A Nuffield Farming Scholarships Trust
report

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The benefits to agriculture and the environment of rebuilding soil carbon

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NUFFIELD UK

Contents

Disclaimer

1. Executive summary

I was brought up on a family dairy farm in North Yorkshire and then studied for a degree in animal science at Edinburgh University. Upon leaving Edinburgh I started a career in farm management.

Over the last twenty years I have been looking at issues such as mastitis, infertility and lameness in the dairy industry, all with a list of drugs, vaccines, and chemicals used to cure the symptoms – and have come to the conclusion that they are all related to the overall health of the cow.

In some incidents mineral supplementation for the animal was enough, but in others this did not achieve the same results, so I started my quest for the answer.

Deciding that the answer probably lay in the worn-out soils with which I was working, I decided to apply for a Nuffield Scholarship to look at the agronomic importance of soil carbon.

From my reading of relevant literature it was becoming apparent that fertility of the soil was related to soil organic matter.

Having subscribed to Acres USA magazine for the last eight years, the USA seemed to be the obvious starting point. Yes, the home of genetic modification, intensive agriculture, concentrated animal feeding operations and corporate dominated processing does actually have a large eco-agriculture movement.

It is a movement that owes its strength to the foresight of Charles Walters in publishing the magazine and enabling a network of like-minded people to become established, along with highlighting the work of William Albrecht as an alternative view on soil fertility.

Australia was my other destination - farmers here are working in a climate which involves thin soils and a regular lack of moisture, combined with no government subsidy. This scenario has driven farmers and researchers to look at ways to build soils which are more resilient to moisture deficits, using methods which fit within their budgets.

A Regen-ag workshop in Sussex, and attending Acres USA conference in Columbus, Ohio, completed my travels.

For the last fifty years, soil fertility has been regarded as the result of a simple chemical test. Based on these results, simple inorganic fertilizers have been applied to our soils. The result has been the production of large amounts of cheap food – with only the use of rescue chemistry to keep disease at bay. Animal production systems based on this cheap grain and fertiliser fuelled forage have necessitated the use of vaccines and antibiotics to keep control of disease. The same has been seen in the human population.

Through all of this the cause of disease is blamed on the pathogen, rather than the presence of hidden hungers in soil, plant, animal, and man. The twentieth century was the age of the chemist, enabling the production of large amounts of food and keeping the ravages of disease under control.

However, the chemist is struggling to stay ahead of nature with the advent of superbugs, so the twenty first century has to be the age of the biologist. By harnessing the power of biology we can maintain our food supply, whilst keeping disease under control through the elimination of hidden hungers.

From my studies I have determined that the fertility of a soil is its ability to hold and recycle nutrients and water in a plant available form. To do this, a soil needs to be biologically active and fed a range of foodstuffs – a combination of rapidly digestible green plant material/animal slurries and slower digestible crop residues and farm yard manure. The biology in the soil is responsible for breaking down this material, releasing the nutrients from it, and building humus.

Humus is the stable carbon compounds found in soils, which have a great influence on the fertility of the soil. As humus levels increase, the structure of the soil becomes lighter and more friable, the soil has a greater ability to hold nutrients – along with a greater amount of buffering capacity, reducing negative impacts of nutrients present in excess, and massively improved water management. High humus soils are capable of absorbing much more rainfall, so reducing run off and erosion. Excess water percolates through the soil and has nutrients removed before entering ground water. This results in clean water entering water courses, and a reduction in the risk of flooding. More water is retained within the soil for future plant use, thus drought proofing the soils.

Spreading compost at rates as low as 1tonne/ha is a great way to add some humus to the soil, whilst at the same time adding a large range of microbes. These microbes are added complete with a "home" and a food source, so giving them a good chance of becoming established in the soil. These microbes are essential to rebuilding soil carbon levels.

The best way to rebuild soil carbon levels is by the rotational grazing of bio-diverse pastures. The stable environment under the ley allows the biology to establish in the soil, whilst promoting the plant's ability to exude large amounts of sugars through its roots (up to 70% of what it produces). This provides a ready food source for the microbes, resulting in the ability to increase soil carbon levels by one per cent every three years (20t carbon/ha/yr).

As this biology begins to work, the level of soil carbon(humus) begins to increase. The biology also begins to cycle and mobilise a full range of minerals and trace elements in the soil, which are then held in a plant available form. The result is a growing crop which is achieving its full physiological potential, so producing complete carbohydrates, complete proteins, and high levels of oils; rather than sugars, non-protein nitrogen, and minimum oil levels.

This improved forage is digested more efficiently by the ruminant, with the potential to reduce methane output by up to twenty per cent, when compared to an animal on the poor quality forage. Output per unit of dry matter intake is potentially higher, so increasing the efficiency further. With nitrogen being present as protein - rather than non-protein nitrogen – it is used more efficiently by the animal. The inclusion of tannin rich plants in the mixture means that excess nitrogen is bound by the tannin in the rumen, and passes through the animal into the dung, where it is slowly released over twenty years – this reduces emissions of nitrous oxide from urea in the animals' urine (lower urea levels).

In conclusion, we need to recognise that soil fertility is related to a soil's ability to hold nutrients and water and that, in order to achieve this, it is important to manage and feed the soil microbes. The best way of doing this is with the grazing ruminant, which leads to many environmental benefits in terms of greenhouse gas emissions.

My quest now is to tweak the grazing management on the farm to achieve these goals.

2. Introduction

I was brought up on a family dairy farm in North Yorkshire and then studied for a degree in animal science at Edinburgh University. Upon leaving Edinburgh I started a career in farm management.

Over the last twenty years I have been looking at issues such as mastitis, infertility and lameness in the dairy industry, which come complete with a list of drugs, vaccines, and chemicals used to cure the symptoms – and have come to the conclusion that they are all related to the overall health of the cow.

In some incidents mineral supplementation for the animal was enough, but in others this did not achieve the same results and so I started my quest for the answers.

Over the last 10 years, I have looked at a more biological approach to soil health – the last 5years have seen me following the work of people such as Robert Elliot, Sir Albert Howard, Friend Sykes, Frank Newman Turner, Lady Eve Balfour and William Albrecht.

Much of such work was done in the first half of the 20th century. Whilst seeing results by following their methods, I was still looking for answers to achieve good production levels from biological methods.

Deciding that the answer was probably in the worn-out soils with which I was working – which had poor organic matter levels in comparison to what the agriculturalists mentioned above were working with half a century ago – I decided to apply for a Nuffield Scholarship to look at the agronomic importance of soil carbon.

3. Why soil carbon?

From reading the literature referred to earlier it was becoming apparent that fertility of the soil was related to soil organic matter.

The use of deep rooting, bio-diverse leys and compost to build soils plus health and production in livestock is a common theme in these publications.

This biological background has been given a chemical insight by William Albrecht. He looked at mineral balances from macronutrients through trace elements. Testing soils and forages revealed imbalances and shortages. Surely using biodiverse deep rooting leys should correct these imbalances in forages through the actions of the different plants within the mixture – but how long would this take? Changes in soil structure were occurring, but still little change in mineral content of the forage, so the decision was taken to add supplemented minerals to the soil – after all, if the livestock above ground require it, then surely those below ground have the same needs, and probably the plants as well.

However is regular supplementation appropriate/sustainable? Or are there ways to improve the soil to sustain good balanced mineral levels in forages? Again this seemed to lead back to carbon.

Time to travel and find the answers!

4. Where to go?

Having subscribed to Acres USA magazine for the last eight years, the United States of America seemed to be the obvious starting point. Yes, the home of Genetic Modification, intensive agriculture, intensive animal feeding operations, and corporate-dominated processing has a large eco-agriculture movement: a movement that owes its strength to the foresight of Charles Walters in publishing the magazine and enabling a network of like minded people to become established, giving, along with the work of William Albrecht, an alternative view on soil fertility. This movement is growing in strength and developing the biological approach/ holistic farm movement into a system which can compete with industrial agriculture, whilst producing nutrient-dense food.

To quote Gary Zimmer: *"You never change things by fighting the existing reality. To change, you must build a new model which then makes the existing model obsolete".*

Over a six-week period, I visited ten States in the **North East quarter of the US**.

I started my journey in Wisconsin, spending time with Gary Zimmer (consultant, farmer and chief executive of Midwestern Bio Ag) on his organic dairy farm, and visiting Midwestern Bio Ag's fertiliser factory. I then met with Lawrence Mayhew (consultant) to get his views on soil carbon.

My journey then took me, via Calwest Seeds, to Iowa to meet Dr Olke, who is doing research into the effect of humates on plant growth.

Leaving Iowa, I travelled to Ohio to meet John Kempf (consultant and fertiliser manufacturer), calling in on farmers along the way who were following MBA's soil fertility program.

Jerry Brunetti (consultant) was my next visit in Pennsylvania, to hear his views on the soil-plant-animal-human interdependency. I then went to see The Rodale Institute (researching organic no till) and a farmer practising holistic grazing management, while on my way to meet Amish farmers and consultants in Lancaster County, Pennsylvania.

The final leg of my journey was through New York State and into Vermont to meet other farmers practising holistic management techniques.

Australia was my other destination - farmers here are working in an environment which involves thin soils and a regular lack of moisture, combined with a lack of government subsidy.

This scenario has driven farmers and researchers to look at ways to build soils, which are more resilient to moisture deficits, using methods which fit within their budgets. Here I visited farmers, consultants and scientists involved in this work.

In New South Wales I met with Hugh Lovel (consultant) and Bill and Rhonda Daly (farmers, consultants and fertiliser/compost manufacturers). Staying with Michael Inwood(farmer), I saw the work he is doing with holistic management and development of an electric yute.

Flying to southern Victoria I visited farmers who had switched to using compost, plus a compost manufacturer, before meeting Dr Ekhard and Dr Mele at Melbourne University. Leaving Melbourne, I travelled to Waragul Research Station to look at their methane research, before visiting farmers in Gippsland.

In November, attendance at a **RegenAg course in Sussex, UK**, re-iterated many of the messages learned abroad – especially the need to regenerate soils (sustainability no longer good enough) and concentrate on water management - keeping water in the landscape.

The end of my travels was a return to the **US to attend an Acres USA conference** in Columbus, Ohio. This was a great event, the theme of which was building resilience in your farms.

It covered all topics from soil regeneration, through plant health to animal and human health, including a discussion on the implications of what we eat and how this can not only affect us, but also the next three generations, unless we take steps to change.

5. The World Wide Picture

a) Soils

The prevailing situation I observed was one of deteriorating soils (several times I was told they are estimated to have aged 5-10,000 years over the last 40 years). This has resulted in many issues:

- Drought/flooding

  Over the last few years, extremes of weather seem to have become more commonplace. This has resulted in some areas receiving extremes of rain or dry weather. This has resulting impacts on crop yields and quality.

- Erosion

  When heavy rainfall occurs, there is now a tendency for large amounts of rain to run off, taking with it topsoil and nutrients. As soils have deteriorated, they appear to have become more susceptible to erosion, resulting in greater quantities of silt and nutrients in the watercourses.

- Nutrient leaching

  Apart from those nutrients lost by surface runoff and erosion, many nutrients are lost through leaching into land drains and underground watercourses.

  This has a two-fold effect – it increases pollution of watercourses and increases the input levels required by the farmer to achieve satisfactory crop yields.

These issues are having a profound effect on the rivers and waterways. The soils are requiring higher levels of inputs (fertiliser and pesticides) to maintain yields, which continue to be more susceptible to weather extremes (a phenomenon which seems to become more prevalent), resulting in an unsustainable system which is ever more dependent upon oil based inputs.

Gradually more farmers, largely driven by their economic circumstances, are looking for alternatives.

b) Health

Over the last 40 years a deterioration in animal and human health has been observed across the world.

In the US while spending on food has dropped from 18% of income in1960 to 9% today, spending on health has increased from 5% in 1960 to 17% of income today.

Food and health expenditure:	23% income 1960 26% income today

c) The UK itself

In the UK there is a similar picture of soil deterioration - it is suffering from drought, erosion and nutrient leaching – resulting in a myriad instances of red tape for farmers. At the same time the need for inputs is increasing. The UK does, however, benefit from a kind maritime climate plus a limited subsidy system and these two factors are creating inertia, with a consequent lack of need to look for alternatives.

The organic farmer is convinced that low yields are part of an organic system, even though Elliot and Sykes, in their day, were out-yielding their conventional neighbours – a situation seen regularly today on my travels in other countries.

Similar health issues in both livestock and human populations as those discussed in the previous two chapters are also being witnessed here in the UK.

6. What is Soil Carbon?

Soil Carbon is anything containing carbon which originates from a living organism, referred to as organic carbon.

This includes everything from animal manures and crop residues freshly added to the soil, to the humic substances, which are the end product of decomposition. This is better explained by splitting it into three categories:

green, brown and black carbon

a) **Green carbon** includes young, lush cover crops and low fibre manures, which provide a rapid release of nutrients for the growing crop.

   As green carbon has a low C:N ratio it is primarily digested by bacteria, releasing its nutrients for crop growth. By growing a cover crop and incorporating whilst young and lush, sufficient nitrogen can be released for the following crop.

   This green carbon is good as a feed for bacteria and for the provision of nutrients for the following crop, but does very little to build soil carbon levels.

b) **Brown carbon** includes crop residues, mature cover crops and manures, which include bedding or derive from ruminants fed on a high forage diet. These substances have a high C:N ratio and are high in lignin, and are therefore slow to break down in the soil. Fungi are the main decomposers of brown carbon.

   As brown carbon is broken down slowly, there is no flush of nutrients to feed the crop, as with green carbon. Instead this material is broken down to form the complex humic substances in the soil.

   This can only occur in soils with active fungal populations. Large amounts of trash lying on the soil surface do not help, unless they are being actively broken down.

   Regular addition of brown carbon to the soil is the best way to increase humus content of the soil.

c) **Black carbon** includes compost and very complex, stable humic substances in the soil. These substances are at the end point of decomposition, being very stable substances in the soil.

   At this point in decomposition there is very little nutrient left, but this black carbon has many beneficial roles in the soil (see next chapter).

   Although very stable, there is a continual loss of black carbon from the soil. The rate of this loss is influenced by the management of the soil – excessive cultivation and the use of high levels of fertilisers (especially nitrogen) will increase this loss. Typically soils lose 2-5% per annum of humus.

In order to maintain healthy soil, regular additions of both green and brown carbon are required. This provides food for both bacteria and fungi, providing nutrition for the growing crop and building humus levels.

d) Summary table

	Characteristics	**C:N Ratio**	**Sources**
Green Carbon	Found in young living plants, builds very little humus, feeds primarily bacteria, rapid nutrient release	Low C:N ratio, high N, low lignin	Pig and chicken manures, young cover crops
Brown Carbon	Found in older, woodier plants, builds humus, feeds primarily soil fungi, slower nutrient availability	High C:N ratio low N, high lignin, breaks down more quickly with added N	Lignified or brown plant material: crop residue, mature cover crops, Manure with bedding, manure from ruminants fed roughage
Black Carbon	Rich black material in soils, forms slowly over time, can be lost with excess tillage or too much applied N	High in complex carbons	Compost, forms in soil over time from decomposition of brown carbon sources

From 'Advancing biological farming'; Gary Zimmer and Leilani Zimmer-Durant

7. How do we define soil fertility?

It is widely considered that the measure of a fertile soil depends upon an ideal pH and good P and K indices. Others think that soil fertility is built by growing legumes to fix nitrogen.

However, from my research it is apparent that a fertile soil is one which has a high humus content coupled with a high population of active micro organisms.

The most productive 'conventional' crops are produced on soils which still have high carbon levels. The best 'organic' soils have high carbon levels coupled to high biological activity. This is where management concentrates on feeding and promoting the biological activity – resulting in soils which continue to improve year on year.

'The measure of a fertile soil is its content of organic matter, or ultimately its humus. Nature bases all her life forms on humus and attempts nothing without it. Indeed, until she has created it, nature's process of plant and animal life cannot go on. …. She has no substitute for humus ….

Upon a basis of humus, nature builds a complete structure of healthy life – without need of disease control of any kind. Nature does not treat disease because she is the example of perfect health – disease is the outcome of the unbalancing or perversion of nature – and serves as a warning that something is wrong.' Frank Newman-Turner.

"Soils high in humus are very fertile soil." Zimmer

'What are the major lessons that I have learned after thirty years of farming? They are:

1) *That the well–being of mankind is interdependent with that of the animal, plant, and the living soil.*

2) *That a fertile soil is one rich in humus.*

3) *That whenever the humus content of the soil is depleted (as in the growing of a wheat crop), the humus must be replaced with more humus manufactured by the biological processes, …'* Friend Sykes

In summary, a fertile soil has nothing to do with available nutrients, but available nutrients have everything to do with soil fertility – fertility is the soil's ability to hold and recycle nutrients and water in a plant-available form.

8. The Role of Soil Carbon

The properties of a soil can be split up into three categories, namely:

Chemical

Physical

Biological

Modern agriculture concentrates primarily on the chemical properties of the soil, occasionally considers compaction and rarely thinks about the biology.

a) **The chemical properties** of a soil are measured in terms of its pH and available water-soluble mineral content. There is also a large reserve of minerals in the soil, which are present in an unavailable form.

   When considering the fertiliser needs of a crop, we measure that availability in the soil then calculate that required by the crop, and apply as required.

   Soil carbon can have a huge effect on available nutrients:

   - **Green carbon** – when incorporating green carbon there is a large release of nutrients in a plant-available form, which helps greatly in supplying crop needs, so reducing the need for fertilisers.

     These nutrients released in this way are in a biological form, which plants use more efficiently – further reducing the need for additional fertiliser. This organic matter breakdown not only contains N, P, K etc. but has a whole range of nutrients available to the growing crop. This better balance of nutrients improves physiological efficiency of the plant, leading to healthier crops requiring less rescue chemistry.

   - **Brown carbon** – this is a great fungal feed – some nutrients are released for plant use by its breakdown, but the main benefit here is the fungi in the soil.

     These fungi include the mychorizal fungi, which form symbiotic relationships with plants – drawing water and minerals from a much wider area of soil into the plant (effectively massively increasing the size of root system available to the plant).

     The fungi also produce many other substances such as growth hormones, antibiotics etc. which help the plant grow and stay healthy.

   - **Black carbon** – as the humus content of the soil increases, it hugely increases the soil's ability to hold nutrients in a plant available form (clay soil has a CEC of 30-50, humus has a CEC of 3-400). This ability to retain nutrients in the soil has a great impact on nutrient use efficiency.

Whether nutrients are added to the soil as fertiliser or released from green carbon, these plant-available nutrients can be held on the humus. This reduces leaching losses, so keeping the nutrients in the soil for plant growth. This increases nutrient use efficiency, as more is kept available for the plant – both cations and anions.

This reduction in leaching losses has a large impact on water quality, by reducing the nutrient load of water leaving farmland. This has a significant environmental impact, helping tackle an area of growing concern to legislators, resulting in red tape for farmers.

In summary, by increasing the use of green and brown carbon sources, with the resulting increase in humus, the need for applied fertilisers is reduced, efficiency of use is increased and leaching to ground water/streams reduced. This is a great step towards a sustainable farming system.

b) **The physical property** of the soil covers such items as soil structure and type (sand, loam, clay etc.) and should also include the soil's nutrient holding capacity and water holding capacity.

Over time soil carbon levels have dropped, especially on soils under continuous cropping systems. This has led to a compacting of these soils, increasing the bulk density of the soil, thus making it harder to cultivate and more prone to water logging/cracking in adverse weather conditions.

This deteriorated soil requires more horsepower to create a seedbed and has a greater weed burden – especially problematic weeds e.g. black grass.

Incorporating large amounts of bulk material as cover crops can help start to open these soils up, but the main improvement comes as the humus content increases. Humus coagulates the clay particles into soil crumbs. This helps reduce the bulk density of the soil, making it more friable and easier to work. This more friable soil is less prone to waterlogging and cracking, making it more resilient to extreme weather.

As the soil structure improves in this way, the weed pressure is greatly reduced, especially in respect to the more problematic weeds.

In summary increasing soil carbon levels improves soil structure, makes it less prone to erosion, easier to work and reduces problematic weed pressure.

Case Study

At Calwest Seeds in La Crosse, Wisconsin, the soil had become compacted and was prone to water logging. Transplanting 3,000 alfalfa plants a year, they were only achieving 50% survival.

Under guidance from MBA they decided to take a different approach to soil management. Maize was planted and fed with a balanced fertiliser. Once tasselled, the maize was rotovated in, and winter wheat planted. This was incorporated in the spring, and the cycle repeated. The following year near 100% survival of the transplants was achieved, the water logging was no longer an issue, and the weed pressure had virtually disappeared.

This was entirely down to the transformation of the soil, thanks to the increase in soil organic matter achieved through this process.

Seeing the transformation in this soil brought home the message that this really is what is missing from many soils today. The fact that this transformation was achieved in a short time space made me realise that nature is forgiving, and can be easily repaired with informed management.

c) **The biological properties** of a soil include the presence/absence of worms, bacteria, fungi and many other organisms – the relative populations and activity of which can have a huge influence on soil fertility.

Achieving benefits to the chemical and physical properties of the soil is only possible with a biologically active soil. To increase the biological activity of the soil requires the provision of food and a suitable environment.

Biology needs aerobic conditions in order to function. This may require remedial work in severely compacted soils, e.g. sub soiling. More important is the incorporation of a food supply in the top 4” of the soil.

To feed a soil to encourage biological activity requires the addition of sources of both green and brown carbon.

This material should be mixed evenly through the top 4” of soil, which is where the majority of aerobic biological activity is concentrated. This encourages the colonisation of the soil with bacteria and fungi. As this happens and the soil begins to improve, earthworm numbers increase. The earthworm is responsible for better mixing of the soils - their burrows helping to aerate the soil to deeper levels.

As the biology establishes and continues to be fed, then the production of black carbon occurs, with its benefits to the physical and chemical properties of the soil.

To keep this process progressing in a positive manner, the biology must be managed. It needs to be regularly fed with a mixture of green and brown carbon sources, along with being maintained in a suitable environment –all cultivation taking place must be considered in terms of its impacts on the soil biology, selecting less damaging methods to the biology which can achieve the result required. In terms of soil biology, the less disturbance the better.

Biodiverse grasslands provide the best environment to build a biologically active soil. These grasslands, especially when rotationally grazed, provide a good, regular food source with minimal disturbance, ideal for encouraging biological activity.

This activity improves the cycling of nutrients, and a release of nutrients from parent soil material – increasing the nutrients available for plant growth, whilst building humus to retain these nutrients in the soil profile available to plants.

In summary, in order to achieve the benefits of increasing soil carbon, it is essential to develop a biologically active soil. To achieve this goal, the soil environment has to be managed effectively. This change of mindset to managing the soil by feeding the biology and thinking of cultivation in terms of its effect on biology is essential to achieving the benefits associated with increasing soil carbon. The ultimate way to achieve this is with rotationally grazed biodiverse pastures.

d) The effect on water

As previously described, increasing soil carbon has a great effect on soil physical structure. By opening up the soil, it becomes more absorbent and porous to water.

This results in the majority of rainfall being absorbed by the soil, rather than running off the surface. This reduces soil erosion and soil wash into watercourses. The soil is not only a loss of valuable top soil, but results in increased silt and nutrient loads in water courses.

The rapid runoff of rainfall results in rivers rising and falling rapidly, with increased risk of flooding, as rainfall landing on farmland rapidly makes its way back to the sea, being of little use to the growing crop.

The more absorbent high-carbon soil massively reduces this runoff, as rainfall rapidly soaks into the soil. Large amounts of this rainfall are held by the humus in the soil profile, where it is available to alter plant growth – an 8%C soil after 4” of rain can hold 1 million litres water per hectare for subsequent crop growth.

Excess water, having had its nutrient load removed by the humus, peculates down through the soil profile into ground water and drains, resulting in the steady flow of clean water into waterways.

In summary, in a world where weather extremes are becoming more frequent, and water more of a concern to society, the importance of increasing soil carbon to retain rainfall in the landscape for the benefit of crop growth and food production cannot be overstated.

Increasing soil carbon has huge impacts on all aspects of soil management. The development of a biologically active soil is essential to achieve this goal. The benefits then realised in terms of soil structure, nutrient cycling/retention and water management are essential for the achievement of sustainable agriculture.

Case study

Meeting Abe Collins in Northern Vermont was a wake up call with regard to the importance of water management. This is the key to consistent provision of a plentiful food supply to a growing world population.

This world wide issue needs to be recognised by governments, but requires solution on a local (watershed by watershed) basis.

Building soil carbon is of huge importance in achieving water management. Abe's grazing management was achieving high animal performance, whilst at the same time producing large gains in soil carbon. His grazing management has inspired me to alter my own grazing management this year, with the intention of grazing some and trampling some – so feeding both the above- and below-ground livestock!

The Regen Ag course I attended in Sussex devoted a large section to keeping water in the landscape. Systems such as keyline ploughing - to slow water movement in valleys - and the use of dams/ponds were emphasised.

On the high limestone country of my own farm I run four hundred cattle, all dependent on either pumped spring water or 'mains' water. There is no natural water on the farm, only the evidence of past dew ponds in several places. This whole water issue has made me think about the possibility of reinstating dew ponds, so we have at least some water stored on farm.

Again we see that an international issue has to be addressed locally, as circumstances vary greatly from one place to another – but it is one which I think can no longer be ignored.

9. Methods of improving soil carbon

There are many ways to increase soil carbon, and they can be divided into:

Direct applications

Those achieved through biology

The first step is to recognise the need to improve soil carbon, then to select methods to achieve the goal while suiting the farm.

a) Additions

- **Compost**

  The use of good quality compost is an advantageous method to add not only humus to the soil, but also bacteria and fungi as well. The benefit here is that these microbes are already supplied with food when added to the soil, so have a greater chance of establishment in the soil.

  Compost, both municipal and farm sourced, is a great way to recycle green waste products in a way that has most benefit to the soil. Careful management of the composting process is required to achieve the production of a first class product, but the results are worth the effort.

  Compost can be used as a vector to add trace elements to the soil – essential for great biological activity in the soil, as well as efficient physiology of the plant and subsequent health of the animal consuming the crop.

  Some people preferred to add the traces at the start of composting so that they were present in a biological form when added to the soil; others preferred to add them at the end of the process, so they are applied to the soil as inorganic minerals. Each method achieved great results.

Case Studies

In Victoria, Australia, dairy farmer Graham Clay had switched from using fertiliser, to using compost over his pastures.

He was buying in green waste and chicken manure, to mix with on farm manures, to make a large tonnage of compost. This was then spread across his pasture. The results were the production of similar amounts of pasture as he was producing with fertiliser, and healthier looking pastures, with a resulting improvement in cow health and production. This together with a total cost equivalent to half what he was originally spending on fertiliser! *contd. overleaf*

At YLAD Living Soils, Young, NSW, Bill and Rhonda Daly, advocate the use of well made compost as the base of a biological fertility program. Application rates of as little as 1tonne/ha is sufficient to see a transformation in soils. In trials they are achieving the same or better results with compost, than replicas using fertilizers. This shows the power of a biological system.

Speaking to these two conventional farmers, who are both passionate about the use of compost, spoke volumes about the potential of a biological production system. Bill Daly's comment that it had 'put the fun back into farming', made me realise that compost is good for the farm and the soul.

- **Humates**

  Humates are derived from soft coal. This material produces a good source of carbon for addition to soils.

  The common use of humates was as an addition to the fertilisers. The addition of the C material helps adsorb the fertiliser so providing the benefits of slow release and reduced leaching when applying fertilisers.

  There is a suggestion that auxins contained in the humates are responsible for increasing crop yields (by 5-10%) - an added benefit. In addition to these benefits, the application of humates benefits the soil by increasing soil carbon – providing extra 'housing' and food source for microbes.

  In the early stages of soil improvement, this is a relatively easy to use addition, however it must be finely ground. This can cause spreading application issues to obtain the maximum benefit.

Case Study

Mid Western Bioag, Wisconsin, USA, believe in adding humates to their fertilisers to help improve utilisation through the ability of humates to adsorb the fertiliser, and so maintaining availability through the growing season. With lower leaching and less luxury uptake of the fertiliser, a healthy, quality plant is produced.

- **Biochar**

  This product has the benefit of utilising woodland waste to produce a quality soil additive.

Other green waste material can be used to produce char, but this can probably be composted more easily and cheaply than turning it into char.

Technology is developing along two lines:

i. those adding the production of electricity to the charring process and

ii. those looking to get maximum amount of carbon into the char, now attaining approximately 80% efficiency.

The first system however produces conflict between the percentage of carbon in the parent material being turned into char and that being used for energy production.

There are few results available on temperate crops but those available on tropical crops are showing significant results with regard to water and fertiliser use and efficiency plus giving yield/growth rate increases.

I am planning trials with char as I see a benefit in using woodland waste that we have available on the farm.

In summary, the use of these products to directly supply a source of carbon to the soil has positive effects on crop production plus water and fertiliser use efficiency.

Compost has the advantage of also adding microbes to the soil, in a way that gives them the best chance to establish in the soil (with a food source and home).

b) Crop sources of carbon

The use of growing crops to improve soil carbon is a popular and important aspect of building a biologically active, carbon-rich soil.

- **Cover Crops**

  These are crops planted to fill a gap in crop rotation, most commonly following an autumn harvested crop and before the following spring sown crop. There are many other chances to grow cover crops and choice of crop grown can allow small windows of opportunity to be utilised.

  Under sowing of the main crop is another way of getting a cover crop into the rotation.

  The use of cover crops helps maintain plant cover on the soil, so protecting the soil from erosion, wind blow, sun etc. The crops pick up free nutrients in the soil so minimising the risk of leaching and helping improve nutrient use efficiency.

As they grow these crops build carbon from atmospheric CO_2 that can then be incorporated into the soil.

The timing and method of incorporation is important in determining the use of the crop. All crops must be incorporated in a way that mixes them through the top few inches of soil, thereby allowing it to be decomposed aerobically by the soil biology.

The stage of crop growth determines the rate of breakdown in the soil and subsequent end result. Bacteria devour young green crops, with most of the carbon being respired and released as CO_2, giving a huge release of nutrients for subsequent plant growth.

Soil showing mixed in cover crop, taken one week after incorporation

The stage of crop growth determines the rate of breakdown in the soil and subsequent end result. Bacteria devour young green crops, with most of the carbon being respired and released as CO_2, giving a huge release of nutrients for subsequent plant growth.

Mature crops are decomposed more slowly by fungi with the majority of the carbon being built into soil humus, resulting in increased stable soil carbon.

Throughout a rotation, the incorporation of a variety of cover crops is important with appropriate following crops – nitrogen-demanding crops should follow young green cover crops, while leguminous crops should follow mature cover crops.

The incorporation of cover crops and crop residues are an important way of adding atmospheric carbon to the soil, feeding the biology, resulting in an overall building of soil carbon coupled to increased nutrient cycling to improve crop growth.

Where soils had deteriorated badly I saw examples of taking land out of production far a year and growing bulky cover crops. Maize was grown to the point of tasselling before being incorporated – adding a huge amount of biomass to the soil. This was followed by winter wheat which was incorporated in the spring before the land was returned to the cropping programme. In some instances the maize/wheat was repeated for a second year, with tremendous results to soil structure, workability, crop growth and weed pressure. This is a more extreme method of soil regeneration, but had produced great results.

In summary, the key to the use of cover crops is to capture atmospheric carbon and incorporate it into the soil with subsequent benefits to soil biology, nutrient cycling, soil carbon and structural improvements. On the whole using opportunistic gaps in the rotation can achieve these goals.

- **Grasslands**

Pasture has always been regarded as the fertility-building phase of the rotation, mainly due to the inclusion of clovers and production of nitrogen in the soil.

Well-managed pasture is the best way to build soil carbon. Pastures are far more efficient at sequestering carbon than trees.

In order to harness the power of pasture, it is important to understand how the plant sequesters carbon. This enables the selection of appropriate grasses, herbs and clovers which can be managed in a way which maximises both animal production and carbon sequestration.

Under rotational grazing the pasture is rapidly defoliated, then left to recover before being grazed again. Immediately after grazing, plants use reserves to push up the first new leaf growth. Once this leaf growth appears, it begins to photosynthesise. This small area of leaf is sufficient To fuel further leaf growth, but cannot support a large root system, so many periphery roots are shut off and allowed to die.

As the leaf area expands, the production of sugar increases (atmospheric CO_2 and soil water$\rightarrow$sugar and oxygen), which maintains further leaf growth and begins to rebuild plant reserves and expand the root system. Once the leaf system reaches a particular size, it is capable of fully fuelling plant growth – above this it produces excess sugar. This excess sugar is exuded through the roots to feed the soil.

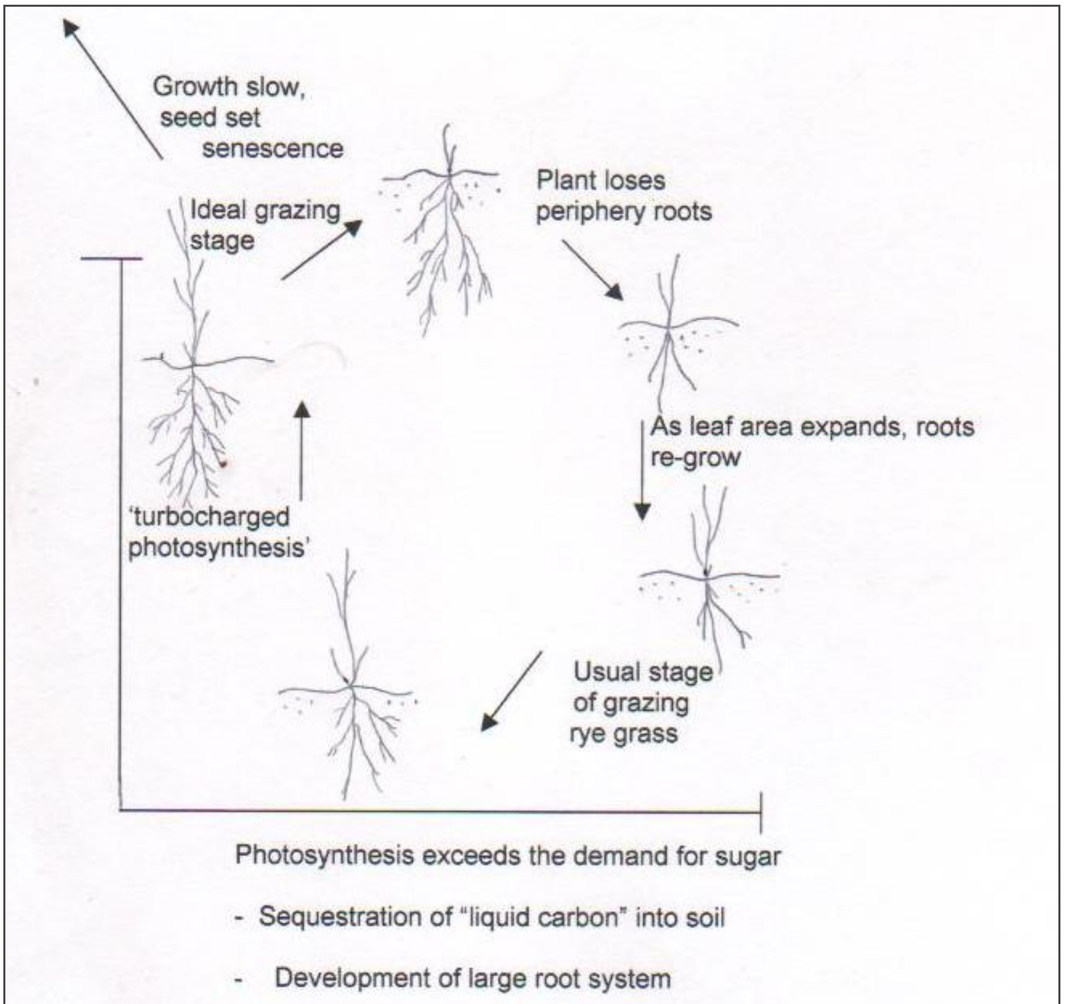

Diagram showing the ideal grazing cycle of grass

A large plant can be exuding 60-70% of its sugar production into the soil. This exudate is used by soil bacteria as an energy source, so is respired and the carbon released as CO_2. This CO_2 leaves the soil and is trapped under the sward canopy, so increasing the CO_2 concentration within the canopy. This increased CO_2 concentration results in an increased rate of photosynthesis, effectively turbocharging grass growth!

Some of it is used by soil fungi which builds carbon into humus in the soil. Ideally soils under grassland contain a 50:50 mix of bacteria and fungi, so 50% of the carbon exuded by the plants is converted to humus.

For example:

A pasture producing 10t dry matter per hectare per year above ground will produce the same below ground, a total of 20t/ha/yr dry matter.

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This growth is 40% of photosynthetic production therefore 30t/ha/yr is exuded into the soil – added to this the mass of roots dying and being digested, along with trampled leaf matter and animal dung.

Probably sequester 40t carbon/ha/yr

50% humified by fungi = 20t carbon/ha/yr humification

This produces a 1% rise in soil carbon every 3 years, as it takes 60t of carbon/ha to build 1% soil carbon.

In order to achieve these goals, the pasture must consist of plants which maintain digestibility and palatability up to the point of flowering. At this point the rate of growth begins to slow because the plant starts to focus attention on seed production. This is then the ideal stage to graze, so stimulating the growth process to start a new cycle.

To achieve this a biodiverse mixture of grasses, herbs and clovers is most successful. Such a mixture has many different types of leaf canopies which maximises the amount of sunlight utilised for photosynthesis.

Underground there are similarly many different depths and structures of root systems, so filling the soil with root material. Different root systems host different ecosystems of microbes so encouraging maximum diversity in the soil.

This diversity is important to build resilience into the system, as differing weather patterns/seasons etc. favour different plants and communities. This biodiverse pasture has the ability to produce a large amount of forage and sequester a significant amount of carbon throughout the year, in all weather conditions.

By returning land to pasture and managing it in this way, large amounts of carbon can be sequestered in the soil. This builds the fertility of the soil, which encourages the production of larger amounts of forage and the sequestration of larger amounts of carbon over time.

In summary, maximising the use of cover crops, and use of careful tillage, can maintain soil carbon levels. The use of rotationally grazed biodiverse pastures has the ability to sequester large amounts of carbon, giving substantial increases in soil carbon levels over time.

Me in pasture

Cow in pasture

10. Incorporating this into farming systems

a) The present system

Since the Second World War there has been an intensification of agriculture. This has been facilitated by improved mechanisation and the development of synthetic fertilisers and chemicals.

This has led to the production of large amounts of cheap grain and the destruction of traditional pasturelands.

The livestock industry has adapted to maximise the use of this cheap grain. This has resulted in the 'factory farm' system of pig and poultry production. Much beef production has moved from grassland to grain-based finishing systems, and dairy cows have followed the same route, with many housed all year round.

This has resulted in food production systems being highly dependent on oil. In America 1 calorie of food requires the use of 10 calories of fossil fuel energy to produce it. This cannot be sustainable in the long term.

The continuous cultivation of land to produce this cheap grain has expended soil carbon levels, such that many are now dangerously low, being 1% or less.

b) The future is biology

The 20th century has been all about chemistry. The intensive use of oil based products to boost crop production, coupled with the widespread use of antibiotics and vaccines, has resulted in the food production methods we have today.

To produce a sustainable, secure food supply with minimal environmental impact requires the realisation that the 21st century is about biology. Many people fear this, as they perceive biology to be about superbugs and nature getting ahead of the chemist but, by harnessing and managing the power of nature, it can work in our favour.

The starting point must be to return ruminants to grazing. The grazing of biodiverse pastures is the most favourable way to reactivate soil biology and begin the regeneration of worn out soils.

Under good management, pasture-based ruminants can be very efficient and productive, harvesting their own feed and spreading their own dung, therefore reducing these production systems' dependency on oil.

There are many examples of pig and poultry enterprises being efficiently managed on pasture. In many instances these livestock are grazing pastures following after the ruminants, clearing up fly larvae and benefiting from vitamins contained in ruminant dung. This vertical stacking of enterprises maximises the production of each hectare of land, encourages biodiversity and helps in the prevention of disease.

Pigs and poultry still require a substantial part of their diet to be supplied as grain. Maybe we will see a levelling of prices and of demand for pig and poultry meat versus beef and lamb, enabling the return of a better balance to the farming system.

Grain production is still going to be one of the cores of food production, both for human and animal consumption. If this is done in rotation with grazed pasture, the benefit of growing grain on ground with raised carbon levels, an active biological system and the addition of dung, will be to produce healthier, more nutrient-dense crops with less dependence on fossil fuel based inputs.

c) Closing the cycle

To close the food production**:**food consumption cycle, as much green waste, sewage sludge and food waste as possible should be composted and returned to farmland.

This is a vital link in returning to the soil nutrients which would otherwise be lost to the system. Returning nutrients in a biological form is more beneficial to a living soil than the application of inorganic fertilisers.

These recycling systems were used years ago and proven to be very effective at returning these to the soil, keeping the soil healthy and producing large crops of nutrient dense food. The prejudice of the fertiliser industry, and the use of cheap oil to produce clean and easy-to-handle products has been to the detriment of our food quality. This is something that must be readdressed, not just because of peak oil and peak phosphorous, but because of the benefit of adding carbon in the form of compost to worn out soils.

In the countries which I visited encouragement was given to composting the carcasses of dead animals and returning their nutrients to the soil – rather than sending the carcasses to the burner. The temperatures reached during composting ensure that any pathogens are killed, whilst the process itself results in little odour or leaching. I think this is a much more sustainable way of disposal.

d) Healthy Food

Ruminants fed on pasture based diets rather than grain based diets are known to produce meat and dairy products richer in Omega 3.

Grains fed animals produce a ratio of Omega 6:Omega 3 of 10-20:1, whereas grass based is 1:1.

This 1:1 ratio is ideal for human health whereas the high ratio grain fed product is now thought to be a cause of many modern ailments.

Pasture based pig and poultry are also known to be richer in Omega 3 and a healthy choice compared to their fully housed counterparts.

Growing crops on carbon rich fertile land, which tends to have a good spread of available nutrients, produces nutrient dense plants. The products of such crops can help address some of the hidden hungers afflicting society today.

It is time to recognise that food and health are synonymous, rather than blaming all health issues on bugs, society, smoking, drinking etc.

11. Environmental Impact

The move to production systems based on a high-carbon biologically-active soil has many environmental impacts.

These high carbon soils are much more efficient in terms of nutrient and water use. Nutrients are retained in the soil rather than being leached, and they clean up water leaving farmland.

The resultant soil structure results in water being absorbed and retained in the soil for later use, rather than running off. This reduces erosion and the flooding risk to land downstream. The retention of the water safeguards crop production and reduces the need for irrigation.

Incorporating large areas of biodiverse pasture on farmland has many benefits:

- It hosts a huge ecosystem of wildlife, from insects to birds/mammals
- It sequesters large tonnages of atmospheric carbon with the ability, if grown over a large enough area, to reduce atmospheric CO_2 levels
- It facilitates a livestock production system with reduced needs for machinery and stored manures, coupled to the production of a healthy product.

a) The methane issue

Methane production by ruminants and from stored manures has recently become an emotive issue.

Firstly**,** methane is a short-lived gas (10-12 years) before it is fully broken down in the atmosphere to CO_2 and H_2O. Sequestering large amounts of carbon through pasture can help to offset this issue.

Secondly**,** research is showing that increasing the oil content of the ruminant diet reduces the methane production – every 1% increase in oil content produces a 3.5% drop in methane production.

Typical ryegrass pasture contains approx. 2% oil. Good quality biodiverse pasture grazed at flowering can contain as much as 8% oil, and this extra 6% equates **to a 20% reduction in methane production by the animal.**

Thirdly**,** growing pasture on high carbon, biologically-active soil produces plants containing complete carbohydrates (pectins) and compete proteins, rather than water soluble sugars and non-protein nitrogen.

This plant material is digested and utilised more efficiently by the animal resulting in more output for the same dry matter intake – resulting in less methane per unit production.

Fourthly, keeping animals at pasture has a far lower carbon footprint, as there is much less requirement to use machinery to produce and feed conserved forage, to store manures (especially slurries known to emit methane) and to use machinery to spread this manure.

Case Studies

Demo Dairy in Camperdown, Victoria, Australia, has covered its slurry lagoon with a plastic liner. Methane emitted from the stored slurry is trapped under the plastic, and released through a flame, so ensuring only carbon dioxide and water is released to the atmosphere. This was done to demonstrate the volume of methane being released from the slurry store.

Future options were to capture the methane in order to utilise it as an energy source, or look at the use of additions to the store to reduce the level of emissions

Penn State University has completed a comparison between high input, fully housed dairy cows, and low input, seasonally calved, out wintered dairy cows – the conclusion was that low input cows produced more milk per unit area of land used, and had 10% lower emissions per unit of production!

This study looked at the whole system, including the need for machinery and buildings, the need for manure storage and forage conservation, and the carbon sequestration by grazing pastures. The result is a detailed greenhouse gas emissions comparison encompassing all aspects of the different systems – something I think is lacking in many carbon footprint calculations.

b) Nitrous oxide

Nitrous oxide is known to be a potent greenhouse gas, usually associated with losses from applied fertiliser nitrogen.

Ruminants fed a diet high in non-protein nitrogen are prone to bloat, and are known to produce large amounts of urea – usually excreted in the urine. This urea can produce nitrous oxide in the same way that applied fertiliser nitrogen can.

High levels of ammonia gas in the rumen are thought to be the cause of frothy bloat in the ruminant. High tannin containing legumes are known to be safe grazing. The reason for this is that the tannins bind the free ammonia in the rumen, preventing problems with bloat and reducing the animal's need to detoxify this ammonia.

The bound ammonia passes out of the animal in the dung and is slowly released from the tannin molecules over the next 20-25 years!

The biodiverse pasture contains several tannin producing species. Grazing a more mature plant grown on fertile soil contains complete proteins and little non-protein nitrogen. The combination of these two points means that animals grazing biodiverse pasture, at the correct stage of maturity, waste little energy detoxifying excess ammonia.

Not only does this result in the production of less urea by the animal, but a reduction in the production of methane, for I am convinced that these two are linked. This results in the waste of a lot of energy and nitrogen by the animal which could otherwise be utilised for production (growth/milk).

With careful pasture management the result is an animal which utilises the pasture more efficiently with lower production of greenhouse gases.

Overall the argument is heavily stacked towards well-managed ruminants grazing biodiverse pasture to produce environmentally friendly food, whilst regenerating worn out soils.

Young stock in pasture

12. Genetics

Over the last fifty years there has been great emphasis on improving animal and plant genetics. This genetic improvement has been concentrated on developing plants and animals which produce high yields on the current high input systems of agriculture.

a) Plants

The plant breeding world has concentrated on breeding varieties which produce high yields, but needing high inputs of fertiliser and rescue chemistry. These plants have the ability to survive with incomplete nutrition, providing that rescue chemistry is used to keep the symptoms of disease at bay.

When growing crops on fertile, high carbon soils, with balanced nutrition, there is a need for appropriately bred genetics. The genetics which perform under the conventional system are not necessarily the ones which will perform under fertile conditions.

In order to move balanced biological farming forward, there is a need for plant breeding to match the system. This final point is key to developing a system which can produce the yields necessary to feed the growing world population, with much lower demands on oil based inputs.

Case Study

Calwest Seeds saw a marked difference in outstanding plants when they changed their soil fertility management. A plant which was about to be disregarded, due to poor performance under conventional fertility management, became the outstanding variety under balanced, biological fertility. This variety has gone on to produce outstanding results in the field, when managed appropriately – so emphasising the need to breed suitable varieties for whatever system employed.

b) Animals

Animal breeding over the same period (the last fifty years) has concentrated on breeding animals which perform with high inputs of grain.

Pig and poultry production has been intensified, with breeding concentrating on feed use efficiency and growth rates to provide a rapid throughput of animals.

Traditionally these animals (pigs and poultry) could thrive on the range, with some supplement. When grazed with or following ruminants they can be complementary, so helping reduce parasites whilst improving output per hectare. I saw this working very effectively in the USA and such stacking of enterprises is producing high outputs per hectare. Again, a change of mindset is required to implement the system.

The breeding of suitable types of animals which can thrive on these less intensive systems needs to be developed.

Ruminants have been removed from pasture and fed intensive cereal rations to promote rapid growth and high milk yields. Breeding animals suitable for such systems has resulted in the development of larger/faster growing species. These animals can no longer thrive on a pasture based system without inputs of grain.

As the rebuilding of soils is best achieved with rotationally grazed pastures, there is a need to focus on breeding suitable genetics. To fit this purpose the focus should be on developing the traditional breeds.

In a world which needs to optimise food production per hectare of available land, it is my view that the smaller ruminant, thriving on pasture alone, is far more productive than the larger, grain dependent animals.

Case Study

In New Zealand the emphasis is on breeding a smaller dairy cow which performs well off pasture, as the way to maximise output per hectare.

In the USA the holistic grazers are developing smaller cattle capable of thriving on pasture and producing good carcasses in 20-24 months.

Each of these systems has minimal requirement for external inputs, and both are efficient users of land with little dependence on oil.

In summary: to efficiently feed a growing world population, with a backdrop of increasing oil prices, we need to emphasise the rebuilding of true soil fertility (a high carbon, biologically-active soil). In order to do this we need to breed suitable animals and plants which can thrive under such a system. The result will be a truly sustainable food production system, rather than the oil guzzling system currently being practised.

13. Conclusions and Recommendations

- **Soil is not just a narrow NPK chemical test, or something to stand cows on. Fertility is about building a carbon rich, biologically active soil.**

    - **Recommendation** : Farmers need to understand the requirement for a broader, more balanced approach to crop nutrition. They also need to recognise that both UK and worldwide soils now have very low levels of soil carbon and need to be regenerated, not just sustained, in order to safeguard our food supply.

- **Carbon building needs to be included in all crop rotations.**

    - **Recommendation :** Farmers must adopt appropriate methods that can be used to help develop a carbon rich biologically active soil, from simple additions (e.g. compost) to the grazing of biodiverse pastures.

- **Grazing well managed biodiverse pastures has the potential to reduce the methane emissions of ruminants by 20%.**

    - **Recommendation :** Livestock producers should adopt rotational grazing of biodiverse pastures.

- **Carbon rich soils are important to the efficient management and use of rainfall and nutrients.**

    - **Recommendations :** The agricultural industry must be encouraged to adopt measures to build soil carbon levels to help with water management and quality for the wider community.

- **You are what you eat**

    - **Recommendation :** By recognising that disease(of soils, plants, animals, humans) is a result of unbalanced nutrition, we can find real solutions rather than cures!

- **The 20th century was about chemistry; the 21st century is about biology**.

    - **Recommendation :** By harnessing the power of biology, farmers can build resilience into their farms, so reducing the risks associated with extreme weather conditions.

14. The journey thus far

Whilst on my travels I have met, and stayed with, many inspiring people. These people have all been passionate about what they do. They have the ability to think outside the box, and many of them are harnessing the power of biology to produce better yields than their conventional neighbours.

This has given me the confidence that the system I believe in can deliver the results.

- At home I am already growing deep rooting, biodiverse leys, grazed on a rotational basis.

- My aim now is to graze these leys at the flowering stage for as much of the year as possible – a later stage than I would normally aim for with milking cows. I intend to leave higher residuals along the way – hopefully trampled to feed the soil. Time will tell if I can achieve this and maintain milk output!

- In these early stages of soil improvement a full range of minerals needs to be supplied to soil plants and animals. I have implemented a foliar regime on all grass and cereal crops to address this issue, as I feel this can obtain the results most cost effectively.

- Having seen the results on my travels, I intend to compost our farmyard manure this year, mixed with extra straw and chipped woodland waste to get an ideal carbon: nitrogen ratio. At the rates I saw being recommended abroad, I should be able to cover most of the farm with the compost this autumn.

I am confident that building soil carbon will improve the health and productivity of the farm. By integrating the ideas above I should be able to achieve this in a shorter time period.

I thoroughly enjoyed the travelling last year, and it has been great to be able to start and put into practice on the farm some of the principles I've seen.

I feel that this is only the beginning of what the 'Nuffield experience' will do for me!

15. Acknowledgements

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