5mm/hr (Jim Johnson, pers. comm., 2018).

Organic matter on top of the soil helps capture all the rainfall that falls onto the soil by lowering the speed of the water flow over the surface of the soil. Infiltration is also improved by the soil structure being protected from the destructive power of rainfall impact.

Once in the soil, moisture needs to remain in the root zone of plants to be used and not lost to either evaporation or deep drainage. The ability to manage this system on the land is a huge opportunity for dryland farmers in Australia to improve their use of water.

Cover crops

Cover crops are used in wetter environments to help retain excess moisture in a paddock and cycle nutrients that otherwise could be lost to the system by leaching. Cover crops are being used in short windows between longer season crops, for example, Mike Porter (pers. comm., 2019) of Otaio, South Canterbrury, New Zealand, aims to have his cover crops in the ground for a minimum of six weeks, around which time the knee high growth of his cover crop, is grazed or terminated.

Controlled Traffic Farming

Controlled traffic farming and the use of tracks on heavy machinery can reduce the impact of compaction on soil structure to a soil. Soil with higher levels of organic matter will have more structural resilience and have an increased ability to recover soil function after a disturbance (Hoyle, 2013).

Protecting soil

Biology and macrofauna require a food source and an environment that is in the right temperature range to flourish. In a trial run on the authors farm in 2018, soil temperature under a cover crop in summer was seen to be reduced by four degrees at ten centimeters depth and fluctuated within a smaller range compared to bare soil (McMaster, Stevenson & Strahorn, 2020).

Water capture and retention methods

Examples of capturing every drop of rain seen in the author's travels include:

1. **Catch crops** that reduce the amount of water that leaves a field, therefore better capturing nutrients. These catch crops often followed high input crops like corn or vegetables that would have high levels of fertiliser applied for best performance. Any leftover nutrients present in the paddock are otherwise at risk of being leached. The brassica family of plants are good scavengers for nutrients and many different varieties are used. Turnips, beets and radishes have the added benefit of a large tap root that will leave behind a hole in the soil full of nutrients and biology, allowing better water infiltration at the same time.
2. **Growing tall plants** and leaving tall residue to capture snow and retain it on a paddock - otherwise lost to wind blowing. Snow can move across the land in a similar way to dust in Australia. Seeding a cover crop into standing corn stalks or planting a crop like

sorghum that has hip height grazing residue can trap fallen snow in a field, which maximises the moisture available to the paddock following snow melt.

3. No fallow or the '**five-minute fallow'**, a term coined in New Zealand and widely adopted, is the seeding of the next crop in the paddock at the same time as harvest of the previous crop. This maximises soil humidity that exists under a crop canopy to assist in starting the next crop. Logistics and labour can be a barrier here.
4. **Seeding 3-5 crops in one operation**. The best example of this was seen at Thibault Presle's farm in France. He had sown buckwheat, canola and clover at the same time. When the buckwheat was harvested it covered all costs for the multiple crops with additional profit. There remained a knee-high canola stand established and clover plants growing underneath the canola. The aim was to harvest the canola, harvest the clover as fodder potentially twice the following year and then lock up the clover for a seed harvest. These five harvests were all possible from the one pass with the seeder. This suited his climate and region where a ready market for all grain crops existed and integrated livestock to fully realise the potential of his paddock and rainfall to generate income.
5. **Grazing done well**, involves leaving 50% of plant behind following a graze. This allows a fully functioning root system to remain active. By grazing 50% of a plant, you do not impede root growth of that plant but when you take 70%, half the root growth of the plant stops (Creider, 1955).

Jay Fuhrer (pers. comm., 2018) illustrated how to identify the 50% height of a plant by cutting a plant out of the soil at ground level and balancing it on his finger. The balance point is lower than expected but represents an equal weight of the plant on either side. It was also obvious during this demonstration that the best quality forage available from a plant is in the top 50% of the plant. Grazing beneath this not only sets back plant performance significantly, but sees animal performance, on the lower quality forage of the bottom half of the plant, slow down. Figure 1 demonstrate this on oats, lucerne, wheat and canola.

Figure 1: Demonstrates the balance point or a level of 50% grazing on (from top left and progressing clockwise) oats, lucerne, canola and wheat.

Figure 2 explains that by grazing too much of the plant, its ability to recover from grazing is slowed down and its ability to utilise moisture deeper in the soil is diminished.

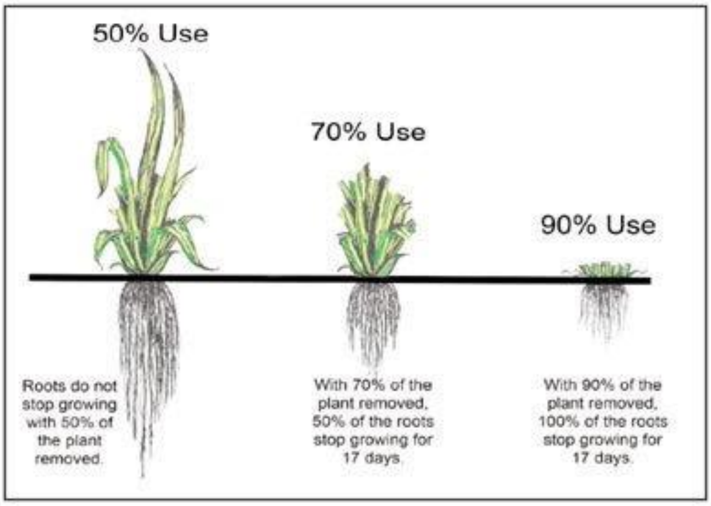


Figure 2: Growth of both tops and roots is significantly impaired if more than 50% of the green leaf area is removed in a single grazing event (Voth, 2015)

6. **Zero till** is a means of establishing crops with little to no disturbance of the soil. This is one of the five soil health principles that will improve how soil can function. Zero till is the tool that was largely responsible in the mid-west of the USA that saw soil structure improve to the point where water infiltration improved from 12.5mm/hour to 162.5mm/hour (Jim Johnson, pers. comm., 2018). It allows large amounts of residue to be retained on the soil surface and not impede the placing of new seed for new crops. The habitat of macrofauna and fungi in the O and A horizons of the soil profile

is also left intact. Less carbon is lost from the soil in a zero till seeding operation compared to minimum tillage. Tillage breaks down organic matter much faster than no till1 (SARE, 2012).

7. **Feeding the underground livestock**. This refers to the macro and micro fauna that exist in soils that rely on crop residue for habitat and a food source. This battles the widely held belief that when you eat all the fodder produced with above ground livestock you have full pasture utilisation and maximum return. This ignores the soil health benefits to be gained and unlocked in a fully functioning soil, where the underground livestock are prioritized to be fed adequately by returning organic matter to the soil.

   Todd McPeak (pers. comm., 2018) in North Dakota is creating significant change in his soils with his grazing system that has largely closed the nutrient loop in his paddocks. Beef cattle are overwintered on pasture with hay supplemented to them through the colder months. This hay is generated on the paddock where it is fed out in, closing the nutrient cycle. The hay is rolled out over as much of the paddock as is practical at the time of feeding out when the ground is frozen. Todd feels this enables him to build soil across large parts of the paddock over the course of a few years, but also allows him to intensively manage and rehabilitate underperforming areas of the paddock. Todd walked the author through productive low-lying areas of his paddocks that prior to this type of management had been unproductive and waterlogged.

8. **Planting a mixed species** cover crop into a cropping system fallow can have many benefits. When flowering plants are introduced, beneficial insects are encouraged to enter the system. This can have advantages for following crops or neighbouring crops in the system. The legume component of any mix can also add fertility to the system for subsequent crops. Grass or cereal components of a cover crop mix with a large fibrous root mass can boost carbon levels of a soil and provide food for soil life. The living roots of a mixed species cover crop are the mechanism that drives soil aggregation, leading to better structure, and water infiltration. A mixed species cover crop with plants that have varied root architecture can access a greater depth of nutrients compared to a monoculture. With increased plant populations, weed

[1] *See "Tools in the toolbox" chapter four in this report for further discussion on zero till.*

suppression can be achieved while generating food for livestock above and below ground (SARE, 2012).

9. **Planting a diverse range of crops** whenever the opportunity presents itself. Alan Mindemann (pers. comm., 2018) in Oklahoma was a good example of this flexible approach. Whenever it rained, Alan would consider what he could plant. His rotation included a wide range of specialty crops that all needed harvesting at different times. Some of these crops were not recommended for his area but with a change in his seeding date out of the 'normal' window he was able to grow the crop profitably. Alan's approach was an example of eliminating the fallow and aiming for a living root in the ground as long as possible.
10. **Grazing winter wheats**. In Australia this has become widely adopted, however it is also gaining acceptance in the USA and New Zealand. In the USA, Jimmy Kinder (pers. comm., 2018) in Walters, Oklahoma, was a good example of growing wheat for forage with the option for grain. His system revolved around stockers (beef animals) grazing his wheat stubbles for at least three months a year. His wheat is planted in September and harvested in June. If harvest wheat prices are not outcompeting the price achievable with extra pounds of beef, the wheat crop was harvested by the cattle.

    In New Zealand, the Foundation for Arable Research (FAR) has found that grazing of winter wheats can improve grain yield potential. Craig Whiteside (pers. comm., 2019) has had good success growing winter wheat by planting earlier and stocking it heavily with lambs at tillering. After a hard grazing, his winter wheat tillered more vigorously and he is hopeful of achieving at least 14t/ha which would be two tonnes above his current average yield. The longer the wheat plant is in the ground the more potential it has for utilising water. The more established the root system of a plant the better it can withstand stress like grazing or environmental changes like heat and cold.

Chapter 2: Livestock Options

To some farmers, livestock is a dirty word and the aim of this Nuffield topic was not to convert those people. Where most agricultural enterprises work best is when managed by someone who truly enjoys what they do. There were multiple farms visited where the primary producer/owner of the operation did not want anything to do with animals personally. This could have been a time of life decision, lifestyle choice, or general disdain for sheep or cattle. This did not stop the business receiving valuable revenue from livestock and their soils gaining the added benefits of livestock. Relationships existed where another party who was prepared to run the livestock fully could pay for the right, under strict guidance and with full regard to the existing crop rotation, to graze their animals. This seemed like a win/win situation where enterprising people were able to run a sizeable livestock business without owning much or any land. At the same time plant production that previously was not monetized in a cropping operation now could be realised.

Australian example

In Australia, the *Grain and Graze* program has been run over large parts of the mixed farming zones of Australia between 2003 and 2016. This program has seen a large improvement in the skills surrounding grazing of cash crops successfully without compromising the potential to harvest grain. The Grains Research and Development Corporation (GRDC) has been the only levy body or government department to support this program for its entirety.

New Zealand example

Trading in New Zealand operates in an environment where young stock from large extensive breeding operations run out of traditional feed every autumn and winter. Multiple farms that were visited had a forage crop worked into their crop choice and crop rotation to take advantage of this situation and supply high quality finishing feed to these young animals. The grazing crops were planted to suit the period of generally low feed availability experienced on breeding operations. In the case of New Zealand, these were the winter months when low temperatures shut down native feed production. Some crops grown to suit this feed wedge were perennial and annual ryegrass, kale, grazing brassicas, sugarbeet or turnip, chicory and plantain. These were at times dual purpose as they were later shut up for seed recovery as well. Breeding operations are primarily conducted in different classes of land to the finishing operations, which saw a geographical divide between breeding and trading enterprises. This was more pronounced than seen by the author in other countries. The forage crops outlined above, were predominantly grown on this better class of land in New Zealand.

Trading can also take the shape of growing out breeding stock for weight gain, commonly referred to as ‘backgrounding’, by other specialist fodder producers. In New Zealand this was driven by the dairy industry in the need to have heifers raised, bulls fattened, and cows agisted over winter. This enterprise was termed ‘dairy support’. Multiple options are available to producers to enter dairy support. The fattening of sexually entire dairy bulls in New Zealand was an enterprise the author did not see in other parts of the world.

United Kingdom (UK) example

Adding fertility to soil through livestock can occur in various ways. Nick Doig (pers. comm., 2018) at Litcham, England, has a free range sow farrowing arrangement that had pigs run on a paddock for two years by another farmer who owned the pigs. The pig activity on the soil was extensive and large amounts of fertility for following crops was gained after the two years. This could be rotated through the farm giving a fertility boost to the whole cropping system.

United States of America (USA) example

Bart Ruth (pers. comm., 2018) had an intensive irrigated cropping system in Nebraska that grew predominantly soy and corn. Around this he grew rye covers between crops that he could agist stock onto. He didn’t own the stock, and this complimented a space in his cropping system. A large contributor to his cropping system’s success was the proximity to a large housed dairy operation. This dairy had a network of pipes that pumped effluent directly to Bart’s irrigators and also spread mulched solids on his paddocks. This access to fertility and water was a major driver to his cropping system and solved a waste problem for the large dairy.

Multi-species grazing

Multiple animal species grazing is seen to be the next step in improving soil health beyond single species livestock integration alone. Jacob Miller (pers. comm., 2018) is introducing sheep into his beef cattle finishing operation with the thought that two-to-six sheep (this is a widely held view in the Midwest, USA) per head of beef can be added to his operation without requiring any extra grass. This is seen as extracting extra profit from the operation without any impact on costs which was a consistent theme in the motivation for introducing livestock into cropping and other existing operations. Jacob has also produced chicken and eggs in his annual pasture-based system, however this was being wound down due to the high labour requirement of this more intensive animal.

Lane Meyer (pers. comm., 2018) in Nebraska has introduced a small goat herd into his beef grazing operation. Goats have the ability to better utilise feed that sheep and cattle will prefer not to eat and add diversity to a grazing system. This supported another of the five soil health principles of adding diversity to simplified ecosystems.

Chapter 3: Rotation Diversity

An opportunity that arises with the integration of livestock into a continuous cropping system is to increase the number of plant species grown over a cropping rotation. Crop rotation is a practise that optimises yield and returns in a continuous cropping system. The introduction of grazing allows a more diverse cropping rotation and provides a multi-pronged approach to controlling problem weeds. These include boosting soil fertility (with the addition of Nitrogen fixing legumes) and providing time between similar crops that can host soil borne diseases and pests. By planting crops in different seasons (winter and summer) problem weed germination can be disrupted, helping control that weed.

The wider a crop rotation, the more opportunity for weed control, as weeds are restricted in their modes of adaption to varied control measures. A wider crop rotation can also take advantage of seasonal changes and be more robust when conditions are less than ideal.

The challenge in broadening a cropping rotation is finding crops that can be adapted into the system to achieve comparable profitability across the rotation.

Rocky Bateman (pers. comm., 2018) of North Dakota chose his cover crop mixes by first finding out what existed in his natural environment for any particular window of planting. If a native example of grass, forb, legume and broadleaf could be found, then planting at least three of these four groups should stimulate the soil biology and macrofauna native in his soils. It was not essential that the exact native species be planted but if a commercially available seed was close enough in type to the native, it could do the same job in stimulating the soil. These covers fit in between his four cash crops of corn, wheat, sunflower, and soybeans grown in rotation. The corn and wheat being the only two crops in his rotation that received fertiliser.

Forage is most efficiently and economically utilised by livestock where it grows. When grown in the paddock it provides the most economical source of feed for a livestock enterprise by avoiding the expense of the cut and carry model of livestock production. By harvesting forage prior to anthesis and grain fill, income can be derived from a crop planted in a window that may be unsuitable for that plant to fill grain. This widens the range of crops that are available to be grown in a rotation.

Some examples of crop rotation seen around the world included both grain crops and forage. For a forage system to be profitable the availability of livestock or proximity to a livestock industry was advantageous.

The New Zealand dairy industry is driving crop selection in large parts of the country as producers provide dairy support. This can take the form of growing perennial and annual ryegrass, kale or beet winter forage, barley/wheat full cut silage, grain/cereal hay, pasture hay or sileage, chicory or plantain in mixes or isolation. These plus other forages enable cattle to be agisted profitably. The author was told by one producer that the agistment of cattle on forages over winter was the most profitable enterprise on their farm. Frost events at flowering or weed pressure in a grain crop may see it redirected to full cut sileage for use in dairies. While milk solid pricing for the dairy farmer in New Zealand remained above $6/kg it enabled on farm wheat pricing to remain above $400/t.

When heifers were placed on dairy support farms, they could be done so on a $/head/day rate or on a liveweight gain basis. One and two-year old heifers were agisted on different rates which reflected their liveweight. These arrangements are generally made on an individual basis between farmers. Agents can also arrange placing large numbers of animals on properties in a short period of time, potentially facilitating an arrangement between one large farm growing fodder and multiple farms supplying dairy animals. When cows are wintered on farms it is generally done so the dairy farm can rest their pastures during the wettest and slowest growth period on the farm. This sees large mobs of large cows intensively grazed on purpose grown forage crops like kale and beet. By arranging bales of pasture forage along a paddock to coincide with daily moves of an electric wire, tractor traffic can be eliminated during wet winters (Figure 3).

Figure 3: Photo of winter grazing field set up with hay at fencing intervals in Southland, New Zealand

This does not overcome the destruction to the soil that can be caused by a large mob of cattle during a wet winter and the detrimental effect of excessive grazing pressure. This is acknowledged as a problem facing the dairy industry as a whole. While financial returns of this form of management remain high (can be the most profitable crop in a standard cropping rotation) some farmers do this with hesitation – hoping for not too much rain in winter. Paddock selection also helps but it is not uncommon for producers to say no to cattle going onto high performance cropping paddocks for risk of soil damage during prolonged wet periods when there is no relief via feed pads or containment yards.

For properties in New Zealand that prefer not to have cattle across their land, the lamb finishing market can turn high performance pastures into profit. Ryegrass forms the backbone of this, but chicory, plantain, beet, turnip and other brassica forages allow a spread of crop choices to be made. Producers can make the decision to own the finishing lambs or share profits on a weight gain basis without the upfront capital expense of owning the lamb.

Alan Mindemann (pers. comm., 2018) had no livestock of his own but agisted another producer's cattle to experiment with intensive grazing and cover crops. He was developing land that had been out of production and aimed to bring it back to life quicker than he could with machinery and cropping alone. Alan had the widest rotation of any producer the author visited (30+ different crops). To compliment this, he also had a specialist seed cleaning and packaging business that benefitted from the range of crops produced and differing times of harvest throughout the year. This also gave Alan great scope to manage agronomic issues in paddocks and pay good rent to his landlords which secured his tenure on that land.

Choosing new crops

When looking to identify what crops can be used it is helpful to ask the following questions.

- Is there an existing market?
- Are there associated benefits/legacy effects from the crop?
- Is the crop going to provide the desired production/income needed?
- Will the crop have negative impacts to the wider crop rotation?
- Can the positive or negative impacts be quantified?
- Are paddock conditions right for the chosen crop to reach its potential?
- Are there alternative uses for the crop?
- Is the Carbon to Nitrogen ratio suitable to meet the crops aims?

The Carbon to Nitrogen ratio in cropping systems that are dominated by wheat and canola (both crops have a higher than 24:1 ideal ratio) can become dominated by this residue with little opportunity for it to break down before the next high carbon plant is planted. Nitrogen will be tied up or immobilised as bacteria work on consuming these carbon dominant residues. Pulse crops with lower C:N ratios than the 24:1 ideal can speed this breakdown up. On the other end of the scale, Hairy vetch's residue at 11:1 will be broken down quickly (Figure 4).

Material	C:N Ratio
rye straw	82:1
wheat straw	80:1
oat straw	70:1
corn stover	57:1
rye cover crop (anthesis)	37:1
pea straw	29:1
rye cover crop (vegetative)	26:1
mature alfalfa hay	25:1
Ideal Microbial Diet	**24:1**
rotted barnyard manure	20:1
legume hay	17:1
beef manure	17:1
young alfalfa hay	13:1
hairy vetch cover crop	11:1
soil microbes (average)	8:1

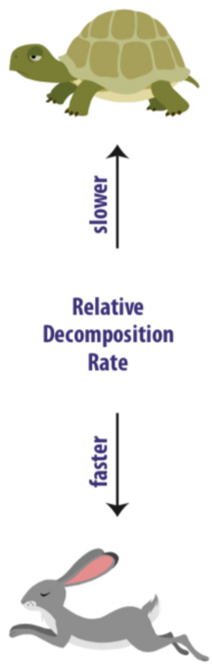


Figure 4: Carbon to Nitrogen ratios in cropping systems (USDA-NRCS, 2011)

Livestock add an income generating tool to process high carbon residues in a cropping paddock that otherwise would generate little income.

In the more advanced functioning soils of Jimmy Emmons (pers. comm., 2018) of Oklahoma it was a struggle to maintain a residue cover of any sort on the soil and this dictated the choice of cover crop to ensure residue persisted. Flax, okra and sunhemp were popular choices as the woody nature of their stalks lasted longer than other residues which could be all gone in one to two months.

The USDA does regular updates of the cover crop chart periodic table. This is the latest version seen at the USDA's Northern Great Plains Research Lab in October 2018.

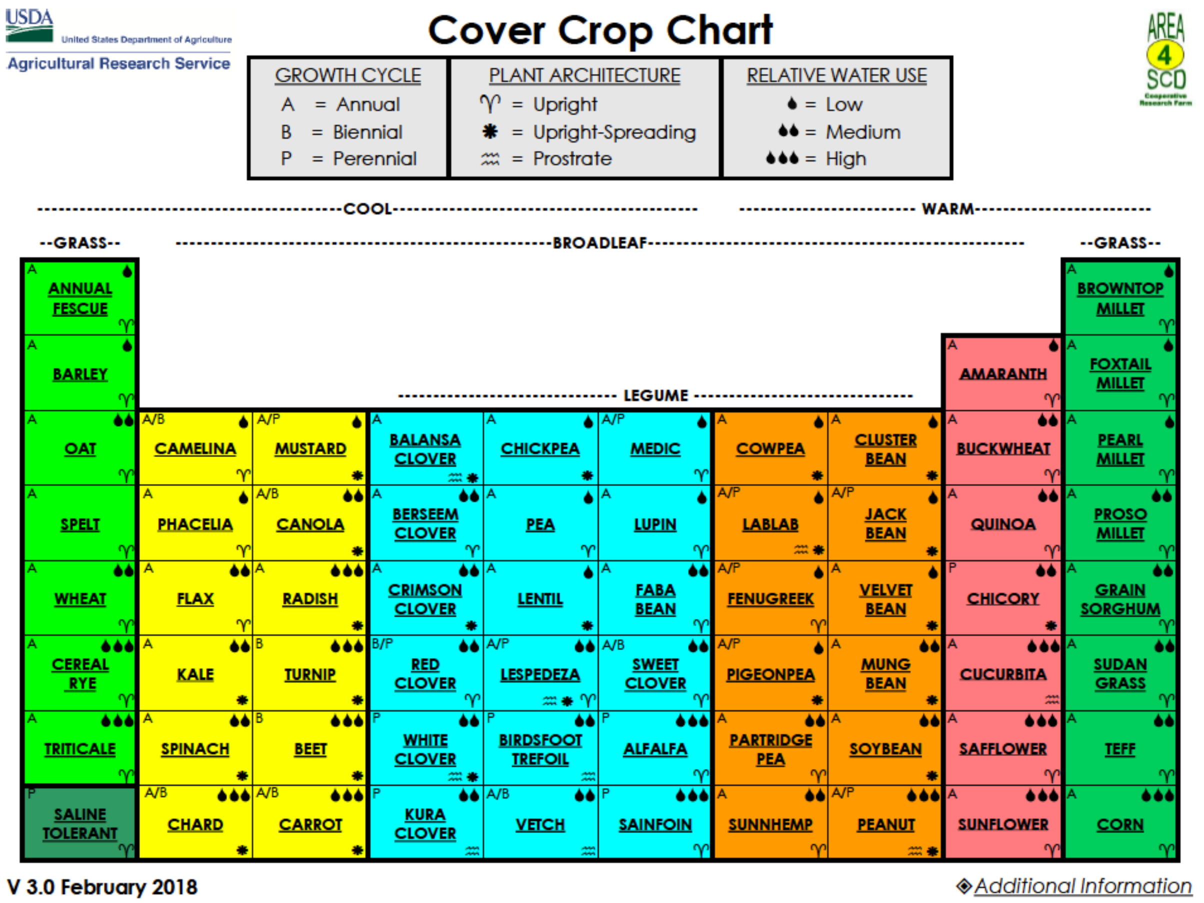


Figure 5: Cover crop chart, USDA, 2018

Chapter 4: Tools in the Toolbox

An aspiration of many farmers is to use ‘all the tools in the toolbox’. Integrating livestock into cropping systems is only one tool of many that are available to producers. Some tools available include light and heavy cultivation, zero tillage, chemical, crop type and variety choices, livestock grazing with set stocking, high intensity grazing, precision agriculture, management decisions and timing. By looking at the range of tools, farmers can better compare the role livestock has compared to machinery within crop production. Farmers can also evaluate these tools through a different lens when the option of including livestock is considered.

Zero tillage

The case for zero tillage has been long discussed in New South Wales (NSW) as to its merits relative to minimum tillage. A Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Farmlink report from 2015 looks at the effect of grazing and burning stubbles on grain yield and quality in no till and zero till controlled traffic farming systems in southern NSW. It found no consistent differences due to no till or zero till. It also found grazing of stubbles sped up Nitrogen cycling and the grazed and stubble retained treatments were consistently more profitable (Hunt, 2015).

Meanwhile there is no comparison to a zero till disc machine’s ability to handle residue. The term “trash” is often used (and “stubble is trouble”) to describe left over plant residue and the regard many have for it in their systems. By having a tool that has the ability to handle large amounts of residue, the way plants are managed at harvest, either by machine or by animal, changes. Instead of harvesting or grazing to ensure trafficability, operations can be tailored to maximise the benefits of residue. Machine harvest can be conducted higher with the use of stripper fronts, giving harvest efficiencies and greater cover post crop, and grazing does not need to be done to bring residue levels down to a manageable level that accommodates dragging a tyne or hoe through it without blocking. Even distribution of residue at harvest is still a priority when high levels of residue are present to assist with consistent soil to seed contact of the next crop. A zero tillage machine allows a farmer to change their crop production system in a way that no other machine allows.

In New Zealand, the locally produced ‘Cross Slot’ machine is marketed as the ultimate zero till machine. The Cross Slot opener is able to enter a wide range of soil conditions, place seed with horizontal and vertical separation from fertilizer, trap more humidity around a seed in the soil than other disc seeders, and plant through a rolled out bale of hay and not block up.

The most widely seen disc machine seen during the research was the John Deere single disc. All machines seen were liked by their owners who had worked through the limitations of each and were achieving the no till results they wanted.

Crop type and varieties of crop grown can be an easy tool to apply to a cropping system when looking to integrate livestock. Longer season crops can be planted that allow producers to take advantage of rainfall that falls in what has previously been considered a fallow. When guidelines are followed around timely livestock removal there is good experience in Australia (*Grain and Graze*) that grain yields need not be compromised. Farms were visited in New Zealand that were adopting this principle to achieve another income stream from the grazing of lambs. The hope was to also push grain yields higher with greater developed root systems from earlier planted crops.

Strip tilling

Strip tilling machines were seen on the author's visits and were providing a high residue handling machine that cultivated the soil only in the row where seed was to be placed. This gave an option to those producers who felt their soils needed cultivation every year but were wanting to achieve most of the no till benefits.

Some of the best canola and wheat crops were planted with a spreader and light cultivation. Something along the lines of a shallow speed till. Even the producers using this practice were surprised by how effective it was. It rated highly also for simplicity and the amount of ground that could be seeded in a narrow window of planting. Planting into high residue loads and grazed stubbles also presented no problems for this method.

Precision agriculture

Craig McKenzie farms in New Zealand and has built a precision agriculture business to complement his family's intensive irrigation business. His statement that "*production is for vanity and profit is for sanity*" resonates as a guiding maxim to the adoption of precision agriculture. This is a multi-layered business that has high levels of data collection and analysis at one end and GPS guidance at the entry level. By gathering large amounts of data through electromagnetic (EM) mapping, yield maps, soil tests, and other sensing equipment like

Normalised Difference Vegetation Index (NDVI), usually from a satellite platform, uniformity of profit from a highly variable paddock can be attained. To solve the issue of whether to build up the better performing areas or lower inputs on lower performing areas and the range between, Craig focuses on what is the most profitable alternative for each zone (pers. comm., 2019).

Management decisions

Management decisions and timing in any cropping or grazing system is integral in utilising any tool and will drive the success of any system. Conducting cropping operations on time and moving stock on time in a grazing operation are things that cost nothing but can give large rewards.

Grazing livestock

Grazing of livestock in a cropping system can be a source of income generation and land improvement when done well. However, when managed poorly can lower productivity and lead to erosion of the soil resource. It is essential that it is managed with the end in mind. To effectively graze any area of land, the stocking rate needs to be appropriately matched to the carrying capacity of the area. Gabe Brown's (2018) book *Dirt to Soil*, discusses high density stocking as being 30-50 tonnes of livestock per hectare of land. To achieve this, many animals are required, fencing partitions may need to be small, grazing duration short, and water needs to be sufficiently available. This stocking rate is a tool of considerable power and if not carefully managed can easily tip over into land degradation and animal underperformance.

Synthetic inputs

No one likes to use more chemicals on their farm than they need to. They are expensive and they harm the ecology of the farm if used poorly. Some farmers have turned away from artificial fertilisers, herbicides, fungicides and insecticides. These tools will generally give very measurable results when applied correctly. Most importantly they can be a reliable profit generating tool in a farm business. If stopping their use is an aim of the business, it can be appropriate and assist with marketing options. A clear goal to the use of these tools should drive any decision regarding their use, or not, in a system. An emphasis on efficiency of applied inputs can be the focus instead of peak production and this still needs individual assessment to profit in an individual's system.

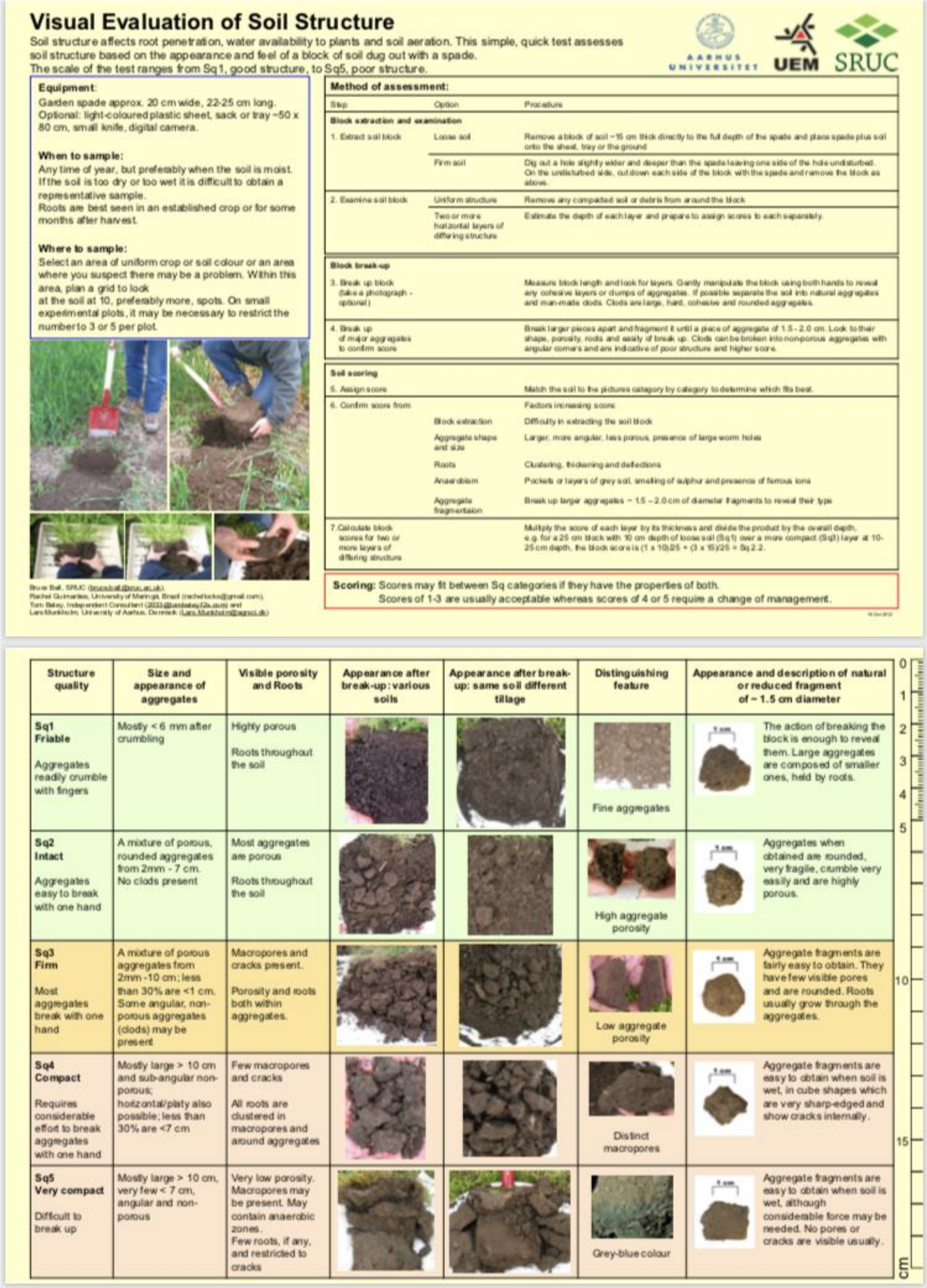
Soil testing

Soil testing is an important tool that farmers use to assess land fertility and nutritional requirements for upcoming crops. It is also an important part of assessing the impact of any changes made to an existing farming system. The scientific accuracy of soil testing gives confidence to purchase expensive inputs that gives a measurable result in crop performance. Standard soil tests will guide the input rates for the macro and micro nutrients, while more advanced testing is emerging that will give an indication of biological activity in a soil.

A number of farms visited by the author in the USA used the Haney soil test as an indicator of biological health of the soil and is carried out in Midwest Labratories, Omaha, Nebraska. This test gives empirical feedback on the practices of those farmers that are focusing on improving soil health. It gives an indication of the level of biological respiration occurring in the soil, tests plant available nutrients in water and provides a soil health indicator number (0-50, with the higher the better). Jay Fuhrer (pers. comm., 2018) was using it alongside standard soil testing to help guide and measure the performance of the trials undertaken on Menoken Farm, North Dakota.

Another objective assessment tool for measuring changes in a soil usually not recorded in a standard soil test is the VESS procedure. Farmers can get some feel for system improvement if the soil feels different to touch, walk on, or drive across, but to have incremental improvement in practices, objective measurement needs to take place. The VESS procedure, as illustrated in Figure 6, offers a means of objectively ranking changes that can occur in soil structure. Tools like these are an important part of moving towards the goal of a healthy soil as without empirical measurement progress is subjective to the individuals bias.

Worm counts and type in a repeatable volume of soil were observed by the author in the fields of France with 2018 Nuffield France Scholar, Guillaume Milard (pers. comm., 2018). This was another measure of objective assessment helping to quantify improvements to soil health. Having objective data to measure performance is critical to improving a farming system.



Visual Evaluation of Soil Structure

Soil structure affects root penetration, water availability to plants and soil aeration. This simple, quick test assesses soil structure based on the appearance and feel of a block of soil dug out with a spade.
The scale of the test ranges from Sq1, good structure, to Sq5, poor structure.

AARHUS UNIVERSITET UEM SRUC

Equipment:
Garden spade approx. 20 cm wide, 22-25 cm long.
Optional: light-coloured plastic sheet, sack or tray ~50 x 80 cm, small knife, digital camera.

When to sample:
Any time of year, but preferably when the soil is moist. If the soil is too dry or too wet it is difficult to obtain a representative sample.
Roots are best seen in an established crop or for some months after harvest.

Where to sample:
Select an area of uniform crop or soil colour or an area where you suspect there may be a problem. Within this area, plan a grid to look at the soil at 10, preferably more, spots. On small experimental plots, it may be necessary to restrict the number to 3 or 5 per plot.

Method of assessment:

Step	Option	Procedure
Block extraction and examination		
1. Extract soil block	Loose soil	Remove a block of soil ~15 cm thick directly to the full depth of the spade and place spade plus soil onto the sheet, tray or the ground
	Firm soil	Dig out a hole slightly wider and deeper than the spade leaving one side of the hole undisturbed. On the undisturbed side, cut down each side of the block with the spade and remove the block as above.
2. Examine soil block	Uniform structure	Remove any compacted soil or debris from around the block
	Two or more horizontal layers of differing structure	Estimate the depth of each layer and prepare to assign scores to each separately.
Block break-up		
3. Break up block (take a photograph - optional)		Measure block length and look for layers. Gently manipulate the block using both hands to reveal any cohesive layers or clumps of aggregates. If possible separate the soil into natural aggregates and man-made clods. Clods are large, hard, cohesive and rounded aggregates.
4. Break up of major aggregates to confirm score		Break larger pieces apart and fragment it until a piece of aggregate of 1.5 - 2.0 cm. Look to their shape, porosity, roots and easily of break up. Clods can be broken into non-porous aggregates with angular corners and are indicative of poor structure and higher score.
Soil scoring		
5. Assign score		Match the soil to the pictures category by category to determine which fits best.
6. Confirm score from:		Factors increasing score
	Block extraction	Difficulty in extracting the soil block
	Aggregate shape and size	Larger, more angular, less porous, presence of large worm holes
	Roots	Clustering, thickening and deflections
	Anaerobism	Pockets or layers of grey soil, smelling of sulphur and presence of ferrous ions
	Aggregate fragmentaion	Break up larger aggregates ~ 1.5 – 2.0 cm of diameter fragments to reveal their type
7. Calculate block scores for two or more layers of differing structure		Multiply the score of each layer by its thickness and divide the product by the overall depth, e.g. for a 25 cm block with 10 cm depth of loose soil (Sq1) over a more compact (Sq3) layer at 10-25 cm depth, the block score is (1 x 10)/25 + (3 x 15)/25 = Sq 2.2.

Scoring: Scores may fit between Sq categories if they have the properties of both.
Scores of 1-3 are usually acceptable whereas scores of 4 or 5 require a change of management.

Bruce Ball, SRUC (bruce.ball@sruc.ac.uk),
Rachel Guimarães, University of Maringá, Brasil ([illegible]),
Tom Batey, Independent Consultant ([illegible]) and
Lars Munkholm, University of Aarhus, Denmark ([illegible])

Structure quality	Size and appearance of aggregates	Visible porosity and Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature	Appearance and description of natural or reduced fragment of ~ 1.5 cm diameter
Sq1 Friable Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous. Roots throughout the soil			Fine aggregates	1 cm. The action of breaking the block is enough to reveal them. Large aggregates are composed of smaller ones, held by roots.
Sq2 Intact Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous. Roots throughout the soil			High aggregate porosity	1 cm. Aggregates when obtained are rounded, very fragile, crumble very easily and are highly porous.
Sq3 Firm Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Porosity and roots both within aggregates.			Low aggregate porosity	1 cm. Aggregate fragments are fairly easy to obtain. They have few visible pores and are rounded. Roots usually grow through the aggregates.
Sq4 Compact Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks. All roots are clustered in macropores and around aggregates			Distinct macropores	1 cm. Aggregate fragments are easy to obtain when soil is wet, in cube shapes which are very sharp-edged and show cracks internally.
Sq5 Very compact Difficult to break up	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low porosity. Macropores may be present. May contain anaerobic zones. Few roots, if any, and restricted to cracks			Grey-blue colour	1 cm. Aggregate fragments are easy to obtain when soil is wet, although considerable force may be needed. No pores or cracks are visible usually.

0 1 2 3 4 5 10 15 cm

Figure 6: Visual Evaluation of Soil Structure (SRUC, 2012)

Chapter 5: Profitability and Risk

Profitability

Profitability is essential when running a farming business. The profitability of a cropping system will be determined by the choice of crop grown, how often that crop appears in rotation, the yield of that crop, and the price received. When considering introducing livestock into a cropping system there does not need to be wholesale changes to crop rotation. Instead, changing variety of crop may suffice (an example would be changing form spring canola to winter canola). Yield need not be penalised if district dates for stock exclusion are followed. This allows the short-term introduction of livestock to a continuous cropping system which would pose little risk to profitability.

For the farmer to have a year-round feed resource available to livestock, crop choices may need to change. While this can give many benefits to a cropping system as outlined in this report, the degree to which profitability may change will be less easily defined over different seasons. This poses a financial risk that needs to be managed and understood. Liveweight gains in a trading system are the most easily measured component of grazing production and would form the basis of returns generated per hectare.

One scenario being explored on the authors' farm at Belmont in Canowindra, NSW, is to widen the forage window available in a cropping rotation by using cover crops over summer between winter grain crops. Either single species or multi species forage mixes being planted between harvest and seeding of the next cash crop, with an aim to harvest summer rainfall and convert it into grazing dollars. The Department of Primary Industries (DPI) conducted a farming systems trial at Canowindra in 2018-2019, and results indicated that while grain yields are reduced following a summer forage crop, extra income generated by grazing can be two to three times the value of the wheat yield reduction (McMaster, Stevenson & Strahorn, 2020).

Every season will bring different challenges for a cover crop as some of the water will be used from the pool that would have been available for use in the following cash crop. Lower cash crop yields should not compromise whole farm profitability when the income generated from grazing and the additional benefit of improving the soil's ability to capture water is also considered. Increasing the time with actively growing crops in the soil and generating large summer biomass will increase the ability to raise soil carbon levels in a rotation. As carbon markets develop this has potential to add another income stream as well as improve dynamic soil properties. The option of growing a summer and winter forage crop back to back as a regular feature in a larger 'crop rotation' is also being trialled on Belmont.

The factors to consider when deciding to grow a cover crop should be tailored to individual farms. Trigger points that pertain to soil moisture and forecast rain will be essential. Other factors to consider will be the mix of plants employed, which can change depending on the use intended, cost of seed, and when to implement the cover crop in the rotation. Also. the length of time for a cover crop to grow can be tailored to receive the benefits of the cover, and also allow moisture accumulation prior to grain production.

With summer rain accumulation driving profitability in Australian winter cropping regions currently, care needs to be taken, and a clear goal established, when looking to plant a summer cover between winter crops. If summer grazing is an aim of planting the cover crop, decisions around seeding rates and fertiliser applications would be best made with this in mind. If summer grazing is not the aim and an introduction of diversity to a simplified system to provide habitat for the soil biology is the aim, then higher seeding rates and additional fertility may not be needed.

Profitability will also be influenced by a producer's underlying asset worth. When land value is high there is an imperative to employ the most profitable enterprise to that parcel of land. This will drive enterprise choice and the intensity to which production is carried out. Integrating livestock correctly can add income to all values and types of land and provide system benefits as outlined in this report when done correctly.

When looking to assess the returns from incorporating livestock into a cropping system it is important to consider the potential system benefits, as well as direct gross margin returns. Increasing soil carbon levels may give access to the developing carbon market. Increased carbon and humus can store more water and drive greater production. Soil loss is reduced and eventually reversed. These and other dynamic qualities of our soil would be expensive to remedy with direct inputs. Grazing livestock can be part of a system that achieves it while generating income.

Risk

Investment lag

Risk is something every cropping farmer deals with due to the time involved between investment and return when planting a crop. By integrating livestock into a cropping system, the time producers are exposed to the risk of no return is reduced. Livestock can harvest income from a crop midway through its growth and turn rainfall that falls outside of the growing period of a cash crop into revenue. Financial tools of many shapes can also be used to manage the lag between investment and return on cropping farms, however livestock have the ability to mitigate risk and increase overall returns made, unlike insurance policies that see price protection as a main benefit.

Soil

The ongoing degradation and loss of soil is a risk to all farmers. New techniques and technology have made significant improvements to the rate of soil loss around the world without eliminating it completely. The principles of soil health outlined at the start of this report are being successfully applied to farms throughout the Midwest of the USA. Organisations around the world are helping farmers mitigate the risk of soil loss.

'No Till on the Plains' is an organisation in the USA that is doing a great job of publicising these successes and acting as a mentor organisation for those looking to emulate these results. The author visited farms that were building soil carbon, diversifying their risk with livestock and remaining profitable in the process.

VicNoTill and South Australia's No Till Farming Association are two Australian organisations at the forefront of promoting practices that encourage good soil management by incorporating no till and animal integration into cropping systems.

The soil health movement is gaining most traction in the areas around the world with a long history of conventional full tillage agriculture. The soils of Europe and the UK are very resilient but in some cases hundreds of years of cultivation is seeing the resource become depleted (Phil Jarvis, pers. comm., 2018). Organisations like GroundswellAg in the UK are leading the way in highlighting soil health, one element of which is incorporating livestock. This is seeing a move to practices that are less damaging to the soil. Reducing or eliminating cultivation is a good first step down this road.

Phil Jarvis (pers. comm., 2018) at the Allerton Project in the UK has trials running that are looking at the differences between full cultivation, minimum tillage and no till on the profitability of cropping systems. He is working on providing research that may see those in the UK achieve their production aims with less cultivation. Paul Jasa (pers. comm., 2018) in Nebraska had a 32-year long trial looking at the benefits to the soil no till provided and was finding the practice of terracing being made redundant where no till was practiced. With better water infiltration on the no till ground negating the need to direct runoff as there was none. Both Phil and Paul were investigating cover crops and livestock integration in combination with no till to provide soil and income benefits.

In the Midwest of the USA, adherents of the five soil principles were experiencing benefits to their cropping systems but they were ready to admit that a transition time of three to five years was needed before their system stabilised into its new state. Three to five years of poor returns for most farmers would put them out of business, so this risk to a change in system needs to be considered carefully.

Modelling and experimentation

Experimentation and modelling of success in the past 20 years, for instance, can give some insight into the risk associated with systems changes. The Australian CliMate App, developed by the University of Southern Queensland and DHM Environmental Software Engineering, can give a quick and easy estimate of an area's past ability to receive rainfall in planting windows and allows basic modelling of success.

In Canowindra, over the last 119 years, it says that there is 50% chance of receiving 100mm of rain in November and December and 61% chance of receiving 100mm between February 1 and April 30. Similarly, a 35% chance of 100mm between March 1 and April 30. This information can be interpreted to mean that 50% of the time a summer crop will establish successfully in Canowindra and if that crop is terminated by the start of February it has a 62% chance of harvesting significant moisture before spring wheat and canola planting. Nearly twice the chance of harvesting moisture compared to a March 1 termination. This is illustrated below in Figure 7.

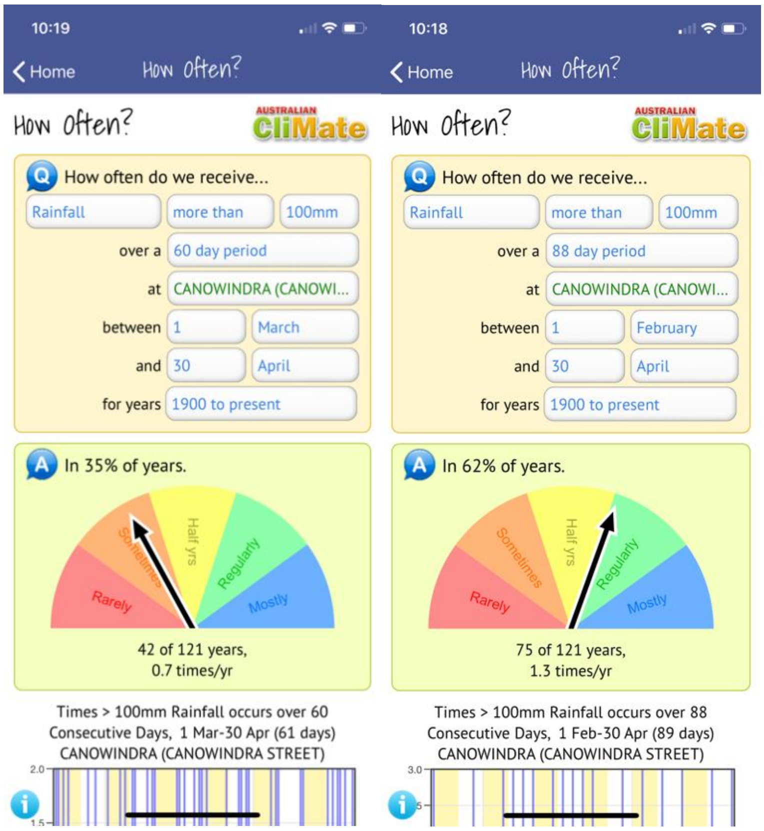


Figure 7: Screen shot of the Australian CliMate app, showing how often more than 100mm of rainfall is received 60 and 88 days prior to April 30 at Canowindra in NSW.

There is nothing to stop every farmer having a go at these things themselves though and being prepared to fail occasionally – in a small way preferably – to break into new ground, which is a healthy approach to taking a business forward.

Henderson Farms in Alabama were successfully pushing the yield envelope in their corn operation and actively trying new things looking to drive their business forward. "*If they didn't fail at something every year they didn't feel they had tried hard enough*" (pers. comm., 2018). Mindset can be the largest barrier to integrating livestock.

Conclusion

The benefits that can be gained by integrating livestock into continuous cropping systems are multiple. Dual purpose grain and graze crops can spread risk and provide greater overall return than grain only. Flowering times can be delayed with grazing to assist with early plantings and frost risk at flowering, allowing flexibility in variety choice and planting windows.

Grazing offers opportunity to grow a more diverse rotation than wheat and canola alone. While an emphasis can remain on grain production the focus on winter only grain can change. A grazing 'crop' allows versatility in planting times and harvest. Extending what can be the busiest times of year on farm and spreading the workload into more manageable pieces. Grazing crops can add fertility, organic matter, and rotation options in terms of weed control for a paddock.

However, grazing can be a damaging tool when not applied in a sympathetic way to the goals of the system, much like a plough can also damage soil structure when not applied with the end goal in mind. Flexibility in a grazing system to stocking rates is important. This can involve each business identifying mob composition between breeding and trading, and relief valves like feedlots and agistment that allow for stock removal when land condition dictates.

Extra management, infrastructure, expertise and labour is involved in introducing animals into a cropping system. Livestock can quickly turn plant growth, generated at any time of the year, into money. Higher rainfall provides greater opportunity to generate income. With better utilisation of rainfall as it falls there is scope to increase the returns generated per 100mm of rainfall received, minimise salinity (leakage from the system), stop erosion, and improve the dynamic properties of soil within every land managers control.

A greater understanding of biological processes in soils and how management, including livestock grazing, influences these processes, can lead to greater efficiency in production.

Recommendations

1. Soil health

An understanding of biological influences and processes in soil is needed equivalent to understanding soil chemical attributes. The GRDC is well-placed to establish long-term trials that monitor and understand changes to biological communities in response to new and developing farm management. CSIRO would have the technical ability to provide gold standard soil biology testing frameworks that can help guide GRDC long-term trials.

The five principles of soil health are easily understood, non-threatening, and will see a better soil resource handed onto the next generation. Profitable practices in line with the five soil health principles need to be targeted by all farmers growing crops and raising livestock.

2. Grazing

Livestock should be integrated into cropping systems with methods outlined in this report. Flexibility and discipline will drive success.

Grazing is a powerful tool and one of the few available to farmers that generates money. For it to be applied successfully by any grazier or cropper, attention should be on plant performance, not just animal performance. A plant managed for best growth will achieve more growth and potential for income generation than one that is regularly sacrificed to achieve an incremental rise in animal performance. High intensity grazing has the greatest potential for positive crop, soil, and animal performance.

3. Crop sequencing

More diversity in crop selection is needed. Soil health considerations need to be more accurately quantified with continued support of trials that span full and multiple sequences of crop rotation. The NSW Department of Primary Industries, CSIRO and GRDC can all contribute to this in a multi-faceted research alliance.

Poly cropping needs further exploration as part of the fit in a more diverse rotation and the GRDC would be well-placed to link this to work done as a result of recommendation 1 above.

The farming systems trial undertaken in 2018-2019 on Belmont (and trials in other areas) requires 10-years of funding. Covers, with minimal soil disturbance, increasing residue levels and diverse rotational crops require time to study their direct and legacy effects in the

Australian environment, across a range of seasons. By fully understanding this adaption of old crop husbandry to modern crop production the potential for large gains in efficiency are possible.

4. Water

Water infiltration rates in soil are an easily completed soil health indicator that all producers can use as an indicator for improving soil health associated with each different crop planted. Research into the movement of water through soil and land needs to continue to give producers a greater understanding of what effects changing management can have in individual environments.

In NSW, salinity is an intermittent problem that if not addressed can have whole catchment implications. This starts with farmers managing the water as it falls on their property, optimising it while it is in the soil root zone and understanding what is happening to water deeper in the soil profile. When winter canola and wheat roots can access 4-5m of the soil profile, this is a minimum depth to set moisture monitoring at. Local Land Services in NSW can further support the understanding of soil water hydrology and how farm management practices influence it.

5. No Till

No-till disc openers should be reconsidered by all farmers as a tool that will allow a system change to their cropping system. Increased residue levels are best handled with a disc, carbon is best accumulated, and the soil food web functions best in the absence of tillage. The level of residue deemed high in current cropping systems may be considered a minimum in the future when there is further understanding of the functioning of soil.

References

Brown, G. (2018). *Dirt to Soil*. Chelsea Green Publishing.

Bateman, R (2018) Personal Communication New Salem, North Dakota, USA

Crider, F.J. (1955). Root growth stoppage resulting from defoliation of grass. *U.S. Department of Agriculture Technical Bulletin 1102*, 23 p.

Doig, N (2018) Personal Communication Litcham, England

Emmons, J (2018) Personal Communication Leedey, Oklahoma, USA

Fuhrer, J (2018) Personal Communication- NCRS, North Dakota, Menoken Farm

Henderson Farms (2018) Personal Communication Madison, Alabama, USA

Hoyle (2013). *Managing soil organic matter: A Practical guide*. GRDC

Jarvis, P (2018) Personal Communication Allerton Project, Loddington, Leicester, UK

Jasa, P (2018) Personal Communication Rogers Memorial Farm, Nebraska, USA

Johnson, J (2018) Personal Communication Soils and Crops Consultant, Noble Research Institute, LLC.

Kinder, J. (2018) Personal Communication Walters, Oklahoma, USA

McKenzie, C (2019) Personal Communication Methven, New Zealand

McMaster C., Stevenson, A. & Strahorn, S. (2020). *Corowa GRDC Grains Research Update*. NSW Department of Primary Industries. Retrieved 20 April 2020, from https://grdc.com.au/__data/assets/pdf_file/0015/392001/10969-Corowa-update-proceedings-2020-Inter.pdf

McPeak, T (2018) Personal Communication NE of Bismark, North Dakota, USA

Meyer, L (2018) Personal Communication Johnson. Nebraska, USA

Milard, G (2018) Personal Communication Chevenon, France

Miller, J (2018) Personal Communication Culbertson, Nebraska, USA

Mindemann, A. (2018) Personal Communication Lawton, Oklahoma, USA

Montgomery, D. (2007). *Dirt: The erosion of civilisations*. University of California Press.

NCRS (2019). Soil Health. Retrieved 20 April 2020, from https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

Porter, M (2019) Personal Communication Otaio South, Canterbury, New Zealand

Press, T., Howard, W. & Mattiazi, P. (2019). *Climate Science for Australia's Future. A report by the National Climate Science Advisory Committee*. Department of Environment and Energy.

Ruth, B. (2018) Personal Communication. Rising City, Nebraska, USA

SARE (2012). *Managing cover crops profitably 3rd edition*. US Department of Agriculture.

SRUC (2012) Visual Evaluation of Soil Structure. Aarhus University and Scotland's Rural College

USDA-NCRS (2011). Carbon to Nitrogen in Cropping Systems. Retrieved 20 April 2020, from https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd331820.pdf

Voth, K. (2015). *Great "Grass Farmers" Grow Roots*. National Grazing Lands Coalition.

Whiteside, C (2019) Personal Communication Clinton, Southland, New Zealand

Plain English Compendium Summary

Project Title:	Integrating Livestock into a continuous cropping system in a high rainfall environment
Nuffield Australia Project No.:	1817
Scholar:	Stuart McDonald
Organisation:	Belcan Partnership 'Belmont' 239 Lockwood Rd Canowindra NSW 2804 Australia
Phone:	+61 427 640 200
Email:	stuartmc1@me.com
Objectives	To research practices that incorporate livestock into continuous cropping systems; better utilise all rainfall that falls; and develop a crop rotation that improves the soil. Specifically, how farmers around the world deal with: 1. Utilising every drop of rain on a dryland farm. 2. What livestock options can be employed to improve return from plant growth 3. Rotation diversity 4. The range of tools in the toolbox 5. Profitability and risk: weighing up returns from a change to system, transition times, how much return is needed?
Background	Benchmarking results on farm were indicating dual purpose crops were the authors most profitable enterprise. The question was how to extend this and look at how livestock incorporation into cropping systems takes place around the world.
Research	Farms, research centers, and universities in France, Ukraine, England, USA and New Zealand were visited to see if livestock were being integrated into continuous cropping systems. Where this was occurring, the extent of the integration, system benefits, and management changes that were involved were identified.
Outcomes	Grazing applied well to a continuous cropping system has the ability to cycle nutrients faster than ungrazed paddocks, generate income while not comprising grain yields, and assist in creating a biologically diverse and healthy soil. If applied badly it can have the opposite effect. Grazing plants evenly with appropriate density and leaving behind sufficient residue are key.
Implications	The benefits of integrating livestock into a continuous cropping system provide extra income from crop production, healthier soils in the cropping system, less financial risk, and better utilisation of rainfall that falls any time of the year.
Publications	Nuffield Australia National Conference, Brisbane, September 2019