

Soil Management for Sustainable Food Production and Environmental Protection



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Churchill Fellow of 2017

WINSTON CHURCHILL MEMORIAL TRUST

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2. Abbreviations and glossary

Agro-ecological farming. Farming that relies largely or entirely on biological processes of soil fertility and pest and disease control for crop and livestock production.

BCSR. Base Cation Saturation Ratio soil analysis method. Also known as the Albrecht or Kinsey method.

CMC. Controlled Microbial Composting

Conventional farming. Farming as practiced by the majority of farms in the UK, relying on RB209 for soil nutrient management, and a primary reliance on artificial fertilisers for N, P and K supply and on agrochemicals for pest and disease control.

Humus. That stable fraction of SOM that is the result of fungal decomposition.

Mineral abbreviations:

pH	A figure expressing acidity
P	Phosphorus
K	Potassium
Mg	Magnesium
S	Sulphur
Ca	Calcium
Al	Aluminium
As	Arsenic
B	Barium
Bo	Boron

Ca	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Copper
Fe	Iron
Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
Ni	Nickel
Pb	Lead
Se	Selenium
Sr	Strontium
Zn	Zinc

Organic Farming. Farming that meets international standards for organic production and relies on biological processes, rotations and management for soil fertility, pest and disease control and animal health. Agro-chemicals are almost entirely excluded.

RB209. The Agricultural and Horticultural Development Board Nutrient Management Guide, which is the standard basis used in conventional farming for calculating fertiliser requirements in the UK.

Standard Analysis. Standard pH, P, K, Mg soil analysis method, commonly used by conventional, agro-ecological and organic farmers.

SOM. Soil Organic Matter as measured by combustion on ignition.

SRUC. Scotland's Rural College

3. About Mark Measures

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I am an independent organic agriculture consultant specialising in advice and training in farm business management, soil management, husbandry and conversion planning. Working with the Organic Research Centre I headed the Organic Advisory Service for 15 years and the Institute of Organic Training and Advice for 10 years. I provide policy advice to Government, technical advice to research and I am joint editor of the biannual “Organic Farm Management Handbook”. I am a partner in a mixed farm.

4. Executive summary

The Fellowship provided an opportunity to study new methods of soil analysis and management and to assess the potential of different farming systems and practices to deliver more sustainable food production and beneficial environmental outcomes. I was able to meet many farmers, advisers and researchers in the USA, Denmark and Switzerland and to discuss different approaches to the management of soil; that after all is the basis for plant, animal and human health and which has overwhelming consequences for the future of the earth.

A common theme was the recognition that better soil management is needed, that soil biology should play a much greater role than in the past and that improved soil analysis methods are needed to support that management. While a standard pH, P, K Mg soil analysis may be adequate in some circumstances it is insufficient for many purposes and additional analysis of trace elements, organic matter and soil biology is needed. The interpretation of the results of such analyses and consequent soil management recommendations are not well developed and in some instances has not been adequately validated by research. This is notably the case with the BCSR analysis and management, which, while it appears to have a positive effect on both the soil and its productivity is not sufficiently well researched to be able to advocate general use by farmers.

The Fellowship identified a number of farming techniques and systems which have a critically important role to play in food and farming in the future. At a practical level the importance of feeding the soil with large quantities of green manures, the role of compost and the use of lower tillage methods were identified. At a systems level three long term farm system trials demonstrate that organic farming is more effective than conventional farming at delivering the multiple outputs of food, food quality, soil enhancement, environmental protection and water quality that will be required in the era of delivering “public goods” which will be required of UK farming in the future.

The key recommendations are:

1. Soil analysis and management methods

- a. Investigate the efficacy of BCSR analysis and management with long term replicated trials and monitoring commercial farms.

- b. Investigate the efficacy of the principle soil health and biology analysis services with long term replicated trials and monitoring of commercial farms.
- c. Develop knowledge on soil biology and commercially applicable methods of soil biology management for food production and environmental protection.
- d. Encourage the Organic Research Centre to expand its research on soil management.
- e. Encourage the use of appropriate soil analysis and nutrient management by organic and agro-ecological farmers.

2. Farming systems and techniques

- a. Support the adoption of organic and agro-ecological farming systems and practices to deliver multiple “public good” objectives.
- b. Improve the adoption of current “best practice” soil management by existing commercial organic and agro-ecological farms.

5. Introduction to the project

Background: sustainable soil management

Soil is the primary source of food and the basis of all human life. The way in which soil is managed has a direct influence on food production, the use of finite resources and the environmental consequences. The *“health of soil, plant, animal and human is one and indivisible”*, was proposed by Lady Eve Balfour and is the founding principle behind organic farming.

We are currently faced with a spectrum of related problems in the UK including: static crop yields, declining soil organic matter levels, inefficient and costly fertiliser usage, unacceptable nitrate, phosphate and pesticide contamination of water courses, excessive flood water run off and soil erosion. Underlying these is the critical importance of soil management. Related issues include the potential for soil organic matter to provide a carbon sink to help address climate change, the fact that many of the resources used in food production are finite - water, oil and phosphorus being the most pressing and the on-going decline in farmland birds and insects, which are often directly or indirectly related to the soil. Soil and farm management will in the future have to address the multiple objectives of delivering “public goods”, including it's environmental and social role, as well as sustainable food production.

The management of soil generally and soil fertility in particular is a poorly developed science. The principle of supplying adequate nutrients to more than meet the particular crop's off take, as recommended by the AHDB Fertiliser Management Guide RB209, has been followed for the last 30 years, to the point that controls have had to be imposed by legislation in the form of nitrogen fertiliser and manure restrictions,

particularly in sensitive areas. Conventional on-farm fertiliser recommendations have been made without reference to soil structure, soil life, soil organic matter or the need to minimize finite resources. Organic and agro-ecological farmers have sought to address the use of finite resources and reduce pollution by use of legumes and recycling and the avoidance of synthetic fertilisers. However they operate with very limited soil analysis information on the management of soils.

There is now renewed interest amongst all farmers in soil structure, use of green manures and encouraging soil life, particularly in parts of the country where serious and growing problems are experienced.

There are new laboratory analysis services offered in the UK, including Soil Health (NRM Laboratories), Base Cation Exchange Capacity (BCSR)/Albrecht analysis (e.g. Kingshay and Glenside) and Soil Life analysis (e.g. Soilbiolab Ltd.). However there is no medium term, let alone long term monitoring of the use of such alternative analysis and associated management recommendations in the UK. Reference IOTA Soil Analysis and Management http://www.organicresearchcentre.com/manage/authincludes/article_uploads/iota/technical-leaflets/soil-analysis-and-management.pdf

To date, the long-term evidence for the use of these new analysis and management services is inconclusive.

Elsewhere in the world food production and environmental issues are just as critical, although local priorities are different. There is however greater experience of alternative soil analysis techniques and management systems.

In the UK there is an urgent need to bring such international experience, research, and farmer knowledge to the forefront in the development of improved food and farming systems.

The Fellowship provided me with the opportunity to meet a wide range of farmers, advisers and researchers in the US, Switzerland and Denmark and to attend the ACRES USA conference. I visited the US as the BCSR technique was originally developed there and it is widely used by advisers and farmers and there is ongoing research into the technique. Denmark on the other hand has relatively few advisers and farmers using the technique but it is useful to understand its commercial application under European conditions. Switzerland does not have any commercial application of BCSR analysis but it does have one of only 3 replicated research projects in the world, assessing the technique and there is a unique farming systems research trial at FiBL. The people and places that I visited was necessarily selective and while I have attempted to take account of a wide range of information and to pull together all the information available from research projects on BCSR soil analysis and management in preparing this report I have not aimed to undertake a full metanalysis of all research.

6. Aims of the Churchill Fellowship

“To be a successful farmer one must first know the nature of the soil.” - Xenophon, Oeconomicus, 400 B.C.

The aim of the Fellowship is to assess the evidence for and efficacy of different soil analysis and management methods and to review different farming systems in order to develop more sustainable food production and environment management.

The objectives of the Fellowship are the following:

1. Assessment of alternative soil analysis and management techniques.
 - a. Visit laboratories and advisers working with Albrecht Base Cation Exchange Capacity analysis, Soil Respiration analysis and Soil Life analysis.
 - b. Visit farms with experience of using such techniques.
 - c. Identify research evidence to support the techniques.
2. Understand the impact of different farming systems on production, soil nutrients and the environment.
 - a. Visit research sites and commercial farms and assess the results.

7. Findings

7.1 Soil and plant analysis techniques

“We know more about the movement of celestial bodies than about the soil underfoot.” - Leonardo Da Vinci, circa 1500’s

Photo: Soil investigation in Switzerland



Photo: Agroscope

The scope of my study is the investigation of soil analysis and management techniques. It endeavours to understand different techniques and their application and to assess whether some of the alternatives methods being used elsewhere have relevance to the UK. While I visited farmers, advisers and researchers working with conventional and organic farming systems the Fellowship focused on the experiences of organic and those agro-ecological farms that have made a fundamental change to their farming system, including a shift away from agrochemical inputs towards genuinely sustainable systems based on ecology and management techniques. The extent to which soil analysis and management based on ecology and soil biology can be applied to a conventional system, which relies largely on inputs, many of which are damaging to soil life and the environment is a moot point.

The critical need for better soil management and health is underlined by the fact that there are more than 2 billion people suffering from micronutrient deficiencies worldwide (World Health Organisation 2012), deficiency which has been compounded by the Green Revolution progressively depleting soil micronutrient pools (Narwal et al 2017 The Nexus of Soils, Plants, Animals and Human Health).

7.1.1 Soil and Plant Analysis

The use of laboratory analysis to guide soil management and the use of inputs in organic and agro-ecological farming is surprisingly limited in the UK. Some farmers do not think the currently available analysis methods and associated recommendations are appropriate for organic farming, and they may be right, others

seem to think that being organic is good enough and follow a zero external input system. This seems to miss the opportunity to ensure optimum fertility conditions for the soil organisms and the plants and to produce quality crops for animal and human health. Soil and plant analysis is perhaps essential if best use is to be made of a farm's finite resources of land and other inputs and to run a profitable business.

The choice of which soil analysis method to select is not simply a matter of comparing the reliability or cost of one method against another; different analysis services offer fundamentally different assessments of the soil and they imply a fundamentally different approach to soil management. It is probably insufficient to rely on the lab report from a standard pH, P, K, Mg analysis if you want to develop a farming system based on soil biology. However the standard analysis may still be useful if interpreted correctly.

The management of soil generally and soil fertility in particular is a poorly developed science, particularly in the UK, although it is now becoming widely recognised that soil fertility is a major limiting factor in the yields and quality of both conventional and organic farming. The need to ensure that all aspects of the soil are effectively managed, including soil biology, physical structure and mineral content, is beginning to be recognised more generally. How that is measured and what that means in practice for the farmer is less easily defined.

The principle of supplying adequate nutrients to more than meet the particular crop's off take, as recommended by the AHDB Fertiliser Management Guide RB209, has been followed for the last 30 years in the UK. Conventional farming follows these fertiliser recommendations, based on soil analysis and index levels, largely without reference to soil structure, soil life, soil organic matter or the need to minimize the use of finite resources. It is finally becoming more widely recognised that we live in a finite world and that should dictate how we use the resources available to us; this is particularly the case for oil and gas, which is used in nitrogen fertiliser manufacture and of mined phosphate. Cheap fertiliser, excess application rates and poor crop utilisation result in only 45% of applied nitrogen fertiliser being used by the crop. Government legislation has had to be introduced to control farm practices, including nitrogen fertiliser and manure restrictions, particularly in Nitrate Sensitive Areas and incentives put in place to encourage winter ground cover and the use of legumes. There are various estimates of between 100 and 200 years of rock phosphate reserves at the current inefficient rate of use, notably in the form of acidified rock phosphate (triple super phosphate) sourced from a few locations around the world, mostly in politically unstable regions.

A distinctly different approach is taken by organic and agro-ecological farmers who aim to provide optimum conditions for plant growth and health by employing specific farming systems and soil management practices. In particular they minimise the use of finite resources and reduce pollution by routine reliance on legumes, thereby totally or largely avoiding the use of artificial nitrogen fertiliser, by recycling nutrients within the farm and through the avoidance of other synthetic soluble

fertilisers which are at risk of leaching and are in some case damaging to soil life. However they operate with very limited soil analysis information to aid their soil management; a good knowledge of what nutrients are limiting and the ability to assess the level of soil biological activity remains inadequate.

Soil analysis and follow up management is essential for all types of farming in order to ensure that the soil supplies the necessary nutrients to the soil organisms and to the plant to optimise crop performance, livestock health and food quality. The fact that relatively few organic farms are undertaking soil analysis, estimated at 10% (Soil Association inspector pers. comm.) is a cause for real concern. Organic farming is not zero input farming; it aims to achieve soil, plant, animal and human nutrition through optimal use of soil inputs and management, stimulating biological activity and efficient use of soil reserves and only using those inputs that are least damaging to soil, plant and human health. It is not possible to do that without some means of assessing the soil.

The challenge is to identify the right soil analysis and management strategy to suit the particular farm and farming system. Not every farmer wants to commit the time and resources that are needed to follow some of the more detailed soil management strategies. The analytical methods needed for routine analysis will be different to those required for diagnosing soil fertility problems. The upland farmer with low financial margins may need something different from the high yielding lowland farm producing vegetables or fruit, with very high margins and demanding crop quality specifications. The needs for long term monitoring of soil health and farming system strategies may be different from that needed for short term mineral additions.

7.1.2 Standard Soil Analysis

The majority of organic, conventional and integrated or agro-ecological farmers and growers throughout Europe and the USA use a standard soil analysis, which only measures pH, phosphate, potassium and magnesium. Recently sulphur analysis has become more widely undertaken as the decline in industrial pollution reduces deposition. There are some regional differences in the extracts used but this analysis is generally only testing for soluble nutrients, those that are readily available to the plant.

The underlying principle behind the use of the standard soil analysis and management is that firstly and of over-riding importance is pH, a measure of acidity, pH is critical in order to optimise nutrient availability and support the functioning of micro-organisms. Different crops are more or less sensitive to pH, but most crops and soil organisms perform best within a range of pH 6.5 to 7. Standard analysis and associated RB209 based management aims to ensure that the major elements of P, K and Mg are maintained at a minimum or sufficient level, usually maintained by fertiliser or manure application. Nitrogen is not routinely analysed as soil N levels are relatively unstable, different sampling and storage methods are required and the

results are less easily interpreted. Nitrogen application rates are usually based on theoretical requirements and past cropping, not on soil analysis.

Conventional farming relies heavily on such analysis undertaken on a routine basis, usually annually and any deficit below a crop-specific threshold or Index is addressed through the use of soluble artificial fertilisers, with some account taken of manure use and previous cropping. However many farms are not analysing on an annual basis, in which case there are routine applications of “maintenance” levels of fertilisers used, sufficient to compensate for the nutrient off-take by the crop.

Organic farming, and increasingly “integrated” or agro-ecological farming, is based on the concept of a biologically active, living soil where nutrients are made available from soil particles to the plant via its root hairs through the action of root acids and soil organisms including earthworms, fungi, bacteria and mycorrhiza. Nitrogen is fixed by free living soil and leguminous bacteria and nutrients are recycled around the farm through careful utilisation of the farm’s manures. Any underlying nutrient deficiencies are addressed through the use of brought-in manures, green waste and mineral fertilisers, which are naturally occurring and generally non-soluble. Soluble, synthetic fertilisers are avoided because of their damaging effect on soil organisms, greater risk of pollution and the risk of luxury nutrient uptake, affecting plant quality and health.

There are evidently severe limitations to the use of standard pH, P, K, Mg soil analysis in organic and agroecological farming:

- i. The methods and interpretation have been developed for use in conventional farming where short-term nutrient availability is the primary concern and yields and nutrient offtakes are higher than expected in organic farming.
- ii. There is no research validating conventional soil Index targets for organic and agroecological farming.
- iii. There is no account taken of soil nutrient reserves, this is a particular problem for P management; the availability and dynamic movement of P between reserve, intermediate and available forms cannot be reliably assessed.
- iv. There is no consideration of total soil organic matter or of the type or quality of organic matter.
- v. There is no assessment of soil biological activity.
- vi. There is no account taken of the soil type and potential long term nutrient release.
- vii. There is no assessment of trace elements.
- viii. There is no consideration of the need to meet the nutrient needs of soil organisms.

In the UK, in an attempt to make the standard pH, P, K Mg analysis more applicable to organic farming soil specialists working at SRUC, Newcastle University and the Organic Research Centre have proposed that soil Index targets for P, K and Mg should be one Index lower for organic farming than the target for conventional. For example

soils growing organic wheat should have an Index target of 1 for P and K, compared to Index 2 in conventional farming. This reflects the lower yields that can be achieved under organic farming and associated nutrient requirements and offtakes and the expected higher level of soil biological activity and nutrient mobilisation. Optimum pH remains the same for organic as for conventional management. Reference: IOTA Research Review: Laboratory mineral soil analysis and soil mineral management in organic farming.

http://www.organicresearchcentre.com/manage/authincludes/article_uploads/iota/research-reviews/nitrogen-supply-and-management-in-organic-farming.pdf

There is currently no research validating these revised Index targets and it is disappointing to find that none of the countries visited on the Fellowship have revised or validated target indices for organic farming.

Some laboratories in the USA, Denmark and Switzerland offer additional analytical services including soil type, organic matter and trace elements, however the uptake is generally low. For example one source commented that trace element deficiencies are not a problem in Switzerland. This seems unlikely given the experience in the UK where deficiencies are quite widely found and may be affecting crop yield, animal and human health.

Soil Organic Matter (SOM) is usually measured by the Loss On Ignition analysis; it is total organic matter, it provides no indication of what fraction is living and although it includes humus it is not the same as humus. Target SOM levels will vary between 2 – 3% on light sandy soils to 3 – 4 % or more on clay soils. Increasing SOM is a very slow process and in any case it is the quality of the SOM which is probably more important to the farmer; the living component which is actively making soil nutrients more available to the plant and increasing yield. SOM is an important carbon sink but not necessarily a principle means of climate change mitigation. Reference: Appendix 1. Soil organic matter and its impact on climate change.

Soil mineral nitrogen analysis (N min) is offered as a separate service by soil analysis laboratories, complimentary to the standard analysis. Although nitrogen is often the major nutrient requirement of a plant it is the most difficult to accurately monitor in the soil due to the fact that analysis is imprecise, levels fluctuate widely according to temperature and moisture and interpretation of the analysis results needs to take full account of soil organic matter and depth. It can be useful to guide fertiliser requirements in conventional farming. It is not widely used in organic farming in any of the countries visited. However analysis in early spring does provide a reasonably good indication of the soil's potential to supply nitrogen during the following growing season. Further, it provides useful information when investigating the cause of problem areas in a field or the effects of different management techniques.

Cation Exchange Capacity (CEC) is sometimes provided with standard analysis. It provides an indication of the exchangeable cations (positively charged ions of

Calcium, Potassium, Magnesium and Sodium) that can be absorbed by the soil. It is largely dependent on the soil organic matter level and clay fraction: generally high organic matter clay soils have high CEC and fertility. It is difficult to change quickly, apart from raising the pH.

7.1.3 Comprehensive Soil Analysis

Many countries and laboratories offer a more comprehensive analysis service; based on and including the pH, P, K, Mg Standard Analysis it also includes a number of trace elements and organic matter. For example the Cornell Soil Fertility Test Package offers a service <http://css.cornell.edu/cnal-forms/CNAL-S-tests.pdf> which includes: Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sr, Zn, pH, buffer pH and organic matter. The service does not provide input recommendations. The service is quite widely used by organic and integrated farmers, including The Rodale Institute on their commercial farm and in their Farming Systems Trial. Equivalent services are available in European countries, including a less comprehensive service in the UK by NRM Analytical Services where the Standard Package is combined with the Trace Element Suite.

7.1.4 Base Cation Saturation Ratio

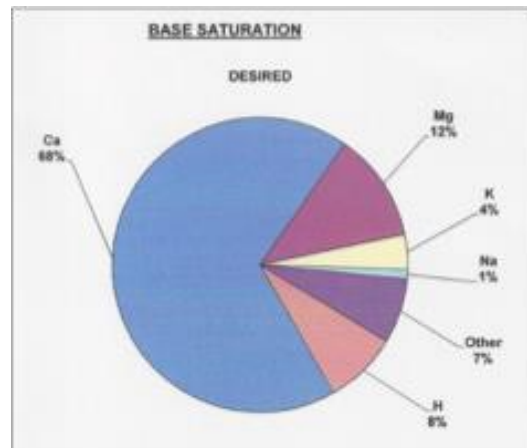
The Base Cation Saturation Ratio (BCSR) analysis and management approach is also known as the Kinsey or Albrecht system. Developed by William Albrecht at Missouri University in the 1930s, today Neil Kinsey <http://kinseyag.com> is one of the leading authorities. The substantial claims for improved soil structure, biological activity, resistance to plant diseases, food quality, animal health and crop yield are compelling. The technique is quite widely, but not universally used amongst “sustainable” and organic farmers in the USA and has a small following in Denmark, Switzerland and the UK. However scientists around the world have categorically dismissed the technique, including at Rothamsted and elsewhere; for example <http://sesl.com.au/blog/what-s-wrong-with-the-base-cation-saturation-ratio-concept> and Menzies et al A Review of the Use of the Basic Cation Saturation Ratio and the Ideal Soil. It remains a fact that there is an almost total lack of research demonstrating the efficacy of the approach. This, together with the tremendous enthusiasm for the system amongst some advisers and farmers has spurred my investigation during my Fellowship.

Gary Zimmer with cover crops at Ottercreek Farm, Wisconsin



The method places great emphasis on the development of soil biological activity and improving the availability of nutrients. Underpinning the BCSR approach is the idea that it is not just a matter of ensuring sufficient levels (or Index) of soil nutrients but that the correct ratio or balance of nutrients is essential for proper plant nutrition. Notably the proportions of the cations Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na) and Hydrogen (H) are considered important, and the following percentages are given as the optimum: 60 -80% Ca, 10 - 20% Mg and 3 - 5% K, 1% Na, 10 - 15% H. The base saturation expresses the percentage of potential CEC occupied by these cations. Figure 1.

Figure 1. The BCSR ideal soil profile



BCSR analysis is provided by a number of laboratories, the best known in the USA being Mid West Laboratories <https://www.midwestlabs.com/test/s3c-soil-testing-package-agriculture> which provides an interpretation guide <https://midwestlabs.com/resource/interpreting-soil-analysis> and the Perry Agricultural Laboratory <http://www.perryaglab.com/soil-analysis.asp>

The BCSR analysis usually includes the following, although there are differences between laboratories:

Organic Matter, available Phosphorus (in 2 or 3 extracts: Bicarbonate P, P1 Weak Bray and P2 Strong Bray), available Potassium, Magnesium, Calcium and Hydrogen, soil pH, Buffer Index, Cation Exchange Capacity, percentage base saturation of the cations, Sodium, Nitrate Nitrogen, Sulphur, Zinc, Manganese, Iron, Copper and Boron.

Additional services include soil type (sand, silt and clay fractions).

The interpretation of the BCSR analysis is complex and usually needs specialist expertise. The aim of the BCSR approach is to ensure optimum nutrient supply to crops by using management practices and fertiliser inputs that stimulate biological activity, enhance soil structure and improve the availability of soil nutrients. Apart from addressing the proportion of cations noted above, with the use of appropriate mineral fertilisers, the method places particular emphasis on calcium and magnesium, to a much greater extent than in typical conventional or organic soil management. Calcium increases flocculation, increases pore space and improves soil structure, while magnesium does the opposite and makes the soil tighter. Sufficient calcium is also considered essential for trace element availability and is particularly important for legumes. The ideal percentages are 68 – 70% calcium and 10 – 12% magnesium. If Calcium is too high add sulphur, which fixes to the calcium, thereby increasing the relative level of magnesium. If calcium is too low add lime, which may

even be needed on some alkaline soils. Continue to add magnesium until calcium:magnesium ratio is 3:1.

Much greater emphasis is placed on trace elements than is typical with both conventional and organic farming in the UK and elsewhere, not just to meet the crop's mineral needs but also to support the soil organisms needs for optimum biological activity; particular emphasis is placed on boron which is needed for calcium uptake, sugar translocation and rhizobia activity, manganese for photosynthesis and zinc for enzymes. However surprisingly selenium does not get a mention, even though it is essential for farm stock and perhaps soil organisms as well.

Adequate sulphur, calcium, zinc and particularly potassium are considered essential to cope with dry conditions and adequate potassium for winter hardiness. There is a preference for the use of sulphate fertilisers rather than chlorides, e.g. potassium sulphate is preferred over chloride due to the latter's higher salt index (the strength of the cation/anion bond) which has a negative effect on germinating seedlings, root growth and soil life; this is consistent with EU organic standards which prohibit potassium chloride, even though it is a naturally occurring mineral. Gypsum (calcium sulphate) is quite widely used as a means of increasing calcium percentage in high magnesium soils: the sulphur combines with the magnesium and consequently leaches out, thereby improving the ratio. Where needed sulphur may be applied as a sulphate of potassium, calcium or copper. Box 1. The Mulder Chart shows how soil nutrients interact with each other.

Enhancing the soil biological activity is a priority for BCSR management. This is managed in a variety of ways; by mechanical aeration or subsoiling to improve soil structure, incorporating large amounts of green manures, adding a low rate (e.g. 3 tonne/ha) of well made compost, ensuring adequate trace elements, particularly boron, zinc and calcium, providing energy to the organisms in the form of molasses, use of humates and avoiding damaging practices, such as excessive cultivations or fertilisers (chlorides) or pesticides. This emphasis on biological activity makes the approach attractive to organic and agroecological farmers and we are all agreed about the importance of mycorrhiza in extending the root system and mobilising and accessing nutrients. What is interesting is the case made for mycorrhiza in increasing the uptake of not only phosphorus but also nitrogen, potassium, calcium, sulphate, zinc and iron. <https://www.intechopen.com/books/plant-science/the-role-of-the-mycorrhizal-symbiosis-in-nutrient-uptake-of-plants-and-the-regulatory-mechanisms-und>

The use of soil fungal inoculants is a contentious issue; there are many advocates, mostly selling something, and then there are the sceptics, including me, who think that if the conditions are right and that if you feed them properly the indigenous fungi and bacteria will flourish and will in any case overwhelm introduced organisms. The type of green manure is important for soil biology and the value of diverse mixtures is emphasised; easily decomposable green manures such as legumes and brassicas should be used before small seed crops with high nutrient demands early in their

growth stage, while rye and other less easily decomposed green manures should be used before legumes such as field beans. Oats and buckwheat are particularly effective at improving nutrient availability, also seen in the P Link trial in the UK.

With a high level of biological activity soil fertility and crop health and yield will follow. If there are indications that biological activity is low, for example the soil appears dead, poorly structured despite good cultivations or smells bad then do some additional analyses. Soil mycorrhizae can be assessed in the laboratory by visual or DNA analysis. Earthworms can be counted in the field.

What I found was that many advisers and farmers in the USA enthusiastically supported BCSR analysis and management, including Neil Kinsey, Gary Zimmer www.midwesternbioag.com and Paul Deckard www.dta-cal.com but that in some cases they place much less emphasis on cation ratios than the critics claimed. In Denmark there are a few organic farmers using the method, enthusiastically supported by at least one adviser, Martin Beck www.martin-beck.dk. There is little if any commercial experience of using the method on organic or conventional farms in Switzerland however researcher Matthias Stettler at Oberacker is an enthusiastic advocate of the BCSR method, inspired by US advisers, attending their training courses and now applying the technique in Switzerland. He has established a long-term field trial, one of only two worldwide, assessing the method. Reference Appendix 2. BCSR soil analysis research evidence.

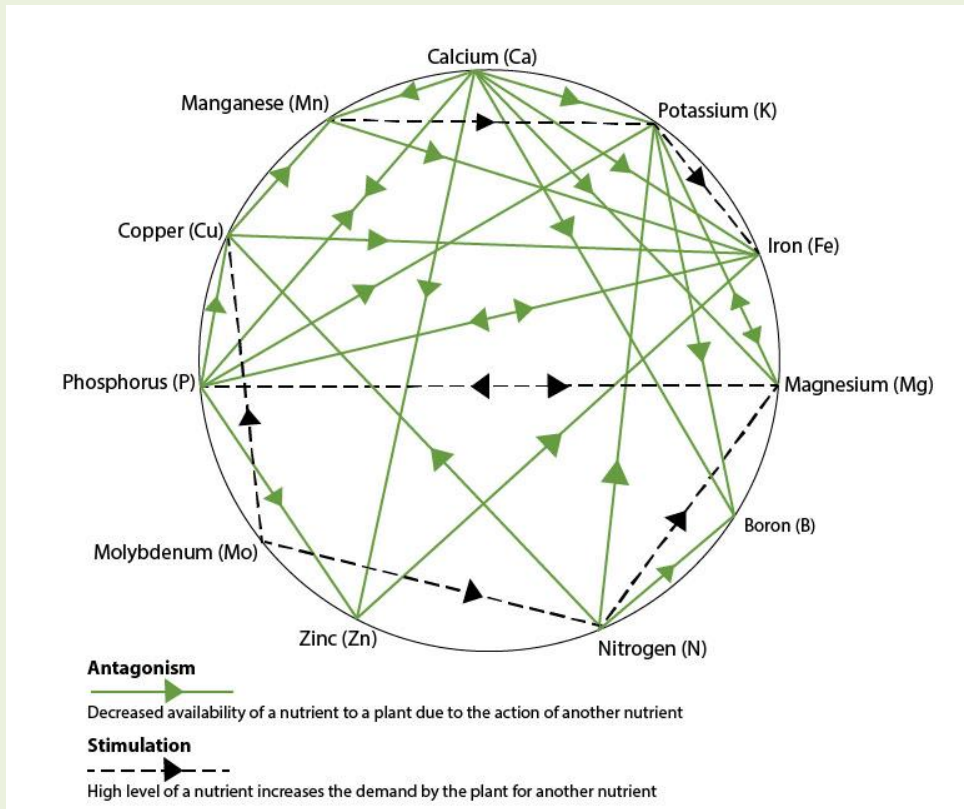
The BCSR method has very strong advocates, but there are differences in the way that individual advisers and farmers use the results. Some are strongly committed to the ratios, others have a pragmatic approach, taking the view that it is a guide and acknowledging that if, for example, you have a high calcareous soil no amount of fertiliser additions are going to achieve the ideal 68-70% calcium and 10-12% magnesium. Some are strongly committed to the use of humates, others find them variable and unreliable. Others have a clear strategy for engaging the biological processes; adding rock phosphate or gypsum to the compost heap is seen as a way of getting the minerals locked onto the carbon, the living and dead remains of the compost bacteria and fungi. Interestingly adding the minerals towards the end of the composting processes is found to be more effective than adding at the end.

Photo: Soil managed by Aaron Wise using Restora-life BCSR management



The most notable feature from a farmer's perspective is that those who follow the BCSR recommendations use a much higher range and level of fertiliser inputs on a routine basis than is typical of organic farms in the UK. Most advisers advocated regular use of humates – mined carboniferous material which is supplying trace elements and stimulating biological activity, as well as use of other fertilisers, either as a one off or annually. These include Chilean nitrate, micro-ground rock dusts, potassium sulphate, monoammonium phosphate (MAP), potassium magnesium sulphate (K Mag), rock phosphate, calcium sulphate (Gypsum), poultry manure and cane molasses, which is used to supply carbon – stimulating soil biological activity and increasing nutrient availability. All these are permitted under NOP organic standards in the USA, though not necessarily in the EU. This is in stark contrast to most organic farms in the UK, many of whom don't even analyse their soils and take a very low cost, low input approach to their organic farming. Those that are more proactive, with a very few exceptions, are not using the range and level of inputs advocated by the BCSR method.

Box 1. Mulder's Chart: Mulder's chart shows how nutrients in the soil can influence the availability and uptake of each other.



Antagonism : High levels of a particular nutrient in the soil can interfere with the availability and uptake by the plant of other nutrients. Those nutrients which interfere with one another are said to be antagonistic.

For example, high nitrogen levels can reduce the availability of boron, potash and copper; high phosphate levels can influence the uptake of iron, calcium potash, copper and zinc; high potash levels can reduce the availability of magnesium. Thus, unless care is taken to ensure an adequate **balanced supply of all the nutrients** – by the use of analysis – the application of ever higher levels of nitrogen, phosphorus and potassium in compound fertilisers can induce plant deficiencies of other essential nutrients.

Stimulation : Stimulation occurs when the high level of a particular nutrient increases the demand by the plant for another nutrient.

Increased nitrogen levels create a demand for more magnesium. If more potassium is used – more manganese is required and so on. Although the cause of stimulation is different from that of antagonism, the result is the same – induced deficiencies of the crop if not supplied with a balanced diet. High levels of molybdenum in the soil and in the herbage reduce an animal's ability to absorb copper into the blood stream, and ruminant animals grazing these areas have to be fed or injected with copper to supplement their diet (see Mo/Cu dotted line).

“Upon this handful of soil our survival depends”- Sanskrit text, 1500 BC

7.1.5 Should you use the BCSR method?

The questions remain: is the interpretation of BCSR analysis reliable and does it improve yields and improve the efficiency of use of finite resources? Is this range and level of inputs really necessary? Is it cost effective? Is it really organic farming?

As in the UK, where Rothamsted soil scientists have roundly dismissed the science behind it, BCSR analysis is not generally supported by the establishment soil scientists in the USA. Most of the criticism stems from the emphasis put on cation ratios i.e. the ratio between Calcium, Potassium and Magnesium. See the following critique from the Sustainable Agriculture Research Association:

<https://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd-Edition/Text-Version/Getting-the-Most-From-Routine-Soil-Tests/The-Basic-Cation-Saturation-Ratio-System>

Some advisers in the USA and in the UK have further evolved the BCSR method, putting greater emphasis on ensuring that minimum nutrient levels are met and playing down the importance of the ratios or percentage of cations. This seems to placate the critics, however the question remains: is the method more effective in terms of resource use, crop yield, health and profitability.

Tim Reinbott of Minnesota University has finally started to challenge the critics with some very useful field scale research and to try to answer the question whether BCSR analysis and management works, or not. Provisional results from this and two other medium term trials show that the BCSR analysis and management does indeed have a positive effect on soil fertility and crop production. Reference Appendix 2. BCSR soil analysis research evidence.

The BCSR method shows the following trends in one or more of the three trials reviewed:

1. A positive effect on crop yield in one or more crops (all 3 trials)
2. A positive effect on soil organisms (2)
3. The need for all elements of the BCSR method to be addressed (1)
4. An increase in crop quality (1)
5. An improvement in soil structure (1)
6. A small increase in margin over fertiliser (1)
7. Greater potential in min till systems (1)

What I found was that many advisers and farmers enthusiastically support the BCSR analysis, some putting more or less emphasis on the ratios, but in any case the approach does at least ensure that adequate nutrients are supplied to the crop. Given the level of inputs used it is likely that crop yields will be higher than for a farmer taking a low input approach, particularly in the medium to long term. Those farms which do not use inputs can expect to deplete some nutrients, ultimately to a point of stable equilibrium, which depending on the soil type may be at a level which restricts

soil biology, crop production and the quality of the food produced. For example some UK soils have inherently low phosphate reserves, in which case improved mycorrhizal activity will make best use of what phosphate there is, but that may be inadequate to maintain yields at the optimum in the long term without the use of rock phosphate.

It is also possible that the real value of the BCSR analysis may lie in the fact that a wide range of elements is analysed, including trace elements, there is some assessment of the reserves as well as available forms of phosphate, the fact that organic matter is included and great emphasis is placed on the role of soil biological activity.

The question over the economic value of the BCSR method is an important one. The fact that there are many long-term profitable farms using the method in the USA suggests that it is cost effective for both dairy and mixed arable farms. In both situations the farms are running enterprises with potentially high returns that can justify the cost of the inputs, however this may not be the case with lower profitability livestock and upland farms. If the cost of producing the forage is greater than the potential returns then the method will of course result in a financial loss. And I heard of at least one report of just that, recommendations to apply fertilisers were followed to the letter and the farm lost money as a result. The one trial in the UK, which monitored the results of the BCSR method in an integrated farming system, showed a small response in terms of reduced cost and increased margins per hectare, but the increase was too small to justify the greater management and input time involved.

7.1.6 Soil Health Analysis

“Essentially, all life depends upon the soil ... There can be no life without soil and no soil without life; they have evolved together.” - Charles E. Kellogg, [USDA Yearbook of Agriculture, 1938](#)

There is now widespread interest in "soil health" and its assessment and management amongst farmers, advisers and academics. This is particularly driven by the recognition that conventional arable farming has resulted in serious soil structure and fertility problems; soil health analysis is being used by some organic farmers as well as on conventional and agroecological farms.

“Soil Health” is described by the United States Department of Agriculture as “Soil health, also referred to as soil quality, is defined as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans. This definition speaks to the importance of managing soils so they are sustainable for future generations. To do this, we need to remember that soil contains living

organisms that when provided the basic necessities of life - food, shelter, and water - perform functions required to produce food and fibre."

It goes on to state "Only "living" things can have health, so viewing soil as a living ecosystem reflects a fundamental shift in the way we care for our nation's soils. Soil isn't an inert growing medium, but rather is teeming with billions of bacteria, fungi, and other microbes that are the foundation of an elegant symbiotic ecosystem. Soil is an ecosystem that can be managed to provide nutrients for plant growth, absorb and hold rainwater for use during dryer periods, filter and buffer potential pollutants from leaving our fields, serve as a firm foundation for agricultural activities, and provide habitat for soil microbes to flourish and diversify to keep the ecosystem running smoothly."

This is indeed a long way from the conventional practice of ensuring sufficient macronutrients for crop growth by following the recommendations of RB209, principally by applying enough soluble N, P and K fertilisers. It necessarily requires attention to soil biology and physical aspects as well as chemical and emphasises the importance of plant and animal diversity, keeping the soil covered and feeding the soil organisms. It requires a recognition that the principle means by which soil nutrients get into the plant is through biological processes and that the health of the soil directly influences the health of plants growing in it and the health of the animals and humans eating the products of the soil. Appendix 3. Soil Health and Appendix 6. The Nexus of Soils, Plants, Animals and Human Health.

The extent to which this is realised in practice is central to the Fellowship. Does a healthy soil require reliance on rhizobial fixation on legumes rather than artificial nitrogen fertiliser, can a healthy soil tolerate the use of agrochemicals and fertilisers known to damage biological activity or lock up minerals, should the nutrient content and quality of food leaving farms be monitored, what is the role of nutrient recycling, how can biological activity be enhanced and relied on to support profitable farm businesses?

Protocols for assessing soil health have been developed, such as that available from the USDA

https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051259.pdf

It is of course also essential that the farmer makes regular and thorough assessment of the soil in the field; physical condition, earthworm counts, smell, crop and stock health. Laboratory analysis compliments farm assessment, but cannot substitute for it. As one farmer said "*soil management as much an art as a science*".

The analysis service varies between labs; it generally includes pH, P, K, Mg and organic matter and some means of assessing soil biological activity. This is measured either by the Solvita carbon dioxide burst (respiration) test, or in some cases the

Active Carbon test using potassium permanganate and soil protein test. Some laboratories include trace element analysis and soil type.

A Soil Health service is offered by Cornell University: Comprehensive Assessment of Soil Health <https://soilhealth.cals.cornell.edu/testing-services/comprehensive-soil-health-assessment>.

Robert Schindelbeck at Cornell University has for some time focused on soil health as a means of addressing major soil fertility, erosion and leaching problems in the North East of USA. They have developed the Comprehensive Assessment of Soil Health (CASH) protocol which encompasses biological, physical and chemical measurements, rigorously selecting appropriate indicators and evaluating the indicators and setting targets by drawing on wide-ranging, replicated research trials.

The CASH service includes:

- | | |
|------------|--|
| Physical: | Available Water Capacity
Surface Hardness
Subsurface Hardness
Aggregate Stability |
| Biological | Organic Matter
Soil Protein – indicative of potential N supply
Soil Respiration
Active Carbon |
| Chemical | pH, P, K, Mg
Trace elements: Mg, Fe, Mn, and Zn |

Figure 2. CASH test results

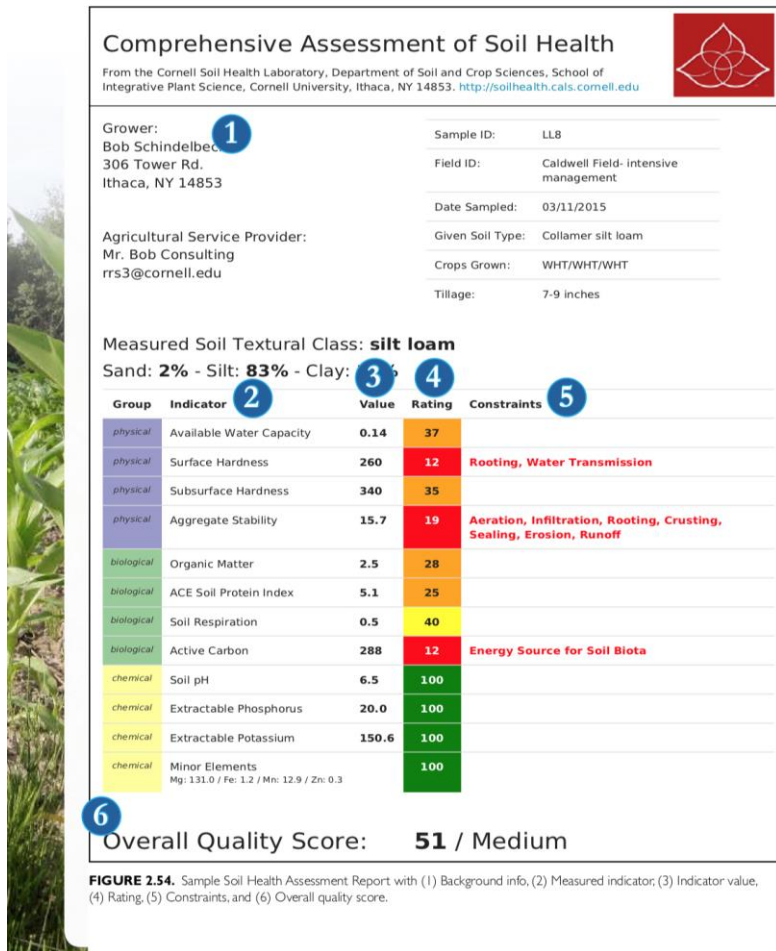


FIGURE 2.54. Sample Soil Health Assessment Report with (1) Background info, (2) Measured indicator, (3) Indicator value, (4) Rating, (5) Constraints, and (6) Overall quality score.

The Soil Health CASH test, see Figure 2. CASH test results, is aimed at taking a long-term view of the soil, it is not intended to be used for short-term fertiliser application, although it could be used for that if wished as the chemical analysis uses standard extraction methods. An excellent manual backs it up <https://soilhealth.cals.cornell.edu/training-manual> which explains in detail how each indicator effects soil functioning and health and what can be done to improve it. There are additional analyses that can be undertaken including salinity, which could be useful for some situations.

The **Haney Soil Health** test is also a fairly recently developed soil health analysis service which includes the Solvita respiration/carbon dioxide burst providing an indication of microbial activity, available nitrogen, phosphorus and potassium, water extractable carbon, C:N ratio and aluminium, iron, calcium, sodium and magnesium. It is offered by a number of laboratories in the USA, including the Ward Laboratories <https://www.wardlab.com/haney-info.php>. A soil health score is calculated from the Solvita respiration results and analysis of water extractable organic carbon and nitrogen. The test has received some US Department of Agriculture support however it has come under criticism for the lack of consistent results, lack of active carbon and

protein analysis and the inadequate proofing of the concept and recommendations <http://agronomypro.com/Haney-soil-test.pdf>.

7.1.7 Soil Health summary

Are they validated? The Cornell Soil Health test has used well documented and validated individual tests that make up the service. An Overall Quality Score is provided, however the caveat to that is that the results of individual tests are more important and my view is that the overall score is an unreliable indicator of overall soil health as it is difficult, if not impossible, to reliably weight the individual components in a meaningful way.

Soil health analysis can be useful to monitor long term changes resulting from farm management and provides information that can be acted on by the farmer; this might include changing cultivation practices or crop rotation, use of cover crops or medium term planning for the use of soil amendments, including fertilisers and manures.

However it needs to be recognised that the scope of the various soil health analysis is limited, particularly in some of the commercial services offered and that there is no attempt to look beyond the field, to see the impact of the soil on the health of the plants, animals and people.

7.1.8 Soil Biology analysis

It is of course apparent to everyone working with organic and biological systems that analysis of the soil chemical content, or minerals, is only half the story, probably not even that. Our reliance on making nutrients more available through biological solubilisation and mineralisation, the importance of mycorrhiza for accessing nutrients and the role of free living and rhizobial nitrogen fixing bacteria all mean that soil biological activity is central. And that is apart from the role of larger creatures including earthworms and insects in soil processing.

However we do not know what are the optimum numbers or proportions of the various soil organisms for agricultural production. More earthworms seem to be a good thing, thriving mycorrhiza will mobilise P, and there are many more good earthworms than bad ones. It has been postulated that ensuring that good bacteria occupy sites on root hairs will prevent bad bacteria from gaining a foothold. We know that many fungi and bacteria need carbon as an energy source and that incorporating residues with a C:N ration of about 24:1 avoids both nitrogen lock up and nitrogen surplus. But it is all rather hit and miss.

The fact that we have no reliable means of assessing biological activity, let alone know how to manage it predictably has always been a fundamental gap in our ability to manage soils more effectively. The Solvita respiration test, protein analysis and the Potassium Permanganate active carbon test have been developed to provide some

indication of soil biological activity as a basis for monitoring the soil biological activity and guiding management.

In the past I have visited laboratories in the USA and the UK providing a service that visually counts fungi and bacteria populations. While this information may be useful to provide an indication of say, mycorrhizal populations there was inadequate information to make farm management decisions on the basis of the relative population numbers provided by the laboratory. The rapid fluctuations in populations of fungi and bacteria and the high costs involved in analysis have meant that these analyses have limited use in commercial farming.

Mycorrhizae population analysis is offered by some laboratories including PlantWorks Ltd. In the UK <http://www.rootgrow.co.uk/landing> . UK Soil Farmer of Year, Simon Cowell uses mycorrhizae analysis repeatedly throughout the season as mycorrhizae play such an import role in soil mineral and water transfer and disease protection and provide a useful indictor of overall soil biological activity. The analysis is considerably cheaper than undertaking a full soil biology analysis and appears to be useful.

The science has moved on and now there are reliable gene screening methods that allow rapid analysis of the whole soil genome.

The service developed by Poornima Parameswaran at Trace Genomics <https://www.tracegenomics.com/#/products> in San Francisco is an example of a new service which might have great potential in future. By using DNA analysis it is possible to assess the soil microbial species, populations and level of activity, providing the following principle information:

1. Identification of **plant pathogens** such as nematodes and fusarium which can be used to decide whether to grow a certain crop or whether remedial action is needed, such as use of bio-fumigants.
2. **Soil biological metrics**, which can be used to identify the cause of poor areas in a field and to guide future management. It includes bacterial and fungal diversity, fungal to bacterial ratio, aerobicity, plant growth promoting bacteria, arbuscular mycorrhiza, and the root disease suppressiveness of the soil. Further detailed analysis provides information on the ability of microbial action to improve nutrient availability; nitrogen, phosphorus, and potassium and the availability of labile carbon, which serves as both food for the microbes cycling nutrients, and a source of the nutrients.

This service does not include soil mineral analysis and is seen as complimentary to the soil mineral analysis discussed above.

The main constraint to all of the methods of analysing soil biological activity is the fact that soil organisms respond rapidly to soil temperature, moisture and substrate, so fungal or bacterial populations and relative numbers one day may be quite

different a few days later. There is potential to overcome the limitations of analysis based on soil respiration and organism counting, by the use of the active carbon and soil protein tests that indicate the potential for biological activity rather than actual current populations or level of activity.

7.1.9 Plant Tissue analysis

The value of plant tissue analysis is well established; it tells you what actually gets into the plant. Although in my experience rarely used by organic farmers in the UK, it is an invaluable diagnostic tool helping to understand why a plant is not performing well despite good soil analysis results. It can help verify plant deficiency symptoms, identify if there is a nutrient lock up and assess the nutrient value of forage for livestock. There are many laboratories offering the service, in the UK, such as NRM who offer a Plant Foliar analysis that includes N, P, K, Ca, Mg, Na, S, Mn, Cu, Zn, Fe, B, Mo and an Animal Health analysis, which also includes selenium. The analysis is undertaken on the leaf material supplied at the right stage of growth, the whole leaf is dried and ground for analysis. Although there are limitations, the required levels are not precise and nutrient needs may be transient, the analysis is however reliable and the interpretation of the results backed up with a great deal of research which indicates general deficiency and sufficiency levels.

Recently Sap Analysis is beginning to be more widely used. As its name implies it is the leaf sap that is analysed, in the laboratory processing the plant is not dried, as it is with tissue analysis, the advantage being that it assesses the nutrients that are available to the plant at that time, whereas tissue analysis includes the many nutrients that are complexed in the cell walls and are therefore not necessarily available to the growing parts of the plant. It is particularly useful as an aid to proactive fertiliser and foliar spray use as it tells what is about to happen.
www.researchgate.net/profile/Anoop...sap_analysis.../ACRES.pdf

The use of the technique has been enthusiastically advocated by John Kempf, a consultant working with organic and integrated vegetable and fruit growers in the USA

www.advancingecoag.com/plant-sap-analysis . He makes use of the fact that Sap Analysis allows him to identify deficiencies 2 – 4 weeks before deficiency symptoms are seen and before tissue analysis could pick up the problem. The emphasis of his work is on improved crop quality, pest and disease resistance and nutritional quality.
https://docs.wixstatic.com/ugd/237db0_c5e14f9baf0d469d9bc8cc937cffca18.pdf

Nova Crop Control based in The Netherlands specializes in Sap Analysis services
<http://www.novacropcontrol.nl/en/method> .

The technique of Sap Analysis appears to be quite sound, but as with all analysis it is only as good as the interpretation, some critics make the point that this has not been effectively standardized and therefore is not something that a lab technician can do; that means getting experienced in-field advice, backed up with the necessary soil analysis is essential and this can be prohibitively expensive. However if higher crop quality and disease prevention can be achieved by early intervention following Sap Analysis this could be very worthwhile for high value fruit and vegetable crops.

7.1.10 Brix analysis

Brix analysis assesses the soluble solids in the plant sap and provides an indication of the sugars present. It is widely used by fruit and vegetable growers as it not only gives an indication of sweetness but also can help in variety selection, harvest schedule and may help inform other aspects of crop production including irrigation, fertility and post harvest management. Brix analysis may also indicate general crop health, although there is little scientific evidence to confirm this.

It is readily analysed by farmers using a hand held refractometer.

Brix analysis is also use by pasture farmers to assess the sugar content of forage. Higher sugar forages provide an energy source for rumen microbes and improve the digestion efficiency of proteins.

[https://www.agrireseau.net/bovinsboucherie/documents/Brix_Measurements\[1\].pdf](https://www.agrireseau.net/bovinsboucherie/documents/Brix_Measurements[1].pdf) If sugars are low this can be addressed in the short term by utilising forage at a more mature stage, changing the time of day of cutting forage, by adding molasses to silage and in the long term by using high sugar grass varieties and species.

7.1.11 Timing of soil analysis

Some have argued that the results of soil analysis change throughout the year and that consequently sampling should always be done at the same time each year. That has not been my experience and Neil Kinsey backs this; his view is that there are only certain elements that change significantly during the year. One is sulphur, the available levels are affected by biological activity and sulphur is readily leached, and the other is nitrogen. Hence sampling at the same time of year is only really needed if these two elements are an important aspect of the analysis.

7.1.12 Summary: the use of soil analysis

“We know more about the movement of celestial bodies than about the soil underfoot.” - Leonardo Da Vinci, circa 1500

Soil and plant analysis is a useful tool to help in the management of organic and agro-ecological farming, regardless of whether that is an entirely closed system with no external inputs or whether it is one that relies more heavily on the use of mineral

fertilisers, imported manures or inoculants. It is probably essential for fine-tuning the system and maximising the soils' biological activity, crop yield and crop, animal and human health and minimising use of finite resources and pollution. Analysis does not provide precise recommendations for a biological system but it does identify significant characteristics of the soil or plant and provides guidance on the management. It can be particularly useful in identifying long-term changes or trends, which indicates if the farm system and management is working and it can be useful to identify problem areas in a field.

The following guidance comes from the experience of talking to many farmers, advisers and scientists over the last 6 months. They would not of course all agree with each other so this is my personal assessment.

1. **The management system.** The individual farmer should choose an analysis and soil management system that suits their situation. A high management, high external input approach is unlikely to be cost effective in an upland pasture situation with low returns from beef and sheep enterprises, but it might be appropriate for a lowland vegetable cropping farm where profitability is closely linked to crop yield and quality.
2. **Analyse to meet needs.** Analysis should be planned according to the purpose and need:
 - a. **Initial analysis** of each field to provide basic information on soil type, organic matter levels and trace element deficiencies
 - b. **Routine analysis**, prior to all high value crops and at least once a rotation or every 4 or 5 years
 - c. **Long term monitoring** of the same 2 or 3 fields every year to provide an indication of whether the system is working, and hopefully improving.
 - d. **Investigating problems.** Detailed monitoring and sub sampling to identify constraints in problem areas.
3. **Initial analysis.** Initial analysis of a new field needs a comprehensive analysis, which should include pH, P, K, Mg, S plus organic matter and trace elements Na, Fe, Cu, Zn, and Bo. In addition Co, I and Se should be included if these are known to be low in the region.
4. **Routine analysis.** The Routine analysis needs can be met by a Standard Analysis including pH, P, K and Mg, plus S prior to cropping. Interpretation and fertiliser recommendations must take account of the lower offtakes and improved nutrient availability under a biological system.
5. **Long term monitoring.** Long term monitoring of 2 or 3 fields every year could use one of a number of methods.
 - a. Standard analysis plus S is the minimum. Include Active Carbon if possible, organic matter if not.

- b. Comprehensive Analysis would provide useful information on trace elements, which would be important where they may be deficient.
 - c. Soil Health Analysis would provide much more information on the overall health of the soil, particularly if it included trace elements, protein and Active Carbon, as with the Cornell Soil Health Analysis.
6. **Investigating problem fields or areas:** Additional trace element, N min and plant tissue analysis is very useful to help resolve problems and identify constraints to yield or crop quality. Higher value fruit and vegetable crops may warrant frequent analysis and proactive management. Sap analysis appears to offer good potential for monitoring actual plant nutrient levels and responding quickly to any deficiencies. Weekly soil N min analysis may be useful in maintaining growth and quality in vegetable crops.

7.1.13 BCSR analysis

Some farmers may want to take a more proactive and detailed management approach with potentially greater use of inputs, in which case the BCSR analysis may be useful; based on existing research and farmer experience it does have some potential. It should be recognised that the claimed benefits in terms of yield, disease resistance and health have not been validated by research. The cost involved is probably only worthwhile if additional professional advice is used for the interpretation and if the intention is to follow through and apply the recommended mineral and biological inputs. In the UK it has the advantage that phosphate reserves and Active Carbon are analysed, the latter providing a reliable indication of biological activity potential.

7.1.14 Trace Element and N analysis

Additional trace element, N min and plant tissue analysis can be very useful to help resolve problems and identify constraints to yield or crop quality. Higher value fruit and vegetable crops may warrant frequent, even monthly analysis and proactive management.

Sap analysis appears to offer good potential for monitoring actual plant nutrient levels and responding quickly to any deficiencies. Weekly soil N min analysis may be useful in maintaining growth and quality in vegetable crops.

7.1.15 Biological activity analysis

Soil biology analysis is particularly useful for identifying soil pests and there may be potential to fine tune soil biology with a detailed knowledge of different soil populations of fungi and bacteria, however the cost is high and I did not come across research validating the management recommendation on my Fellowship. Mycorrhizae analysis may provide a useful and cost effective means of monitoring

biological activity, particularly if the individual farmer develops an understanding of how it can be used to inform soil management.

Soil analysis is not the precise tool that the numbers might suggest, but it can provide a good indication of the level of minerals in the soil, the level of biology activity and physical characteristics. It provides an essential tool in deciding the correct soil management, including the use of mineral and organic inputs to make best use of the available resources to improve crop yield, quality and disease resistance with minimal environmental impact. Soil analysis can be usefully combined with soil nitrogen analysis and with Plant Tissue or Sap Analysis, which may provide a more accurate indication of what nutrients are being accessed and utilised by the plant and whether there are any deficiencies. Interpretation of analysis should always be supported by field observation: dig pits, count earthworms, look at water percolation and assess physical structure and plant and animal health.

7.2 Farming systems and techniques for food and the environment

“Whoever could make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country than the whole race of politicians put together.” - Jonathan Swift, Gulliver’s Travels, 1726

It was not my intention to assess the shortcomings of conventional soil management on my Fellowship; the problems of profligate use of finite resources, pollution, wildlife and environmental damage, loss of soil organic matter and poor food quality are all well documented. My aim was to explore ideas and practices of soil management and farming systems which deliver quality food with minimum negative impact on the environment, particularly those developing biological systems in which soil life is fundamental to fertility building, nitrogen fixation, nutrient mobilisation, recycling, soil structure and crop and human health. Organic and Biodynamic are the most clearly defined and well developed agro-ecological systems of farming, while no-till or direct drilling, use of fertility building crops and return of human waste are all relevant practises which I came across on my Fellowship and will be considered here.

7.2.1 Organic Farming

The Rodale Institute in Pennsylvania <https://rodaleinstitute.org> is best known for its replicated Farming Systems Trial running for the last 35 years comparing organic management with conventional. There are a number of treatments including 1. Organic arable with manure, 2. Organic stockless arable system, 3. Conventional arable.

The results have been written up and there are some publications although no published papers within the last 10 years. A report on the results is available <http://rodaleinstitute.org/our-work/farming-systems-trial>

Dr. Kris Nichols at the Rodale Farming Systems Trial, Pennsylvania



Farming System Trial key results:

- Organic farming yields match conventional yields.
- Organic outperforms conventional in years of drought.
- Organic farming systems build rather than deplete soil organic matter.
- Organic farming uses 45% less energy and is more efficient.
- Conventional system produced 40% more greenhouse gases.
- Organic farming systems are more profitable than conventional.

Organic stocked and organic stockless systems outperform conventional in terms of soil structure, biological activity, organic matter levels, water percolation and drought resistance. Intriguingly organic yields are comparable with conventional; the experience elsewhere is that organic cereal yields are 50 – 70% of conventional. This appears to be partly due to low N use in the conventional and relatively high organic yields on these good soils.

Soil organic matter levels increased from 3.5 to 4.2% over the first 20 years of the trial, thereafter stabilising. Rodale think that levels can be further increased by further changes in management, though I rather doubt this as it is generally not possible to continually increase levels, particularly in organic cropping systems where cultivations, carbon breakdown and cycling is a part of the fertility system. The commercial potential for direct-drilled organic crops has still to be demonstrated.

The DOK Trial was established in 1978 by the Research Institute of Organic

Agriculture (FiBL), Switzerland to compare organic and conventional farming systems. It is a replicated plot trial with four treatments and a control: 1. Organic, 2. Biodynamic, 3. Conventional with manure and 4. Conventional with only mineral fertilisers. The conventional systems have some restrictions on the use of inputs and are more akin to UK “integrated farming” systems.

The trial has been comprehensively reported and the results widely published as peer reviewed papers, as such it is the longest running, most comprehensive and authoritative research project investigating the differences between the outcome of organic and conventional farming systems.

Photo The DOK trial, Switzerland



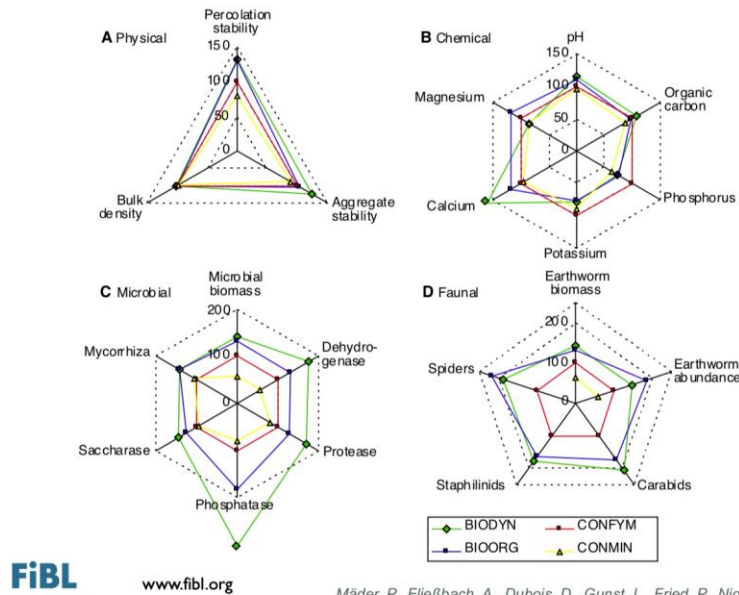
DOK Trial key results

1. Crop yields in the organic systems of the DOK trial are 15-25 % lower compared to conventional.
2. Soil quality (structure and biological activity) is higher in the farming systems with the use of manures.
3. The biodynamic system showed the highest soil quality.
4. The microbial communities in soils of the biodynamic and organic farming systems are different from the ones of conventional farming.
5. Nitrous oxide emissions are lower in the biodynamic system as compared to conventional.

The results are more fully reported here [https://okologi-kongres.dk/wp-content/uploads/2017/12/G2-Fliessbach DOK Kolding2017.pdf](https://okologi-kongres.dk/wp-content/uploads/2017/12/G2-Fliessbach_DOK_Kolding2017.pdf) It is particularly interesting to note that crop yield and soil aggregate stability is related to the soil microbial biomass and that in virtually all respects the organic and the biodynamic treatments resulted in improved soil properties, Figure 3.

Figure 3. Soil properties

Overview on soil properties Överblick över jordegenskaber



Mäder, P., Fließbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U., 2002. Soil fertility and biodiversity in organic farming. *Science* 296, 1694-1697.

Fließbach A. (2017)

The Aarhus University Foulum research centre manages a farm systems trial, in association with other sites in Denmark. A large plot, arable rotation trial, the results over 20 years are now showing some useful results, which have been published in peer reviewed journals.

Foulum farming systems trial key results

1. Soil phosphate levels after an initial drop in the organic plots have stabilised at levels above the minimum required, probably partly due to the improved mobilisation of reserves under organic management.
2. Soil organic matter levels in some organic rotations have been maintained, while others have shown a slight decline. Conventional organic matter levels have declined slightly in comparison on some sites
3. Weeds have been effectively controlled under organic management
4. Slurry is more effective if it is injected and there is no indication that this is negatively affecting soil life
5. Their opinion is that a conventional, standard pH, P, K, Mg soil analysis is adequate
6. Organic rotations with 2 years of green manure are at great risk of nitrogen leaching
7. Over winter cover crops definitely reduce nutrient leaching

8. Over winter cover crops seem to provide about 70kgs N/Ha to following crops, either by fixing N or preventing leaching
9. 25 cm row width does not reduce cereal yields compared to narrower rows
10. Sulphur use is being researched but the results of its use in organic farming are inconsistent
11. Manure application and the use of one-year green manures increased organic matter levels, unlike digestate, which had no effect.
12. Organic plots have higher biological activity than conventional.

This trial is useful in that it provides clear information on the hotly contested issue of soil organic matter accumulation, which is discussed in Appendix 1. Soil organic matter and its role in climate change mitigation. Essentially there was little difference found between organic and conventional farm systems in terms of carbon sequestration.

The risk of nitrate leaching from the organic system was identified, however the trial also demonstrated the efficacy of catch crops as a means of addressing that risk, which supports their widespread use by organic farmers.

7.2.2 Direct drilling

The original and principle investigation of the Oberacker trial is to compare direct drilling with ploughing. Details of the project are available here https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0ahUKEwjsvpWpzIDcAhXFe8AKHc92ASgQFghNMAc&url=https%3A%2F%2Fwww.lan-dbrugsinfo.dk%2FPlanteavl%2FPlantekongres%2FFiler%2Fplk_2015_show_06_Wolfgang_G_Sturny.pdf&usg=AOvVaw0LAWHlJ30i85lftZwHbuYs

Photo: Oberacker trial, Switzerland



Amt für Landwirtschaft
und Natur
des Kantons Bern

Fachstelle Bodenschutz
www.be.ch/bodenschutz



2015

Internationales
Jahr des Bodens
www.boden2015.ch

and results here:

<https://www.researchgate.net/publication/303867929> Two decades of no-till in the Oberacker long-term field experiment Part I Crop yield soil organic carbon and nutrient distribution in the soil profile

This trial is conducted under conventional farm management and it uses a diverse rotation with beans and inputs that are generally lower than in conventional farming in the UK. The principle results of the trial are:

1. Total carbon (soil organic matter) is similar for both the direct drilled and the ploughed plots
2. Although the yields of some crop were favoured by either direct drilling or ploughing there was no significant difference between these tillage treatments in the yield of all crops together, averaged over 20 years.
3. The soil nutrient and carbon distribution in the soil profile was very different between the two treatments, with direct-drilled soils having much higher levels near the surface. This may have implications for soil sampling depth.
4. Earthworm populations were much higher (40%) in the direct-drilled plots.

The trial did not address the well-documented negative impact of the agrochemicals used in direct drilling systems on soil and other organisms.

7.2.3 Fertility building

Christine Jones, Australian scientist and advisor ran a day-long workshop at ACRES USA Conference, which brought a new focus on feeding the soil. She makes the following points

1. In Australia soil organic matter (SOM) has dropped from between 4 and 25% in 1840 to typically less than 1% in farmed land.
2. Food quality is now 2 – 5 times less nutritious than 60 years ago; declines of Cu 24%, Ca 41%, Fe 54%, Mg 10%, K 16%
3. Nutrient decline is coupled with chemical residues, which are toxins, reducing nutrient availability and the first line of defence against pests and diseases at root level.
4. There is declining health of plants, animals and people.
5. There is a reduction in availability of soil nutrients.
6. Climate change is aggravated by GHG from fertiliser manufacture and SOM loss.
7. Nitrate and phosphate pollution of watercourses and sea.

Her view is that these are easily reversible and that the fundamental mechanism is photosynthesis, capturing carbon and feeding the soil life and increasing its fertility: photosynthesis is the basis of the pyramid of life, not soil. Published papers are available on www.amazingcarbon.com. The farming system that she advocates is

based entirely on capturing large quantities of carbon in the form of carbohydrates in green manures and incorporating these in the soil to feed soil organisms to mobilise mineral reserves, maximise access to nutrients and water and support nitrogen fixing organisms.

Further information is available in Appendix 4. Feeding the soil: restoring biodiversity to agricultural soils.

7.2.4 Compost

The recycling of organic materials to the soil is widely recognised as an essential component of sustainable food and farming. Returning nutrients and adding organic matter is common practice amongst livestock farmers, albeit with varying degrees of effectiveness. Proper storage, treatment, spreading equipment, timing and ensuring that the right quantities are applied to the more appropriate point in the crop rotation or pasture are highly variable. The main aim is nutrient return, which tends to encourage high application rates, but there is now more widespread understanding that a possibly even more important function is inoculation and stimulation of soil biological activity.

The role of compost as distinct from fresh farmyard manure is discussed in detail in Appendix 5. Compost. As with most things there is no one answer, but different ways of doing things to suit the individual farm and farmers. The main points are:

1. **Low organic matter soil.** Composting of manure helps to stabilize and increase the organic matter by converting readily decomposed carbon and nitrogen into stable humus through the process of assimilation by bacteria and other organisms and incorporation into the soil in the remains of their dead bodies.
2. **Slow nutrient release.** Composting creates more stable compounds of carbon and nitrogen that are released much more slowly – often over many years – than the readily available nutrients from fresh manure. Poultry manure for example has high levels of ammonium, which may result in excessive nitrate levels in crops and is very susceptible to leaching out of reach of the plant roots. Composting with high carbon material will improve its value to the soil.
3. **Raw materials.** Green waste, including municipal waste and excessively strawy materials need to be composted in order to break down the high carbon fraction and to produce something more homogenous that can be assimilated by the plant and which avoids localized nitrogen lock up.
4. **Conventional manure.** Organic standards require that conventional manure is composted or stored in order to break down some of the agrochemical contaminants; bacteria have the ability to digest many complex agrochemicals and render them innocuous.
5. **Enhance disease suppression.** High bacteria and beneficial fungi populations in well-made compost have the ability to suppress diseases in crops. This is partly a consequence of strong plant growth – avoiding the lush growth typical of fresh manures. It may also be a consequence of inoculation of the soil with beneficial

- organisms, which in various ways protect the plant from disease. Amongst the theories which have been put forward to explain this effect are: predation on undesirable organisms by beneficial nematodes, occupation of root surface sites which might otherwise be points of infection, the effect of naturally produced antibiotics on pests and camouflaging the plant roots from the disease organisms. Whatever the mechanism it has been clearly demonstrated that compost reduces certain diseases such as pithium in seedlings. Composting may well be justified for these reasons alone, when growing certain high value crops.
6. **Reduction of contamination.** Composting farmyard manure produces a much more friable product which may be essential to speed up assimilation in the soil or to avoid contamination of grassland prior to grazing or silage making.
 7. **Reduction of weeds.** The high temperatures and decomposition processes involved in composting substantially reduces weed seed viability provided that thorough composting throughout the windrow is achieved. A purpose built turner is particularly important here.

7.2.5 Use of human waste

The principle of nutrient recycling and return of human waste (sewage) to the soil should by now be basic to all societies. But, as in Germany, human waste is prohibited on all farmland in Switzerland. In the UK of it has always been permitted <https://www.gov.uk/government/publications/sewage-sludge-in-agriculture-code-of-practice/sewage-sludge-in-agriculture-code-of-practice-for-england-wales-and-northern-ireland> except for organic farming where the EU Regulation prohibits it. Similarly in the USA human waste is used in conventional and integrated farming but is very strictly prohibited in organic farming. There is a groundswell of opinion in the UK to relax the rules for organic farming, but strictly on the basis that it is free from all chemical and biological contaminants. At FiBL they are experimenting with techniques that might be acceptable in Switzerland and which are almost certainly potentially useful to UK conventional and organic farmers. Potentially useful techniques include the use of urine from separation schemes, phosphate recovery and “double loop “systems, which are also proposed in Denmark. Struvite is a high phosphate granule produced from urine and is currently being considered by the EU under the Organic Regulation.

Ultimately of course it is necessary for domestic waste to be separated from industrial waste and for households to stop using pollutants. The removal of residues from human medicines may remain an issue that needs to be addressed.

7.2.6 Summary of farm systems and practices

Organic farming has great potential to deliver multiple objectives as demonstrated by the Rodale, Aarhus University and FiBL DOK trials. A fundamental shift away from maximising yield to one focusing on maximum reliance on soil biology, nutrient recycling, rhizobial nitrogen fixation and other fertility building measures, use of manures and compost and avoidance of inputs damaging to soil microbes or the

environment are all delivered by organic farming. Organic farming has been shown to result in improved soil, plant, and animal health and food quality. Use of finite resources is lower and there are environment and wildlife benefits. The use of certain soil and plant analysis techniques has the potential to significantly enhance the productivity, resource efficiency and food quality of organic farming systems.

Soil fertility building is fundamental to sustainable farming systems. Feeding the soil organisms with carbon from green manures, cover crops, bi-cropping, leys, composts and organic wastes is critically important as a means of maximising biological activity in order to make nutrients available to plants and to encourage nitrogen fixation.

Soil management. Minimising soil disturbance is important if damage to earthworms and soil fungi is to be avoided; shallow ploughing, direct drilling and reduced cultivation are valuable techniques.

Recycling nutrients in the farming and food system is essential if sustainable systems are to be developed in the long term. Composting of farm manures and community green waste is appropriate in some situations for both nutrient recycling and microbial inoculation. New methods need to be developed for ensuring that human waste is free from contaminants and can be effectively used in organic and agro-ecological farming.

Soil and human health. There is an important link between soil management and human health in terms of not just providing sufficient carbohydrates and protein and avoidance of contaminants, but also in terms of the supply of essential trace elements and antioxidants, the benefits to the gut micro flora and the immune system, taste and the subtle benefits of working with the soil. Appendix 6.

8. Conclusions of my Fellowship

I was able to achieve most of the aims of the Fellowship, including meeting most of the people and visit most of the places planned. I was able to better understand the BCSR and Soil Health analysis and management methods and discuss the use of the methods with farmers. I tracked down the principle research into these methods, although frustratingly that research remains incomplete. I was able to visit the 3 principle organic and conventional farming systems trials in the world and discuss their implications with the researchers involved. The following conclusions are drawn.

8.1 Soil analysis and management methods

1. Each farmer should choose an analysis and soil management system that suits their situation.

2. Initial analysis of a new field needs a comprehensive analysis, which should include pH, P, K, Mg, S plus organic matter and trace elements Na, Fe, Cu, Zn, and Bo. If needed Co, I and Se
3. Routine analysis is important every 5 - 6 years: use Standard Analysis i.e. pH, P, K, Mg plus S for crops.
4. Long term monitoring of the same 2 or 3 fields every year:
 - a. Standard analysis, plus S and Active Carbon. (Analyse for organic matter if Active Carbon analysis not available)
 - b. OR Comprehensive Analysis would provide useful information on trace elements, where needed.
 - c. OR Soil Health Analysis would provide much more information on the overall health of the soil,
5. Potential for BCSR, but claims for yield, disease resistance and health have not been adequately validated. Needs good interpretation and use of inputs but expensive and it is a higher input strategy.
6. Potential for mycorrhiza analysis but the use and management indications need further development.
7. Additional trace element, N min and plant tissue analysis is very useful to help resolve problems and identify constraints to yield or crop quality.

Assessment of soil and plant analysis techniques has been an important part of the Fellowship, but it should not be forgotten that analysis is only a tool, one which can help inform the farming system and soil and crop management to produce more and better quality food with minimum environmental impact, more profitably.

The different soil analysis methods assessed can be applied to the UK, but there is a need to develop them to ensure that they meet our requirements. Most important is the need to establish long term trials to develop improved soil management guidelines and to assess the efficacy of these methods in terms of soil and plant productivity and health while minimizing environmental impact and enhancing food quality under organic and agroecological conditions.

8.2 Farming systems

We are now entering a new agricultural policy context in the UK where delivery of public goods and services will take precedence over the historic primary focus on commodity food production. In this world maximising delivery on any one output is no longer the aim, more important is to be able deliver multiple outputs, tailored to the needs of the region.

Organic farming systems and practices have been shown to effectively deliver on this remit and some agro-ecological farming methods show the potential to adopt many similar practices.

High green manure incorporation, reduced tillage and more targeted soil management, farm and community recycling and the use of manures and other organic materials in the soil are all valuable techniques which have widespread application in more sustainable farming systems.

9. Recommendations

The following recommendations are made:

1. Soil analysis and management
 - a. Organic and agro-ecological farmers should be much more proactive in analysing their soils and using the results to help inform their soil management.
 - b. There is a need to investigate the efficacy of BCSR analysis and management with long term replicated trials and monitoring commercial farms.
 - c. Investigate the efficacy of the principle soil health analysis services with long term replicated trials and monitoring of commercial farms
 - d. Develop knowledge on soil biology and commercially applicable methods of soil biology management for quality food production and environmental protection.
 - e. Organic Research Centre should expand its research on soil management.

2. Farming systems and techniques
 - a. Support the adoption of organic and agro-ecological farming systems and practices to deliver multiple “public good” objectives.
 - b. Improve the adoption of current “best practice” farm systems and management by commercial organic and agro-ecological farms.
 - c. Put in place appropriate policy, financial incentives, training and advice.

Next Steps:

I have the following underway or planned:

1. Presentations at 3 conferences or public events for farmers
2. Submission of a paper on Soil Carbon to the English Organic Forum
3. Prepare technical handouts for farmers
4. Submit an article to the Organic Research Centre Bulletin
5. Contribute to the River Teme catchment policy
6. Run a workshop for farmers on soil nutrient management.

“For what will it profit a man if he gains the whole world and forfeits his soil?”

- Edward Goff 2018, based on Matthew 16:26

10. References and further information

10.1 Advisory leaflets

Basics of soil fertility produced by Organic Research Centre and FiBL

http://www.organicresearchcentre.com/manage/authincludes/article_uploads/4002-soil-fertility.pdf

Soil Analysis and Management produced by IOTA

http://www.organicresearchcentre.com/manage/authincludes/article_uploads/iota/technical-leaflets/soil-analysis-and-management.pdf

Soil Biology Primer

<https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/biology>

[Soil and Fertility Management in Organic Systems](#). Creator(s): Organic Agriculture Centre of Canada, Dalhousie University. Issuing Organisation(s): Dalhousie University, OACC.

Soil Health USDA <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health>

Vermicomposting: The Future of Sustainable Agriculture and Organic Waste Management <https://www.wcmt.org.uk/sites/default/files/report-documents/De%20La%20Vega%20A%20Report%202016%20Final.pdf>

10.2 Text books and reports

1. Advanced Biological Farming, Garry Zimmer, Acres
2. Biological Transmutations, Professor C Louis Kervran, Acres
3. Hands On Agronomy, Neil Kinsey, Acres
4. The Formation of Vegetable Mould Through the Action of Worms With Observations on their Habits. Darwin, C. (1945). London: Faber and Faber
5. Mycorrhizal fungal establishment in agricultural soils: factors determining inoculation success. New Phytologist, Erik Verbruggen, Marcel GA Vander Heijden, Matthias C Rillig & Toby Kiers
6. The Nature and Property of Soils. Brady, N.C. and Weil, R.R. 13th. edition, 2002, Prentice Hall
7. Phosphate fertilisers: what are they? Can you use them ? what do they do? C.J. Lovatt & R.L.Mikkelsen. Better Crops/Vol 90 (2006)
8. RB209, AHDB
9. A rock and a hard place — Peak phosphorus and the threat to our food security. Tomlinson, I. (2010). London: Soil Association
<http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.6456&rep=rep1&type=pdf>

10. A Review of the Use of the Basic Cation Saturation Ratio and the “Ideal” Soil. Peter M. Kopittke, Neal Menzies University of Queensland 2007
<https://dl.sciencesocieties.org/publications/sssaj/abstracts/71/2/259>
11. Scope for innovation in crop nutrition to support potential crop yields. IFS paper proceedings 700, R Sylvester-Bradley and PJA Withers Dec 2011
12. Soil Fertility and Fertility Use Efficiency, Thomas Bradshaw, Nuffield International Scholarship
www.nuffieldinternational.org/live/Report/UK/2011/thomas-bradshaw
13. Soil Husbandry, “A practical guide to the use and management of Soils” Tom Batey 1988
14. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming Fliebach, A. et al (2006).
15. Soil quality - A critical review. Bunemann E. et al. (2018)
<https://www.sciencedirect.com/science/article/pii/S0038071718300294>
16. Vermicomposting: The Future of Sustainable Agriculture and Organic Waste Management Churchill Fellowship Report
<https://www.wcmt.org.uk/sites/default/files/report-documents/De%20La%20Vega%20A%20Report%202016%20Final.pdf>

10.3 Research trials on soil analysis methods

1. Game and Wildlife Conservation Trust, Loddington, UK. Reference: Soil Fertility Management Using Bioscience. Dr Alastair Leake, Phil Jarvis (GWCT, Allerton Project), & Nicola Winning (Scottish Rural Colleges).

2. Missouri University, USA. Results not published.

3. Oberacker, Switzerland

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0ahUKewjsvpWpzIDcAhXFe8AKHc92ASgQFghNMAc&url=https%3A%2F%2Fwww.lan-dbrugsinfo.dk%2FPlanteavl%2FPlantekongres%2FFiler%2Fplk_2015_show_06_Wolfgang_G_Sturny.pdf&usg=AOvVaw0LAWHlJ30i85lftZwHbuYs

<https://www.vol.be.ch/vol/de/index/landwirtschaft/landwirtschaft/bodenschutz/bodenzustand/dauerbeobachtungsflaecheoberacker.html>

10.4 Research Trials on Farming Systems

1. Aarhus University, Foulum, Denmark
<https://www.sciencedirect.com/science/article/pii/S1161030118300108>
2. FiBL DOK trial. USA Report on farming systems trial
<https://shop.fibl.org/CHen/mwdownloads/download/link/id/90/?ref=1>

3. Oberacker, Switzerland
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=8&ved=0ahUKEwjsvpWpzIDcAhXFe8AKHc92ASgQFghNMAc&url=https%3A%2F%2Fwww.landbrugsinfo.dk%2FPlanteavl%2FPlantekongres%2FFiler%2Fpl_plk_2015_show_06_Wolfgang_G_Sturny.pdf&usg=AOvVaw0LAWHJ30i85ftZwHbuYs
<https://www.researchgate.net/publication/303867929> Two decades of no-till in the Oberacker long-term field experiment Part I Crop yield soil organic carbon and nutrient distribution in the soil profile
4. Rodale Institute, USA. Report on the farming systems trial
<http://rodaleinstitute.org/assets/FSTbookletFINAL.pdf>

10.5 Soil Analysis services

Base Cation Saturation Ratio analysis.

Glenside (via NRM) UK <http://www.glensidegroup.com/albrecht-soil-survey>

Kingshay UK <https://www.kingshay.com/shop/comprehensive-soil-analysis>

Kinsey Ag USA <http://kinseyag.com/index.html>

Midwestern BioAg USA <https://www.midwesternbioag.com>

Mid West Labs USA <https://www.midwestlabs.com/resource/interpreting-soil-analysis>

Restora-Life service USA <https://www.restoralifeminerals.com>

Comprehensive Analysis

Cornell USA <http://css.cornell.edu/cnal-forms/CNAL-S-tests.pdf>

Soil Health analysis

Cornell Soil Health USA <https://soilhealth.cals.cornell.edu/testing-services/comprehensive-soil-health-assessment>

Haney Test USA <https://www.wardlab.com/haney-info.php>

Mid West Lab USA <https://midwestlabs.com/wp-content/uploads/2016/12/190-Haney-Test-Explanation.pdf>

NRM UK <http://www.nrm.uk.com/services.php?service=soil-health>

Woodsend USA <http://www.nrm.uk.com/services.php?service=soil-health>

Biological analysis

Trace Genomics USA <https://www.tracegenomics.com/#/products>

Soil Bio Lab UK www.soilbiolab.co.uk

Plant analysis

Plant tissue analysis

NRM UK [http://www.nrm.uk.com/files/documents/NRM Plant Tissue Analysis.pdf](http://www.nrm.uk.com/files/documents/NRM%20Plant%20Tissue%20Analysis.pdf)

Sap analysis

OMEX UK <http://www.omex.co.uk/agriculture/services/sap-analysis>

11. People and places visited on my Fellowship

USA

Jeff Moyer and Kris Nichols, Rodale Institute <https://rodaleinstitute.org>

Robert Schindelbeck, Cornell University <https://soilhealth.cals.cornell.edu>

Aaron Wise, dairy farmer Pennsylvania

Leon Brubacher, dairy farmer, Pennsylvania

ACRES USA Conference:

Christine Jones, Amazing Carbon www.amazingcarbon.com

Tim Reinbott, University Missouri

<https://extension2.missouri.edu/find-your-interest/agriculture-and-environment>

John Kempf <https://www.advancingecoag.com>

Neil Kinsey, Kinsey www.kinseyag.com

Gary Zimmer, Wisconsin, <http://www.midwesternbioag.com>

Sandy Syburg, farmer and composter, Wisconsin

<https://www.purplecoworganics.com>

Dan Olson, farmer and seed merchant, Wisconsin

Dan Mosgaller, Organic Valley, Wisconsin <https://www.organicvalley.coop>

Poorima Paramswaran, Tracegenomics, California <http://www.tracegenomics.com>

Joanna Ory Organic Farming Research Foundation, California www.ofrf.org

Denmark

Erik Fogg, Sven Hermansen, Tove Mariegaard Pedersen, Michael Tersbol and Anette Vibke Vestergaard, SEGES www.seges.dk

Janne Aalborg Nielsen Organic Denmark <http://organicdenmark.com>

Lone Hedeard, Gothenborg, Farmer

Mads Helms, Sommerbjerggaard, Farmer

Axel Månsson and Dorrit Andersen, Farmer and vegetable packer
<https://www.maanssons.dk/en/>

Martin Beck, adviser <http://martin-beck.dk>

Peter Sorenson, Foulum research centre http://dca.au.dk/om_dca/au-foulum/

Switzerland

Urs Nigli, Robert Obrist and Else Bunemann-Konig, FiBL, Switzerland.
<http://www.fibl.org/en/switzerland/location-ch.html>

Matthius Stetler and Andreas Chervet, Oberacker <https://www.vol.be.ch/vol/de>

Andreas Gubler and Ana Hug, Agroscope <https://www.agroscope.admin.ch>

12. Appendices

Appendix 1: Soil Organic Matter and its role in climate change mitigation

"... the Latin name for man, homo, derived from humus, the stuff of life in the soil." - Dr. Daniel Hillel

Soil organic matter (SOM) is the focus of much attention in both organic farming and conventional circles; conventional arable farmers have become more aware of the

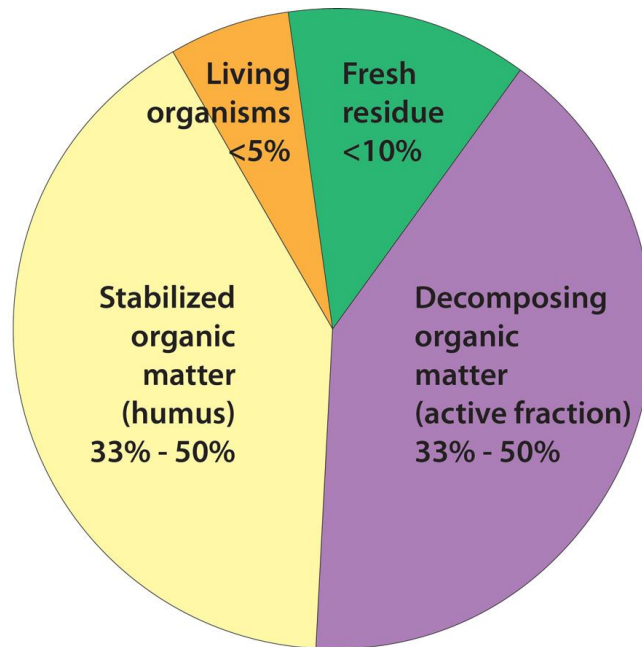
fact that SOM is critically important and that poor rotations and lack of organic matter inputs might be something to do with their poor soil structure and static or declining yields. SOM levels continue to show a decline in arable cropping systems. Organic farmers have always believed that SOM is important, not just for soil structure but also for mineralisation of nutrients, which results in nitrogen release, needed for crop growth and they have in the back of their minds the idea that SOM has something to do with pest and disease control. More recently it has been realised that SOM plays an important part in overall soil biological activity and nutrient release. The potential for carbon sequestration and for the soil to function as a carbon sink has led some to think that SOM can play an important and major role in reducing green house gases and addressing climate change.

Many organic farming practices will contribute organic matter to the soil; grass clover leys, use of farmyard manure, compost, green waste, cover crops and green manures will all contribute to SOM. The extent to which these inputs will result in a net sequestration of carbon is dependant on how they are processed in the soil, the level of nitrogen input and C:N ratio, the initial SOM levels, cultivations, soil type and climate. The evidence for long-term on-going carbon sequestration from organic farming is not clear-cut and categorical statements that organic farming will have a significant impact on green house gasses and climate change should be treated with caution. However there is no doubt that organic farming practices will, in general be beneficial.

The fate of organic matter, or carbon, added to the soil is particularly dependant on its form; fresh manure and slurry will contribute little to the build-up of SOM, but it will supply readily decomposable material that will provide nutrients to the plants. Compost, on the other hand will provide a more stable form of organic matter, which will contribute to SOM build up. Mineralisation is the oxidation of the chemical compounds in organic matter by the soil microorganisms, in the process releasing nutrients, particularly nitrogen, phosphorus and sulphur in a form available for plant uptake, together with the release of carbon dioxide. This process of mineralisation is brought about by cultivations and aeration and is absolutely central and fundamental to providing the nutrients for organic crop production.

Humus is an important component of SOM and of compost. Figure 1. Humus is relatively stable and is primarily the result of fungal decomposition of lignin and has many roles in the soil including water holding, soil structure and nutrient retention.

Figure 1. Components of soil organic matter



Farms making effective use of well-made, composted manure or green wastes have the potential to build SOM. Fresh or once turned FYM and green manures will not result in the same build up of SOM as composted material, although they will of course be tremendously important for providing nutrients in a plant-available form, either directly or indirectly as a result of biological breakdown and increase the living organisms in the soil. Multiple cultivations, whether that is ploughing or repeated use of cultivators will tend to deplete organic matter as it encourages aeration and thus mineralisation.

Soil type will have a major impact on SOM accumulation potential; dry, light sandy soils will tend to be difficult to build SOM and such soil in an arable rotation will often have naturally low levels of 1.5 – 2.5%, unless they have evolved under acidic conditions in which case levels of 6 – 10% may be found. Clay loam soils in the UK will typically have SOM in the range of 3 – 4.5%. Clay soils will tend to have higher SOM than other soil types.

The breakdown of organic matter by bacteria is also affected by temperature, climate change will increase soil biological activity and speed up the process of decomposition of SOM. Hence SOM is a vulnerable carbon sink and should not be seen as a major means of mitigating climate change.

Finally we need to recognise that the SOM accumulation is likely to reach an equilibrium. Depending on the soil type, management practices, organic inputs, rotation and the cultivations used the accumulation of SOM will tail off at some point; it is not realistic to expect to be able to increase SOM from say 4% to 10% under normal farming practices, an equilibrium will be reached before that. As stated in the IFOAM EU Group/FiBL report “soil carbon sequestration is difficult to measure,

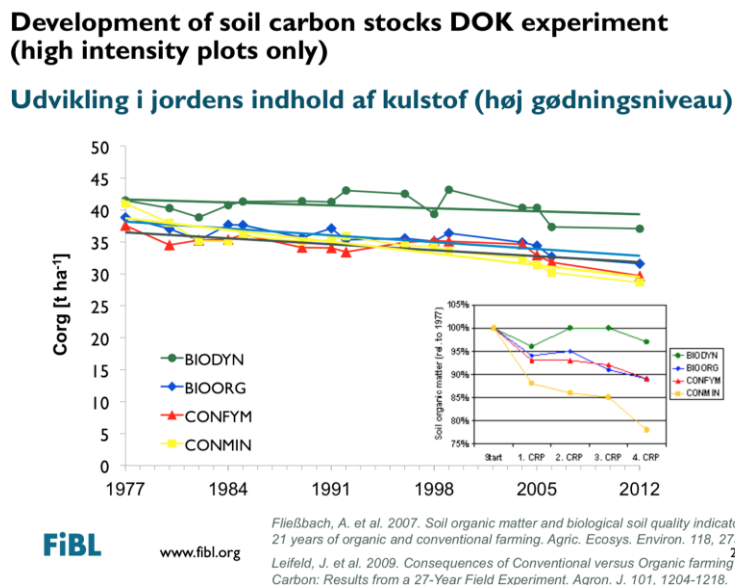
reversible and not permanent. It therefore cannot be considered to be a real mitigation tool”.

Does organic farming increase SOM?

The evidence from farm experience in the UK is limited because there has been very little thorough and reliable monitoring; inconsistent sampling methods and field locations, changes in analytical methods and infrequent sampling are all a problem. Experience from the arable organic farms that I have worked with is that sometimes, but not always, SOM levels initially increase following conversion to organic farming from continuous non-organic arable cropping; an example from Holme Lacy College shows an increase from 2.7 to 3.1% over 10 years, an average of 0.04% SOM per year. Experience elsewhere is that subsequently increases are small.

Replicated research over long periods of time is a more reliable indication. The 40-year-old DOK trial at FiBL (Switzerland) compares conventional, organic and biodynamic systems.

Figure 2. DOK-trial soil carbon



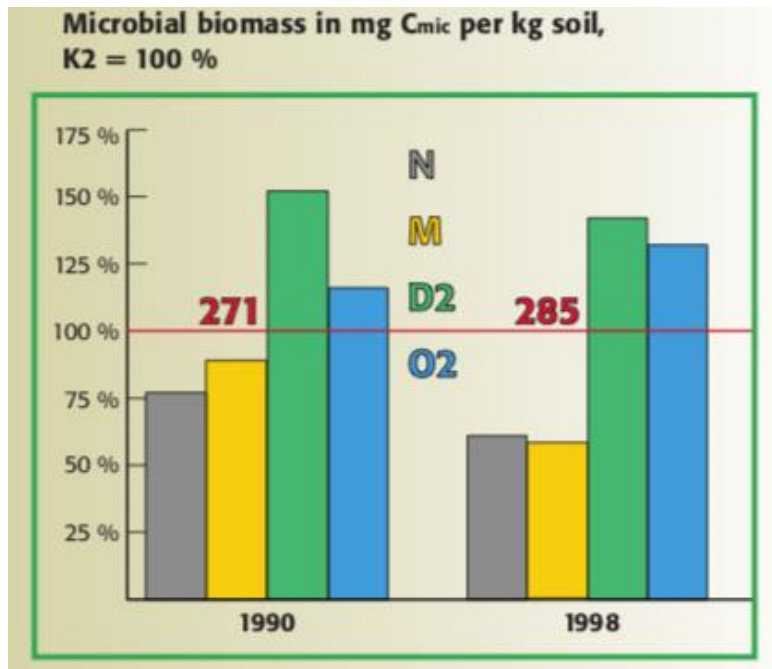
Fliessbach A. (2017)

The results after 35 years, Figure 2. show that SOM levels have declined slightly in all four treatments. The conventional and the organic treatments are not significantly different, however it would be expected that if the conventional had followed a continuous cropping rotation that this would have resulted in a greater decline and that the difference between the organic and the conventional would be expected to be greater. The biodynamic treatment resulted in a small but significantly higher level

of SOM than the conventional or the organic; this may be a result of the use of well-composted manure rather than the fresh manure in the organic.

Interestingly there is a significant difference in the soil microbial biomass between some treatments, Figure 3., showing that Organic (O2) and Biodynamic (D2) has greater biomass than Conventional both with manure (M) and without manure (N).

Figure 3. FiBL DOK-trial Microbial Biomass



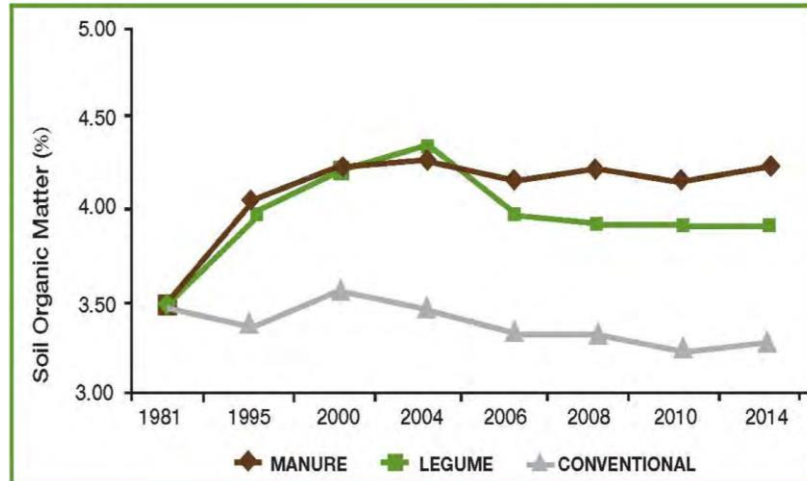
FiBL Dossier No 1. (2000) Results from a 21 year-old field trial. Organic farming enhances soil fertility and biodiversity

The Aarhus University (Denmark) farming systems trial was set up in 1997 on 3 sites, the one at Foulum continues to run. A replicated trial compares organic using both green manure and manure with a continuous cropping non-organic rotation. While there are significantly higher levels of carbon inputs to the soil under organic management and there is indication that a one-year green manure with residues returned does increase SOM, overall the conclusion is “not able to detect consistent differences in measured Soil Organic Carbon between systems”.

The Rodale Farming Systems Trial (USA) has been running since 1981, it is a replicated trial comparing an organic manure system with an organic legume system with a conventional continuous arable cropping system. Figure 4. The SOM levels in both the organic systems increased from 3.5% to approximately 4.25% in the first 20 years (0.37%/year) thereafter stabilising or in the case of the organic legume system subsequently declining to approximately 3.9%. The conventional has shown some

recent decline to approximately 3.3%. In the absence of trial data and peer-reviewed papers it is not possible to know the statistical significance of these results.

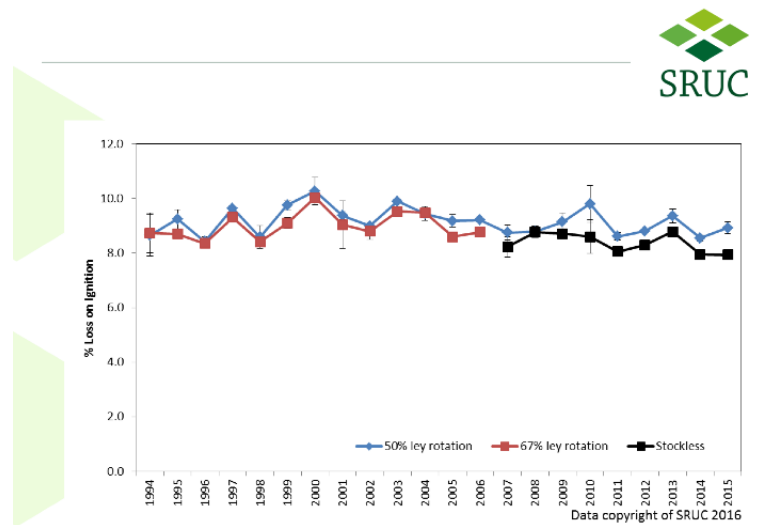
Figure 4. Rodale SOM levels



Rodale Institute Farming Systems Trial Brochure (2015)

The Scotland Rural College (SRUC) organic systems trial was set up in 1991 following a period of ley arable farming. The results, Figure 5. show over a period of 20 years that organic ley-arable under a rotation of 50% ley, 50% arable maintains SOM, but that under the prevailing conditions SOM did not increase, even during the conversion period. This reflects the previous cropping regime and the fact that these are inherently high SOM soils, in the order of 8%. The stockless organic rotation introduced 8 years ago indicates a slight decline in SOM, but which may not be significant.

Figure 5. Tulloch rotational trial, SRUC Aberdeen. Soil Organic Matter



SRUC Aberdeen (2018)

The conclusion of the meta-analysis of research undertaken by Organic Research Centre in 2011 is that:

1. Organic cropping systems have considerable potential for increasing soil carbon, through the incorporation of fertility building grass-clover leys and use of livestock manures within diverse crop rotations, when compared with specialist (e.g.: monoculture) cropping systems;
2. The exact amount of carbon that can be sequestered through organic management of cropping systems is still uncertain, due to the disparity in assessment methods, and farming/land-use systems;
3. The difference between the wide range of organic and conventional farm types is not yet clear, partly because of the current difficulty in defining these systems and their individual characteristics;
4. Organic management of grassland is unlikely to increase soil carbon levels over those from conventional management, but the reliance on legumes and biological instead of industrial nitrogen fixation will still have a positive impact on climate change mitigation through reduced fossil energy use and related carbon dioxide and nitrous oxide emissions

A metanalysis by Gattinger A. (2012) undertaken at FiBL concluded that there are higher SOM concentrations and stocks in topsoils under organic farming than under conventional farming. The review points out that “the estimation of carbon sequestration alone does not equate to climate change mitigation because offsetting emissions with sequestration only buys time and does not negate the need for emission reduction, and (ii) soil-derived N₂O emissions, production emissions of different fertilizers, and energy-related emissions from farm machinery and

irrigation, as well as emissions from livestock and manure, need to be accounted for in a life-cycle analysis". The SOM advantage to organic farming varied widely between studies and in many instances the advantage was due to the fact that organic farming avoided the decline in SOM levels found under conventional all-arable farming.

The ratio of Clay to SOM is considered important by some of authorities (Agroscope and Aarhus University) and it may be a more important measure of the need and potential to increase SOM levels than SOM% per se.

Claims that the practice of Mob Grazing results in substantial increase in organic in the order of a change from 3 to 5% over 3 or 4 years have not been substantiated under UK conditions.

The use of very high levels e.g. 50 tonnes/ha/year of imported manure, compost or green waste will undoubtedly result in SOM increase over time, up to a point, but that is not typical of organic farming.

The studies that I have seen have focused on arable systems, the situation with permanent pastures is very different, and soils under permanent pasture generally have higher SOM and will have developed an equilibrium. This higher level may be due to both the lack of cultivations and the use of manures and fertilisers as well as forage residues. In my experience there is very little difference in SOM levels between conventional and organic management of permanent pastures.

Conclusions

Based on the evidence of the three farming systems trials that I visited under the Winston Churchill Fellowship in 2017/18, the results of the SRUC trials, my personal experience and the review of research by Organic Research Centre I draw the following conclusions.

1. SOM is important for soil physical, biological and nutrient reasons and mineralisation of SOM is particularly important in organic farming.
2. The following practises have the potential to increase SOM: grass clover leys, farmyard manure, compost rather than fresh manure, green waste, over-winter cover crops and annual green manures.
3. The following will tend to decrease SOM: cultivations, continuous cropping, and nitrogen fertiliser.
4. Given that organic arable farming involves many of the beneficial practises identified above, there is likely to be some advantage obtained through organic farming in arable systems compared to conventional all-arable systems, particularly where longer leys are involved.

5. There is no evidence that organic arable farming offers potential for on-going, long-term sequestration of carbon in the soil. The indications are that increased SOM levels of between 0 and 0.4% per year may be possible during the first 10 – 20 years of organic conversion, but that this depends on the initial SOM levels, soil type and management practices. Thereafter increases are unlikely.
6. SOM is likely to be higher under some established organic arable rotations than under conventional rotations, but this is not necessarily so and will depend on various management practices, particularly the length of the ley and use of compost.
7. 65% of organic farms in the UK are permanent pasture, not in an arable rotation. These farms are unlikely to show a significant difference between conventional grassland farms.
8. Organic arable farming has higher levels of soil microbial biomass compared to conventional. Organic farmers wanting to improve crop productivity should focus on improving the quality and biological activity of their soils rather than merely focusing on total SOM.
9. Given the wide range of results from arable system comparisons and the fact that the majority of organic farming in the UK is permanent grassland generalised claims that organic farming will contribute significantly to climate change mitigation through carbon sinks should be avoided.
10. Climate change mitigation is one the principle challenges of our time and urgently needs to be addressed by a radical change in the food and farming system as a whole, including food distribution and with a particular focus on drastic reduction in the use of fossil fuels and by ceasing deforestation. Organic food and farming systems offer the best agricultural system to do that. Soil carbon sinks play a supporting role.

Mark Measures July 2018

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Appendix 2: BCSR Soil Analysis Research Evidence

Despite the enthusiasm for the BCSR soil analysis and management system, the claims made, its widespread use in the USA and the greater management time, inputs and costs involved, the BCSR method has still not been subjected to replicated research that has been published as a scientific paper. Coming as I do from a research institute where rigorous research and review is a necessary prerequisite to making any claims, let alone advocating a technique to commercial farmers, this is both frustrating and mystifying. Those whose living is based on selling advice or inputs associated with the method point to William Albrecht's papers and tell me that with their 20 or 30 years of experience in the field that they know it works and the lack of research evidence does not seem to bother them. Why farmers are willing to risk their livelihoods is another matter. The more innovative farmers have been rightly seeking a biological approach to soil management and there is a natural affinity to new soil management methods that resonate with their ideas. And lets face it the rational, reductive science of conventional agriculture has failed us in the development of genuinely sustainable farming and food production. Practical farm experience should not be dismissed, and if a farm is functioning successfully and profitably in the long term, with good soils and healthy crops and animals there is every reason to take notice and recognise that, as is often the case, science may be behind the curve.

However there are a number of places where there is interesting work going on which should provide some evidence of the efficacy of the BCSR system. In the USA there is the systems trial at Missouri University, in Switzerland there is a conventional, tillage trial at Oberzollica and in the UK the Loddington 3 year field trial. There is reputed to be work in Australia but it cannot be traced.

Missouri University

Tim Reinbott leads a replicated research project investigating the efficacy of the BCSR analysis and management in a conventional situation, which has been running for the last 8 or 10 years. The work is not published or peer reviewed so cannot be fully referenced, however selective results have been presented at a number of conferences including ACRES USA 2017. The following slides and information are from that presentation.

The objectives of the trial are given in Slide 1.

Slide 1. Trial objectives

Original Questions That I Had About The Albrecht System:

- ▶ Does The Level of Base Saturation of Ca and Mg Really Make A Difference?
- ▶ Aren't proper levels of P and K enough?
- ▶ Do We Need "Fresh" Calcium
- ▶ Are Micros Really That Important
- ▶ Sulfur?

South Farm Research Center
University of Missouri

Reinbott T. (2017)

The plot trials include a control with only nitrogen applied, a treatment following the full BCSR recommendations, another following conventional N, P, K and S recommendations and various other treatments using the BCSR recommendations but excluding various different macro or micro mineral inputs. See Slide 2.

Slide 2. Treatments

Setup Treatments

- ▶ No P, K, S, Micros or anything else except N for Corn
- ▶ Full Recommendations
- ▶ NPKS only no micros
- ▶ Recommendations except KMg used
- ▶ Recommendations except KMg and no Pell lime
- ▶ Micros only
- ▶ P and K only

South Farm Research Center
University of Missouri

Reinbott T. (2017)

The full recommendations following BCSR are given in Slide 3.

Slide 3. Recommendations

Recommendations

- ▶ P-250 lb/acre DAP
- ▶ K-200 lb/acre KCl
- ▶ S-15 lb/acre
- ▶ Ca-Pell Lime-300 lb/acre
- ▶ Mg-0 lbs/acre
- ▶ B-15 lb/acre Borate
- ▶ Cu-5 lb/acre CuSO₄
- ▶ Zn-20 lb/acre ZnSO₄

South Farm Research Center
University of Missouri

Reinbott T. (2017)

The following is an example of the results presented, Slide 4.

Slide 4. Yields

Soybean Yield 2015 and 2017

Treatment	2015 Yield	2017 Yield
	(bu/acre)	
▶ Control	42	54
▶ Recommendations	45*	63*
▶ PKS only	43	52
▶ Recom.+Mg	41	61
▶ Recom. No lime +Mg	39	65*
▶ Micros only	40	57
▶ P and K only	35	-

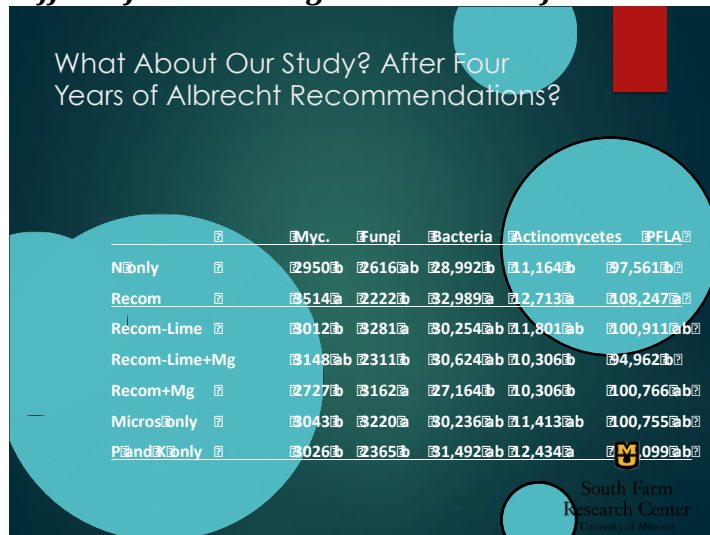
South Farm Research Center
University of Missouri

Reinbott T. (2017)

Apart from the statistically significant positive effect of the BCSR management on yield by 7 - 14% compared to the Control (N only treatment) and also the N, P, K, S treatment, the response was greater in dry years than wet years and the BCSR management resulted in increased quality of the crop in terms of protein by 9% and increase in beneficial amino acids. The reduction in yield as a result of deleting different aspects of the BCSR recommendations indicates that the full spectrum of analysis and treatments is needed to get the best results, in terms of both yield and quality. It appears that is not just a matter of getting the P and K right but also there is a response to the use of S, Ca, B, Cu and Zn.

Response by forage crops is also significant in terms of yield (30%) and protein. There is a beneficial effect of BCSR management on soil biology including actinomycetes, mycorrhizae, bacteria and active carbon, which provides carbon for microbial activity. Slide 5.

Slide 5. Effect of BCSR management on soil life



Reinbott T. (2017)

The trial also showed a beneficial effect of BCSR management on soil structure: aggregate stability, aeration and water infiltration and water holding capacity.

The indications from this trial are that in order to be effective all the components of the BCSR management system need to be addressed and that the benefits of the system are:

1. Improved crop and forage yield
2. Improved crop and forage equality
3. Improved drought resistance
4. Improved soil mineral availability
5. Improved soil structure
6. Improved soil biological activity

Although the results look very positive the fact remains that we do not have access to the trial protocol and the results of the research has not been peer reviewed or published.

Oberacker, Switzerland

My interest in Albrecht soil analysis took me to the agricultural school and university at Oberacker, where the 20-year, plough v direct drilled, rotational, conventional trial has been subdivided for the last 10 years to study the impact of following the BCSR system. The trial results have yet to be written up.

Andreas Chervet and Matthius Stetler at the Oberacker trial



My hosts Andreas Chervet and Matthius Stetler, who are the researchers involved explained that in certain crops there are differences in performance between plots receiving standard conventional management and BCSR analysis and management. For example barley is performing better under BCSR management. Their observation is that BCSR management is more effective under direct drilling than under the ploughed system, where the standard Swiss soil analysis and management regime is more effective. I could certainly see that the plots looked different in April when I visited, but at this stage it is not possible to quantify the impact of BCSR on yield, plant health or cost effectiveness.

GWCT Loddington, UK

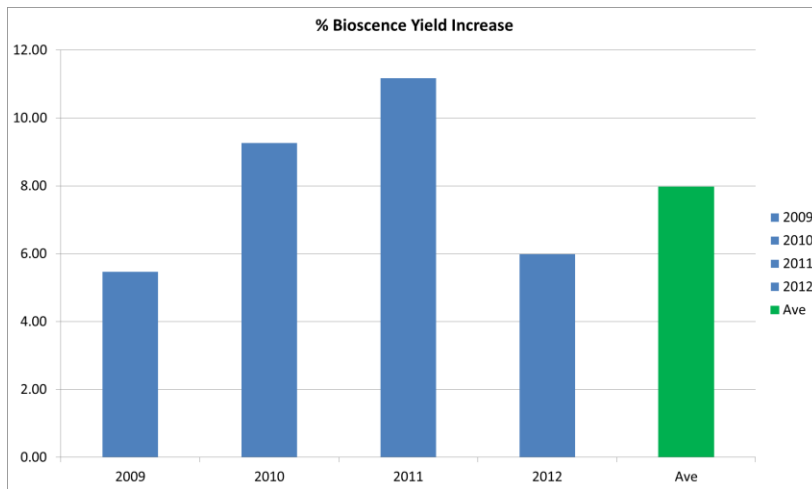
The Game and Wildlife Conservation Trust at Loddington ran a field scale rotational Bioscience trial over four years comparing BCSR (Albrecht) analysis and management with a conventional soil management in a continuous cropping conventional farming system. The results of the trial have been written up and published but as a split field treatment the replication is limited and no statistical analysis is available.

The BCSR management (Bioscience) included the use of N, P, K, boron, copper, zinc, nitrogen-fixing bacteria, mycorrhizal fungi and carbon balancer as an energy source. The nitrogen application rate was lower than for conventional.

The conventional management included the use of nitrogen, phosphate, potassium, manganese and magnesium.

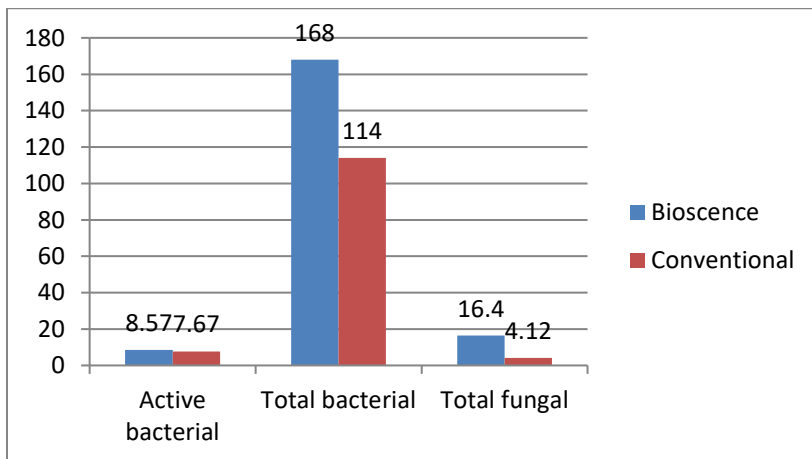
The results of the trial showed that the BCSR method resulted in 8-12.5% lower nitrogen use, 8% higher yield (Table 1.), higher soil organism biomass (Table 2.) and a £6/ha increase in margin over fertiliser. The opinion of the farm manager is that this increase in margin is insufficient to compensate for the increase in management complexity and time involved.

Table 1. Bioscience yield increases and 4-year average



Leake A. et al.

Table 2. Organism biomass data for Paradise West 28/10/2010 (micrograms/gram)



Leake A. et al.

Summary of BCSR research results

The research evidence for the efficacy of the BCSR method is very limited. Both the Missouri trial and the Oberacker trial are fully replicated and have the potential to provide robust results, however the results that have so far been reported have not been fully published and the trials have not been written up and peer reviewed. The GWCT Loddington trial has been written up but has not subjected to statistical analysis.

The BCSR method shows the following trends in one or more of the three trials:

1. A positive effect on crop yield in one or more crops (all 3 trials)
2. An increase in the number of different soil fertiliser types used (3)
3. A positive effect on soil organisms (2)
4. The need for all elements of the BCSR method to be addressed (1)
5. An increase in crop quality (1)
6. An improvement in soil structure (1)
7. A small increase in margin over fertiliser (1)
8. Greater potential in min till systems (1)

In these trials the BCSR method does appear to make a difference and it has the potential to increase yields and quality while reducing the environmental impact due to the reduction in nitrogen fertiliser use. The size of the effect and the impact on profitability cannot be ascertained reliably from the results so far available. The trials have not demonstrated that soil phosphate reserves are more effectively utilised under the BCSR method although that may well be the case as the higher levels of biological activity would be expected to increase mobilisation of and access to reserves.

The trials did not attempt to address the contentious issue regarding the importance of the ratios of the base cations; indeed in the UK trial the role of the ratios is downplayed by the advisers making the recommendations.

None of the trials attempted to address the suitability of the BCSR method under organic as distinct from conventional conditions of management.

None of the trials used humates as a source of minerals and stimulating biological activity, an input quite widely used by commercial farmers using the BCSR method in the USA.

Conclusions

The concepts behind the BCSR method are consistent with the aims of more sustainable systems of farming and soil management; in particular the lower use of nitrogen fertilisers, making better use of phosphate reserves, improving plant health as well as crop yield and quality and a focus on soil structure. Achieving this by improved biological activity by supplying sufficient carbon as an energy source and ensuring that sufficient macro and microelements are provided for the soil organisms

as well as the plant or animal is all good soil management which is not in the least contentious.

The importance of the correct cation ratios to optimise nutrient supply and the extent of the need to supply calcium to the soil is not clear and there is a difference of opinion amongst BCSR practitioners.

The extent to which trace elements are constraining soil biology and soil fertility is not clear, although BCSR practitioners put great emphasis on the importance of certain trace elements such as calcium and boron for biological activity, consequently application of these trace elements is often routine. There is generally agreement that crop nutrient deficiency will affect yield and livestock health, which must be addressed.

The use of soluble carbon in the form of molasses is less familiar to organic and integrated farmers in the UK and the use of free living N fixing organisms and mycorrhizal inoculants is often challenged because it is commonly found that such inoculants are quickly overwhelmed by the indigenous organisms. It is likely that it is more important to provide the right organic inputs of manures and green manures, avoid damage to soil physical structure and avoid those fertilisers and agrochemicals known to be damaging to soil organisms.

Appendix 3: Soil Health

The terms “soil health” and “soil quality” are becoming increasingly familiar amongst farmers and policy makers worldwide as some farmers realise that there is more to soil than merely receiving and releasing chemical fertilisers, like a sponge and policy makers grapple with soil loss, pollution and the problem of feeding some infinite number of people in a finite world. The terms soil quality and health are not strictly speaking synonymous although they are often used in that way.

A current definition of soil health is **“the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals and humans”** (Natural Resources Conservation Service – USDA-NRCS, 2012²; Soil Renaissance, 2014). <https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health>

This does emphasise the need for “continued” long term capacity and that it is a living system, though it lacks the emphasis on the role of soil in maintaining the health of plants, animals and humans; we appear to have lost a central perspective here. One has to go back to Doran and Parkin³, in 1994, who defined soil quality as **“the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health”** for mention of health and to McCarrison, Howard and Balfour to get a clear declaration “that health, whether of soil, plant, animal or human, is one and indivisible”. Balfour went on to point out that it “consists of a mutual synthesis between organisms and environment” and “inherent in such a definition is that health is not a state but a dynamic process.”

Soil health or quality is therefore not something that can be precisely measured by chemical or biological analysis, even if such partial analysis may be useful in managing soil and it is not confined merely to ensuring sufficient nutrients are supplied for plant production needs. It also needs to recognise the nutrient needs of soil organisms for them to function effectively e.g. boron is essential for nodulation of legumes, and animals e.g. selenium.

Soil Health: What does it do?

A healthy soil first and foremost provides quality food that sustains the health of the animals and humans that eat it, and in addition it provides clean water, diverse wildlife, landscape and a carbon store, all of which have the potential to influence human health.

Soil Health: What are its functions?

Soil has multiple functions, which need to be considered when looking at soil health. They can be categorised under four principle headings:

1. Physical and structural role: soil provides an anchor for plants and foundation for buildings, carbon storage, water management and gas exchange.

2. Nutrients and mineral supply: soil provides chemically bound mineral reserves to soil organisms, plants and animals. Soil regulates but in some circumstances supplies excess or toxic minerals.

3. Biological activity: soil supports soil organism and plant biodiversity, micro and macro-organisms which process soil, fix nitrogen fixation and make nutrients more available e.g. plant root acids and mycorrhizae make nutrients more available to plants. Bacteria and fungi limit pathogens affecting plants, animals and humans although there are others that may cause disease. Soil is a source of microbes that have been widely used in human medicines.

Photo Nitrogen fixing rhizobia



4. Well-being: Taste and terroir of food, the smell of soil.

Effect of soil microorganisms on mental health – gardening is good for you!

Human and animal gut micro flora is influenced positively by soil.

“Life force”, which may reflect the continuum between soil, plant, animal and human.

Presence of antioxidants influences the immune system.

Soil Health: Assessment

For many years we have been stuck with physical and chemical assessment of soils, which bear little relationship to what nutrients are available and utilised by the plant and even less to the effect on animals and humans eating the products. An assessment of a soil for health also needs an assessment of its ability to supply nutrients to soil organisms, to animals, and to humans, and an assessment of the biology and soil **functioning**. It needs an understanding of the effects on human well-being and a better understanding of how to manage and positively influence soil health. If health is more than the just crop yield and an absence of disease how do we assess soil health?

It is more than a matter of ensuring that adequate minerals, trace elements, amino acids and carbohydrates are supplied to the plants growing in it, it is a matter of understanding and managing the biological processes and ensuring thriving soil organisms, plants, animals and people.

Soil health analysis has the potential to reduce the use of fertilisers by making better use of soil reserves and biological nitrogen fixation, reduce the use of pesticides by improving crop and animal health and encouraging natural predators.

Soil Health tests. Laboratory Soil Health tests may be useful for the farm management, Cornell University have been offering theirs for many years; it is a lab test which includes physical, chemical and biological (Solvita, soil protein, active carbon) parameters. However its scope is limited to ensuring nutrient supply for plant, it doesn't consider the implications for the soil organisms or the wider aspects of animal and human health.

<http://www.css.cornell.edu/extension/soil-health/1concepts.pdf>

<http://www.css.cornell.edu/extension/soil-health/manual.pdf>

The NRM Soil Health Test to some extent is equivalent to Cornell's in that it also tests for pH, P, K, Mg, soil type, SOM and respiration rate but it is limited in that it does not look at trace elements, and confines biological activity to the Solvita respiration test.

Soil biology analysis.

Total soil biology. In the past laboratories have offered services that provide a manual count of bacteria, fungi and other soil organisms. The extreme fluctuations in populations due to soil temperature and moisture and the lack of reliable information on interpretation of the results and providing farm management recommendations has meant that this is now little used in the UK.

More recently DNA analysis has been developed which is able to provide an accurate and comprehensive analysis of the soil organisms present. These methods are already able to provide good assessment of predatory nematodes for example but have potential to be able to monitor and manage other aspects of soil biology.

Mycorrhizae analysis. In an effort to avoid the high cost of total soil biology analysis and to build a picture over the season some farms analyse for mycorrhizae regularly throughout the growing season as an indication of soil biological activity.

Earthworm counts. Easily undertaken by farmers, providing some indication of the type, number, breeding and health of worms.

Other soil health assessment

Organic matter. While SOM analysis has a certain following the fact that levels are relatively unresponsive to farm management means that they have limited value in the short to medium term. Organic matter quality is probably a more useful measure, e.g. soil active carbon.

Plant health. Assessed by the productivity, health and absence of disease of plants growing in it.

Animal health. Assessed by the health of the animals eating from it and the quality of the food produced.

Recycling. The extent of recycling and processing of plant material, animal and human manure provides an indication of the functioning of a living soil and degree to which it is operating as a (closed) system. It is a process not a state.

Resilience to variable weather and climatic conditions.

An overall soil health index is often sought but is probably of little value as assessment of individual functions is more useful to inform soil management.

Healthy Soil: evidence

DOK Trial

The DOK Trial was established in 1978 by the Research Institute of Organic Agriculture (FiBL), Switzerland to compare organic and conventional farming systems. It is a replicated plot trial with four treatments and a control 1. Organic, 2. Biodynamic, 3. Conventional with manure and 4. Conventional with only mineral fertilisers.

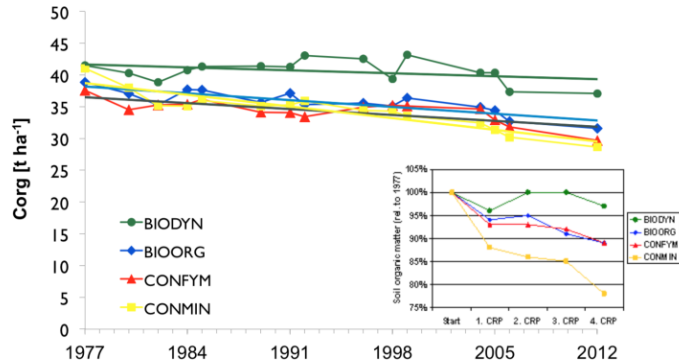
The trial monitored a number of soil quality or health parameters, drawing the following key conclusions.

1. SOM levels showed some small decline over time, with some small advantage to the biodynamic management. Table 1.

Table 1

Development of soil carbon stocks DOK experiment (high intensity plots only)

Udvikling i jordens indhold af kulstof (høj gødningsniveau)



FiBL

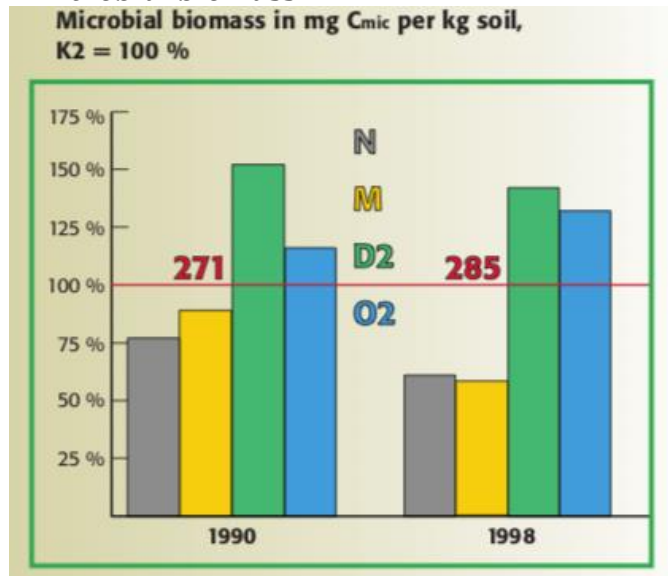
www.fibl.org

Fließbach, A. et al. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agric. Ecosys. Environ.* 118, 273-284
 Leifeld, J. et al. 2009. Consequences of Conventional versus Organic farming on Soil Carbon: Results from a 27-Year Field Experiment. *Agron. J.* 101, 1204-1218.

Fließbach A. (2017)

2. The microbial biomass was highest for the biodynamic and organic management, an increase of 25%. Table 2. and Table 3, with greater mycorrhizal colonisation and mycorrhizal diversity.

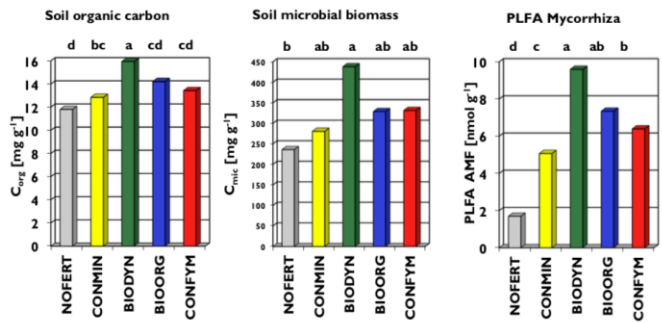
Table 2. Microbial biomass



FiBL Dossier No 1. (2000) Results from a 21 year old field trial. Organic farming enhances soil fertility and biodiversity

Table 3

Sensitiveness of indicators (2004)



FIBL

www.fibl.org

26

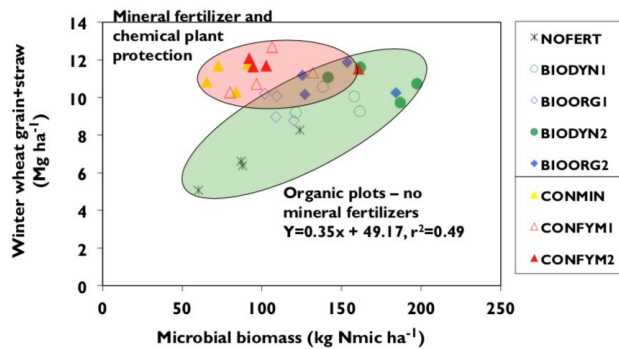
Fliessbach A. (2017)

3. Yield is positively correlated with microbial biomass. Table 4

Table 4

Correlation soil microbial biomass – yield

Sammenhæng mellem udbytter og mængden af mikroorganismer



FIBL

www.fibl.org

31

Mäder et al., 2001

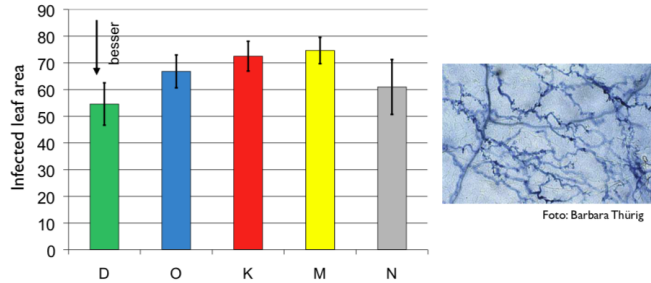
Fliessbach A. (2017)

4. The management system affected the suppressiveness to plant diseases. Table 5.

Table 5

Suppressiveness of soils towards plant diseases

Jordens evne til at modstå plantesygdomme
lav søjle = mindre sygdom



FiBL

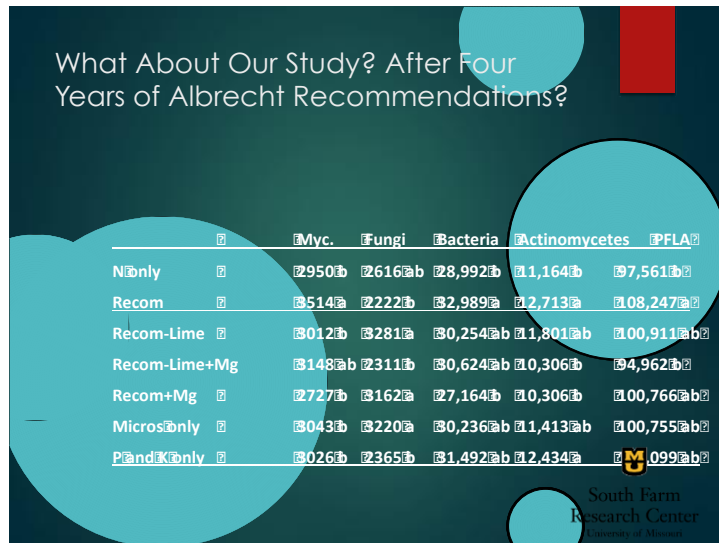
www.fibl.org
Tamm, L., et al. 2010. Soil type, management history, and soil amendments influence the development of soil-borne (*Rhizoctonia solani*, *Pythium ultimum*) and air-borne (*Phytophthora infestans*, *Hyaloperonospora parasitica*) diseases. *Eur. J. Plant Pathol.* 127, 465-481.

Fliessbach A. (2017)

The DOK trial showed that soil structural stability was improved under organic management.

The Missouri University replicated research trial is investigating the efficacy of the BCSR analysis and management in a conventional situation. It has shown that following the BSCR management regime increases soil biological activity and also crop yield. Table 6.

Table 6. Effect of inputs on soil biology



Reinbott T. (2017)

The Aarhus University Foulum research centre manages a farm systems, arable rotation trial, over 20 years. The results show higher levels of biological activity under organic management than conventional.

Clearly the farming system and practices influence biological activity, there are indications from the DOK trial that this in turn increases yield.

Healthy soil: how to manage for it

The principle aims are to provide good soil conditions, high recycling and return of organic materials, appropriate mineral status and high biological activity.

Continually assess the soil visually and use appropriate soil, plant tissue and sap analysis to assess the soil needs and management.

Key practices to improve soil health

1. Maintain good soil structure and drainage
2. Reduce tillage and depth of ploughing to a minimum
3. Use a good crop rotation with high crop diversity
4. Use cover crops for continuous ground cover
5. Use green manures to maximise carbon return to the soil – feed the soil organisms
6. There is increasing evidence that different organic inputs influence soil microbial type, abundance and activity in different ways
7. Include legumes in the rotation to fix N and enhance soil microbial activity
8. Use livestock manure efficiently to recycle nutrients, add carbon to encourage fungi and provide soluble nutrients
9. Compost manure or vegetable waste for high biological activity, carbon accumulation and healthy crops
10. Maintain pH ideally in range 6.3 - 7
11. Use mineral fertilisers to ensure sufficient macro and micro nutrient levels and availability for soil microbe, plant, animal and human health
12. Use soil amendments and inoculants where they are shown to be effective e.g. rhizobia inoculants.
13. Avoid agrochemicals that suppress soil biological activity e.g. Ivomectin, Glyphosate, Super phosphate, nitrogen fertiliser and nematicides.

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Appendix 4: Feeding the soil: restoring biodiversity to agricultural soils.

“Green is the most important factor for soil health” Christine Jones 2017

This is a radical view of farming and soil management, which exposes the failings of conventional food production, challenges some organic farming practices and places photosynthesis and carbon at the centre of future food production and land management. The following summarises some key messages from a one-day workshop by Christine Jones, including a few of my own comments.

The problems of conventional farming are well known, but Christine Jones reminds us of some:

1. In her home country of Australia soil organic matter (SOM) has dropped from between 4 and 25% in 1840 to typically less than 1% in farmed land.
2. Food quality is now 2 – 5 times less nutritious than 60 years ago ¹ and ² ; declines of Cu 24%, Ca 41%, Fe 54%, Mg 10%, K 16%
3. Nutrient decline is coupled with chemical residues which are toxins reducing nutrient availability and the first line of defence against pests and diseases at root level.
4. Declining health of plants, animals and people
5. Reduction in availability of soil nutrients
6. Climate change aggravated by GHG from fertiliser manufacture and SOM loss
7. Nitrate and phosphate pollution of water courses and sea

Her view is that these are easily reversible and that **the fundamental mechanism is photosynthesis, capturing carbon and feeding the soil life and increasing its fertility**: photosynthesis is the basis of the pyramid of life, not soil. Published papers are available on www.amazingcarbon.com

Instead of putting all the emphasis on legumes, as we tend to do in organic farming in the UK and using high levels of soil fertilisers, foliar feeds and inoculants as is common practice in organic farming in the USA, Christine provides guiding principles to inform local practices which will drive a change in agriculture.

Key Principles:

1. **Maintenance of year-round living cover**
2. **Provide support for soil microbial activity**
3. **Promote plant and microbial diversity.**
4. **Land responds positively to the presence of animals provided management is appropriate.**

“as to methods there may be a million and then some but principles are few. Those who grasp principles can successfully select their own methods” - Ralf Waldo Emerson

What does this mean in practice?

1. Green crop cover

Ensuring that the soil is always covered by green plants, and lots of them, actively growing if possible, is the most important factor for soil health. Maximising photosynthesis will produce sugars, which will promote root growth and most importantly produce root exudates, which will stimulate soil microbiology to improve soil nutrient availability, either directly or indirectly via mycorrhiza and build SOM.

Crop cover can be maximised by growing permanent pastures, leys and cover crops; bare soil is unacceptable at any time of year and pastures should not be over grazed, increasing sward height will increase rooting depth.

This will increase diversity of microbes, hold soil, reduce temperature and improve water relationships and root depth and increase plant exudates.

Carbon is the key driver for soil microbes, preventing erosion, keeping lower temperatures in hot weather and improving water holding capacity, nutrient supply and content and crop yield. It is much more important than conventional nitrogen fertilisers, which damage microbiological activity e.g. super phosphate shuts down mycorrhizal activity, and she proposes more important than leguminous N fixation.

There are thousands of free living and associative N fixing bacteria in soil, so it is not just legumes that are the major means of fixing N and she thinks they are not always essential. A view somewhat at odds with organic farming practice.

The proportion of carbon to nitrogen in the crop residues or green manures is important. Rye straw has a C:N ratio 82:1, which will result in slow decomposition and nitrogen starvation of the crop, vetch is 11:1, which will rapidly decompose but with inadequate carbon will not maximise potential biological activity. The ideal ratio for the soil microbes diet is a C:N ratio of 24:1, for example lucerne hay. FYM at 17:1 is a little high in N but works well.

2. Support microbial activity

Creating the right environment and substrate is more important than bacterial inoculation. Christine's view is that it is very rarely worth inoculating with either bacteria or fungi, the only exception being potatoes with mycorrhiza and legumes with rhizobial bacteria. Provide the right conditions instead i.e. cover crops, wide diversity of crops, green manures, manures, rotation, and structure.

Mycorrhiza; it is in their interest to keep plants alive, which they do by supplying them with water and nutrients in return for energy in the form of carbon.

Annuals produce more sugars than perennials, important for root and soil relationships.

3. Diversity

Crop diversity is essential, a similar argument to that of Martin Wolfe at Wakelyns Agroforestry, with diversity of both species and types. Multiple mixes do better than simple mixtures and over a certain number of species underground networks behave differently. Diversity seems to supply more N and become more drought resistant. This might mean planting 20 plant species in a cover crop – and we thought we were doing well with 3 or 4! The Jena trials ³ in Germany and ORC's work on Multispecies Leys support the importance of crop diversity.

4. Animals

The role of animals is challenged by some, but they are of course part of the natural ecosystem so not surprisingly we find that they have an impact on soil functioning. The work of J. R. Leake in the UK has shown how mycorrhizal activity and nutrient supply is increased by the use of manure, the very long-term effect of farm-yard manure on soil organic matter has been demonstrated at Rothamsted and Kris Nichols at Rodale observed that the pulling effect of cows grazing grass has a beneficial effect on root senescence and soil fertility, compared with cutting. Christine encourages us to include animals, provided of course they are fed and managed properly but recognises that there may be other ways of achieving the same results in stockless systems.

5. Some other soil management lessons

5.1 Composting

Christine challenges the use of aerated compost, which will be bacteria dominated and produce humic acids; she argues that even with CMC type composting methods they will not be stable and that anaerobic, plastic covered, fungal dominated static piles of compost is preferable.

The process at root hair level is the one that really builds humus. Humus is not the same as soil organic matter, but contributes to it. Adding clay to compost could build humus, not otherwise.

5.2 Organic Matter

SOM is made of recently died or decayed material of vegetable or animal origin, which is active, unstable and part is rapidly processed in the soil and in the process of mineralisation; an essential stage in making nitrogen and other nutrients available to plants in an organic system. We can't test for humus, but we can do a potassium permanganate test for labile carbon, deducting this from organic matter gives the humus level.

5.3 Mycorrhiza

They are involved through some unknown mechanisms in moving water, sugars and other nutrients to the plant, which can signal its needs to the fungi. Plants can communicate with each other by sending chemical signals down roots and through fungal hyphae, e.g. to stimulate a pest response in neighbouring plants.

5.4 Cultivations

Ploughing and subsoiling damage mycorrhiza as well as earthworms; they may both take many months or years to recover. Cultivations should be avoided or minimised, e.g. by shallow ploughing. Ideally tillage should be limited to 5 cms.

5.5 Fertiliser use

Christine maintains that mineral fertiliser are largely unnecessary in organic and agro-ecological farming; her approach is based almost entirely on supplying carbon to the soil in order to maximise biological activity and enhancing nutrient mobilisation and transfer. The soil has more than sufficient nutrients for crop needs in the long term and application of fertilisers is almost entirely unnecessary. Even phosphate is not needed for the old soils of Australia. If there is one thing that might need adding it is Sulphur.

5.6 Practical results

Christine provided a number of practical examples of the results of applying these management principles, particularly the Hagarty ⁴ study comparing a split treatment field, which found a 30 – 50 % increase in SOM compared with conventional over 5 years, greater at depth, improved nutrient cycling, soil structure, biological activity and water holding capacity and increased stocking rates through the following practices:

1. Keeping soil covered
2. Stopping the use of N and P fertiliser and herbicides
3. Using vermi-liquid and diluted compost extract
4. Rotational grazing of a tall sward with longer intervals.

“ In the same way as it is important to ‘feed the rumen not the cow’ it is also important to ‘feed the soil micro biome not the plant’” Christine Jones.

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⁴ Ampt P and Doornbos S. Communities in Landscapes project: Benchmark study of innovators. University of Sydney 2010
<http://www.amazingcarbon.com/PDF/CiL%20project%20SEIS.pdf>

Appendix 5: Compost

The importance of compost is much debated in organic and agro-ecological circles, considered by some to be central to soil fertility, for others it barely gets a mention. The generally agreed position in the UK is that aerobic composting is important if green waste or wood chips are to be made suitable for applying to the soil. It is worthwhile doing some degree of composting of farmyard manure if soil organic matter levels are low, to control disease and weed seeds and to make the material more friable and therefore more easily incorporated by soil organisms. The composting process itself may vary from turning 2 or 3 times with a fore loader to multiple turning with a specialist turner, inoculation and carefully controlled temperature and carbon dioxide levels. For more information see <http://www.organicmeasures.co.uk/To%20compost%20or%20not%20to%20compost.pdf> Good quality farm-yard manure may not need composting if the main aim is to provide more readily available nutrients.

Christine Jones (Australia) instead proposes that anaerobic compost is the most effective way of stimulating soil biology. Edwin Blosser (USA) made the case at the ACRES conference for the use of very precisely managed aerobic compost and Sandy Syburg (USA) argues that compost and its products are invaluable to farming to build soil organic matter and contribute nutrients and the only way of effectively using organic “waste”. Some ecological farmers in the UK see very light, annual applications of well made compost as an essential means of inoculating soils with mycorrhizae.

Composting Made Simple – conference presentation

Edwin Blosser <http://midwestbiosystems.com>

In Edwin’s view compost is central to organic soil management in order to effectively utilise green waste and stimulate soil biological activity.

The basis of his composting technique is the Luebke Controlled Microbial Compost (CMC) system, which has been adopted by some farmers in the UK following the workshops that I organised in 2003 at Holme Lacy College. His experience is that through aerobic composting following a system of closely controlled temperature,

carbon dioxide and moisture (45%) that organic waste can be rapidly converted into high quality compost.

Apart from the mix of organic materials of the correct C:N ratio, some clay is added to help stabilise the product. Edwin also thinks that inoculation is essential, not only that but Edwin uses 3 different inoculants during the rapid composting process, completed in 8 weeks. This is rather at odds with my experience, which is that good quality compost can be made without the need for inoculation. But is the end product the same?

Well made aerobic compost will help build soil organic matter, provide a home and substrate for microbial activity, counter drought, requires less fertiliser, help prevent disease, produce a more friable material, reduce moisture in plants and add and balance minerals.

Anaerobic compost can burn roots, lose nitrogen as gases, and lose energy in the form of carbohydrates.

Edwin gave an example of a farm that increased soil organic matter (SOM) from 2.6% to 2.8 % over 10 years with standard compost. Over the following 10 years SOM increased to 16% with CMC type composting with inoculation. Is this possible? In my experience such rapid increases to such a high level can only be achieved by exceptionally high compost application rates.

Edwin gave another example where after 30 years of 4 inches green waste applied annually the SOM was still only 2%. Replacing the green waste with compost made from the same material the SOM increased to 5.9% over 5 years.

Experiences of a farmer and compost producer

Sandy Syburg farms 300 acres of organic arable crops in South Wisconsin, however his principle business is composting municipal green “waste”, 100,000 tones a year using an aerobic composting process. While perhaps not as controlled as Edwin Blosser’s system he does monitor temperature and carbon dioxide and uses top of the range turning equipment to produce a high quality compost <https://www.purplecoworganics.com/farmers/full-cycle-ag-system/>

Our discussions at Oconomowoc focused on soil management and the role of compost to supply nutrients and organic matter, stimulate biological activity and make nutrients more available. The basis for compost use is soil analysis; the company offers a free soil analysis service to customers and again they rely on Albrecht analysis undertaken by Mid West Labs. There is no use of plant tissue analysis. The company offers a wide range of compost products to commercial farmers including straight compost and with added rock phosphate, calcium, sulphur, trace elements and humates, liquid products and non-peat growing media for plant raising. Interestingly by adding rock phosphate towards the maturation stage of the composting process,

which is enhancing phosphate availability, which contrast with the lock-up that we sometimes experienced in the P Link trials.

Food quality and the health of animals and people underlie the objective of soil management expressed by Sandy and many other organic farmers that I met. The small but significant difference between organic and conventional food in the UK (Reference Quality and Low Input Food, Newcastle University <http://www qlif.org>) is accentuated by the very poor production methods of conventional farming in the US. Based on Washington University food quality data Sandy's view is that soils that have had any mineral deficiencies rectified with minerals from compost will be of higher nutritional value than those that have not.

The common experience of the organic farms that I visited in the USA is that soil mineral monitoring is excellent, there is little or no soil biology monitoring except occasionally for earthworms on a few farms, and that inputs of macro and micro elements and stimulants in the form of inoculants and humates, as soil and foliar applications on an annual basis is general. None of the farms that I visited focused strictly on a closed system approach, relying entirely on biological fixation of nitrogen.

Photo The effect of use of compost on root growth



Appendix 6: The Nexus of Soils, Plants, Animals and Human Health

Singh, B.R., McLaughlin, M.J., Brevik, E.C. (eds) 2017 **The Nexus of Soils, Plants, Animals and Human Health** Catena-Schweizerbart, Stuttgart

A book review by Mark Measures 2018

This book demands your attention! It starts off with the statement “soil and human health are interconnected” because “healthy soils produce healthy crops that in turn nourish humans and animals allowing for their health and productivity”. It goes on to point out “nearly 800,000,000 people are undernourished and nearly 40% of the world’s population are suffering from micronutrient deficiencies”.

Initiated by the International Union of Soil Science the book provides an overview of the linkages between soil and plant and animal and human health. It is the third in a series of publications produced each year for the Decade of the Soil 2015-2024. It consists of chapters contributed by specialists throughout the world dealing with individual aspects of soil health. With a strong research and science orientated approach, the editors set it clearly in the principles established by the founders of the organic movement in the UK; “the health of soil, plant, animal and human is one and indivisible”. It is very comprehensively referenced.

The first three chapters take a holistic perspective of the role of soil in terms of plant and animal and human health and consider the historical perspective of the principle. It faces head-on the challenge set by our far-sighted forebears in the organic movement; Balfour, Howard and McCarrison who in turn follow millennia of commentators concerned with farming and human health, stretching back to Hippocrates and Moses.

It identifies the role of soil in terms of nutrient supply, food production and nutrient content, the importance of soil biodiversity and the wider environmental relationships. It acknowledges the decline in food quality with the increase in yields resulting from conventional inputs and the effect on soil organic matter. As well as the need to ensure adequate trace elements it highlights the problems of soil pathogens and excess heavy metals.

Subsequent chapters are contributions from scientists who take a narrower or more reductionist view of the links, including the impact of soil structure and microbial processes on macro and micro-nutrients, the role of genetic engineering and the relationship of soil organic matter to crop production and climate change.

This book focuses on nutrients and minerals, ensuring that there is neither excess nor deficiency of the plant or animal’s needs. It deals specifically with issues of protein supply. It considers nutrient supply from the soil and recycling through organic

matter, the action of soil organisms making nutrients more available and the need to avoid excesses, which may inhibit uptake or utilisation by the plant or animal.

The book does not address some of the more subtle aspects of food quality and health, sometimes described as “life force” or “vitality”. It doesn’t deal with some essential soil-related qualities of food such as taste or “terroir”, which undoubtedly have some impact on human health, nor the biological qualities i.e. antioxidants, which affect the immune system, or the impact on the maintenance of a healthy gut flora. It does not consider the benefits to human health of working with the soil.

It puts considerable emphasis on some negative impacts of the soil on human health, such as soil pathogens and soil borne diseases.

It leads on to the concept of soil health and the need to ensure that this recognises the impact of soil on the health of plants and the animals and people that eat them. Soil health is now widely advocated in farm, research and policy circles but in my experience this newfound thinking does not generally go beyond the functioning of the soil and rarely does it recognise the interconnections with human health.

The book shows how many of the problems of human health can be addressed by the way we manage the soil; we might not always agree with some of the means advocated and it does not provide any radical new insight into the concept of health, but it does set out the science in the context of a comprehensive awareness of the issues and the inter-connections between soils, plants, animals and humans.

It sets out the principles, which of course are all too familiar to those involved with organic farming. It provides an invaluable research perspective on aspects of soil nutrient management. You may therefore wonder why I haven’t mentioned organic farming in this review; that’s because this book only makes a cursory mention of organic farming, and that in an historical context. Is this just an attempt to avoid the “O” word for fear of frightening the horses? Or are the editors really unaware of the worldwide organic movement that has been putting the all-important principle of the link between soils, plants and humans into practice for nearly a century?