

Making the Most of Your Soil's Biological Potential:

Farming in the next Green Revolution



A report for

By Simon Mattsson

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Executive Summary

“Every great tragedy forms a fertile soil in which a great recovery can take root and blossom, but only if you plant the seeds.” (Steve Maraboli).

For the author this quote alludes to the degradation of soil health and the tragedy that most farmers do not fully appreciate the ability of nature to cycle nutrients. They are missing out on the benefits to their agricultural systems that flow from simply growing plants and animals which support soil biodiversity and natural cycling by returning nutrients and organic matter to the soil.

Biodiversity is essential for the survival of all species, including humans. It is the source of our foods, medicines and industrial raw materials. Our economic prosperity is dependent on it, from agriculture to tourism. Farmers have a key role in maintaining and enhancing the biodiversity on their land, while doing their best to manage pests, diseases and weeds in a sustainable way.

Regenerative agriculture (RA) is an approach to managing agro-ecosystems for improved and sustained productivity, while preserving and enhancing the resource base and the environment. Four linked principles of regenerative agriculture recurred through the author’s travels:

1. Implement a continuous regime of minimum mechanical soil disturbance.
2. Maintain permanent organic soil cover.
3. Maintain a living root in the soil.
4. Plant diverse crop species in sequences and/or associations.

RA is a system, not a recipe, and adopting only one or two of these principles will either not work or only give limited results. It appears the Queensland sugar industry has not paid much attention to the potential of maintaining a balance of soil biology, and it is for this reason adopting this system and the biological needs of all four principles applied together that will create a positive change in soil condition.

The underlying principle in “soil health” is that soil is a living, dynamic and ever-so-subtly changing whole environment, not just an inert, lifeless growing medium, which modern farming tends to represent. Is it then surprising that soils highly fertile from the point of view of crop productivity are also lively from a biological point of view?

If all farmers were to apply these four principles in all of their everyday operational activities it would lead to a fundamental shift in the preservation of soil. Such a shift in management of our agriculture resources would require major investment not only in the way the land was managed but in education of how it should be managed. Should this cost be borne by our farmers when it is our society at large, who will be the major beneficiaries?

The Queensland sugar industry has further to go to adopt RA than most other agriculture industries, but our industry has more to gain in that adoption than any other given our close proximity to the iconic Great Barrier Reef.

The author would like to think Australians want change and that they are willing to pay their fair share to ensure that it happens. Fundamental change at any level takes time and education, and with government terms only three years, to ensure change happens it will need to span successive governments so the push to change and the funding for that change must come from the populous at large.

RA will take many forms depending on the industry and environment. RA is a set of basic principles and it is up to the individual implementing them as to how those principles will be applied. That person's success will be measured by how well they adapt those principles to their crop choice and environmental situation.

A farmer's greatest resource is his or her soil; there are plants and animals adapted in nature on every part of this planet, every farmer must determine what plants and animals are best suited to their environment which in some cases will mean needing to change so to best fit into the natural environment. RA is a tool man can use to mimic nature and with the help of modern technology should be able, over time, to work out how those four key principles work together to enable greater productivity, while at the same time maintaining our social licence to farm and regenerate our landscapes. But let us not be held back from the application of regenerative agriculture while we wait for science in this country to verify what the author has seen already verified in other countries.

Figure 1 Dual Crop of Sugar Cane and Sunflowers



The author's father standing in a dual crop of sunflowers and sugar cane on the author's farm. The author believes this to be an Australian first and one of the ways the Australian sugar industry can adopt the principles of regenerative agriculture. (Photo: Simon Mattsson, June 2015).

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Foreword

The Sugar Yield Decline Joint Venture (SYDJV) established beyond any doubt that crop rotation with a legume fallow had a significantly positive effect on productivity. It was one of the key findings and probably the easiest and cheapest for any farmer to adopt and yet, ten years later, we see only around 30% of Mackay cane land using this practice. Mackay Sugar's productivity trend line over the last 20 years is a continual downward trajectory, slipping to the low 70 tonnes per hectare (tph) in the last five years. There are many reasons for this declining productivity; however, it is clear that declining soil health is playing a huge part.

The sugar industry has adopted many new varieties over the last 17 years that combat Orange Rust, Sugar Cane Smut, Pachymetra Root Rot, Ratoon Stunting Disease and Fiji Disease but still our average production has continued to decline. The latest threat is Yellow Canopy Syndrome, the cause of which is yet to be diagnosed. Most of the research to combat these disease problems has focused on developing resistant varieties, with only limited effort being put into looking at *why* these new pathogens have proliferated in the first place.

My father always encouraged me to try new things so as we entered the industry (moving from cattle stations in central Queensland) we looked to adopt the latest technologies: our first fallow cover crop of soybeans was in 1985, our first block of cane harvested without burning in 1986 and by 1990 we harvested 100% green and have very rarely burnt cane since. We changed to billet planting in 1985 and stopped tilling to apply fertiliser in 1987 when we bought our first three-row stool splitter for granular fertiliser application.

In spite of all my efforts on the farm, I was not stopping my declining yield trend. Prior to a major weather event in 1998 our farm's long term average was 103tph. Since 1998 there has been a succession of disease and unfavourable weather events. Despite a very favourable 2013/2014 season, I was still only able to achieve 95tph.

I felt that our focus needed to change from trying to fix the symptoms to investigating the underlying causes. In a healthy environment, no one pathogen is able to gain ascendancy because a healthy system has a balanced soil biota and the balance between predator and prey maintains a healthy system.

The search for a "better way" led me to a Nuffield Scholarship; my expectation of access to people and their research has been far exceeded. Over the last two years I have travelled to

11 different countries (USA, NZ, South Africa, Kenya, Russia, Poland, Czech Republic, Germany, Chile, Peru and Brazil) and met an amazing array of people from some of the leading research institutes and farming enterprises in the world. The knowledge they have imparted has totally changed my perspective of what makes a healthy soil. None of this would have been possible without the support of my sponsor Sugar Research and Development Corporation (SRDC). Special mention goes to Annette Sugden and Carolyn Martin, both of whom worked hard to make both the application and the funding a reality.

Thanks to Nuffield, my “aha” moment came as I was standing in a field on Gabe Brown’s ranch in North Dakota, USA, when I realised that a healthy soil is a living, self-sustaining whole ecosystem and said to myself: this must be the long term answer for agriculture.

Abbreviations

AMF	Arbuscular Mycorrhizal Fungi
ARS	Agriculture Research Service
BNF	Biological Nitrogen Fixation
CEC	Cation Exchange Capacity
FAO	Food and Agriculture Organisation
GBR	Great Barrier Reef
GRDC	Grains Research and Development Corporation
GSP	Global Soil Partnership
N	Nitrogen
NZ	New Zealand
QLD	Queensland
RA	Regenerative Agriculture
SRA	Sugar Research Australia
SRDC	Sugar Research and Development Corporation
SYDJV	Sugar Yield Decline Joint Venture
tph	Tonnes Per Hectare
UN	United Nations
USA	United States of America
USDA	United States Department of Agriculture
VAM	Vesicular-Arbuscular Mycorrhizal Fungi
WHO	World Health Organisation

Acknowledgments

Our operation is a small family affair and which includes myself, my 83-year-old father and my wife Sue, with our two children only just getting to the stage of being interested in helping.

Having had to drastically downsize our operation in recent years to reduce debt, as we contemplated my Nuffield Scholarship application a major concern was how to keep the farm ticking over during my absences. I will forever remain grateful to Sue and dad for their efforts.

I must sincerely thank Nuffield Australia and my sponsor Sugar Research and Development Corporation (SRDC) for taking a risk on a scholar who has a limited education (having not even finished high school), particularly considering I wanted to tackle a topic as complex as soil biology. Terry Hehir (previous chairman of Nuffield Australia), Annette Sugden (SRDC) and Carolyn Martin (SRDC): to you three I owe the most.

Finally, my heartfelt thanks go to all those people who have helped along the journey of my Nuffield quest. There are too many of you to name but I am sure you know who you are. I will mention one last person, Fiona George: thank you. Without you, this document would not be what it is. I will forever be in your debt.

Figure 2 Multi-Species Inter Crop Trial



The author in his multi species inter-crop trial. Can eight different species inter-seeded in ratoon cane crop boost productivity through increased biological diversity in the long term? (Photo: Sue Mattsson, Marian, Sept 2014).

Objectives

This report sets out to investigate how regenerative agriculture (RA) can be integrated into the monoculture sugar cane farming system of North Queensland.

It is the author's view that the industry must adopt the principles of RA if it is to play its role in protecting the Great Barrier Reef (GBR), while at the same time remaining economically viable and maintaining a social licence to farm. As a means to implementing the principles of RA, this report seeks to answer the following questions:

1. Why is carbon so important for biological function and can we build soil carbon levels given our cropping system and tropical climate?
2. Can we influence soil biology in the nutrient cycle through management?
3. How can our industry "harvest sunlight" better?
4. Can we find a biological solution to weed and pest control in sugarcane?
5. How can we emulate nature in our current cropping system through increasing plant diversity?

Given the Queensland sugar industry's geographic spread and its proximity to the GBR, it is little wonder that the social expectations and political pressure on the industry to be environmentally sustainable appear to be ever-increasing. As farm custodians, farmers must do what is necessary to not only maintain their economic viability but to also constantly seek new ways to improve their influence on the surrounding environment.

Introduction

Mackay Sugar is a farmer-owned company with three milling sites at Mackay (Farleigh, Marian and Racecourse) and one at Mossman in far north Queensland.

Its three sugar mills in the Mackay district receive cane from a cultivated area of approximately 83,000 hectares, of which approximately 71,500 hectares of land yields a harvest annually.

The last 25 years have seen the local average production per hectare slide from about 90tph to the low to mid 70tph range. The author's farm has seen a slide from a pre-1998 long-term average of 103tph to 90tph today. This decline in production has many factors, some of which are beyond the farming sector's control. It is possible that external factors have helped to mask the underlying root cause of this continuous downward spiral. Should Mackay Sugar fail to find some solutions to this productivity slump, the entire milling group is at risk of folding.

The Sugar Yield Decline Joint Venture project in 1996 defined "yield decline" as "the loss of productive capacity of sugarcane growing soils under long-term monoculture", although it has now clearly emerged that yield decline is a complex issue largely associated with many factors being out of balance, perhaps the most important of which is the influence of organic matter in the farming system and the contribution of trash residues and legumes (SRDC Project, YDV002). Yield decline is not unique to the sugar industry or even Australia; it is being experienced across conventional farming systems in a broad range of agriculture industries in countries all over the world, as I witnessed in my overseas research. A key result of this research is a deeper understanding of the key principles of regenerative agriculture and how they may be applied in the Australian cane industry.

This system revolves around the promotion of a natural system which relies on continuously building biodiversity. The biodiversity of our sugar cane cropping land has declined along with our productivity over the last 25 or so years and is now dominated by pathogens such as nematodes, probably due to excessive tillage and loss of soil organic matter (Stirling, 2015).

RA key principles are:

- Minimise soil disturbance: limiting tillage has been proven across various agricultural commodities and all continents to aid in improving soil health, helping to reduce erosion, improving water infiltration, improving gas exchange and most importantly allowing soil biology to proliferate without disturbance.

- Maintain organic soil cover: permanent organic soil cover also does all of the above, plus regulating soil temperature and it provides the primary food sources for a diverse range of biology and insects.
- Maintain living roots in the soil: a living root feeds sugars to the soil as energy for microbial activity which enables nutrient cycling for most efficient plant use, builds soil structure and increases soil carbon.
- Aim for greatest plant diversity: diversity of plant species enables all the above to happen as well as providing food either directly or by feeding the animals that we eat and while they are doing that those plants are feeding the soil with the carbon that is essential for life. The more diverse an ecosystem, the more chance that system has to be self-regulating.

Re-establishing biodiversity not only needs all of the principles applied together, it will also help to build soil health once a critical level is reached so that the system becomes self-sustaining. Natural systems work by constantly renewing themselves in balance.

Chapter 1: Carbon and soil biology

Carbon and its influence on soil structure

Soil structure describes the way the sand, silt clay and carbon particles are clumped together to form aggregates of varying size. Soils with good structure are friable (crumbly) so the soil breaks up easily when squeezed.

Carbon derived from decaying plants and animals, plus secretions from soil organisms like earthworms and bacteria, is the glue that binds soil particles together to form aggregates (Magdoff and van Es, 2000). The right blend of large and small aggregates creates pore spaces important for plant growth. Pore spaces regulate the movement and storage of air and water for the living organisms in the soil which influence root development and affects nutrient availability.

In a large portion of the Queensland sugar industry, it is now common to find agricultural soils with less than one per cent carbon content. This low carbon level is a combination of various factors including: naturally low levels because of high rainfall; high temperatures and a high rate of continual cycling of organic matter by biology; and modern farming practices such as frequent tillage which exposes organic matter to oxidation and speeds decomposition, the use of heavy harvesting equipment on moist soil causing compaction which in turn limits air and water infiltration and the continual cropping of sugar cane year after year limiting plant diversity (Stirling, October 2015).

While an optimal level of soil organic carbon is difficult to quantify because the quality and quantity of different organic carbon fractions needed to support various functions varies with soil type, climate and management, it is generally considered that soils with an organic carbon content of less than one per cent are functionally impaired (GRDC, 2013).

Carbon's role in alleviating compaction

Soils with low carbon content are more prone to compaction and erosion because the “glue” in the form of carbon that forms aggregates and allows pore spaces between them, is absent. This can lead to poor water infiltration (influencing plant available water and susceptibility to erosion) and low oxygen availability.

Soils with higher carbon content resist soil compaction in five ways:

1. Surface residue can act like a sponge to absorb weight and water.
2. Organic residues are less dense than soil particles.

3. Roots create voids for more water and air.
4. Roots help to control oxygen in the soil.
5. Living roots supply exudates, the glue holding macro-aggregates together.

(Hoorman, de Moraes Sà and Reeder, 2011).

Soils with more carbon will have a larger population of macro biology such as earth worms which are able to further alleviate compaction as they borrow through the soil in search of food. Certain types of soil organic matter can hold up to 20 times their weight in water” (Reicosky, 2005). Hudson showed that for each one percent increase in soil organic matter, the available water holding capacity in the soil increased by 3.7 percent (*in* Bot and Benites, 2005).

As most beneficial soil organisms are aerobic (needing oxygen to survive), in highly compacted soils with very few pore spaces, anaerobic biology will dominate or soil organisms will be totally absent. Crops grown in soils with low carbon content, high levels of anaerobic biology or a lack of aerobic biology are less resilient and more prone to parasite and disease attack, leading to ever-increasing need for inputs of fertilizers, irrigation and pesticides to compensate for the reduced capacity of the soil biology to perform their natural functions (Magdoff and van Es, 2000).

Organic material as food source for soil biology

Maintenance of organic material living and dead, both in and on the soil, is what largely determines the health of a soil (Gabe Brown, 2014). Organic matter is the central component of a complex soil food web. Soil biology relies on organic carbon in its various forms to provide the food source for other organisms which then go on to be the food source for other biology thus increasing the diversity of all biology that is present in any one field. Low carbon levels thereby limit the number and diversity of soil organisms, which in turn limits the ability of a soil to harness the services that those organisms perform: provide good soil structure, increase water holding capacity and cycle nutrients that feed healthy, high yielding crops.

Various kinds of both macro and micro biology have different relationships with plants. (Nichols, 2014). Each organism has its role in the decomposition of plant and animal material that is then incorporated into the soil as organic matter. This means that the greater the plant diversity, the greater the diversity of soil biology and the greater the range of nutrients that will also be made available in plant-ready form to be taken up.

Nutrient contribution from soil organic carbon

Soil organic matter is composed of nutrients that have been in plant and animal tissue. In their organic form these nutrients are in a plant-available form. Soil organisms, both large and small, play an important role in turning organic material into organic carbon - key to maintaining a healthy soil. Different organisms consume organic material at different stages of the decomposition process, releasing the stored nutrients in a plant-available form. Decaying bodies of soil organisms also release nutrients. This process is called mineralisation (see Chapter 2 for more detail).

As long as nutrients are stored in organic matter, they are not subject to leaching or volatilisation but can be released slowly and as plants require them. By encouraging a diverse soil biology, diverse services are provided to crops. The total store of nutrients in the soil, both labile and locked up, become increasingly available through the interaction between soil biology and soil organic carbon.

While organisms are consuming organic material they are also moving it from the surface deeper into the soil profile and making it available to other organisms and so the process is repeated until the original material becomes humus, the most stable form of organic carbon.

Humus

Humus should be differentiated from decomposing organic matter. The latter is rough-looking material and remains of the original plant are still visible. Fully humified organic matter, on the other hand, has a uniform, dark, spongy, jelly-like appearance, and is amorphous. It may remain like this for hundreds of years; however, humified organic matter, when examined under the microscope may reveal tiny plant, animal or microbial remains that have been mechanically, but not chemically, degraded. This suggests a fuzzy boundary between humus and organic matter. In most literature, humus is considered an integral part of soil organic matter (Krull, Skjemstad and Baldock).

Once organic carbon becomes humus (the point at which fungi can no further decompose the carbon), it then contributes to improving soil structure by alleviating compaction through its moisture holding ability; it can hold up to 90% of its own weight in water. It also has a negative charge and can therefore improve cation exchange capacity, thereby reducing leaching of important, positively charged ionic nutrients in the soil until plant roots can take them up. Humus can be “stripped” from the soil through cultivation (which speeds up the oxidation

process and exposes the soil to weathering), and through application of inorganic fertilisers which reduce the plant's need to release exudates to feed soil biology for the uptake of nutrient which in turn reduces the amount of biology in the soil which slows down the potential formation of humus.

Figure 3 Gabe Brown, North Dakota, USA.



Gabe Brown on his farm in North Dakota, in a field that was a multi species cover crop, winter grazed, leaving reasonable residual cover on the soil. (Photo: Simon Mattsson, April 2014).

Chapter 2: Soil biology and nutrient cycling in an agricultural system

Rhizobia and other methods of fixing nitrogen

Agriculture has known about the benefits of soil biology for many decades and in particular already knows that rhizobia is directly responsible for the conversion of atmospheric nitrogen to plant available nitrogen in conjunction with legumes. Special bacteria live in nodules formed on the roots of legumes where they form a symbiotic association with the legume, obtaining nutrients from the plant and producing nitrogen in a process called biological nitrogen fixation, or BNF. Biological (N_2) fixation is the reduction of atmospheric dinitrogen (N_2) to ammonium (NH_3) catalysed by the enzyme nitrogenase (Herridge, 2011).

There is also now a growing awareness of other forms of biology that can fix atmospheric nitrogen called free-living diazotrophs. (Susanne Schmidt, 2015; Orr, James and Leifert, 2010). These organisms, too, have a symbiotic relationship with plants but do not have to reside in or on the plant roots. This emphasises the importance of plant diversity in cropping lands as different species have different relationships with soil organisms and can help to cycle and hold nutrients.

Science (Brackin *et al*, 2015) has also gone on to prove that there is a mismatch between artificially applied nitrogen and crop use, with up to 60% of applied nitrogen being unavailable for plant uptake due to the plant's inability to take up large amounts of applied nitrogen in single applications, depending on soil type, cation exchange capacity and crop stage. This is of particular relevance to the sugar industry where a single application of nitrogen for a twelve-month crop cycle is common practice, and the entire industry is on the doorstep of the Great Barrier Reef, where nitrogen runoff from cane fields has been proven to be adversely affecting water quality (<http://www.gbr.qld.gov.au/taskforce/interim-report/> December, 2015).

Arbuscular Mycorrhizal Fungi (AMF) or VAM (Vesicular-arbuscular Mycorrhizal Fungi)

Arbuscular mycorrhizal fungi (AMF) (also known as VAM) are proven to be largely responsible for the release of phosphorus and some micronutrient from soil particles. This is another symbiotic relationship and is the largest that science knows of at this stage. It is thought that

at least 80% of the plant species on the planet have this relationship. The fungus lives half in and half out of the plant root and is able to extend its hyphae to take up and transport minerals directly into the plant. This is especially so with minerals such as phosphorus that does not move through the system easily. The system of hyphae also “retains moisture while producing powerful enzymes that naturally unlock mineral nutrients in the soil for natural root absorption” (<http://www.microbesmart.com.au/index.php/what-is-vam>). “In vegetation as different as the prairies of Kansas, the dry scrublands of California, and the rich rainforests of Costa Rica, the presence of these fungi has been shown to be essential for the sustained growth and competitive ability of plants” (Janos 1980a, Allen and Allen 1990, Hartnett et al. 1993, Koide et al. 1994).

AMF are highly ecologically diverse so the more diverse plant species within a paddock the more diverse the AMF that are likely to be present. This suggests that a diversity of plant species in the paddock is essential in order to get the greatest agricultural benefit from these organisms (Bever *et al*, 2001). Unfortunately, AMF can be easily destroyed in agricultural systems that use heavy machinery as the vast networks of filaments are destroyed through cultivation. There is surprisingly little information on AMF in Australian sugarcane (with the exception of some older literature that detected AMF). Recent molecular studies detected a surprising absence of AMF in sugarcane (Paungfoo-Lonhienne et al. 2015) which highlights a need for further investigation, especially to determine if RA increases their presence. Of interest is also that there is evidence to suggest that fungal matter forms an important precursor of soil organic matter. Domesticated soils under crops often have lower organic matter content than soil under native vegetation or pasture, and fungal biomass generally follows the same pattern.

Mineralisation: Organic Matter in the System

Soil biology itself is continually dying and or being consumed by other organisms, then being excreted and becoming part of that soil-available nutrient pool. The consumption of organic matter by soil biology releases nutrient for plant uptake. In essence, this is a form of slow release fertiliser.

There are several types of mineralisation but this report will limit itself to organic mineralisation which is described as either being induced or influenced by biology (Whalen, 2014). This process revolves around the decomposition of organic material both in and on the

soil surface. For example, mineralisation provides much of the nitrogen that plants need by bacteria that convert it from organic forms stored in nodules on plant roots (see above, Rhizobia). Phosphorus-solubilising bacteria supply plants with phosphorous through mineralisation, and other organisms provide plants with other macro and micronutrients.

From the time a plant begins to grow, parts of it are also dying off and decomposing or it is being consumed by insects or other organisms. Those organisms die or are consumed by other organisms, and so it goes on. This is commonly referred to as nutrient cycling, or as Michael Horsch would say, the “soils decomposition engine”. (Michael Horsch, 2014). The more “alive” a system is the more nutrient cycling there will be and, conversely, without both living plants and organisms present there will be very limited organic-mineralisation.

Because bare fallow and or chemical fallow are common practices in the sugar industry, there is little organic matter being cycled through this process, so organo-mineralisation is restricted. This is masked by the practise of cultivating the soil prior to planting which causes a spike in nutrient cycling due to the introduction of air into the soil enabling a short, intense burst of biological activity. However, as a soil degrades, this burst of mineralisation from cultivation decreases and many cane growers have commented to the author how they have noticed the difference between planting a new crop of cane into new ground and old ground (Deguara, 2014).

Biological fertility

“Alive” soils contain biological diversity, and I heard this common theme many times throughout my travels. (Brown, 2014; Wratten, 2015; Bolonhezi, 2015). Since returning to Australia I have implemented the one principle that enables soil biological diversity. Plant diversity is essential to create soil biological diversity which is essential for soil biological fertility to develop. All plants use a range of nutrients in differing amounts and those nutrients become fixed within the plant tissues only being released to the soil once decomposition begins. The nutrients from decomposing organic matter are immediately plant available once they enter the soil solution; therefore in a diverse cropping system with plenty of organic residue from a variety of crops grown there will be significant amounts of a wide variety of nutrients available as long as the system is cycling.

In addition, as we have seen above, in a healthy and diverse system, diverse organisms can fix and release unavailable and immobile nutrients directly from the soil, thus supplementing plant-available nutrients to the crop. This is where the real power of a diverse ecosystem comes from, cycling all of the nutrients necessary to grow healthy plants without the need for synthetic inputs. Jenkinson (1977) aptly described microbial biomass as “... *the eye of the needle through which all nutrients pass...*” (in Herridge, 2011).

Figure 4 Monitoring Carbon Sequestration Trial



CO₂ flux monitoring equipment in a long term carbon sequestration trial being funded by the Department of Energy in Nebraska. (Photo: Simon Mattsson, April 2014).

Chapter 3: Farming sunlight: the role of plant diversity in an agricultural system

The power of photosynthesis

“It now seems quite certain that intercropping with complementary plants, a practice known as “companion planting”, can increase yields quite substantially” (Goldsmith, 1991). This was confirmed to the author by personal communication with Prof Stephen Wratten (March 2015).

There is increasing awareness of the many benefits of companion planting; it seems as though agriculture has come full circle: for example, when European settlers arrived in North America in the early 1600s, the Iroquois had been growing the “three sisters” for over three centuries – a vegetable trio of corn, beans and squash. While there are many benefits of this practice, common throughout human civilisation, one that is not often thought of is how this harnesses the power of photosynthesis.

Plants, through the process of photosynthesis have the ability to extract carbon from the air and feed it to the soil through their roots. The author’s research has led him to understand that being able to take full advantage of sunlight over agricultural land is one of the major differences between farmers who practise regenerative agriculture and those who may leave a field fallow to store moisture for a cash crop that will be planted at a later date.

A key principle of regenerative agriculture is to always have a living root in the soil and “solar panels” (photosynthesising plants) harvesting carbon. To this end, a regenerative farmer considers a broad range of plant species suitable to the season which encourages a diverse crop rotation program. This thinking has been highlighted in numerous scientific publications as being advantageous to soil health and farm productivity. (Fuhrer, April 2014; <http://www.grazeonline.com/plantdiversit>; Cardinale *et al*, 2007).

The sugar industry has many opportunities to increase sunlight utilisation through avoiding bare fallow (that is, always maintain living roots in any fallow ground), and by using fast-growing annual plants as companions in ratoons that boost sunlight utilisation and add numerous diverse plant species to the cropping operation planting in ratoons straight after harvest.

Exudation

Plants feed the carbon extracted from the air through photosynthesis in the form of sugars and other compounds through their roots to the rhizosphere. The rhizosphere is the area of soil immediately surrounding plant roots. Here, plants “perceive and respond to their environment” (Ryan and Delhaize, 2001); it is the zone of influence (Nardi *et al.*, 2000). According to Marschner (1995), nearly “5% to 21% of all photosynthetically fixed carbon [is] transferred to the rhizosphere through root exudates”.

While in North Dakota, the author met Dr. Kris Nichols who has been studying AMF for the last two decades¹. Her most recent work investigates glomalin, a glycoproteinaceous substance produced by AM fungi. Glomalin contributes to nutrient cycling by protecting AM hyphae that are transporting nutrients from the soil to the plant in exchange for carbon from the plant and to soil structure and plant health by helping to form and stabilize soil aggregates (Nichols, 2014).

Plant-soil biology synergies

Plant symbiosis is the close and persistent co-existence of individuals of more than one species, at least one of which is a plant (Nichols, 2014). In most cases both the plant and its symbiont derive an advantage from the interaction. The soil biology relies to a large extent on plants for its food. There are three basic types of symbiosis: commensalism, parasitism, and mutualism. In the first two varieties, only one of the two creatures benefits from the symbiotic relationship. Mutualism is distinguished from the other two types of symbiosis, because in this variety both creatures benefit. The most common form of symbiosis known to farmers is the association between legumes and rhizobium bacteria. We have already examined the importance a mutualistic relationship: AMF (or VAM) (see Chapter 2, above).

Unfortunately for the sugar industry, symbioses can be easily disrupted through inorganic fertiliser application and cultivation. There is emerging science suggesting that inoculation with AMF, for example, may be possible, similar to inoculation with rhizobia. However, the most suitable strains for use with sugar cane have not yet been identified.

¹ Dr. Nichols has found that glomalin is a major component of soil organic matter (ca. 15-20%) in undisturbed soils and may be an agriculturally managed soil carbon sink. Kris has been examining the impacts of crop rotations, tillage practices, and livestock grazing management on soil aggregation, water relationships, and glomalin.

Extending the rhizosphere

Soil micro-organisms, particularly fungi, allow root influence to extend much further and into smaller spaces to access nutrient and water. There are two broad categories of mycorrhizal associations with plant roots, ectomycorrhiza and endomycorrhiza, differentiated by how they interface physically with the plant (“ecto” means the hyphae extend from the root surface and “endo” extend from within the cells of the host plant (McNear, 2013).

To capture nutrients for the plant, both the ecto- and endomycorrhiza extend hyphae centimeters into the soil, resulting in a ten-fold increase in the effective root surface area and a two to three-fold increase in the uptake of phosphorus (and other nutrients) per unit root length compared to non-mycorrhizal plants) (McNear, 2013). It is not only the quantity of hyphae but also their small size (<200 µm) that helps in nutrient acquisition, as they are able to get into small soil pores and cracks that the plant root would otherwise not be able to access.

The network of fungal hyphae emanating from the plant roots also has a significant impact on soil quality. It is thought that when plants of various species are grown together this intertwining of fungal hyphae allows for much greater plant access to moisture and nutrients, hence the reason why multi species cover crops have been shown to be more beneficial for soil health than single species cover crops (Nichols and Brown, 2014).

Plant diversity

Different plants provide food sources for different organisms. Of the myriad species of plants and animals available for human consumption, modern agriculture uses only a few. According to the United Nation's Food and Agriculture Organization (FAO), only nine plant species provide 75% of our total food supply, and only 15 mammal and bird species make up over 90% of livestock production (<http://www.fao.org/docrep/004/V1430E/V1430E00.htm>).

Considering the statement above in the context of modern agricultural systems, it is not hard to see how farmers have become increasingly reliant on a synthetic approach to answering its needs for fertility, pest and disease control. And yet, it is now widely understood that crop rotation is essential to maintain productivity and reduce the need for such inputs. There is also growing evidence that the more plant diversity in a rotation, the greater the potential benefits will be. The science to establish exactly how and why the extent of plant diversity can have this positive influence is yet to be fully explained.

A key moment of understanding for the author was while visiting the farm of Gabe Brown (North Dakota, USA) in mid-2014. Gabe has experimented over the last 15 years with numerous plant combinations and now commonly covers 25% of his cropping area every year with a blend of up to 74 different cover species; he routinely uses 25 different plant species. This diverse system is the basis for Gabe's fertility program on his entire cropping country.

Resources available to US farmers (see Appendix 1, Tables for Cover Crops) to help them select cover crops for almost any situation are yet to be developed for Australian conditions². In sugar cane, there is the added complexity of combining extra plant species as an inter-row crop. The author has commenced a trial adding eight different plant species to an existing ratoon cane crop for the past two seasons. Discovering what combination of plant species will prove most suitable will most likely take many years and no doubt there will be many possible combinations depending on a range of different conditions. However the underlying principle behind the success of farmers such as Gabe Brown has been that maintaining plant diversity is key. Perhaps one day we will be able to fully explain why this is so important.

² There are many different resources available in the US to help farmers select cover crops for almost any situation. The charts in Appendix 1 are examples of some that have been developed over 15 years of US research and are available to farmers wanting to select the best combination of plant species for their given situation.

Chapter 4: A biological solution to weed and pest control

Plant, predator and prey relationships

It is estimated by WHO that more than 40% of all world food production is being lost to insect pests, plant pathogens and weeds, despite the application of more than three billion kilograms of pesticides to crops. Insect pests destroy an estimated 15%, plant pathogens 13% and weeds 12% (Gurr and Wratten, 2004).

Native plants are regulated by a variety of natural enemies such as insects and pathogens that attack the seeds, leaves, stems and roots of a plant. If plants are introduced to a new region that does not have these natural enemies, their populations may grow unchecked to the point where they become so prevalent that they are regarded as weeds. The biological control approach aims to reunite weeds with their natural enemies and achieve sustainable weed control as biological control agents. (Department of Environment, 2014).

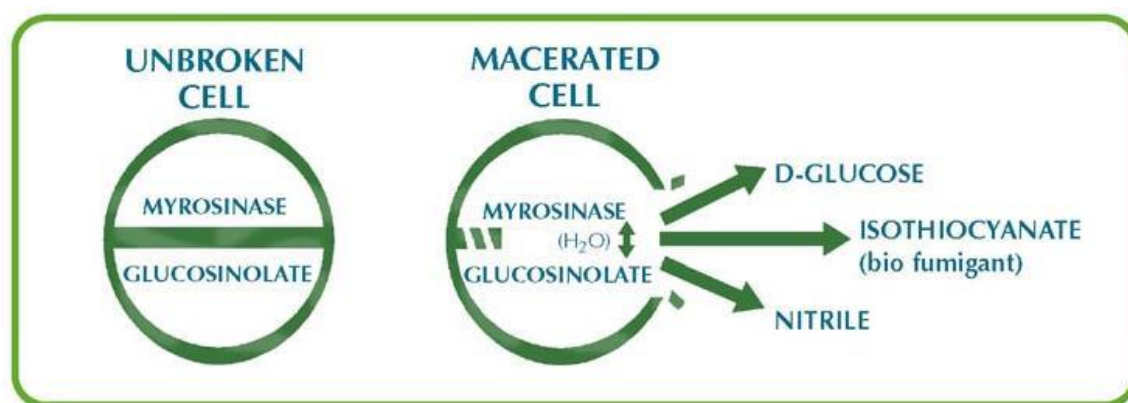
It is the author's belief that, while the traditional view of biological weed control is of an organism that eats or weakens the weed, for every insect or pathogen there will be one *or more* plant species that it needs at each stage to complete its life cycle; it is possible that a weed we are trying to control may only be one part of the control agent's life cycle. Biodiversity and plant diversity offers great potential for managing insect pests if we are seeking to harness nature's ability to self-regulate. It can be achieved through ecological engineering to provide: resistant genes and anti-insect compounds; a huge range of predatory and parasitic natural enemies of pests; and community ecology-level effects operating at the local and landscape scales to check pest build-up (Wratten and Gurr, 2012).

Breaking the cycle of weeds and pathogens

It has been suggested that the use of rotation crops can lead to a reduction of soil borne pathogens by one (or all) of three methods (Wratten, 2015). Firstly, the crop may interrupt or even break the host-pathogen cycle of inoculum production, or its growth or survival. Secondly it may change the physical, chemical or biological nature of the soil, making it less conducive for pathogen growth and development; in turn, this may also benefit microbial activity, diversity or even plant growth promoting bacteria. Finally, crop rotation may lead to direct suppression of pathogens through the inhibition or production of toxic compounds in the

roots or plant residues or through the stimulation of microbial antagonists, such as in brassicas (Larkin *et al.* 2010). This results in so-called bio-fumigation as toxic compounds (isothiocyanates (ITCs)), released during the breakdown of brassica plant tissues, are exploited by incorporating the plant into the soil as a green manure. The grower may also derive some additional benefit from, say, a brassica such as daikon, in its known ability to break up soil compaction and sop up any residual fertility, particularly nitrogen, which may have been left over from the previous cash crop.

Figure 5 Basics of the Bio Fumigation Process



(Taylor, 2013).

Coupled with bio-fumigation is the allelopathic effect that certain plants are able to exert over other plants. Allelopathic crops can potentially be used to control weeds either as a smother crop, in a rotational sequence, or when left as a residue or mulch, especially in low-till systems, to control subsequent weed growth. For example, in one study, rye mulch had suppressive effects on pigweed and common purslane, but had no effects on velvetleaf and common lambsquarters. (Ferguson, 2003). Growing *Desmodium* with corn is now common practice in some parts of Africa where witch weed is a huge problem as *Desmodium* exudes allelopathic compounds that have been shown in Kenya to kill witch weed (Khan and Pickett, 2013).

While varietal resistance and seed treatments are valuable tools for managing these diseases, good crop rotation practices should be paramount in a producer's cropping plans as the first line of defense for a broad range of potential crop diseases that are either soil-borne or residue-borne. Many root rot disease pathogens like fusarium root rot, pachymetra root rot in sugar cane, or root rot in peas will survive in the soil for several years and leaf diseases like septoria and tanspot, which survive on crop residue, can be significantly reduced through good crop rotation practices.

As a result of the Sugarcane Yield Decline Joint Venture conclusions, legume fallow practice has grown in popularity in recent years; however, the sugar industry lags behind standard crop rotation in other Australian industries. Even if all annual sugar cane fallow was planted to a legume, it would still be less than one quarter of standard crop rotation practice in grains. While yield decline is a complex issue caused by a number of factors being out of balance in the sugarcane cropping system, perhaps the ultimate expression is through adverse effects of pathogens on sugarcane root systems (Garside *et al*, 2004).

Getting the biology right

Farmers are generally aware that when planting legumes they need to match the correct strain of rhizobium to be able to fix maximum nitrogen and achieve the best yield. It is the author's belief that this will be so for many different kinds of soil biology and their plant synergists, despite many biological inputs being labelled "snake oil" by sceptics. Often, the farmer will achieve more from addressing underlying soil issues (such as compaction, organic matter and soil moisture) than the application of biological products in isolation.

Substantial work has been done to characterise the role of microorganisms in biological control of plant diseases. The biological mechanisms underlying the success of antagonistic microorganisms, for example, may include initial competition for occupancy of inoculation sites, competition for limiting nutrients or minerals, antibiotic production, and parasitism (Van Driesche and Bellows, 1996). Competitors also function by occupying and using resources in a non-pathogenic manner and in so doing exclude pathogenic organisms from colonising plant tissues. Here, Mycorrhiza deserves special consideration.

Mycorrhizas are formed as the result of mutualistic symbiosis between fungi and plants and occur on most plant species. These associations formed early in the evolutionary development of plants and are found in around 80% of all species (Nichols, 2014; Denison and Kiers, 2011). They assist plants with the uptake of nutrients (especially phosphorus and micronutrients). There are now numerous studies showing the importance of VAM (see Chapter 2) and most studies agree that if VAM spore numbers are limited, then host plant growth will be retarded or perhaps even result in death, implying that the more species of VAM that are present, the stronger plant growth and pathogen suppression will be. Sugarcane has been confirmed to host several species of VAM (Magarey, Bull and Reghenzani, 2005); however, it is clear to the author that the lack of other plant species in a sugar cane monoculture will be severely

restricting the potential for the necessary diversity in AMF species to be present to achieve maximum yield and pathogen suppression.

Chapter 5: Emulating nature for productivity and environmental benefit

Embracing regenerative agriculture

The difficulty lies not so much in developing new ideas as in escaping from old ones. - John Maynard Keynes.

How can we emulate nature in our agriculture system? In conventional agriculture systems farmers have been taught and encouraged to plant monocultures on the premise that they need to eliminate all competition for nutrient and moisture to maximise the productivity of their cash crop. This simplistic approach perpetuates the need for synthetic inputs and, as the soil's natural fertility declines, there is an ever increasing downward spiral. This is most likely the first paradigm that will have to be broken in the shift to a regenerative future.

If we observe nature it becomes clear that nature does not often allow a monoculture to occur and if it does it is very short lived. Nature provides many of the answers. Perhaps to move forward using the principles of regenerative agriculture we need to be willing to accept those answers while we wait for science to catch up and tell us *why* they work. Plant diversity is very much the norm with quite often several hundred species of plants and animals living in balance within a given ecosystem. Nature maintains plant residue on top of the soil continuously (bare soil or major soil disturbance is extremely rare) or it is very low impact such as the breaking of the soil surface by cloven hoof animals in comparison to modern human activities. This mostly undisturbed, hugely diverse ecosystem has continued without our assistance for millions of years. We need to look for the answers to our agricultural problems within nature if we wish to exist into millennia.

Regenerative agriculture is not a new invention, merely a new name for what was common practice for 10,000 years on farms all over the world prior to the advent of synthetic fertilisers in the early to mid-20th century. Our forebears practiced a diverse crop rotation with legumes and livestock as key parts of their fertility program, low impact tillage, which naturally limited its frequency and aggression, and plant diversity and living roots in the ground year round (such as the “the three sisters” approach by American Indians).

The knowledge base in the area of regenerative agriculture and soil biological function is now very extensive and well established in many countries throughout the world; the author met

many of these people on his study travels through the United States, New Zealand, Chile, Peru and Brazil.

Enhancing natural nutrient cycling

The answers to how a natural ecosystem can exist without any added nutrient or pest control must lie in its ability to cycle nutrients through the constant growth and death of a diverse range of plants, animals and, in particular, soil biology. As discussed in earlier chapters it is clear that there is a range of plants that grow well together and many more that do not. Although as farmers we may not fully understand the processes involved, should that stop us as trying to copy what very obviously works in nature, and through experimentation, ultimately determine which combinations will best promote and protect whatever our chosen cash crop may be?

Harnessing competition

Nature relies on plant competition to determine ecosystem make-up while conventional agriculture relies on herbicides to eliminate competition to the cash crop. The power of plant interaction is obvious in nature and to an ever-growing number of people who have learnt how to use those plant and animal interactions to both produce nutritionally rich food and care for their environment (see, for example, Salatin and Brown). Having witnessed this during his travels, the author has begun farm trials to gain a better understanding of what combination of plants may work best in north Queensland conditions. The farmer has the power to manipulate plants and animals on a given area of land and if done appropriately, it can have a profound influence on the health of the plants and animals growing on that land and also the soil within that given area, the environment surrounding that farm and the humans that rely on that farm for their food.

Ralph Waldo Emerson said: *As to methods, there may be a million and then some, but the principles are few. The man who grasps the principles can successfully select his own method.* The author believes in the old saying: *we are what we eat.*

Conclusion

There is now no doubt that soil biology is as crucial to maintaining healthy soil function as soil chemical and physical elements. While science is proving to be both the solution and the barrier to acceptance of this basic fact as it struggles to maintain pace with discoveries in the biological world, this is changing with increasing global support. For example, in 2011, the FAO launched the Global Soil Partnership (GSP) to support sustainable management of soil resources for food security and climate change mitigation. The UN declared 2015 the International Year of Soil, a campaign to raise awareness, support policies, and promote investment toward soil security as well as enhance soil collection and monitoring. And on 4th December 2015, on the occasion of the 12th annual World Soil Day, the GSP released its first report on the state of the world's soils.

Australia has signed up to the 4/1000 initiative³ along with about 150 other nations in an attempt to “declare or to implement practical programmes for carbon sequestration in soil and the types of farming methods used to promote it” (<http://4p1000.org/understand>) but it must now move to implement policies to achieve the initiative's targets. It is clear that the urgency of the message on the health of our soils is on the radar of many of the world's governments, but not yet Australia's top agricultural priority.

The Queensland sugar industry has further to go to adopt regenerative agriculture than most other agricultural industries, but that industry has more to gain given its proximity to the iconic Great Barrier Reef.

The questions the industry needs answered are:

1. Why is carbon so important for biological function and can we build soil carbon levels given our cropping system and tropical climate?
2. The role of soil biology in the nutrient cycle: can we influence this through management?

³ The 4% Initiative, launched by France, sets out to bring together all willing contributors in the public and private sectors (national governments, local and regional government, companies, trade organisations, NGOs, research facilities, and others) under the framework of the Lima-Paris Action Agenda (LPAA). The aim of the Initiative is to demonstrate that agriculture, and agricultural soils in particular, can play a crucial role where food security and climate change are concerned (<http://4p1000.org/understand>).

3. Harvesting sunlight: how can our industry make better use of what we have in abundance?
4. How can we emulate nature in our current cropping system through increasing plant diversity?

The author believes this report has shed some light on these questions; however there is much work to do and urgency with which issues must be addressed grows by the day.

Figure 6 Commercial Sunflower Crop in Sugar Cane



The author and family in their first commercial crop of sunflowers and the first for the district. The inaugural “Sunset in the Sunflower” event was designed to raise awareness within the local community of the benefits of improving soil health. The author firmly believes the whole community must contribute to environmental preservation; however it is the farmer’s responsibility to educate the public as to how this can be achieved within their own financial constraints. (Summer Rain Photography November 2015).

Recommendations

It is the author's hope that the following recommendations will assist especially the Queensland sugar industry, but also all farmers, wherever they are and whatever they farm, to improve soil health, profitability and environmental outcomes. Most of these recommendations will be relevant to all sectors of agriculture that rely on soil for the nutrition of their commodity. It is up to the reader to decide and verify the best possible course of action, weighing the risks and benefits for him or herself. The most important point is that the following principles need to be applied *as a system* to gain the greatest potential benefit.

1 Minimise mechanical soil disturbance

There have been limited attempts in the sugar industry to reduce tillage in the planting phase (in spite of key recommendations by the Sugar Yield Decline Joint Venture) and no-till planting of cane is still widely regarded as impossible.

The author attempted minimum-till planting following a soybean fallow crop in 2015 with excellent results. This was a single pass with a coulter followed by a narrow ripper leg. If mounted on the front of the planting tractor it could rightly claim to be no-till.

Figure 7 Soybean Thrash



Soybean thrash after single pass with coulter and narrow ripper leg just prior to planting cane, author's farm. (Photo: Simon Mattsson, Marian, May 2015)

2 Maintain organic soil cover

While green trash blanketing is common practice these days in ratoon cane crops, the impacts of tillage or spray out of the previous cane crop in the fallow phase could be greatly reduced

by immediate cover crop planting. Careful selection of a cover crop species mix will take into consideration the season and objectives of the cover crop.

3 Maintain living roots in the soil

Although cane is a perennial crop and maintains a living root in the soil for the duration of the crop cycle, we could plant a cover crop such as legumes immediately the fallow phase has started. (as recommended by the SYDJV more than ten years ago).

4 Greater plant diversity is better

Sugar cane is a perennial C4 deep-rooted grass which, in a healthy soil, will develop a large root system with huge potential to build soil carbon levels. While multi-species fallow management once every five to six years offers potential for soil improvement, the author recommends introducing plant diversity into the crop.

A dual crop of sugar cane and sunflowers in the plant cane phase of the crop cycle offers great potential for an additional cash crop and is currently under trial at the author's property. Soybeans harvested in April 2015 yielded 2t/ha; sunflowers harvested in October 2015 yielded 1.7t/ha and the cane crop will continue to a normal harvest in August 2016, with the expectation of 90t/ha that will show a successful companion cropping and harvesting system.

Figure 8 Multi-Species Intercropping Trial in Sugar Cane



The author in his multi-species intercropping trial. (Photo: Sue Mattsson, September, 2015).

5 Measure and evaluate soil and plant health

Comprehensive soil sampling (used by the author) highlights several underlying nutrient issues that need to be addressed to enable biological function and enhanced production: plant available calcium. The author recommends a lime top up of between 200 to 500kg/h every year or two. There is much more than the cane industry nutrient management standard (Six Easy Steps) that can be done as various forms of soil and crop testing become more cost effective and accurate. The onus is on the grower to fully inform themselves of the nutrient requirements for their crop and to consider that Six Easy Steps is merely the starting point for a nutrient management plan and not the end point.

Figure 9 Ultra-fine lime application



Ultra-fine lime applied banded at 300kg/h in third ratoons on the author's farm. (Photo: Simon Mattsson, Marian, October 2015)

6 Alleviate compaction

With the challenges of an industry reliant on large, heavy equipment expected to work in wet conditions to maintain mill throughput, the cane industry's only real attempt to address compaction to date is to move to controlled traffic farming with row and wheel spacing's matched to current harvesting equipment of about 1.9m.

Building soil organic carbon can go some way towards not only increasing water holding capacity and nutrient cycling, but also helping the soil recover after a compaction event.

Tillage radish is a proven plant species that alleviates compaction; adding organic matter such as compost can also help.



The author in his multi species inter-cropping trial with large daikon radish, typically used in parts of the USA to alleviate compaction, (Photo: Sue Mattsson, September 2015)

7 Reduce synthetic inputs

There are several ways that growers can replace synthetic inputs with products that will either do less harm to soil biology or perhaps even assist soil biology to proliferate. For instance, the author has replaced superphosphate with soft rock phosphate and muriate of potash with sulphate of potash, both of which are “kinder” to the soil. The author planted his first cane without fungicide in August 2015 and has seen no detrimental effects yet.

Regular use of legumes can reduce the amount of applied nitrogen by as much as 80% of the Six Easy Step recommendations. (SYDJV 2004)

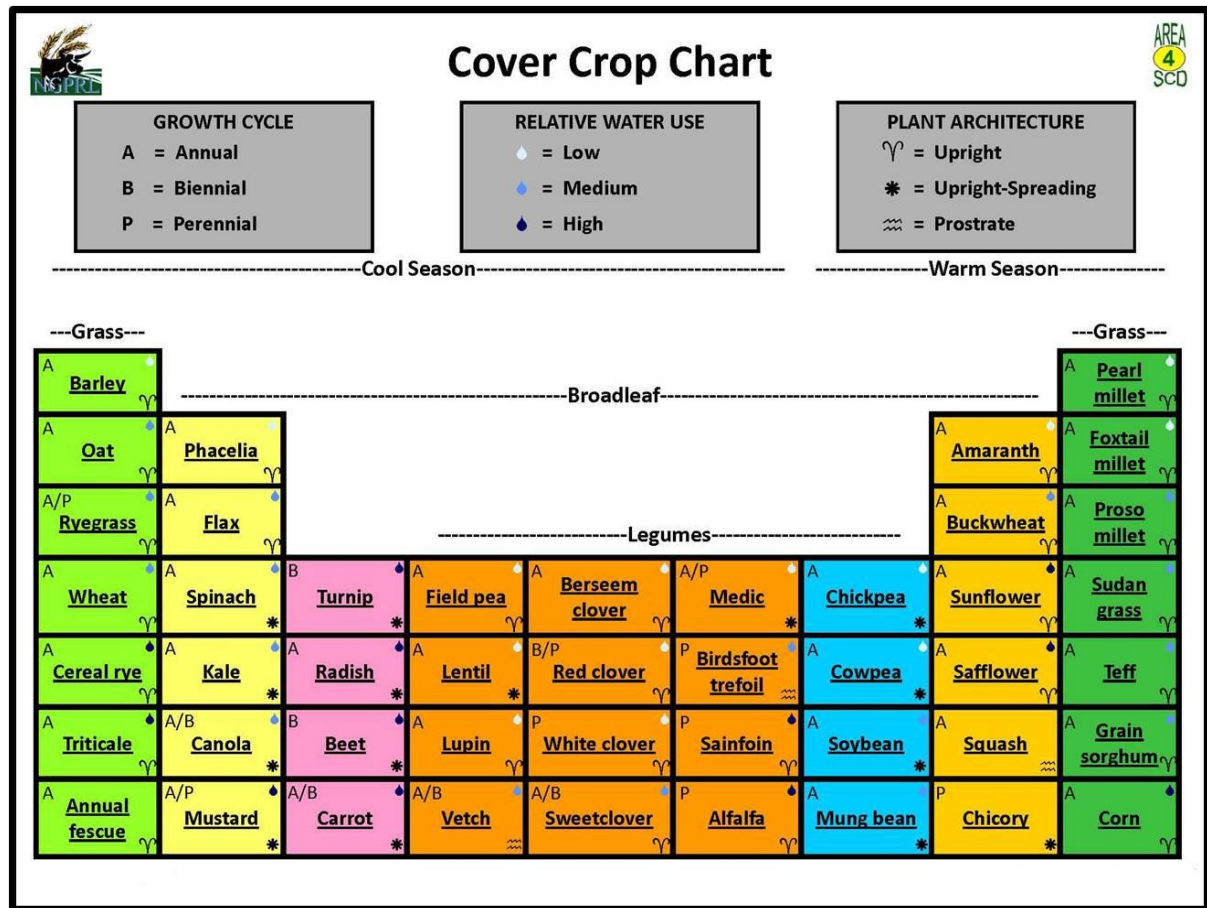
In addition to the recommendations above, the author suggests two further options:

Biological amendments and stimulants. In spite of the vast array of these products available, the author believes that these products are very unlikely to work in isolation without first applying all of the above recommendations. Buyers need to inform themselves about each product and why it is needed.

Integrating livestock into the rotation. This provides the opportunity for a pasture fallow, the best way to build soil carbon, but is also likely to be the most difficult scenario for change due to the need for basic infrastructure such as fencing and water facilities. For the gurus of regenerative agriculture, livestock are widely thought of as the missing link in many modern cropping enterprises. (Brown, 2014)

Appendix 1 Cover crop chart for USA

Figure 10 Cover Crop Chart Published by USDA ARS Mandan ND



COVER CROP USES

Purchase cover crops at www.ufseeds.com

BENEFICIAL INSECTS	CHICKEN FORAGE	COMPACTION CONTROL	DEER ATTRACTANT	EROSION CONTROL	FORAGE	GREEN MANURE	NITROGEN FIXATION	NITROGEN SCAVENGER	NO TILL	ORGANIC MATTER	WEED SUPPRESSION
Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Alfalfa
Barley	Chicory	Clover	Chicory	Barley	Chicory	Barley	Clover	Barley	Barley	Barley	Barley
Clover	Clover		Clover	Clover	Clover	Buckwheat	Cowpeas	Flax	Buckwheat	Buckwheat	Buckwheat
Buckwheat	Cowpea		Cowpea	Cowpea	Forage Pea	Cowpea	Forage Pea	Rye	Clover	Flax	Clover
Chicory	Flax		Forage Pea	Oats	Rape	Flax		Ryegrass	Flax	Forage Pea	Forage Pea
Cowpeas	Forage Pea		Rape	Rye	Turnips	Forage Pea		Vetch	Forage Pea	Oats	Oats
Flax	Rape		Turnips	Wheat	Vetch	Oats		Wheat	Oats	Rye	Rye
Vetch	Turnips		Vetch			Rye			Rye	Ryegrass	Ryegrass
	Vetch					Ryegrass			Ryegrass		Vetch
						Vetch			Vetch		Wheat
						Wheat			Wheat		

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Plain English Compendium Summary

Project Title: Making the Most of Your Soil's Biological Potential: Farming in the next green revolution	
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Objectives	This report sets out to investigate how regenerative agriculture (RA) can be integrated into the mono-culture sugar cane farming system of North Queensland for improved soil health with economic and environmental benefits.
Background	The last 25 years have seen the local average production slide from about 90tph to the low to mid 70tph range. This decline in production has been for many reasons, some of which are beyond the farming sector's control. It is likely these external factors have helped to mask the underlying cause, which the author believes is directly linked to poor soil health.
Research	Research has been conducted in Australia, New Zealand, USA, Brazil, Chile, Peru, Kenya, South Africa, Poland and Germany on different trips totalling 15 weeks. Many personal interviews were conducted, and information gathered verified and enhanced through extensive literature review (internet, books and scientific papers).
Outcomes	This report outlines the principles of regenerative agriculture as witnessed and researched by the author and how those principles can be applied in the North Queensland sugar industry. The suggestions are part of ongoing trials on the author's farm, full results of which won't be known for several years.
Implications	The Queensland sugar industry is under constant public and political scrutiny for its environmental performance, particularly with respect to the impact on the Great Barrier Reef, which some suggest could be extinct within the next 50 years. This report outlines a production system for the sugar industry that could significantly improve the industry's environmental impact while improving the overall long-term economic viability of the sugar industry.