Cover Crops

Nutrient Use Efficiency and Fertiliser Application Methods

A report for

By David Cook
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Executive Summary

With a continual decline in agriculture's terms of trade, producers are looking to increase production, cut costs or re-allocate resources to other enterprises. As a result, systems have been developed and introduced into broad acre farming in attempt to maximise production, which include no-till seeding, continual improvements in crop rotations and varieties available, various agronomic strategies and a range of precision agriculture technologies, such as auto steer on tractors, yield mapping, controlled traffic farming and crop imaging.

The underlying resource that drives the whole system is obviously the soil, and all farmers aspire to have a healthy soil with a high organic carbon level. While all the practices above have had an impact on production and soil quality, the pressure to maintain profitability in the business under constant cost-price squeeze naturally means that compromises are sometimes made. However, in a good year (financially) the machinery shed is often filled with new machinery before the farmer considers what "upgrade" the soil will get (possibly some lime, gypsum, a deep ripping or extra fertiliser will console them).

Soil health is essentially a function of the soil's organic carbon level, the higher it is, the healthier the soil. In the absence of any 'soil health' soil test, an organic carbon test can be used as a predictive test. While there has definitely been a change in recent years in the attitude to building soil organic carbon, most farmers are struggling to make any substantial gains in achieving this, despite all their best efforts. One of the main reasons for this has been the loss of diversity in crop rotations, often leaving only two alternating crops (e.g. wheat and canola, corn and soybeans) and a loss of livestock and hence pasture from the system, which reduces the period of plant and root growth throughout the year.

Increasing diversity in a rotation involves more than just seeding a wider range of crops at the usual time of seeding (autumn or spring). It also means introducing crops considered out of season (eg. warm season grass (millet) and broadleaf (e.g. cowpea) species in a Mediterranean environment). These so-called cover crops are not intended to be harvested or grazed, but as a dedicated soil ameliorant, which have an immediate effect on the following crop but also on the capacity to build soil organic carbon. The more often living plants and roots are living in the soil, the greater the capacity to increase soil organic carbon. The perceived negatives of such a strategy are more than outweighed by the positives. The complexity comes into designing a system with the available species that suits the local environment, and that is what many will argue cannot be done on their farm or soil type. Results from around the world has shown it to be successful in area with rainfall from 400-1200mm (16-48") of rain.

One of the major expenses for cropping farmers is fertiliser, especially nitrogen fertiliser, but the reality is that only somewhere between 25-50% fertiliser applied is utilised by the crop in the year of application. However, there is a definite difference in nitrogen uptake between fertiliser applied as ammonium nitrogen and nitrate nitrogen, as the uptake pathways within the plant vary for the two sources. With ammonium nitrogen, plant growth regulates nitrogen

uptake, whereby with nitrate nitrogen, nitrogen supply determines plant growth. CULTAN (controlled uptake long term ammonium nutrition) is a method of fertiliser application where ammonium is applied to the soil once per year in a concentrated band, thus alleviating the need for multiple applications. One application technique used for the CULTAN system is a spiked injector and farmer experience with it in Germany has shown nitrogen uptake efficiency of greater than 90%.

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Foreword

There are three reasons I found myself as a Nuffield Scholar for 2013.

Firstly, when I returned home to the family farm in 1997, having bought half of the neighbouring farm, my parents Neville and Wendy gave me free range to change farm management as I saw fit on their farm as well as mine, having worked as an agronomist for three years' post university graduation. Neville's father had granted him the same opportunity after leaving school. This passing on of responsibility gave me the chance to lead, rather than just follow.

Secondly, the decommissioning of part of the local irrigation system in 2008 saw our farm revert to a rain fed (dryland) farm with the loss of six irrigated enterprises including high value seed and lucerne (alfalfa) hay production. This coincided with a run of drought years that started in 2003 with little pasture production on the remaining rain fed part of the farm. A decision was made to sell the entire sheep flock at the end of 2007, given that the loss of our irrigation water seemed inevitable and the soil loss from grazing low DM based pastures was unacceptable (confined areas for feeding ewes over summer had been established and sheep had not been grazed on crop stubbles since 2000).

Lastly, given the farm converted to a dryland cropping farm, the decision was made to change to a full stubble retention system with the purchase of a Cross Slot no-till seeder with neighbours, Peter and Viv Jeffrey. The loss of diversity in the crop-pasture-livestock system that the farm business previously relied on for the usual reasons – cash flow management, soil fertility, weed, pest and disease control, meant a change in focus of the management to achieve the same result. This opened up the opportunity to look at expanding our seeding window from beyond the usual April-May period for winter crops to mimic the benefits of the previous enterprise mix.

I first became interested in cover cropping and/or opportunistic summer cropping after visiting Dwayne Beck at the Dakota Lakes Research Farm in South Dakota in 2004 and seeing the trials with summer crops in a summer dominant medium rainfall environment (450mm/18"). The trials showed positive crop responses in the following wheat crop after sunflowers and millet compared to the stubble fallow treatment, which is contradictory to the accepted practice of spraying summer stubble fallows to conserve moisture for the following winter crop.

An opportunity presented itself in the first year of our system transition (2009) when a paddock was not seeded due to wet weather. A summer crop trial was established in spring as part of the University of Melbourne 'Farms, Rivers, Markets' project. The replicated trial included sunflowers, mung beans, white French millet, lab lab and safflower. It was intended to measure the following crops yield and moisture use compared to the standard sprayed stubble fallow. All crops were harvested as a result of above average summer rainfall, however the following year the crop was affected by a wet winter and flooding that resulted in much of the paddock not being harvested, so the trial was unfortunately abandoned.

The millet treatment in the trial was the standout financially and with part of the farm not seeded in 2010 and 2011 due to wet conditions, shirohie millet was sown as a cover crop, but both years the crop was harvested for seed due to the stored subsoil moisture and above average summer rainfall. As in the trial, the gross margins were the best ever recorded. Wheat was double cropped into the millet for a gross margin of $1800/ha in 2009/10 – an exceptional result for a Mediterranean environment with 500mm (20") of annual rainfall.

With the loss of pastures from the farm, I was committed to keep legumes in the rotation so not to have to rely on nitrogen fertilisers for all the crop nitrogen requirements. The current system for applying the bulk of the nitrogen is urea spread throughout the season depending on yield potential and available soil moisture. The efficiency of N uptake with this system is poor (40-50%), so I am interested in what options there are in terms of application equipment and fertilisers to increase this nitrogen uptake efficiency. I was interested in the CULTAN (Controlled Uptake Long Term Ammonium Nitrogen) system I saw in Germany in 2012, where ammonium based fertilisers are injected into the soil with a spoked injector, eliminating losses and regulating uptake by the plant when it is required.

The opportunity to undertake travels around the world under the banner of a Nuffield Scholarship was a chance not to be missed. I am always looking at how and why we do the things we do, and I'm sure I will be able to provide some options and answers to these questions, either through this report or on-farm trials that I conduct.

Acknowledgments

Firstly, thank you to Nuffield Australia for choosing me to be an ambassador for the organisation when they awarded me a scholarship. The depth and variety of knowledge of the Nuffield Scholars is huge (and humbling at times) and it is a great group to be a part of.

Without sponsors like The William Buckland Foundation, the opportunity to undertake the scholarship would not exist, so I am very appreciative of their sponsorship of me and fellow Scholars.

A huge thanks to all those who hosted me on my travels. The hospitality everywhere I went was tremendous and very enjoyable. Show me another industry where potential competitors would open up their business to show you how to improve your own.

Thanks to new found friends I travelled with on the GFP.

Finally, the biggest thanks go to my wife Tracey and parents Neville and Wendy who have always encouraged and supported me in everything I have taken on, even if sometimes they thought I might have bitten off too much. I'm still chewing!

Abbreviations

CULTAN - Controlled Uptake Long Term Ammonium Nutrition

ha - Hectare

Kg – Kilograms

mm - millimetre

NUE - Nutrient use efficiency

OC – Organic carbon

OM – Organic matter

WUE - Water use efficiency

Objectives

Having chosen a range of topics for my scholarship, the overall objective of my studies was to identify and develop a farming system that builds soil organic carbon at a level greater than the existing systems considered for a Mediterranean environment.

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The key questions I wanted answered to achieve this objective were:

1. What is the importance of soil health and what is the relationship to plant health?

2. What role do cover crops have in crop rotations to build soil organic carbon (OC) levels?

3. Do fertiliser application systems exist that could improve nutrient uptake efficiency?

Introduction

The cropping system of most farms in Australia is based around two to three crops in a set rotation that is heavily reliant on ever-increasing use of inputs, such as fertiliser and crop chemicals, to maintain production. The unrelenting decline in agricultural terms of trade (that is, the ratio of prices received to prices paid for inputs) has seen farmers innovate and adapt to maintain production and profitability (Productivity Commission, 2005). The tightening of margins in grain production has meant that the crop rotation growers which are using is not often the preferred one, due to the poor profitability of alternative rotation crops, whether that is real or perceived.

The enterprise mix of many Australian broad acre farms has changed significantly in the past 20 years. Many were originally based on a crop and pasture rotation that included sheep and/or cattle, but the drought conditions and increasing returns from crops over this time has seen many farms increase the cropping intensity significantly, many to the point of all livestock being removed from the farm.

The effect of this change in the farm enterprise mix has often resulted in the simplification of farm management and the ability to farm more land given the freeing up of labour previously required for the livestock enterprise. However, this change has often required an increase in capital investment for machinery, a higher demand on working capital due to the increased variable costs associated with cropping, and a change in the generation of farm income, from many months of the year with the crop-pasture-livestock system, too often only a few weeks of the year on cropping farms. The obvious observation to be made is the risk involved with the exposure of the entire farm income to a relatively short period of time in a system that has required increased capital investment and working capital.

The move to a continual cropping system has not been without its agronomic challenges. Farmers have a limited range of crops available to suit their soils, environment and growing season, and often grain legume options are not grown because they are considered to be ‘profit resistant’. That is, although the crop might be beneficial in a given rotation, the repeatability of a good crop gross margin is considered low due to a combination of the following – reliable yield potential, erratic market demand and pricing, agronomic issues and specific equipment required for production. Even though the crop might have agronomic and financial benefits to the following crop, if the gross margin in the year it is grown does not compare to other crops grown, it will be discarded. The financial return in that year overrides the return from that crop being part of the system over a longer time frame.

Even with the advances in many areas of crop production in recent years (seeding technology, agronomic knowledge of crops, precision agriculture, GM crops), the reliance on fertilisers, herbicides, insecticides and fungicides has become the basis of current crop production. While many desire to get off this treadmill, but do not considering organics to be an alternative, the opportunity to explore and develop cropping systems from a different perspective are worth pursuing. If it assumed that the current state of the health of soils could be improved, how can this be achieved, and if it can, will it have a direct effect on plant health and subsequently production?

One area that has received increasing attention in the mainstream media in recent years, somewhat spurred on by the climate change debate, has been soil carbon sequestration. Soil organic carbon (OC) levels are very low in Australian cropping soils (0.5-1.5%), along with the inherent levels of many nutrients, and it is traditionally believed that this is due to the age of the soils. However, the description of early explorers were that, "soils were variously described as mulched, peaty, soft, loose, friable and high in humus, even in relatively low rainfall areas" (Jones, 2001). It is estimated the average pre-settlement organic carbon levels were in excess of 5% (Morris, 2004). Soils of this nature can store significant amounts of rainfall and more importantly, allows for its release over a period of time as plants demand it for growth.

Organic carbon plays a major role in all biological, chemical and physical systems within soil. Research into building OC in soils has become a major investment priority of research bodies in Australia, including the GRDC (Grains Research and Development Corporation) and the CSIRO (Commonwealth Scientific and Industry Research Organisation) and has led to the development of the soil quality initiative (www.soilquality.org.au). This has established benchmarked sites to identify and highlight the nature and extent of soil biological, chemical and physical constraints to production systems.

One system from the northern hemisphere that is used for its beneficial effect on soil health and OC levels is the use of cover crops. This system is focused on having plants growing for as many months of the year as possible, obviously an easier feat in areas where rainfall falls evenly across the year compared to Australia where the after-harvest period of November/December to seeding in April/May is characterised by high temperatures and often very low rainfall.

Of the inputs used in cropping systems, fertiliser, especially nitrogen, is often the major cost. Knowing the rate of different nutrients to apply, when and in what product form is a continual challenge, with decisions often made on a subjective basis rather than objectively. The big unknown is of the fertiliser applied, how much is actually used by the crop, lost by numerous processes (eg. volatilisation, leaching, runoff) or tied up in the soil, potentially for use at a later time. This nutrient use efficiency (NUE) has a large effect on crop production and profitability. As an example, for urea broadcast on wheat and canola crops in Australia, a common method of fertilisation, the range for NUE is 30-50%. There is potential to explore application systems and fertiliser types and combinations that could increase the NUE for all nutrients, but in particular nitrogen and phosphorus, the two main nutrients applied.

It must be remembered that modern crop production system is less than 80 years old, with the advent of artificial fertilisers and crop protection chemicals in the middle of the twentieth century. Major advances in wheat yields were made in the 1960s and 1970s with the introduction of crop herbicides (especially glyphosate – Roundup™) and fungicides in the 1980s. Whilst monocultures have long been the mainstay of crop production, the loss of diversity in the rotation and the exclusion of pasture and livestock have concentrated all the weeds, insects and diseases into a tight rotation where the margin for error is very small. Where nature uses diversity to overcome such problems, modern agriculture is heavily focussed on intervention for control.

The question often asked is where is the next quantum leap in crop yield coming from? Is it precision agriculture (various options available), genetically modified (GM) crops (not available to all as a producer or consumer) or something else that is yet to be developed or discovered? One alternative is to look at crop production techniques and/or systems that are used in other parts of the world and assess whether they can be utilised locally. Adopting a system that has been developed and validated by others can be an efficient and effective way to introduce change to a business with lower risk and less problems than with an unproven technology, no matter how appealing it might be.

In their book 'Resetting the compass: Australia's journey towards sustainability', Yencken and Wilkinson (2001) state "*the unsustainability of current agricultural systems relates to the fact that, unlike natural systems, they are unable to use all of the water that falls over a year and so they leak much more water, nutrients and salt into the subsoil than the natural systems they replaced*". In effect, the current agricultural production model has lost focus on the basic relationship between soil humus and water holding capacity. Historically, farmers, often unknowingly, have been working against the natural system to enable production, but now they need to look at working with it. Solutions to problems in agricultural systems do not always come in a drum!

Soil Health

What constitutes "soil health"?

The agricultural industry, like many other industries, is subjected to the mantra of being healthy, and much has been written about the importance of healthy soils, while many products are marketed as being beneficial to soil health. So, what constitutes a healthy soil and what is the impact of this on plant growth and yield within a crop and/or pasture production system?

Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (United States Department of Agriculture, 2014). The critical point is that the soil is made up of living organisms (biota) and they need food, water and shelter to survive and thus perform critical functions for plant growth. Management practices that build soil organism levels in balance will have a direct positive effect on plant growth.

The rhizosphere is the microbiologically active portion of the soil near the plant roots and drives most of what happens biologically in the soil. The soil organic material (plant roots and root exudates) feed the soil biota and in an undisturbed soil (e.g. no-till system) they build a stable and continuous soil pore network and enable key functions, such as carbon, nitrogen, phosphorus and sulphur mineralisation, and nitrogen fixing to occur (Clapperton, 2009).

Clapperton rightfully points out that "*much is yet to be discovered. Science has a limited understanding of the abundance and diversity of organisms in the soil, let alone trying to figure out all the biological interactions that unite the soil's chemical and physical properties for 'soil health"*.

This is what the author found with many of his farm visits. Often management changes that had been made were to the whole system and not just to one or two particular areas, with little specific research that supported the changes made. This has been reflected in more systems based research being conducted in recent years by agricultural research bodies around the world.

So, if soil health is important, how can it be measured so farmers can assess the health of their soils; but more importantly, assess what any management changes they make will have on soil health.

What is the relationship between soil organic carbon and soil health?

Without developing a new test for soil health, can any of the existing parameters that are measured in regular soil testing be used an indicator for soil health? As soil biota compromise a significant part of the soil organic matter (OM) pool and given soil organic carbon (OC) is a measure of the organic carbon in soil OM, soil OC could be used as an indicator for soil biological activity, and therefore soil health.

The influence that soil OC has on the chemical, physical and biological properties of soil is shown in Figure 1, many of which would be considered important in the context of soil health. When OC in soil is below 1%, soil health may be constrained and yield potential (based on rainfall) may not be achieved (Anger and Kay, 1999).

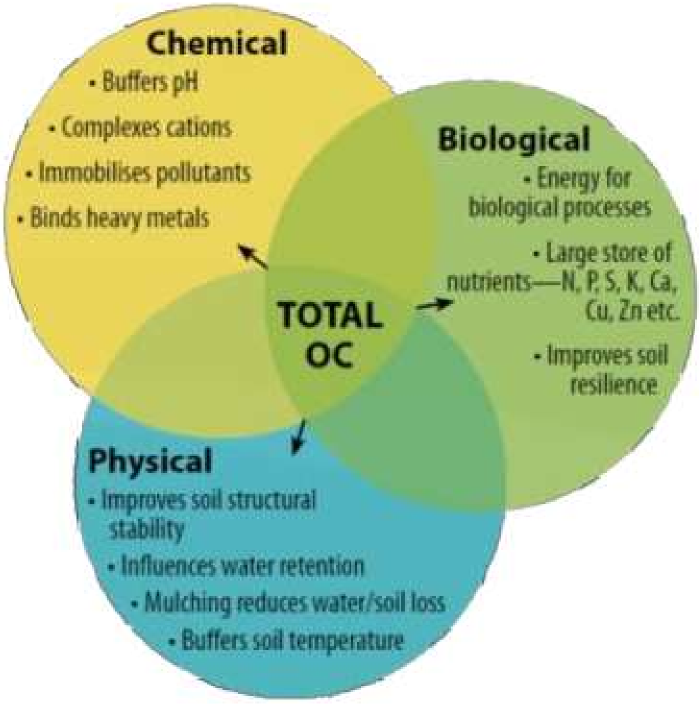

Figure 1: Some of the beneficial physical, chemical and biological processes in soil affected by total OC **(Carson, 2014)**

While soil type determines the potential storage of OC in a soil and climate determines the obtainable stored OC level, it is management that determines the actual amount of OC that is stored in the soil, as shown in Figure 2 (Ingram, 2001).

Clay soils generally have higher OC levels because the clay particles protect the OM particles more than in sandy soils, where OM particles exposed to breakdown by soil microorganisms, and to oxidation. The climate determines the attainable OC storage level as the more rain, the more plant growth, the more residue (OC) that is added to the soil. Depending on the soil type, increasing OC will have different effects on soil characteristics. In clay soils, increasing soil OC will have less relative effect on water holding capacity and the ability to retain cations (calcium, magnesium and potassium) due to the presence of clay particles; in sandy soils, increasing OC levels will improve both of these traits by a relatively greater amount (Baxter, 2012)

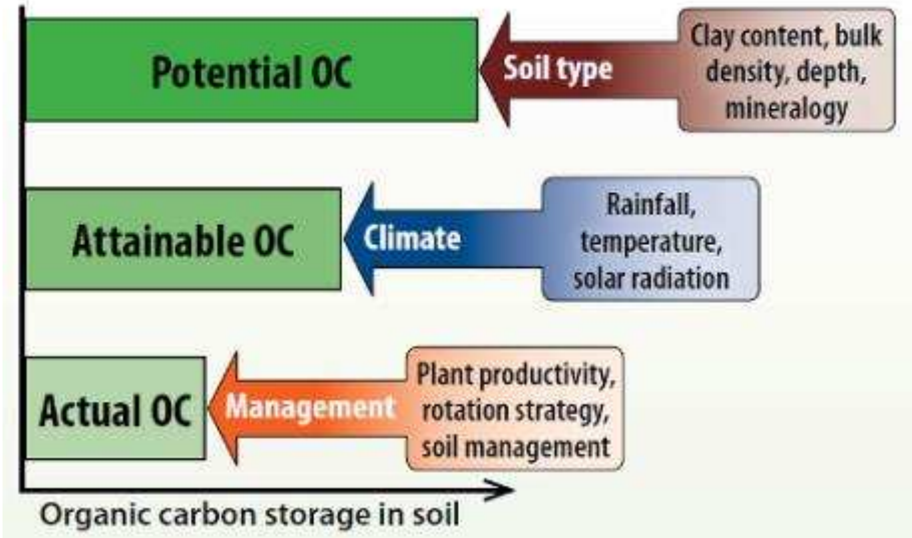

***Figure 2*: *The influence of soil type, climate and management factors on the storage of organic carbon (OC) that can be achieved in a given soil* (Carson, 2014).**

It is the management practices that either increase inputs or decrease losses that will determine the actual storage of OC in soil. Those that increase the inputs include:

- Increased plant growth – roots, shoots and root exudates returned to soil.
- Growing plants for longer periods of the year.
- Improving soil structure – reduce OC losses from decomposition and erosion (Carson, 2014).

One of the important aspects of increasing OC levels is that it increases the ability of a soil to absorb and hold water, the main factor that farmers list as limiting yields. Consequently, this measure of soil OC can be used as an indicator of soil health, until an alternative is developed, which may not be in the short term given the nature of the complex system being measured.

So, while each soil has a limit to the amount of OC that it can store, the challenge is to use management to try to achieve the highest OC level for each soil type in a given climate (low rainfall versus high rainfall). Like other benchmarks used in crop agronomy (e.g. water use efficiency, nutrient use efficiency, harvest index), can attainable soil OC level benchmarks be determined?

The of role of cover crops and diverse crop rotations

Cover crops

A cover crop is a crop seeded between existing crops where there would otherwise be nothing grown (i.e. the fallow period between crops). The primary purpose of a cover crop is to improve the soil resource and to benefit the following crop. It is not intended to be harvested, though can be grazed.

There are a number of benefits a cover crop can provide, as outlined below (Bowman, 2007).

1. Prevent erosion - the crops cover the soil surface to protect against water and wind erosion.
2. Conserve soil moisture - the residue reduces evaporation and aids water infiltration, but can result in an excess or a shortage of available moisture if used incorrectly.
3. Nitrogen fixation – the decaying residue releases nitrogen to the following crop.
4. Suppress weeds – either through competition or allelopathy.
5. Enhance nutrient cycling – different species can solubilise specific nutrients (e.g. buckwheat and oat roots can solubilise P).
6. Prevent nutrient leaching – act as a catch crop to stop leaching into groundwater (e.g. nitrogen).
7. Reduce pest problems – e.g. brassica crop's effect on nematodes.
8. Reduce fertiliser and chemical input requirements.
9. Provide organic matter for soil microbes.
10. Provide wildlife habitat and increase species diversity.

When deciding to use a cover crop, the question of what the purpose of the cover crop is for needs to be addressed as this will influence what species are used and when they are seeded in relation to the cash crops in the rotation.

Any species can be used as a cover crop and Table 1 is a summary of commonly used crops and their characteristics.

Cover crops can either be sown as a monoculture or as a multiple species mix, often where at least one species of each crop type is used (warm season grass, warm season broadleaf, cool season grass, cool season broadleaf). Farmer experience has resulted in the multiple species mix being more commonly used than a single species, although some farmers have had excellent results with a monoculture. Jamie Scott, Warsaw, Indiana, USA uses annual rye grass cover crop between corn and soybean crops whereas he uses a 13-14 mixed species cover crop between his wheat and corn crops. It is generally accepted the more diversity the better, due to the different roles the cover crop species play: deep rooted species help alleviate compaction; legumes add nitrogen and organic matter; and non-legumes produce high biomass which help with weed competition. However, consideration must always be given to the purpose the cover crop is playing as to what mix is used.

While no-till seeding is the most successful method to establish cover crops, a common problem in the northern hemisphere with establishing a cover crop after harvest (July/August), is the short period of time before the winter freeze kills the cover crop. This can be overcome by establishing the cover crop prior to harvest, usually by spreading the seed into the paddock, either by air or by high clearance self-propelled spreaders (often based on self-propelled sprayers), as shown in Figure 3. Rates used for aerial seeding are commonly double that used by ground seeding and the risk of poor establishment is obviously higher, especially under low rainfall conditions. Any species that survive into the spring are either sprayed out or rolled with a crimp roller before the spring crop is seeded.

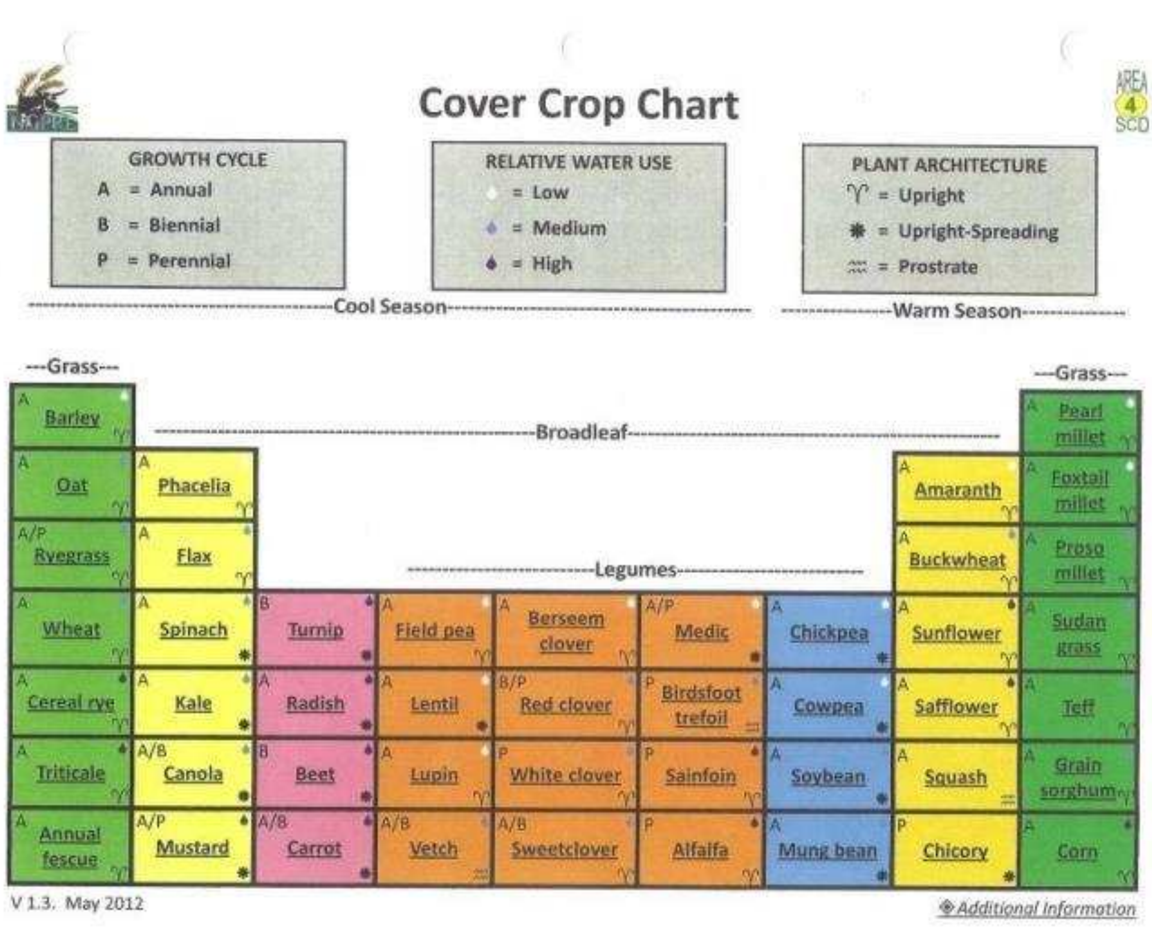

Table 1: Cover crop selection chart (Northern Great Plains Research Laboratory, 2012)

Figure 3 Self-propelled high clearance air seeder for seeding cover crops into corn at Van Tilburg Farms, Ohio

The importance of maximising ground cover

The importance of residue to no-till farmers is well understood for their cash crops and the benefits are shared with many of those of cover crops (e.g. moisture conservation, erosion control, weed suppression, organic matter for microbes). Having plants growing for as many months of the year as possible helps to build soil OC levels (Ostendorf, 2010). It also maintains a continual fresh food source for the soil microorganisms, that either go dormant or die if exposed to hot dry conditions over summer (after harvest and until the following crop), such as occurs in Australia. Summer sown cover crops also regulates the soil temperature which is beneficial to the soil micro-organisms life-cycle. Continual ground cover also has other benefits such as taking up nutrients (e.g. nitrate N) that are otherwise prone to leaching, using rainfall that could otherwise grow weeds and weed competition. Rick Bieber in South Dakota described what he called the 25 second fallow. That is, the time it takes for the harvested grain to go through the header (combine), with the cover crop seeded straight behind.

So, while cover crops can be used to increase the amount of ground cover, the question is what effect is there on the soil moisture and nutrient levels for the following crop. Is there a trade-off between the moisture and nutrients the cover crop uses and the short and long term benefits for the crop rotation overall? Adding cover crops into a no-till system can also potentially exacerbate some of the issues already associated with stubble retention: reduced soil temperature from the residue cover, thus potentially slowing seed germination and early plant growth; providing a habitat for crop pests such as slugs; and the establishment of crops in levels of high residue with existing seeding equipment. Like any other management practice, cover crops need to be managed to fit the system in which they are to be used.

Cover crops in practice

Many farmers visited have been using cover crops for a number of years as part of a no-till system with considerable levels of success.

Dave Brandt, Carroll, Ohio, USA

Dave started using no-till in the 1970's and has grown and evaluated various cover crops over the years to complement his strategy to improve soil health and crop yields. He uses a number of different mixes depending on the crop rotation, using anywhere from two to fourteen species in a mix. Dave has worked closely with Ohio State University over the years undertaking research to quantify the agronomic, economic and environmental benefits of no-till and cover crops. The results have been wide and varied and include:

- corn yields on long term no-till with cover crops and 20kg N/ha of fertiliser out yielded corn with 150kg N/ha on long term no-till with no cover crop; soil compaction was reduced by 40% where a cover crop comprising oilseed radish was included; four years of cover crops improved soil health as measured by soil chemical and physical properties including bulk density, active and total organic carbon, total nitrogen and aggregate stability (Reeder, 2014); and
- a five-year trial found that soil nutrients levels just prior to a corn crop following a cover crop had significantly higher nutrients levels compared to no cover crop, which was mainly attributed to the oilseed radish in the cover crop mix extracting the nutrients from the soil profile (Dobberstein, 2015)

Rick Bieber, Trail City, South Dakota, USA

Rick runs a farming operation that incorporates cash crops (corn, winter wheat, spring wheat, sunflowers, millet, peas, flax, (linseed)) with cover crops and livestock over a number of properties owned and leased with an annual rainfall of 400mm. One of the main issues faced all farmers in the region has been the gradual loss of productive land to salinity on the undulating landscape resulting from removal of the native perennial prairie species which have been replaced with annual species. Associated with this has been severe erosion that has occurred with the high intensity rainfall that is common in the summer months. This has rendered significant areas of land unusable, either as scalded areas or saline marshes. The usual practice is to seed around these areas and exclude them from the seeded area of the farm. Rick's approach is that when a new farm is purchased, this land is too valuable to ignore, so he undertakes costly rehabilitation earthworks to correct the erosion and drain the wet areas. The whole area can then be seeded and the system he uses with permanent ground cover has removed the conditions where the salinity problems cannot occur.

A number of Rick's neighbours, who use tillage in their system, based on a 400mm annual rainfall, have installed centre pivot irrigators to supplement winter and spring crops and to enable full summer cropping to occur. Rick's experience, similar to many others practicing the same system in South Dakota, is that the introduction of no-till and a diverse crop rotation including cover crops has resulted in crop yields that are as good as those with irrigation, given the moisture retention they have versus the moisture loss in the tillage system. More importantly, they are more profitable as they don't have the added cost of irrigation infrastructure and running costs.

Rick has done a lot of experimenting with the system he uses, including the sequences in his rotation (e.g. corn after sunflowers, which is not a common rotation), corn on a cover crop where the cover crop is either cut for hay or sprayed, rotational grazing of one cycle per year and corn seeded into lucerne (alfalfa). Research on Rick's farm in conjunction with Cheryl Reese from South Dakota State University (SDSU) in 2011 studied the effect of cover crops and crop nutrients (nitrogen, phosphorus and potassium) on the water use efficiency (WUE) of corn.

Before he introduced cover crops in 1998, a typical WUE was 9.9kg/ha/mm rain. The trial showed that corn yield, with no cover and no added nutrients, was 15.8 kg/ha/mm rain (6.1t/ha), 18.1kg/ha/mm (7.0t/ha) with cover and no nutrients, and 31.2kg/ha/mm (12.1t/ha) with both cover crop and added nutrients.

While moisture loss from the cover crop in a low rainfall environment is a potential problem, SDSU conducted another study to measure this soil moisture loss in spring 2011. Moisture in the cover crop was 63mm compared to 75mm in the plot with no cover, only a 12mm difference. Rick thought this was a "good trade-off" given the benefits of the cover crop. The average corn yields across the farm were 8.4t/ha under the cover crops and 7.4t/ha without cover crops, while the cost of production was 12% less with the cover crops (Sorensen, 2014).

Explaining why this this increase in WUE has occurred is complex and is likely due to a synergistic combination of the following factors and others that are currently unknown. These include soil N captured by the cover crop which could otherwise be lost through ground water leaching; the cover crops roots support a healthy population of soil biota which is beneficial to the following crop; different rooting structures of the various cover crops have accessed nutrients and moisture previously unavailable and enable better storage and utilisation of rainfall; and cover crops provide habitat and food for earthworms and other soil biota for them to continue their work in the soil.

Gabe and Paul Brown, Bismarck, North Dakota, USA

Gabe converted his farm to a no-till cropping system incorporating a diversified crop rotation, cover crops and livestock following repeated crop failures in the 1990's. His approach is to mimic the native pasture species that once existed and he has established native pasture with up to 140 species, of which approximately 90% are native, and grazing each area once before returning the following season, as the bison did on their yearly crossing of the prairies.

He described his system as "beyond organic", as he has doesn't use any synthetic fertilisers, rarely uses herbicides but has eliminated the tillage that organic farms rely on for weed control and crop establishment. The use of cover crops combined with high stocking rates and cell grazing has allowed the livestock to be integrated into their holistic system.

Jamie and Jim Scott, Warsaw, Indiana, USA

Jamie and his father Jim farm corn, soybeans and winter wheat in a three-year rotation with a 900mm (36 inch) rainfall using a no-till system that started in the 1980 and cover crops since 2003. The entire farm has cover crops seeded each year, either as annual rye grass between corn and soybeans or a cover crop mix (12-14 species) sown between the wheat and corn.

The advantage of the cover crops was highlighted in the 2012 drought where the corn yield was 1.25t/ha (20 bushel/acre) better on the cover crop areas. One observation Jamie has made since cover crops have been introduced is that the antler size of the native deer that graze the fields are significantly bigger (Figure 4), an indication of a possible improvement in the nutrient levels of the crops they are grazing.

This is one of the often neglected although extremely important benefits of cover crops; the improved cycling and increased availability of a range of micro nutrients/trace elements, which are sometimes neglected in crop nutrition. There has been an increasing awareness of the role of a balanced supply of macro and micro nutrients to plants and the nutritional benefits to both animals and humans that consume them (Ryan, 2010).

Farm soil test results have shown that under a continual corn rotation, the soil OC level has increased slightly. There had been no change under a corn-soybean rotation, but since the cover crops have been introduced, the OC levels have increased by 1 to 1.5 %.

Figure 4: Typical deer antler size comparison from crops grazed before cover crop were introduced (LHS) and since cover crops have been introduced (RHS).

Companion planting

One adaptation of cover crops is companion planting, where two or more species are planted together in the same season, where the additional species are a cover crop or another cash crop. They can be planted at the same time or, if at different times, the second planting is interseeded into an existing crop. Whilst not meeting the true definition of a cover crop, there can be synergistic advantages of companion planting compared to the monoculture of the individual species.

The author visited three people that had been successfully using companion crops for a number of years.

Nicolas Courtois, Geneva, Switzerland

Nicolas is an agronomist with AgriGeneve and works with no-till farmers in the Lake Geneva region of Switzerland. Nicolas has been working with combinations of cover crops and/or companion crops. He is often seeding the cover crop with the main season crop in the autumn, so when the cover crop is killed by the cold temperatures in winter, the main crop is left to harvest in the spring.

Four strategies he has trialled are as follows:

1. Canola sown with buckwheat after wheat harvest (mid-July, one month earlier than canola seeding) with the buckwheat harvested before winter. The canola is then harvested the following summer. The canola yield is slightly reduced but is more than made up for by the buckwheat harvest.

2. Canola sown with low rate of nyger and buckwheat and red or white clover after wheat harvest (mid-July). The nyger and buckwheat form a cover crop for the other two species and are killed by the winter frosts. The canola is harvested the following July and the clover six weeks later. The clover has not affected the canola yield

3. Canola sown with buckwheat, nyger and legumes (mid-August). Buckwheat and nyger were killed by October/November frosts, legumes by December/January frosts, canola

harvested July. Over a four period of trials, the yield of the canola was not significantly different to canola grown conventionally.

4. Perhaps the ultimate companion crop strategy trialled for one year is a seeding of canola, buckwheat and red clover after wheat harvest in July. The buckwheat was harvested in autumn (November), the canola the following summer (July) and the red clover in the second autumn (October), resulting in three crops harvested in 15 months. However, the buckwheat yield was low, the canola yield reduced by 20% and the red clover was hard to harvest, but there needs to be more research in plant densities and weed control, as it has the potential to be a herbicide free no-till system. Alexandre Dormoy farms in the Haute-Marne region of France and is also experimenting with this mix on his farm.

Figure 5: Canola, buckwheat and red clover 60 days after seeding

Nicolas has made a number of general observations from his trials, which are often consistent with results of other trials with European colleagues:

- Different mixes are used for each crop for best results.
- It is important to sow the cover crop as a separate operation for the best result (as opposed to spreading).
- The cover crop should be sown as soon as possible after winter crop harvest.
- The more legumes in the mix, the more yield in the following crop. For economic response and for the potential transmission of disease issues, the mixtures contain about 50% of pulses.
- By choosing the right species by freezing and with a good crimp roller, it is possible to terminate the cover crop without herbicide.
- A second-year crop effect is evident after cover crops and varies between crops.

Cronin Farms, Gettysburg, South Dakota, USA

Dan Forgey is the farm manager for Cronin Farms, a 3,600 ha mixed farm growing winter wheat, spring wheat, corn, soybeans, sunflower, field peas, lentils, flax (linseed), oats, barley and teff grass combined with an 850 head cow and calf operation. Cover crops utilise 10% of the cropped area but one companion crop mix Dan has been planting in since 2008 involves seeding forage soybeans in alternate rows of corn. Roundup Ready corn is seeded and the first application of Roundup is applied to the corn before the soybeans are seeded to reduce the weed burden.

The 2012 drought in the USA was the worst since the 1950s and most of the corn crop was decimated, but Dan took photos of the corn and soybean areas compared to corn in the same paddock (Figure 4 and Figure 5). The corn had not been as drought stressed where the forage soybean was grown as a companion crop. Why that is, none of the researchers who have studied this can exactly say although they have indicated it probably has to do with a symbiotic relationship between the plant roots of the two crops. A similar phenomenon was observed in 2014 after a very dry July and August, critical months for corn crop growth (Forgey, 2014).

Figure 6: Monoculture corn on Cronin Farms during 2012 drought

Figure 7: Companion crop of forage soybeans seeded into corn on Cronin Farms during 2012 drought (photo taken in same row as previous photo).

NOTE. Date on photo is incorrect.

The role of diverse rotations

Most farmers use crop rotations in varying degrees and know the importance of them for weed, disease and pest control, and nutrition management. However, in many countries travelled to by the author, a limited number of crops, often only two, were grown in rotation by the majority of farmers. Other than the number of crops grown, there is also the issue of the types of crops grown – warm season versus cool season grass or broadleaf.

Obviously, the decision to use warm or cool season crops (or a mix of both) is based on the seasonal rainfall patterns and climate. However, is rainfall the main limiting factor in what crops are grown? This is usually the reason given, even though the management of weeds, diseases, pests and/or nutrition can all have a bigger impact on yield if poorly managed (i.e. low water use efficiency).

The introduction of no-till systems combined with stubble retention has seen a paradigm shift in the cropping systems that can now be used compared to those based around a conventional tillage system. The improvement in soil structure and the ability to store moisture under a no-till system is acknowledged widely as a benefit. The question is: Has the potential benefit of increasing OC and changing the crop rotation been fully realised?

Not being able to compare an existing system to one with a higher OC level is the problem, as unlike most other management variables (e.g. phosphorus and nitrogen levels, crop types/varieties, disease strategies), it cannot be easily replicated for comparison. If any tangible benefit cannot be measured, despite the potential importance to the system, increasing OC levels may remain a goal but the radical change that might be needed to achieve it is stifled because of the direct experimental lack of evidence. However it is possible to estimate the effect of changed OC levels on soil properties and performance using modern simulation models (such as APSIM, developed by the CSIRO).

The South Dakota experience – the Dwayne Beck effect

One area that has demonstrated the adoption of radical change in a farming system is western and central South Dakota, USA. One of the main drivers for this change has been due to the research, development and most importantly extension by the Dakota Lakes Research Farm, managed by Dwayne Beck since its establishment in 1983.

The area has a summer dominant rainfall pattern and receives approximately 450mm (18 inches) of rain annually. The traditional cropping rotation was spring wheat alternating with a long fallow under a conventional tillage system.

Originally owned by the South Dakota State University, it is now owned by a not-for-profit group comprising local farmers. The South Dakota State University conducts and manages the research on the farm and the production side of the farm provides approximately 80% of these funds. Therefore, like commercial operations, the farm needs to be profitable to fund research.

When the research farm was set up in 1983, the traditional cropping rotation was spring wheat alternating with a long fallow under a conventional tillage system. Given a substantial investment in land, labour and machinery would have been required for production to be able generate sufficient income to support research, the plan to overcome this limitation was to use diverse crop rotations combined with a no-till system. It was anticipated that this would enable high water use crops (e.g. corn), normally considered marginal under tillage, to be grown and to form the basis of a diverse crop rotation.

The philosophy of Dwayne Beck is that research is all about systems, it goes beyond the agronomy. A holistic approach was adopted from the start as there was little research into the farming practices the farm was intending to embark on, so research was needed to fill the gaps as the system was developed.

The main change in thinking that has taken place at the farm and for surrounding farmers has been the realisation that long term farm profitability and sustainability is based on natural cycles and principles.

Warm season grass, warm season broadleaf and cool season broadleaf crops have been introduced to the traditional cool season grasses (winter cereals) that have been traditionally grown. Stacked rotations (where a crop is grown two years in succession and has a long break until grown again) have been developed based on a corn-corn-soybean-soybean-wheat-wheat rotation with cover crops grown in between. The aim of this rotation is to keep the crop sequence and interval diverse. Compare this to the rotation used in many systems (wheat-canola, cereal-canola-legume in various combinations), where weeds and insects adopt life cycles on this regularity and which form the basis for resistance in a population.

One of the trials conducted on the farm for a number of years has looked at the yield potential of drought resistant corn. The yield difference between rain fed and irrigated plots across other sites in the USA has been 40-50%, but on the research farm, it has only been 10%. So, what does that say about the soil health that has built up over the years from this systems approach?

Soil phosphorus levels are <5ppm (Olsen test) on all soils on the farm, a level considered critically low and hugely responsive to phosphorus in a traditional soil testing scenario. Starter fertiliser is used in all crops and the soil mycorrhizae network developed with the rotation is a major source of P to the plants, accessing the phosphorus normally considered unavailable to plants.

The OC levels have been raised in the soil surface but not at depth (>25cm) so lucerne (alfalfa) has been introduced to look at building OC levels deeper in the profile.

Barriers to change

The first assumption that many famers make is that a cover crop is going to use up the moisture that is available to the following crop. The aim is to match the water demand of the crops grown with the water availability of the soil types farmed, since different crops have different water use requirements. In a Mediterranean environment, like Australia, many would argue that the pattern of rainfall is so erratic that it would often prevent a cover crop being grown before a cash crop when it is moisture limited to start with.

That argument raises two questions. Firstly, is plant available moisture (PAW) the major limitation to crop yield? Secondly, what is the effect on the yield potential if the soil PAW level is increased?

As rainfall patterns are unpredictable and appear to be getting more so under the current climatic conditions, the ability to store or utilise moisture when it falls is critical. In south eastern Australian rain-fed farming areas, most crops are grown from April to December. Any rainfall that falls between crops over the summer period is attempted to be conserved by the fallow spraying of summer weeds that use up moisture and nutrients for the following crop. Research conducted by the GRDC across Southern Australia has shown that summer weed control is the most effective way to maximise this summer fallow efficiency (the proportion of summer rainfall that is available to the following crop), but is more important in years or sites with low growing season rainfall. The trials also showed that retained stubble makes only a small difference to preserving summer rainfall, unless more than five t/ha is retained (GRDC, 2012).

The problem is that most seeding systems cannot handle stubble levels that high, so stubble is removed (burnt or baled for straw) to allow crop establishment. However, this negates the added benefits of maintaining stubble in a no-till system.

So, in years where conserved summer rainfall is followed by above average autumn/winter rainfall, waterlogging can become a problem, especially in the chromosol (duplex) soils. The resulting low yields in these areas often leaves a high level of plant available water in the sub soil at harvest time, which is exposed to the summer weed problem. This carryover of soil moisture also has implications for slug populations, a problem in no-till systems around the world, as the moisture harbours the slugs over summer ready to attack emerging crops in autumn.

If soil moisture levels are high in a paddock after harvest, an opportunistic cover crop could be planted immediately. However, most farmers would be reluctant to seed a crop in the heat of summer, given it would be considered to have a high risk of failure. The author's own experience in these situations is that the cover crop has competed well with summer weeds, and although the cover crop may use moisture and nitrogen considered available for the following crop, are the benefits of the cover crop potentially greater? These benefits include soil pore space, nutrients brought to surface by deep rooted species, nutrient scavenging by roots of different species, nitrogen from legumes and moisture conservation from the residue cover. Small amounts of rain over summer, when growing a cover crop, is likely to be more beneficial, especially if that amount of rain cannot be stored in the profile.

This cropping system could be changed so that a cover crop is seeded in the autumn and allowed to grow over the winter period and then terminated (sprayed or crimp rolled) in the late winter or early spring to allow for a spring crop to be seeded. Choosing the right spring crop would be influenced by the PAW built up over winter and this would dictate whether a high water use (grain sorghum, corn) or low water use (millet, cowpea) crop is used and when the cover crop is terminated.

The number of options for cover crop scenarios and combinations is large. The ability to identify likely contenders for a specific area and system will involve trial and error whilst maintaining an open mind to the challenges introducing such a system will bring.

Nutrient use efficiency

Background and current trends

Nutrient use efficiency (NUE) is the amount of yield per unit of nutrient available in the soil derived from both the soil reserves and added fertilisers. As fertiliser is a major cost for cropping farmers, especially where fertiliser prices have doubled for short periods in recent years, any change in the nutrient use efficiency will significantly affect the crop gross margin and farm profitability.

In a grain production system, over 50% of applied nitrogen fertiliser may not be available for crop uptake. Some nitrogen is lost from the soil (volatilisation and leaching) while some is locked up in the soil organic matter in forms unavailable for plant use (GRDC, 2013). The efficiency of nitrogen used in the UK in 2011 was predicted to be just 45%, while even in a good year the efficiency only gets up to 60% (Bradshaw 2012). In most intensive agricultural production systems, over 50% and up to 75% of the nitrogen applied to the field is not used by the plant and is lost by leaching into the soil (Raun and Johnson, 1999; Hodge et al, 2000; Asghari and Cavagnaro, 2011 *in* Tetu, 2011).

Global consumption of synthetic nitrogen increased from 11.6 million tonnes in 1961 to 104 million tonnes in 2006. Over 40 years, the amount of mineral N fertilizers applied to agricultural crops increased by 7.4 fold, whereas the overall yield increase was only 2.4 fold. This means that nitrogen use efficiency has declined sharply and implies that nitrogen use efficiency is higher at reduced levels of crop production when the use of nitrogen fertilization is much lower.

Moreover, improvement in yield for most crops over the last 50 years has been estimated to be 40% due to improvements in cultural practices and 60% due to genetic gains, thus indicating that breeding for improved NUE is still possible (Edgerton, 2009 *in* Tetu, 2011).

Of the phosphorus applied to grain crops in Australia, often less than 30% is taken up by the crop it is applied to. The remainder is held in the soil pool in forms that are often poorly available to plants (McNeil, 2012). However, topsoil tests across the wheat growing regions indicate that phosphorus levels are often higher than the critical level at which a response to additional phosphorus will occur (Brennan, 2012). So, growers are looking at reduced or zero phosphorus applications, especially in the lower yielding areas or seasons of high fertiliser prices.

Given the importance and cost of fertilisers to grain production, management that focuses on improving nutrient use efficiency can have a significant impact on both the income (increased yields) and expenses (reduced fertiliser usage) side of the crop gross margin.

Management of nutrient use efficiency

Research dedicated to NUE has revolved around the supply of nutrients as fertiliser in terms of fertiliser type, rate, timing and application method. Nutrient response curves for different nutrients, crops, soil types and cropping systems have been determined and best management strategies developed for what are considered the three main nutrients, nitrogen, phosphorus and potassium.

Significant variation exists in genotypes of wheat and barley for nitrogen use efficiency. Research by the University of Western Australia revealed that some genotypes lost half their yield under low nitrogen conditions, while others could produce 40% more yield under low nitrogen conditions compared with optimal fertilisation (Leonard, 2012)

As nutrient uptake does not only occur in top 10cm of soil where fertilisers are placed, crops will take up nutrients at depth if they are present and in an available form for plant uptake. Most growers would not know what nutrients are at depth as they are generally not tested for, with the exception of nitrogen. Growers have been educated on the importance of phosphorus in the first 4-8 weeks of crop growth, but are generally unaware that the bulk of phosphorus is taken up, like nitrogen, in the reproductive growth stages, not the earlier vegetative stages.

While nutrient use efficiency research is generally based on fertiliser type, timing and application method, as that can be controlled by the researcher, there is a largely untapped pool of nutrients in the soil that can be utilised if they can be released. The use of cover crops to make these available for plant uptake (e.g. extraction by roots, root exudates solubilise nutrients or mycorrhizal fungi colonisation of roots) is an alternative to only focusing on the addition of fertilisers to provide the nutrients required.

The industry standard for nitrogen fertiliser requirement for corn production in the USA is one pound of nitrogen is required per bushel of corn (equivalent to 1kg nitrogen to 56kg corn). A consistent figure that was quoted by corn farmers visited that used no-till and cover crops was that they were consistently applying between 60-70% of the industry standard, and in some cases even less or none at all, as in the case of Dave Brandt and Gabe Brown as mentioned earlier.

The challenge is to find balance in the system where the soil-derived nutrients can be measured and accounted for and the fertilisers can be added to satisfy the remaining nutritional requirements of the crop.

CULTAN - Controlled Uptake Long Term Ammonium Nutrition

Where nitrogen fertilisers are broadcast on crops, regardless of the type of nitrogen fertiliser used (ammonium, nitrate or urea), nitrate is generally the dominant form of plant available nitrogen due to the nitrification process that occurs in the soil. While most plants are adapted to use nitrate as their primary source of nitrogen nutrition (rice is an exception), nitrate that is not taken up by plants is susceptible to leaching, runoff or denitrification, so it requires careful management to keep it in the root zone of the growing plant.

Application of nitrogen to crops can either be in the form of broadcasting solids, foliar application of liquids, streaming of liquids directly onto the soil or soil injection of liquids or solids (either as a band or a point injection). Broadcasting urea relies on follow up rainfall or irrigation for uptake by plants. It is also subject to volatilisation losses if sufficient rainfall is not received after application, especially on alkaline soils, while waterlogging after application results in losses through denitrification and/or leaching. Foliar application can be an efficient method to supply nitrogen but is limited in the amount that can be applied due to leaf burn from high application rates. Streaming nitrogen through nozzles avoids the problem of leaf burn but is still subject to potential volatilisation losses or low uptake without following rainfall.

The basis of the CULTAN system is to increase the availability and reduce the potential losses of the nitrogen applied as fertilizer, by placing it in the soil in a narrow concentrated band (depot), either as a liquid or solid form of ammonium. The application of anhydrous ammonia pre-planting is a commonly used example of the CULTAN system in irrigated and rain fed cropping areas that use high rates of nitrogen. Nitrogen applied this way is in a highly concentrated band is toxic to soil microbes until the band gradually diffuses over time with soil moisture and the uptake of nitrogen occurs over a longer period of time. By keeping the nitrogen in the ammonium form, the potential for denitrification and leaching losses is reduced. Figures 7 and 8 show the differences in root growth when ammonia or nitrate is placed in a band in between two corn plants (seen at either edge of the photo).

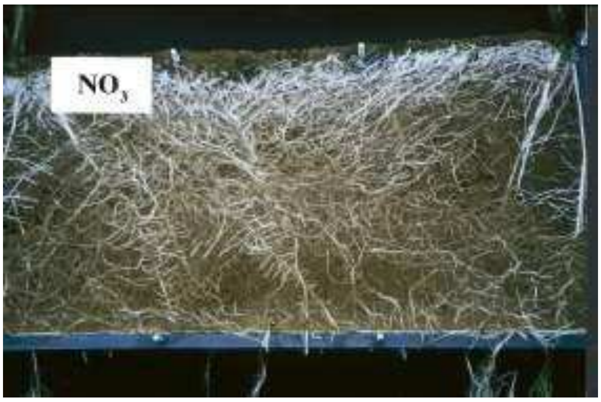

Figure 8: Root growth with nitrate as nitrogen source (Scherer, 2007)

Figure 9: Root growth with ammonium as nitrogen source (Scherer, 2007)

Observations that have been made during research on the CULTAN system have included:

- a reduction in the sensitivity of cereals to root and leaf diseases (e.g. take all).
- the ability of corn to fill a second cob on each plant.
- a reduction in the need for growth regulators in cereals.
- increased in nitrogen use efficiency to greater 90%.
- A prolonged time for ear maturity in corn, resulting in increased yields.
- the uptake of calcium and phosphorus was higher (Scherer, 2007).

CULTAN in Germany

Two farmers in Germany, Ulrich Zink and Tomas Sanders, use the CULTAN system in their cropping system. The application system they use is a series of spiked wheel injectors that are fitted to a boom sprayer spaced at 360mm (14.5”) (Figure 9). Wheat target yields are from 10-

13t/ha, depending on soil type and rainfall (average 500mm -20 inches). Measurements made in Germany have recorded root growth of up to two centimetres per day towards the ammonium band (Zink, 2014).

Figure 10: CULTAN applicator on Ulrich Zink's farm, Germany

The liquid that is used is either liquid ammonium sulphate (AMS - 8% N: 9% S) or a mix of one part urea ammonium nitrate (UAN – 32% N) to two parts AMS (15% N:6% S). According to the CULTAN theory, the ideal product contains only ammonium based nitrogen fertiliser, but at only 8% nitrogen, a compromise is made using the UAN/AMS blend. Even at 15%, to apply 120kg/ha of nitrogen requires an application of 800L/ha of the blend, with speed at that rate limited to around 6-7km/hr. Ullrich uses a nitrogen use efficiency of 90% for the crop nutrient budgets that he does where he is using AMS or UAN/AMS solutions. Compare this to a typical value of 50% for broadcast urea in Australia for nitrogen use efficiency.

Legislation restricts the amount of nitrogen that German farmers can apply in the autumn (fall) to 60kg/ha. This is due to the majority of fertiliser applied being either urea or nitrate, so there is the potential of leaching, volatilisation and/or denitrification over winter when crops are dormant. Although ammonium applied as the CULTAN system doesn't suffer from these losses, the restriction still applies, so typically the crops are seeded with DAP and ammonium sulphate is applied to a level of 60kg/ha of nitrogen.

The CULTAN system is used in early spring when up another 90-120kg/ha of nitrogen is applied to cereal crops. It isn't used in the canola crops due to the damage done to the canola plants, so a change in the legislation to enable higher rates to be used in autumn would allow CULTAN to be used in canola (and wheat) in the autumn. The advantage of being able to apply more of the nitrogen under the CULTAN system in autumn is that, on 2013/14 prices, the cost of nitrogen was €0.35/L in autumn versus €0.50/L in spring, a difference of 43%.

Ulrich established a paddock demonstration in September (autumn) 2013, where nitrogen was applied after seeding at rates of 100 and 300kg/ha of nitrogen, compared to the rest of the paddock which had the usual 60kg/ha. The purpose was to show researchers the difference, if any, in applying rates greater than the legislated amount and to enable them to monitor any losses in the system. When inspected in March (spring) 2014, there was no observable difference in the growth of the canola between the three rates (Figure 11), a repeated observation expected from the CULTAN system. Compare this to the expected difference from applying

60kg/ha to 300kg/ha of nitrogen (130 v 650kg/ha of urea) after seeding in an autumn canola crop.

The potential for the CULTAN using the spiked injector is not confined to broad acre cropping systems. It has potential in direct seeded rice systems, intensively grazed pastures where nitrogen is typically applied after each grazing, and horticultural crops where multiple applications of fertiliser are used.

Overseas research and more often farmer experience has shown the potential cover crops and the CULTAN system have. The challenge now is to quantify through research and development how they could be utilised in Australian farming systems and what role they have in increasing soil organic carbon levels and improving soil heath.

Figure 11: Canola response to CULTAN post seeding application (autumn/fall) of 100kg/ha (right) and 300kg/ha (left) compared to 60kg/ha on the rest of paddock (rear)

Conclusions

Having studied a range of topics that are all related to developing a farming system able to stabilise the production and income levels with varying climatic, environmental and agronomic challenge, there are a number of conclusions to be made:

- Understanding the system is of paramount importance – every enterprise, every choice, every management decision influences the entire system.

- Our understanding of the biological interactions that occur in the soil between the microorganisms and the effect on plant growth and quality is very limited, but research is focusing on this all around the world.

- Management can be used to alter the actual amount of OC that is stored in the soil, but it is limited depending on the soil type and climate.

- Soil OC can be used as an indicator of soil health in the absence of an alternative simple and repeatable test.

- Cover crops can be used as part of a diverse crop rotation to build soil OC levels.

- Maintaining constant ground cover has benefits that outweigh perceived production constraints from excess water use.

- Building soil OC levels is like climbing a ladder – each rung takes you to a new level.

    - Rung 1 – introduce a no-till system.
    - Rung 2 – retain all stubble residue (occasional strategic burning is acceptable).
    - Rung 3 – develop diverse crop rotations, include warm and cool season grasses and broadleaf crops wherever possible.
    - Rung 4 – introduce cover crops.
    - Rung 5 – integrate livestock into the system, thus recycling the nutrients and provide manure back to the soil and plants.

- Benefits of a cropping system based on no-till, a diverse crop rotation and cover crops include:

    - Increased nutrient availability.
    - Reduced weed, disease and insect pressure.
    - Reduced reliance on synthetic inputs – fertiliser and chemical inputs.
    - Redistribution of labour and machinery demands.

- Multi-species companion planting is an alternative to cover crops, with similar benefits. Nutrient use efficiency is very low for nitrogen and phosphorus, the two main fertilizer nutrients used.

- Nutrient use (of synthetic fertilisers) is focused on the top 10-15cm of soil but there is a pool of nutrients tied up in soil organic matter (some at depth) in forms unavailable to plants that can be released through using different plant types, their roots, the exudates released from their roots and the symbiotic relationships that they form with other plants and microorganisms.

- The CULTAN system is a fertilisation system based on banding high concentrations of ammonium fertiliser in the soil compared to broadcasting or banding nitrate or urea based fertilisers.

- The supply of nitrogen under the CULTAN system to the plant is regulated by the plants requirement for growth, not on the release of the nutrients from nitrate and urea fertilisers applied.

- The CULTAN fertiliser system is claimed to have a nitrogen use efficiency of over 90% compared to 50% for nitrate or urea based systems.

- The potential for the CULTAN system using the spiked injector is not confined to broad acre cropping systems. It has many other potential applications, including amongst others, direct seeded rice systems, intensively grazed irrigated/high rainfall pastures where nitrogen is typically applied after each grazing, and horticultural crops where multiple fertiliser applications are used.

- Overseas research and more often farmer experience has shown the potential cover crops and the CULTAN system have. The challenge now is to quantify through research and development what role they can play in Australian cropping, grazing and horticultural industries and how this could increase soil organic carbon levels and improve soil health.

One of the issues faced by each year by cropping farmers in southern areas of the Australian grain growing region is that the soil profile, especially at depth, is often dry when seeding commences in April/May following typically low rainfall in summer and early autumn. Dry seeding is the accepted norm for most growers in these regions where a no-till seeding system, predominantly based on tines, is used to start seeding on a date according to crop maturity rather than when moisture is available.

Following the summer crop trial in 2009 undertaken on the author's property, the rainfall data for Dookie College was analysed, (consisting of 130 years of for the district) and examined the changes in growing season rainfall (GSR) for both winter (April-October) and summer (September-February) for 2004-2010. This period contained five years where GSR was at least 40% below the long-term average of 394mm and the other two years were at least 15% above the average. These years will be remembered for a number of drought years interspersed with a number a wet harvests, not usual for the area but a possible example of the changing weather trends emerging.

The average for the winter GSR for those seven years dropped by 24% to 300mm, whereas the summer GSR (used September-February to represent a short season spring seeded crop) only reduced by 4% from the 130-year average of 288mm to 276mm. Interestingly, the GSR for December-March had increased from an average of 142mm to 190mm for the same period, a rise of 34%.

Given the paradigm shift in moisture conservation with a no-till full stubble retention system, is the premise of seeding a small percentage of a crop rotation as an early spring crop into a soil that is likely to have a good profile of moisture any riskier than seeding an entire year's crop (and income) into a soil profile that has no stored moisture. Combined with this is the fact that in a dry seeding, no pre-seeding control with a knockdown herbicide has been achieved on an ever increasing number of herbicide resistant weeds (e.g. ryegrass, brome grass, wild oats, and wild radish). This increases the pressure on the in crop-selective herbicides, which are often the herbicides to which weeds have developed resistance.

Integrated weed management has become an important consideration in no-till systems, given the historical reliance on herbicides as the dominant form of weed control. For growers that do not have livestock, the few alternatives to herbicides that have been developed include narrow windrow burning, chaff carts, baling the straw and chaff directly out of the header and the Harrington seed destructor. While these can successfully reduce the weed numbers, they are dealing with the problem, not treating the cause. Using cover crops can help change the dynamics of the population by competing with the weed and allowing knockdown chemicals to be used for control.

Admittedly, in their current state, the lighter sandier soils have low water holding capacity that will limit their ability to provide a spring crop with sufficient moisture through to maturity, except in years of above average rainfall. The medium and heavier textured soils, which have a greater water storage capacity, are able to store enough water to get the crop established and through the vegetative stage.

The recent emergence of global warming has resulted in the need to look at ways to sequester elevated carbon dioxide levels. The ability of agriculture to achieve this is real but the ability to measure the carbon dioxide captured by crops on each farm and how to price this in terms of any emissions trading scheme is complex. So, whether or not it is adopted as a policy to combat climate change, agriculture management practices targeted at increasing soil OC levels are in effect already helping to combat the problem.

It is essential that increasing soil OC levels is made the highest priority on all farms, because increasing the plant available water in soils will have a direct benefit on crop and pasture production, along with the associated soil health benefits. This, in the long term, will have the biggest effect on the continuing viability of any farm, anywhere in the world.

Recommendations

The experience gained with cover crops and opportunistic summer cropping in recent years, has proven that summer crops can be grown successfully, but only where with a wet summer, which may only occur every five years. The question is: can the diversity of the cropping rotation be altered to include warm season crops and cover crops so the benefits outweigh the failures that are likely to result from trying to establish spring sown crops in a Mediterranean environment?

Dwayne Beck's advice in 2004 was to "*plan to fail. There is more benefit in seeding a crop and having it fail than not seeding a crop at all*".

Below is a list of the opportunities that could be explored along with associated issues, risks and benefits.

1. Seed cover crop or opportunistic summer crop immediately after harvest if moisture available (end December or early January), remembering that:

    - There is a low chance of sufficient rainfall to get established.
    - There are few short season crop choices for cash crop (e.g. mung beans, cow peas) without overlapping into following winter crop.
    - If the summer cash crop is profitable, a reduced return is acceptable from a late seeded winter crop.
    - Low cost cover crops can be a better option, due to rainfall variability and a moderate amount of growth can be beneficial.
    - Even if planted in January, enough growth can be achieved before seeding in April/May period to be of benefit (cover crops often only get 6-8 weeks of growth in northern hemisphere before they are terminated).

2. Seed cover crops during harvest into low residue harvested crops (canola, grain legumes), regardless of rainfall, where:

    - Crop establishment is likely to be better if seeded before rain than seeding into moisture (marginal) after harvest.
    - There are logistic issues with having the seeder operating at harvest.

3. Spreading cover crops into exiting crops just prior to harvest.

    - Seeds germinate on late season rain, don't compete with maturing crop and mulch from spread harvest residue help conserve summer rainfall.
    - Ideally use a self-propelled sprayer or high clearance tractor with spreader attached.
    - Small seeds germinate easier on the surface but it is harder or not possible to spread to the full width of controlled traffic tramlines.
    - Predation of seeds by ants.

4. Plan for percentage of crop to be planted to a spring sown crop.

    - Plan for percentage of rotation (5-10%) to be dedicated to low water use crops (e.g. mung bean, cowpea) and/or short season (e.g. safflower) spring sown crops.

- Early sown options preferred (e.g. safflower) if relying on rain fed conditions to establish crops at a cooler time of the season and to avoid moisture stress at flowering (e.g. mung beans flowering in February).
- Opportunity to manage resistant weeds (e.g. ryegrass in Australia) as can be controlled over winter.

5. Use a cover crop in the autumn followed by a spring crop.

    - Forget convention, seed a cover crop mix in early autumn, grow through the winter and terminate (spray out, crimp roll or both) in late winter or early spring depending on the seeding date of the spring crop.
    - Matches the species to moisture availability, which means having a plan of different options to seed.
    - Controls annual resistant weeds (e.g. ryegrass).
    - Cover crop can be grazed in late autumn or early winter if required, but full ground cover needs to be achieved by the end of winter.

6. Use winter dormant species earlier in the season than usual or out of season.

    - Instead of seeding in the accepted window (April/May in southern Australia), plant a percentage winter dormant varieties of canola or wheat from March onwards if moisture is available and weeds are controlled.
    - Why wait when there is moisture available in case the traditional seeding window ends up dry with little or no rainfall.
    - Spreads demands on machinery and labour and the risk of frost at flowering.
    - Include winter dormant species in spring or summer seeded cover crops to avoid them seeding down.

As you can see, there are plenty of options available and probably even more yet to be discovered.

Bibliography

Angers, B. A. & Kay, D.A. (1999). Soil Structure. In M. Summer, *Handbook of Soil Science* (pp. 229-276). Boca Raton: CRC Press.

Asghari, H., & Cavagnaro, T. (2011). Arbuscular mycorrhizas enhance plant interception of leached nutrients. *Functional Plant Biology*, 38, 219-226.

Baxter, N. (2012, January-February). Soil carbon: easy to misunderstand, vital to have. *Ground Cover*, p. 23.

Bowman, G. C. (2007). *Managing Cover Crops Profitably, Third Edition.* College Park: Sustainable Agriculture Research and Education.

Bradshaw, T. (2012). *Soil Fertility and Fertiliser Use Efficiency.* Nuffield Farming Scholarhip Trust.

Brennan, L. (2012, March-April). Best-bet strategies to make fertiliser pay. *More profit from nutrition*, pp. 3-4.

Carson, J. (2014). *How much carbon can soil store?* Perth: Soil Quality Pty Ltd.

Clapperton, J. (2009). Pesticide Effects on Soil Biology : Part 1. *Leading Edge - The Journal of No-Till Agriculture*.

Edgerton, M. (2009). Increasing crop productivity to meet global needs for feed, food and fuel. *Plant Physiology*, 149, 7-13.

Forgey, D. (2014, July 14). Personal Communication. (D. Cook, Interviewer)

GRDC. (2012). *Summer Fallow Management.* GRDC.

GRDC. (2013). *Grains Research Update Southern Region.* GRDC.

Hodge, A., Robinson, D., & Fitter, A. (2000). Are microorganisms more effective than plants at competing for nitrogen? *Trends in Plant Science*, 5, 304-308.

Ingram, J. a. (2001). Managing carbon sequestration in soils: Concepts and terminology. *Agriculture, Ecosystems & Environment*, 111-117.

Jones, C. (2001). *The Great Salinity Debate: Part III, Soil Organic Matter: past lessons.*

Leonard, E. (2012, March-April). Steps toward more nutrient efficient cereals: nitrogen. *More profit from nutrition*, p. 5.

Marschner, H. (1995). *Mineral nutrition of plants 2nd Ed.* London: Academic Press.

McNeil, A. (2012, January - February). Biological release of P form the soil bank. *Ground Cover - Soil Biology initiative Supplement*, p. 9.

Morris, G. (2004). *Sustaining national nater supplies by understanding the dynamic capacity that humus has to increase soil-water storage capacity.* Sydney: The University of Sydney.

Ostendorf, M. (2010). *Going undercover with cover crops.* Brookfield, Lessiter Publications.

Productivity Commission. (2005). *Trends in Australian Agriculture.* Australian Government.

Raun, W., & Johnson, G. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy journal*, 91, 357-363.

Ryan, E. (2010). *Trace Element Nutrition:A study in the management of trace elements - their significance in sustaining community health, crop.* Nuffield Australia.

Scherer, K. S. (2007). Source / Sink – Relationships in Plants as Depending on Ammonium as "CULTAN". *International Symposium "Sink-Source Relationships in Plants"*, (pp. 1-29). Kaliningrad.

Sommer, K. (2000). "CULTAN" cropping system: Fundamentals, state of development and perspectives. In M. a.-L. Lips, *Nitrogen in a sustainable ecosystem: from the cell to the plant.* (pp. 362-375). Leiden, Backhuys.

United States Department of Agriculture. (2014). *Soil health.* Retrieved October 18, 2014, from United States Department of Agriculture: http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/

Yencken, D. a. (2001). *Resetting the compass : Australia's journey towards sustainability.* Melbourne: CSIRO Publishing.

Zink, U. (2014, March 12). Personal communication. (D. Cook, Interviewer)

Plain English Compendium Summary

Project Title:	**Cover Crops, Nutrient Use Efficiency and Fertiliser Application Methods**
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Scholar:	David M.H. Cook
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Objectives	To look at farm management practices that could be used to build soil organic carbon levels and what application technology is available that could reduce the amount of fertiliser, especially nitrogen, used to grow crops.
Background	Less diversity in crop rotations for grain production has resulted in an increasing reliance on chemicals and fertilisers to sustain production. Soil organic levels, for the majority of cropping soils, have not increased as a result of changed farming practices in the past 25 years to the degree that was envisaged. Nitrogen fertiliser use remains one of the biggest costs for crop production, especially where legume crops are not used, which can supply nitrogen to following crops.
Research	The author visited cropping and livestock farmers and consultants in Europe and North and South America who are using cover crops as part of their cropping system to improve soil health and ultimately crop production. Two farmers in Germany were also interviewed who are injecting nitrogen fertiliser into the soil as a means to reduce nitrogen fertiliser use while maintaining yields (the CULTAN principle).
Outcomes	There is a wide range of ways farmers are using cover crops to improve soil health, but the common theme was they have all developed a system that suits their crop rotation and meets their objectives. The soil injection (CULTAN) system for nitrogen fertilizer utilises at least 90% of the nitrogen applied, a higher result than most other application systems.
Implications	The use of cover crops has been more widely used in the northern hemisphere but the principles could be applied with adaption in the southern hemisphere. There are many positive effects of using cover crops for soil health and crop production but this needs to be weighed up against whether the cover crop is going to use the following crop’s moisture and nutrients.
Publications	AGF Seeds/SANTFA South Australian Cover Crop meetings, January 13-15, 2016.