EARTHWORM OPPORTUNITIES FOR UK FARMERS

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Sponsored by The Dartington Cattle Breeding Trust

Table of Contents

INTRODUCTION

Key Thought: Can I build topsoil? Yes. How can I do it? Feed earthworms!

I am most grateful to the Dartington Cattle Breeding Trust.

My thanks also go to my husband, Tony, and sons Charles and Torin, who have been unhesitating in their support during the course of my Nuffield application, travelling and consequent questioning. Their light-hearted approach to new ideas I brought to the kitchen table has kept my feet on the ground, and provided a forum for fascinating debate!

My parents and my parents-in-law were generous with their time and energy, helping with children, home and livestock in my absence, and I could not have contemplated travelling so far away without their input.

I am a first generation dairy farmer. We have lived in Monmouthshire for the past 21 years, having started our farming in Sussex in 1981, and have always concentrated on low-input dairying, in particular maximising production from grazed grass.

Recent organic conversion presented a new range of concepts and fresh challenges, and my interest in earthworms grew as I became more aware of the importance of protecting and improving our soil.

Rising energy, fertiliser, fuel and feed costs, coupled with additional environmental awareness and management guidelines within the European Union, are necessitating innovative business adjustments and thinking. Developments in the waste management industry also offer exciting opportunities for agriculture. The challenge of rising nutrient costs, and the difficulty of managing raw manure on land, led me to look at the potential for earthworms to enable more effective nutrient release, reduction of bought-in fertilisers, and an increase in quality soil organic matter. These benefits can be significant for both organic and conventional systems.

Aim of my study:

Cleopatra declared earthworms sacred and ordered their protection, so great was the importance placed upon their presence and action in the fertile Nile Valley. Charles Darwin's last book and one of his most important was 'The formation of vegetable mould through the action of worms with observations of their habits'.

I wanted to explore potential use for earthworms and their casts, and to get behind the hype so often associated with this industry. The aim of my study was to report on the relevance and importance of earthworms and other soil biology to farmers and agriculture, and to explore opportunities in this area.

My conclusions and recommendations are broad and practical. I trust that I have applied common sense, experience, observation and independent thought processes.

I have an increasing concern for the direction in which global agriculture is moving. So often, farmers and the land under their care are quashed beneath a weight of allied commercial interest and beurocracy. The resulting work load and increasing business vulnerability have, in my view, led to low self-esteem and confidence. I feel that if farmers give themselves space to reconsider nature's processes afresh, it is possible to reverse this situation. Healthy soil, combined with good business management, can ensure a sustainable, profitable future for UK farmers. Without healthy soil, farm businesses are too vulnerable.

My hope is that this report addresses:

- why healthy soil biology is important
- what is required to achieve this
- practical options for farmers to consider
- areas of opportunity

My Travels:

Australia – The challenges of the soil and climate in Australia have sparked very innovative thinking and practice. I visited worm farms, worm waste-disposal units, farmers using biological soil applications, compost sites producing top quality products for variety of uses, and also the Western Australian No Tillage Farmers Association (WANTFA) I met those applying new ideas within commercially sound operations.

I journeyed across NSW, from cattle country to the very dry rice-growing areas, down into Victoria, Gippsland, across to Mount Gambier and South Australia and finally to Western Australia – to the Margaret River vineyards and the arable area East of Perth.

India - I saw practical on-farm use of worms and wormcast, and different approaches to production and end-products. The reverence within India for the cow enables good acceptance of the value of cattle, manure and the natural processes within soils and plants.

Europe - Holland and the UK have a wealth of knowledge and experience.
It was important that I could apply my findings within the European context, bearing in mind both climatic conditions and regulations within which we farm. I focused on compost, compost sites, waste guidelines and wormcast production and research.

China - I visited China as part of a group, focusing on the dairy industry.

Development of the Study
Although my initial interest had been in earthworms, my general focus moved to encompass the whole community of organisms in the soil, and the potential benefits available to farmers.

- I attended an Elaine Ingham Soil Foodweb Course at Laverstoke Park.

- Biodynamic Workshops and meeting many Biodynamic practitioners in Australia, India and the UK opened my mind to other factors we should consider

- No Tillage production methods in Australia and permaculture units in India assisted the course of my findings.

- Vermicompost units in Australia, India, Holland and Ireland enabled comparison of differing techniques and scale.

- Quality compost production units in South Australia, Western Australia and Holland had innovative developments working with farmers.

BIOLOGY AND HABITS OF THE EARTHWORM

Summary:
A basic knowledge of the habits and requirements of the 3 categories of earthworms, with an understanding of their necessity as part of the cycle of nature within the soil, is required in order for consideration of opportunities for agriculture relating to each type separately.

1. THREE BASIC TYPES

Although there are many species of earthworm, they can all be broadly put into one of three categories:

- **Epigeic**
- **Endogeic**
- **Anecic**

  - Epigeic are litter dwellers and feeders and do not bury far down into the soil.
  - Endogeic live in the top 30 cm or so of soil, and also the surface litter. They form horizontal, irregular burrows.
  - Anecic are the deep dwelling worms, larger in size and forming permanent vertical burrows.

Epigeic worms. These are the worms frequently used for worm farms, home composting and naturally found in forests and anywhere there is a surface litter of vegetation. The most well-known in temperate countries are ***eisenia fetida*** **('red worm'),** ***eisenia andrei***., ***dendrobaena rubida and lumbricus rubellus.*** Epigeic worms feed on soft organic matter and have a less functional gizzard than other categories.

Endogeic worms tend to be slightly larger, consume more soil as part of their diet than the epigeic worms. These would frequently be found in our soils if we dug a soil sample. They possess a strong, functioning gizzard. Endogeic worms sometimes excrete casts on the surface, but usually use their extensive network of horizontal burrows, lining the sides, and working within the top 15 cm of the soil.

Anecic worms, a common example being the *Lumbricus Terrestris*, 'nightcrawler' or 'dew' worm, can leave big mounded casts on the surface of the soil. Their burrows often extend more than 2 metres below the surface. They are slower to reproduce, difficult to breed in artificial conditions and can live longer than the other 2 types.

They surface during the night (hence the name 'dew'), sometimes keeping the end of their flattened tail within their burrow and drag organic matter into their burrows, to consume when it has further decomposed. They often form middens of material on the surface, above their burrow.
They feed on humus and soil and bring soil and rock particles from lower levels up to the surface levels. The process of grinding is important. The surface area of the ingested material is hugely increased, allowing microbes to feed and multiply in greater numbers on the undigested food when it is excreted as cast.

2. EARTHWORM BODIES

- Ideally, earthworms like their habitat to contain 60-80% moisture, temperatures between 17-25 degrees Centigrade, partially decomposed material and/or soil high in organic matter and with a great variety of bacteria and fungi.

- They can live in a broad pH range but prefer slightly acidic conditions of around pH 5. Earthworms have a buffering effect on pH of soil, bringing it closer to neutral, whether the original soil was acid or alkaline. The wormcast produced from acid soil may have up to 75% reduced acidity compared to the surrounding soil from which it was produced, primarily due to intestinal calcium secretions.

- Earthworms breathe through their skin. Aquatic worms do not have the lower series of holes along the sides of their bodies. All earthworms have an ability to survive in water for a period of time.

- They are very sensitive to moisture, temperature and light.

- The head end of the worm is more sensitive than the rear end.

- Should their skin dry out, they die.

- If temperatures become too high, they die if they cannot move to a cooler place.

- If temperatures are too low, they slow down their feeding and breeding and can die, but are able to survive very low temperatures if certain other conditions are kind.

- The casts contain microbes which are deposited on the lining of their burrows (the drilosphere) and on the soil surface.

- The worm's digestive system is made up of a tube within its body, with different compartments through which the ingested food passes. These are: pharynx where mucus is released, gizzard where fragmenting and grinding occurs, oesophagus where calciferous glands release calcium carbonate, intestine where enzymes are secreted in different parts for digesting the food and finally undigested food is excreted.

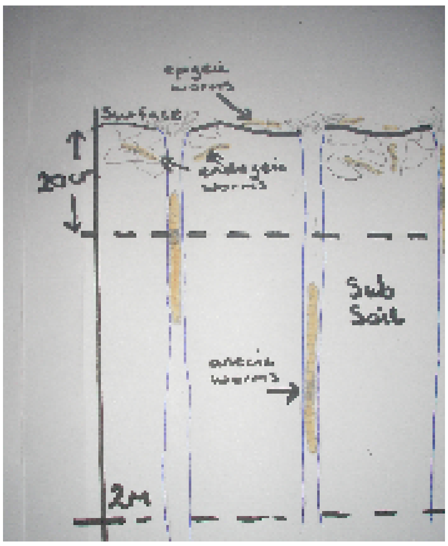


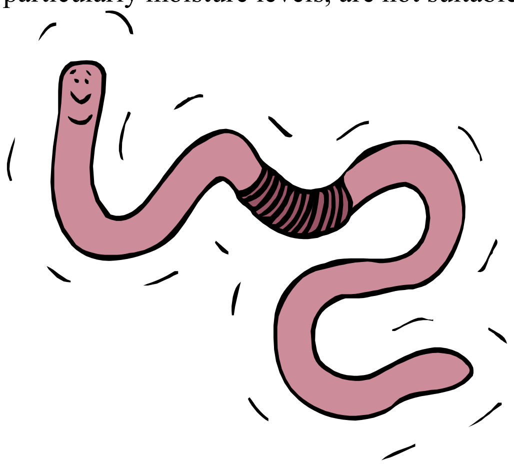
Illustration of working depths
of the different types of earthworms.

3. ACTION WITHIN THE SOIL

- It has been estimated that with a healthy population of endogeic and anecic earthworms, 1100 miles of burrows could exist per acre, if undisturbed:
    - Epigeic and endogeic worms, who richly line their burrows with wormcast, could form 800 miles of haphazard burrows, encouraging air, moisture and root growth.
    - Over 300 miles of larger permanent vertical burrows from the anecic worms could act as a main road for the rock deposits and soil from up to 2 metres below the surface to be brought up, having been mixed and ground within the intestine of the worm.
- More than 15 tonnes of castings per acre per year could be produced in fields. Earthworm deposits or casts contain up to ten times the amount of soluble plant nutrients as the original soil, in addition to various plant growth hormones, enzymes, and vitamins.
- Most microorganisms survive the passage through the earthworm, and increase in numbers, particularly when the wormcast is finally excreted when the numbers explode. Some are digested and used by the worm. Pathogenic organisms generally do not survive passage through the earthworm. When fungi are taken in, some are ingested but many pass through and also the spores survive.
- The coelomic fluid is the liquid inside the worm that is also excreted through the skin and affects the wormcast. It is of particular interest and significance, detailed later in the report under 'Vermiwash', and its protective qualities are an example of how the earthworm can enhance its own living conditions.

4. REPRODUCTION

Most earthworms have male and female sex organs, but require another worm to mate with, and they both then produce eggs - small cocoons which change from an olive colour to brown as they get closer to hatching. These cocoons are capable of remaining dormant if conditions, particularly moisture levels, are not suitable for hatching. It is possible to see the active baby worms inside the egg if moisture is sufficient. Cocoon numbers, frequency of production, incubation length and life-expectancy vary from species to species. Generally, the smaller, litter-dwelling species produce more cocoons, containing more baby worms, with shorter life-cycle and life-expectancy. For example, the *Eisenia Fetida* takes 30 days from hatching to maturity, produces about 3 cocoons per week, with about 3 worms per cocoon. The anecic worms produce fewer cocoons, containing perhaps only one baby worm and their life-cycle is longer, reaching maturity at one year old.



The 'saddle' or clitellum does not develop until the earthworm reaches sexual maturity.

THE EARTHWORM ROLE WITHIN SOIL BIOLOGY

Summary:

. If we have a reasonable understanding of our soil biology, we are then able to consider in an informed manner each and every activity involved in our soil and crop management.

It is my strong belief that by doing this we are able to work with the natural processes and provide the best chance for enabling the crop to acquire truly balanced nutrition and hence also the animal and human feeding upon it.

This is a highly controversial area, and perhaps the best way forward for us, as farmers, is to practice appropriate management practices to enhance the full range of beneficial biology and to be able to report on the health benefits, whether measured or sensed, in ourselves, our livestock and the crops we grow.

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Inter-relationships between soil organisms
How to nurture organisms and their beneficial actions - Do's and Don'ts
Importance of Carbon:Nitrogen ratios

5. INTER-RELATIONSHIPS BETWEEN SOIL ORGANISMS

i. General:

When I first put on mask and snorkel to view the activity below the surface of the sea, the feeling of awe and wonder at a vast living world, normally unseen, was challenging and will remain with me always. I have experienced the same during the past months of Nuffield travelling and study with regard to the soil and the life therein.

Although aware that the presence of earthworms was 'good', I had not appreciated their part within the range of organisms. I had also been unaware of the limited extent of our current knowledge with regard to the biological organisms and their individual and inter-related roles within the soil life.

The Soil Food Web course at Laverstoke Park, Hampshire, was an excellent introduction to the range and function of the whole biological cycle within the soil.

Understanding how the organisms form part of an interdependent cycle continually reinforces to me the importance of the diversity. How damaging to the soil fertility, health and mineralization any break or damage to any part of this cycle can be, formed a central part of my thinking process during the course of my Nuffield travels.

I have become very aware that, particularly in relation to soil microbiology, there is still so much that we do not fully understand. Whether scientist, nutritionist or farmer we perhaps have an understanding of 5 percent of the functions of the various interactions occurring within the soil between organisms, plants, chemicals, enzymes and minerals.

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> "The tree has the knowledge and we eat the wisdom. We cannot know full knowledge"

Dr Vasundhara – head of Division of Aromatic and Medicinal Crops, University of Agricultural Sciences, Bangalore, who produces and uses vermicompost as tea and compost.

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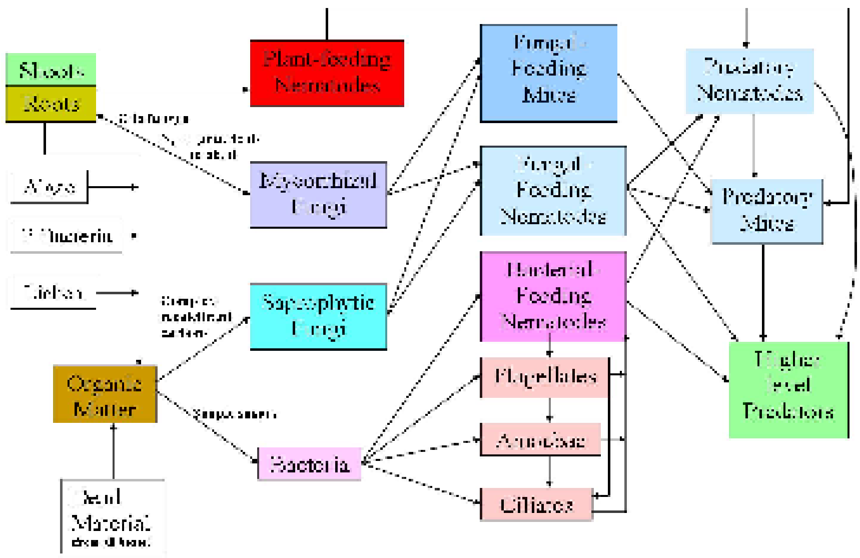
From microscopic bacteria and fungi through to the more obvious earthworm, every organism has its part to play. Each has a particular preference and requirement.

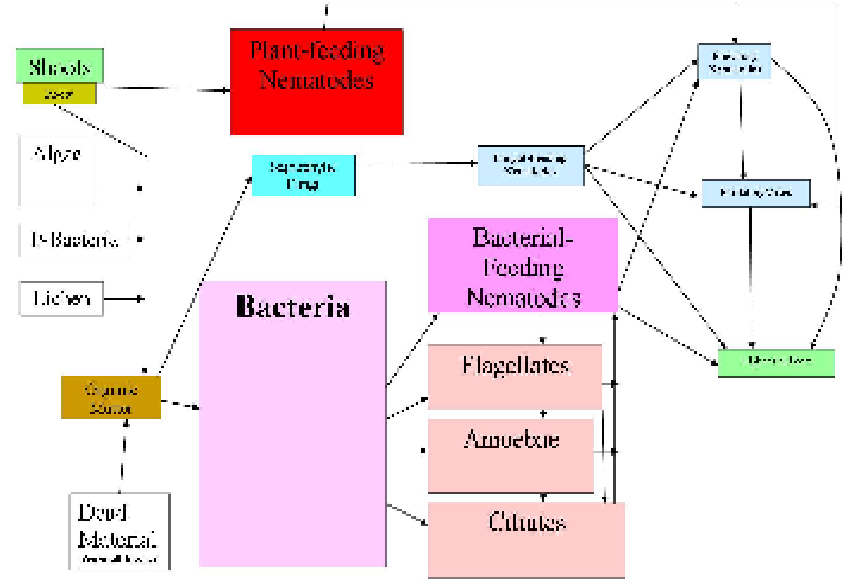
Various bodies, including The Soil Foodweb, with Dr Elaine Ingham, have attempted to categorise these. While some in the world of soil science question how exact we can be in determining 'target' numbers and ratios, I think that the raising of awareness of these is relevant to all farmers.

The cycle within the soil is similar in many ways to that of the ocean.
Small organisms are preyed upon by larger ones, shown in the simplified chart below. Excreta and/or dead organisms provide feed for plant life. The plants are part of the cycle, exuding 'goodies' for the organisms in return for nutrients. Around the rhizosphere or root areas there is in operation an intense barter system.



The Soil Foodweb in Lawns, Vegetable and Row Crops systems

Soil Foodweb charts printed with kind permission of Elaine Ingham.



The Soil Foodweb in Weed Systems

Different crops prefer a different ratio of organisms, particularly between bacteria and fungi. For a guide, the Soil Foodweb website offers suggestions. I will explore this later in the report.

ii. Primary Decomposers

Bacteria and Fungi are the 'first stage' of the cycle

- They feed upon organic matter and as they eat they either grow or multiply.
- They make use of the carbon from the organic matter as energy
- Different organisms feed on different material and compete in various ways
- Different types will become active and prosper according to their living conditions
- Generally, the more plant-beneficial ones will thrive in 'houses' with an aerated environment and plenty of food and moisture. As conditions become less than ideal, the non-beneficial types are able to multiply and dominate
- At different temperatures different types will perform their function to a greater or lesser extent.
- These organisms will feed themselves before they are able to 'share'.
- If conditions are not suitable for a particular type, they will become dormant or, in extreme conditions, die.
- Growth and multiplication can be very rapid indeed
- Fungi are very susceptible to damage from 'slicing and dicing' by soil disturbance or cultivation
- Conditions for thriving beneficial bacteria may unfortunately discourage a good fungal community
- Bacteria and Fungi are the primary decomposers of organic matter. They eat, grow and/or multiply and hold the nutrients within themselves. These nutrients will only become available to the plants when the bacteria and fungi either die or are eaten by another organism and subsequently excreted in chelated, plant-available form, and remain as such.

- Additional required plant substances such as vitamins and enzymes are made available by the soil organisms. Even the organisms' own vitamin and enzyme requirements may need to be provided by other specific microbes.
- When eating and growing, the bacteria cluster together and form well-glued clumps of aggregate. These are a most secure way to hold nutrients in the soil, retain moisture and air in the pockets within the clumps and protect themselves from being leached. The fungi grow bigger by extending their length, and by forming branches. These also form a secure and stable physical structure within the soil.
- Organic matter is feasted upon by bacteria and or fungi depending on its type. Humus is the result of microbially decomposed organic matter. Humus has three times more nutrient holding capacity than clay. This point is crucial in appreciating the benefits of healthy soil biology.

Mycorrhizae fungi:
These are root-working fungi and are not involved in organic matter breakdown.
They form a working association with their plant, exchanging carbon-rich products of photosynthesis from the plant for nutrients and water pulled in by the hyphae arms of the mycorrhizae.

This enables the plant to access mineral nutrients beyond the immediate area of the roots. The mycorrhizae also assists plant growth and health, and protects it in various ways, including production of plant growth hormones and antibiotics.

Endomycorrhizae are Vesicular Arbuscular Mycorrhizae, growing between the cells within the root without harming the plant (VAM)

Ectomycorrhizae live outside the root and are visible to the eye.

Different types form associations with different plants:

- Endomycorrhizae (VAM) with grasses, row crops, broadacre crops
- Both Endo and Ectomycorrhizae with deciduous trees and shrubs
- Ectomycorrhizae with evergreen conifers/pines.

It is estimated that 80 percent of all land plants could form these associations with appropriate mycorrhizae. Brassicas are among those not forming such associations.

The ability for mycorrhizae fungi to draw nutrients to the plant is staggering, both in terms of the relevance to present day agriculture and also the physical distance that the hyphae, or mycelium, are able to extend in order to find and deliver to the plant. There is particular importance with regard to phosphorous. The presence of VAM effectively increases a plant's root system tenfold.

Mycorrhizae will feed and protect a plant, but need to be present from an early stage to maximise the benefit, particularly for protecting the plant from fungal attack. Using carbon from the plant, the fungi make and grow a substance called glomalin. This is, in effect, a sticky glue that falls from the hyphae and attaches to soil particles and organic matter, forming clumps. These clumps are very tough and secure carbon storage units. The glomalin molecule is unique among soil components for its strength and stability, being very difficult to break down by wind, rain or even microbes.

Mycorrhizae fungi are as delicate as they are important
It is a slow and laborious procedure to reintroduce Mycorrhizae to a field if the original population has been destroyed, particularly as the type you require may differ from those

commercially available – you really need to physically dig up and inoculate deprived fields with clods from any fields still containing your local Mycorrhizae. This is likely to be old established permanent pasture that has had few artificial inputs. Many of our agricultural soils will be empty of Mycorrhizae.

Earthworms could play a vital role here in the reintroduction of VAM to our pastures. VAM spores will survive passage through the earthworm and thus could be spread across wider areas in a shorter space of time.

Practices which may damage or destroy Mycorrhizae include:

- Use of fungicides
- Use of non-composted manure
- Ploughing and other cultivations resulting in cutting of the hyphae
- High phosphorous levels deter and can destroy mycorrhizae: Levels 1, 2 and lower 3's are tolerated, but greater than 30ppm extractable or available Phos is not good for them.

Mr John Reeves from the Forest of Dean, UK has been studying Mycorrhizae Fungi for many years. His work, thoughts and discussions have helped me to recognise the importance of protecting and encouraging the levels of mycorrhizae within our soil life.

iii. Secondary decomposers

Bacterial and Fungal feeders:
This group of organisms is essential to enable the nutrients held within the bacteria and fungi to be released in a form available to the plants.
As with the bacteria and fungi, living conditions within the soil greatly determine their health and number. They are a fascinating group – some with ingenious ways of tackling their foes. I now find myself imagining them busying away beneath my feet when I am walking across fields.

A very brief description of some are:
Protozoa:
Flagellates – suck up bacteria
Amoebae – feet ooze out and the body follows. Eat certain types of bacteria or eat and spurt them out as they move along.
Cilliate – vacuum cleaners with sucker mouths. Their cilliae look like rowing arms. These thrive in anaerobic soils and so their numbers are relevant.
These three bacteria feeders will eat each other if they fit into their mouths!

Nematodes: tiny worms, some of which are visible to the eye
Types include:
Bacteria feeding nematodes
Fungal feeding nematodes (have a spear with which to puncture the cell wall and suck out the contents)
Predatory nematodes – eat other nematodes. Have a tooth and either eat or bite and suck.
Plant parasitic nematodes – punctures the root cell wall and suck out the contents. A few are tolerable, but the Soil Foodweb estimate that more than one per gram of soil is likely to cause economic loss. Therefore when looking at samples it is important to check your dilution calculations and know the significance if you see even one of these.

Microarthropods: these wander around, possibly covering half a metre per day and as they do so act as taxi-cabs and move the smaller organisms with them. Their travelling habit again emphasises how difficult it is to monitor effects of soil treatment because the organisms in the soil are unaware of surface trial plot markings!

The Soil Foodweb labs are able to identify and give approximate counts of the different groups of organisms. The ratios of the various types and the numbers of potentially threatening organisms can be revealing. They also assess the activity levels. I now have a microscope at home, and it is fascinating to look at liquid samples and watch life happening within a drop of compost tea (see later section) or diluted soil.

6. NURTURING ORGANISMS AND THEIR BENEFICIAL ACTIONS

> ‘The soil must be man’s most treasured possession:
> So he who tends the soil wisely and with care
> is assuredly the foremost among men’
>
> Sir George Stapleton

i. HOW TO ENCOURAGE THE BENEFICIAL ACTIVITY

The earthworm has evolved with amazing self-preservation characteristics. While we are aware that the earthworm is vulnerable and sensitive to ammonia and inorganic salts, it is able to consume a range of toxic materials and still survive. Release of calcium from its internal calciferous glands helps reduce the impact of acidity from applied fresh waste. The ability to ingest pathogenic organisms and destroy them, together with the protective qualities of the fluid it excretes and the neutralising of the soil pH around itself makes the earthworm a unique survivor. Should the worm not like something about its living conditions, an applied chemical or other aspect it can, within reason, move away if it has time to realise what is changing.

Unfortunately, many of the other soil organisms are not so well-equipped, and even the earthworm cannot survive some of our agricultural practices and inputs. Suppliers of insecticides, pesticides, fungicides, artificial fertilisers and any other soil or foliar treatment should have a response to our questions about the effect of the product on each sector of organisms within the soil, before we commit to its use. The nutrient and life-cycle can be damaged by negative effects on any group of the organisms.

The difficulty of setting up trials to look at soil biology and effects of treatments to agricultural fields is fully understandable when one realises that each farm, each field and different parts of the fields could have widely varying ratios and diversity of biology depending on the history of the crops, forms of tillage, pesticide or fungicide use and organic matter content. Aspects such as drainage, parent rock type and rainfall are just a few of the other major influences.

The degree to which we can alter the ratio and diversity of the soil biology is a hot question! As with so many agricultural inputs, vested commercial interest can influence opinion and advice. However, there are many areas of agreement in relation to soil biology between farmers, scientists and manufacturers. Probably the main areas are:

- **Full range and diversity is crucial**
- **Beneficial organisms have to have air, water and food**

ii. RANGE AND DIVERSITY

Diversity and balance are expressions frequently used with suggestions to help achieve truly healthy soil and thus healthy plants, which are then able to largely defend themselves from disease or predatory attack.

The process of nutrient cycling is a major role of the various organisms in the soil.
We are able to identify and allocate roles to a tiny percentage of organisms, for example B Vitamin producers, free-nitrogen fixers. We are unlikely to fully identify type and role, but we are aware that they will exist for every conceivable function connected with the living world. Recent research suggests that damage to manganese-solubilising bacteria, due to certain spray use, is resulting in manganese deficiency in soy bean crops.

Micro-organisms are also able to perform protective functions. The presence of the range of organisms, and the subsequent range of the roles they perform, can bring benefits that farmers are possibly not fully utilising. This could include the plants having a physical coating of beneficial fungi on their leaves to prevent attachment of disease-causing organisms, or having a balanced nutrient content and thus not giving attack-attracting signs to predators.

If we are able to limit the habitat conditions within our soils to those that naturally select for beneficial organisms, the natural processes within the soil will go a very long way towards ensuring healthy, disease-free plants and crops. This message was clearly given to me by many and varied farmers I met in Australia and India.

iii. AIR, WATER and FOOD:

The requirements of living organisms in the soil are very similar to those of above-ground livestock including cattle and humans. Although there is an intricate series of inter-related activity occurring within the soil, I think that it is important not to become daunted or intimidated by science.

There is no doubt that damaging actions can be hugely detrimental to the quantity, diversity and quality of the soil organisms. This will impact on both the quantity and quality of our farm produce, whether this can be seen visually, tested with modern scientific tools or remains in part beyond our current level of understanding.

However, the basic requirements of Air, Water and Food are simple to grasp.
As farmers we are able to consider these three aspects when establishing systems or treatments within our farm management. Ideally soil should contain 25% air and 25% water and have a humus organic matter of 5% or greater.

We have to work within the limitations of our farm's parent rock, and we may have individual beliefs or conditions we choose to apply. Whether mixed, arable or livestock enterprises form our farm business, we can all consider the options and incorporate the most appropriate and practical for our situation.

In the various countries I visited I saw a wide range of farming system, from highly mechanised, vast areas to much smaller labour-intensive units. Some options will suit one system better than another. I do not believe that establishing a system that encourages healthy soil biology will in any way compromise the commercial profitability of a business. In fact I believe the opposite is the likely result.

The **Chemical, Physical and Biological** aspects of the soil are linked and entwined. It would not be correct to say that one should be addressed before the other. An overall view of the relevance of each, combined with on-farm knowledge, should help each farmer to determine the most appropriate way forward for their situation, and which step or steps to take first. It may be that a damage-limitation exercise is appropriate, if certain practices or inputs are considered necessary. Materials readily available on, or close to, a farm may influence decisions.

I will give a few examples of options to consider. Many are well tried and tested.

AIR

Compaction is one of the major problems within agriculture generally.

Oxygen levels may dictate the type of active organism and its ability to dominate:

- At oxygen levels greater than 6ppm = Aerobes producing 1 set of enzymes
- At oxygen levels between 4-6 ppm = Facultative anaerobes producing two sets of enzymes and therefore requiring lots of energy
- At oxygen levels lower than 4ppm = Anaerobes producing one set of enzymes

Anaerobic conditions allow anaerobic organisms to become active. This is generally undesirable. As pH decreases with the reducing air, the anaerobic organic acids subsequently produced can damage plants

Causes of compaction can include machinery or livestock traffic, severe chemical inbalances, lack of organic matter and soil biology particularly earthworms, or heavy rain on exposed soil.

Heavy doses of slurry can cut off the oxygen supply to earthworms and others.

Examples of remedial activies may include:

- No Till or reduced tillage,
- Controlled Traffic Farming, limiting compacted areas to specific tracks, The advantages of CTF are not restricted to arable fields. Recent work in Denmark has shown significant increases in yield and also longevity of sward, due to reduced damage.
- Use of penetrometer to establish depth of compaction
- improved grazing management to avoid continual livestock pressure,
- addressing for example the Calcium:Magnesium ratio to encourage clay particles to repel each other and therefore provide air spaces (see later section on Compost for biology-friendly soil applications methods)
- Encourage earthworms and their aerating habits
- Mechanical aeration (need to assess benefits alongside detrimental aspects)
- If possible grow plants with a variety of root depths. Appreciate the action of certain ‘weeds’ in providing deficient minerals and aeration channels.

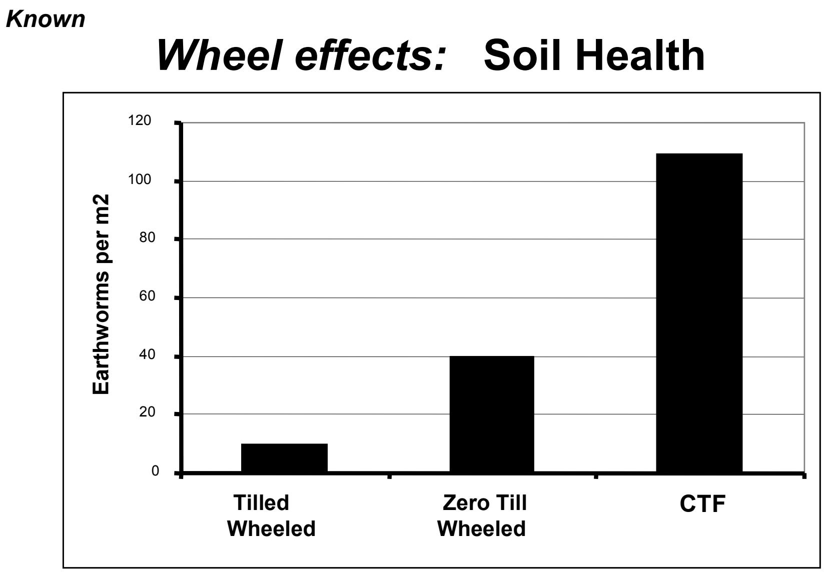
The degree to which improved levels of soil biology and their activity will ensure continued control of compaction will vary according to soil type, severity of compaction and above all understanding the original cause of the problem. If the original cause is not addressed then the compaction is likely to return and any measures taken to improve the situation temporarily will have to be financially justifiable in the short-term, because long-term the problem is likely to recur.

David Acocks farms near Bendigo, Australia on progressive, highly successful conventional mixed farm enterprise units, adopting many new ideas and with knowledgeable input from his wife Denise and their sons. Having discussed depth of topsoil and organic matter importance, David's parting comment to me was 'If I had to say one thing as far as advice it would be – Don't Plough!' Soils under their management were increasing topsoil depth year by year, and any ground they took over, which underwent similar management, began to rapidly improve in these areas also.

> "The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was ploughed, and still continues to be ploughed, by earthworms"
>
> - Charles Darwin, 1881

Tillage activities can lead to a never-ending cycle of remedial action.
Not only will ploughing cause havoc to the top inches of the soil - with its intricate web of organisms; moisture loss is considerable; potential compaction caused; and the effect on earthworm numbers of repeated tillage activities is disastrous.

A beneficial snowball effect may be launched: As living conditions improve, biology improves – earthworms form good vertical burrows, roots find channels, worms bring surface organic matter underground and the microbes can have a feast and produce humus and store precious carbon – nutrient cycling ensures good root growth, helping to also retain air in the soil… and so the cycle continues.



Controlled Traffic Farming data – printed with kind permission

WATER:

Water is often the most limiting factor on a farm. This may be for a number of reasons, including lack of rainfall, soil type, low-level of organic matter, low microbial activity, evaporation from bare soil, leaching, or the cost and availability of purchasing water for irrigation.

- Again, understanding the reasons for the water limitations is the first step towards addressing how to manage the conditions.

- Dehydration can be caused by too much salt. This will dehydrate both the organisms and the soil by osmosis.

- Zero or Reduced Tillage appeared to be the number one mechanical protection of limited moisture.

- Ensuring as little bare soil is exposed to the elements at any time of year. Bare soil can result in mineral salt deposits caking the surface as water evaporates. Many large units around the world are moving towards inter-crop green cover such as clover. This can protect the soil structure and moisture, feed organisms, provide nitrogen and prevent weed growth.

- Plants with better balanced nutrition use less water. Diverse, beneficial soil organisms combined with earthworm activity and casts are more likely to be able to provide the range of plant requirements, including those we are well used to supplementing, but also those we do not normally include. 'Let nature provide and let nature select' is particularly relevant with regard to maximising water use efficiency.

- Humus is the residue of microbial decomposition of organic matter. Increasing the humus level of the soil will increase the water retention ability. This is particularly important in drought-prone situations. A soil with 4% humus content will have twice the water retention capability as that of a soil with 2% humus content. It is important to know that this is humus level and not necessarily the 'organic matter' content of soil. Standard 'organic matter percentage' tests often include decomposing and undecomposed organic material.

FOOD:

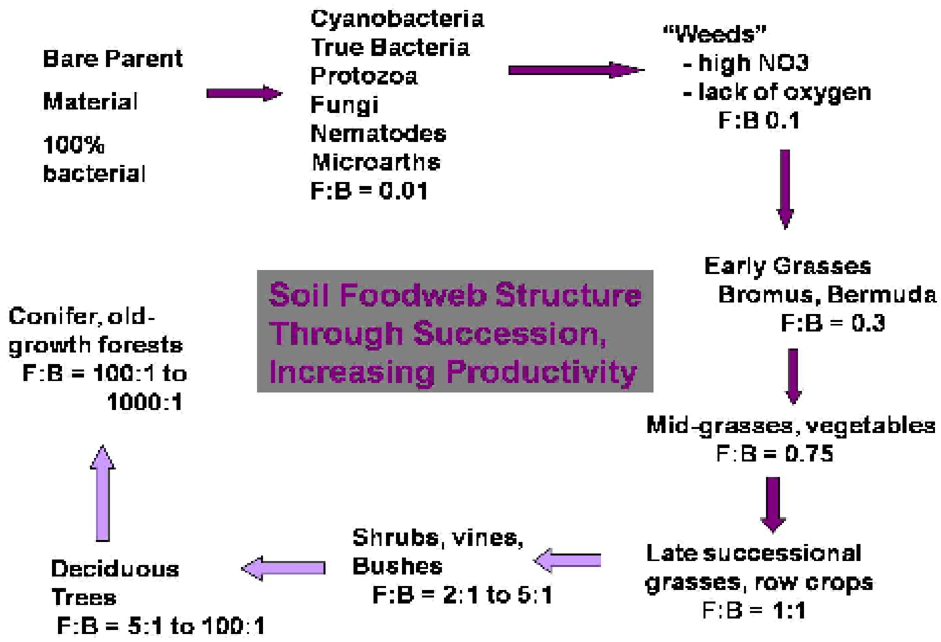
Food for microbes, earthworms and other soil organisms is another hot area for debate. Available materials, value of the crop, area of land, type of crop and personal opinion will all influence the food ingredients, preparation and quantity applied.

Food options may include:

Manure
Farm Yard Manure
Slurry
Chopped straw
Green manures
Crop residues
Mulches
Compost
Liquid feed: molasses, kelp, fish hydrolysate
Clover between cereal rows (shown to increase earthworm numbers, good quality feed for them)

Considerations will include cost, availability, and a reasonable understanding of the bacteria:fungi ratio preferences for the crop you are growing.

The Soil Foodweb suggests that as plants progress from early to late succession, the ratio will begin to move from bacterial dominated towards a ratio of 1:1, with bushes and trees then requiring a fungal dominance.



Thus, the approximate recommended ratio for certain common plants could be:

	Fungi:Bacteria
Orchards and shrubs	3:1
Pasture and crops	1:1
Early annuals	0.3:1
'Weeds'	0.1:1

Although we may not wish to analyse our soil biology numbers to this extent, I think it is relevant to have an idea of the requirement. Therefore, when choosing the form of organic matter or 'feed' to add to the soil, we can ensure that we are not inadvertently selecting for the wrong ratio trend. This could have noticeable impact on the health and productivity of the crop, particularly if a system is established and continued year after year.

The microbes require organic matter. Carbon reserves are used as energy for feeding, and nitrogen used to build and increase numbers. Bacteria thrive on simple sugars and fungi are capable of breaking down tougher and more complex materials such as lignin.

If simple sugars are the main feed, the bacteria will multiply rapidly, but the fungi will not get the opportunity and may not thrive. Bacteria find it more difficult to feed on the complex carbons and so these are the feeds to include if fungi are required.

It is worth mentioning food for larger organisms also. Cliff Royle, Chief Winemaker at Voyager Wines, Margaret River showed me the long grass now left between every 5th row of vines in order to provide food for the garden weevil, which can cause such problems to them.

The gradual move away from pesticides and fungicides is resulting in less disease, and beneficial insects are now increasing.

Cliff also commented on the importance of utilising our senses, such as taste and sight, rather than relying solely on, for example, brix and sap pH tests. I am sure that we could learn much from our dairy cows' senses, if we sharpened up our observation of their feed preferences in the fields.

At Voyager, they are introducing new methods little by little and gaining confidence in this approach, without risking a disaster if one part doesn't succeed. I think this makes good sense, and saw it in practice in India with farmers gradually moving from artificial fertiliser to wormcompost over two or three years.

7. IMPORTANCE OF CARBON:NITROGEN RATIOS

Living things are made up of carbon and nitrogen of differing ratios.

For example:

	Carbon:Nitrogen Ratio
Bacteria	5:1
Fungi	20:1
People, Green leaves, Protozoa	30:1
Nematodes	100:1
Brown Material	200:1
Deciduous Wood	300:1
Conifer Wood	500:1

These are approximate ratios, given more for the purpose of comparison.
The C:N ratio of plant may change during the course of its growth, and different parts of the plant may have differing proportions.

When we eat food of the same ratio as ourselves, there is little 'waste' if we eat what we require for maintenance and growth. Organisms will ensure that they eat until they are 'full' or satisfied. If the diet of any organism is higher or lower in Carbon than itself, there will either be an excess of carbon to deal with, or an excess of nitrogen.

The ratio of soil biology may determine the form of these excesses Soil pH influences the ratio of bacteria and fungi, and also the form in which any excess nitrogen is released.

Excess Nitrogen
For example, a protozoa (C:N 30:1) feeding on bacteria (C:N 5:1) will have to ingest six times its required nitrogen in order to consume the desired amount of carbon. This nitrogen will then be 'blown off' in certain forms.

Different plants require the nitrogen to be excreted in different forms. This is often determined by the pH of the soil because at different pH levels different microbes will be working, and producing nitrogen in different forms. As a general rule, lower pH soils favour fungi and higher pH soils favour bacteria. Therefore as an example, perennial plants would need fungi rich soils because the nitrogen released at pH of lower than 7 by fungi would be in the form of NH_4 (Ammonium) which is what they prefer.

At higher levels of pH, the bacteria are able to produce suitable enzymes to convert NH_4 to NO_2 (nitrite) and NO_3 (Nitrate), which is preferred by annual plants.

Excess Carbon
Another example would be fungi or bacteria feeding on leaves which have a higher carbon content than they are. There will be a resultant excess of carbon. The bacteria will store some carbon and also release some as carbon dioxide, which can then be used by the plant growing in the soil above.

Fungi are able to store a greater proportion of excess carbon as they grow. This is another very important aspect of soil biology. If our soils are becoming depleted of fungi, we are losing a stable way of storing carbon and building up the soil's organic matter content.

I think that there are considerations here relating to the health of our livestock and ourselves. If incorrect balances are occurring within our soils, the potential for unsuitable biological activity is significant. Whether the soil foodweb ratios are strictly accurate is less important than the principle of ensuring that the soil is being fed with appropriately balanced carbon:nitrogen material, either a feed we bring to the soil or feed that the management of the field enables to be provided in situ.

Healthy, balanced soil, with the opportunity for nature to manufacture all the known and unknown substances required, can result in plants, livestock and people with the ability to resist disease. I suspect that we could protect our cattle to a great extent from potential problems such as TB, Bluetongue and Foot and Mouth. In years to come this may be well-accepted.

'The nation that destroys its soil destroys itself'
Roosevelt – 1937

WORM AND WORMCAST PRODUCTION METHODS

Summary:
Small-scale production units can be self-financing and produce vermicompost of great value to the soil. Larger-scale production of worms or vermicompost requires careful financial assessment, and involves issues other than agricultural returns.

Basic definitions and data.
Large-scale production
Small-scale production
Inoculation options
UK production

8. BASIC DEFINITIONS AND DATA

Vermicompost is the term for compost produced by feeding organic matter to earthworms. This is being done in various ways and for different purposes, including:

- Quality product for plant and soil use
- Quality material for incorporation with other compost materials
- Niche market innovative products such as compost tea
- Waste Disposal with a saleable end product

Vermiculture is the term used for growing earthworms within a controlled environment, usually for periodic harvesting and selling of live worms for a number of markets.
Worm Markets:

- Fishing bait/recreational activities
- Setting up of new commercial units
- Protein feed
- Live inoculation of soil
- Remediation work with toxic soils
- Retail outlets – garden suppliers
- Pharmaceutical and research work

Vermiwash is a dilution of the coelomic fluid of the earthworm. Pharmaceutical companies are well aware of the protective health qualities of this fluid. While neat extraction produces little, it is straightforward to produce diluted quantities. This is showing fascinating results in very small doses for soaking seed prior to planting and other such inoculations. From a general farming aspect, we are able to benefit from this fluid by encouraging the earthworm numbers in the soil. Within its cast, and wherever the worm travels a fluid deposit is left, with all its valuable properties. When stressed, particularly by heat or cold, extra quantities are excreted.

In India, diluted vermiwash applied to breeding ponds of mosquitoes has successfully reduced both their numbers and the health of each stage of their breeding development.

9. LARGE-SCALE PRODUCTION

I think that large-scale production of worms as a financially sound enterprise is difficult. The existing markets are well catered for, and unless time and money is put into establishing new ones there is likely to be a very limited number of buyers for the worms and they may pay a price which barely enables the unit to break-even, if labour costs are included, before any repayment of capital.

A large and successful worm production unit in Holland uses indoor, temperature controlled facilities for the initial and final stages of production.
The investment and automation is impressive, the worms extremely strong and healthy and the staff well-trained. Good communication between all involved ensured accurate feeding and quick response if the worms began to show any sign of problem. The ability to control temperature in each of the production rooms ensured good flexibility. Feed used was consistent and balanced, and could be liquefied if necessary for young worms.

Many of the worms for selling returned to the indoor unit having been 'reared' to maturity on an outside farm. These farmers usually purchased the young worms and then sold the young adults back to the unit. The full management advice came from the breeder, but the outside unit establishment cost and financial and production risk appeared to be the farmer's. Some farmers used indoor facilities, and others had outdoor beds for rearing

At the main unit, the worms were mechanically fed, but manually checked, once every week and housed in plastic trays – many thousands of them. It is an efficient and thriving business, selling worms all around the world. Regular artic Lorries of the bedding in which the young worms had been reared and returned were sent on to a compost production unit where it was used as a quality ingredient for purpose-made compost.

This unit is involved in innovative projects using earthworm inoculation. This is detailed later.

I saw a similar picture in South Australia, where a small-scale but well run worm farm was doing everything right, but not able to find suitable outlets for the worms, despite previous guarantees. Fortunately the scale was not too damaging financially, the owner did not have to work full-time with the worms and he was able to get a good price for some of the worm compost from a local compost-tea ingredient producer.

Worm composting of 'waste' materials has received a lot of popular attention over recent years. Two of the largest and most mechanised are in America and South Australia. Both units are producing quality vermicompost, using a standardised feed and production system with consistent product for selling.

The investment in infrastructure is significant. Outside grant funding was required for establishment and for ongoing investment and some running costs.

Tom Herlihy's unit in America uses 'waste' dairy manure. His company are selling one tonne boxes of the finished product for about $800/t. Encouraging reviews from large scale producers, mainly high-value nursery units, using the wormcast have led to smaller volume, higher retail value bags now being sold via supermarkets across America. The plant growth and health properties of the worm cast are the main value to the end user. The nutrient value, in plant-available form, of the compost is of secondary importance, but still considerable.

Knowledgeable attention to detail, and an understanding of the potential value to plants, have shaped the approach, and maintained the integrity of both the company and its products.

Sunburst, the unit in South Australia, is using paper and cardboard waste, feedlot manure, fish waste and abattoir waste as their ingredients. Again, the attention to a balanced worm diet and consistent end-product is impressive.

They now use only five suppliers for materials, and the abattoir waste and feedlot manure has to have been composted for 3-4 months before Sunburst will accept it.
The working relationship between the compost site and the supplying businesses was obviously an excellent one, with all parties fully understanding what was required in order for the Sunburst site to have sufficient throughput for all their waste to be handled smoothly. The manager, Terry Gay is clearly a good communicator. So many good business ideas fail because other basics such as communication are not in place.

Each batch of partially composted feed is fed to a trial box of worms before being fed to the 50 metre long feed beds. Each bed is automatically fed and watered, the feed being layered about an inch thick on the top of the bed and a one inch thick layer of worm cast being sliced off the bottom of the bed. Watering and feeding times and amounts can be varied according to temperature. This flexibility is important to maximise production.

In addition to the sale of worm compost, there was a simple and efficient production of compost extract.

Not all of the waste was fed to the worms. The cost of installing further worm beds and sourcing or breeding sufficient worms would be currently prohibitive because the value of the end product at present is not high enough.

Further projects were under discussion, but the budgets had to allow for ongoing grant funding to cover shortfalls in the cost of production and the likely price that farmers would be prepared to pay for the vermicompost. I would suggest this is a vulnerable business position.

Automated worm feeding at Sunburst Unit, South Australia

This is an important consideration. If the value to the soil, the plant, farm livestock and the farm business of well-produced wormcast becomes more apparent, then the price that farmers will be prepared to pay may rise to a sufficient level to alter the stand-alone viability of large-scale vermicompost production in the UK. The risks then would be that too many low-quality vermicomposts may filter into the market. This could result in poor or inconclusive benefits, and may negatively affect the confidence that farmers were beginning to feel towards the concept of vermicompost providing additional plant growth and health components, compared with other composts or artificial inputs.

10. SMALLER-SCALE METHODS

The visit to India proved to be the highlight of my Nuffield travels.

I was privileged to be able to spend time with Dr Radha Kale and her husband, discussing vermicomposting and visiting various farmers and research units producing vermicompost.

In addition to the information, advice and practical demonstrations of production systems which I was able to gather, the time spent with Indian farmers, both men and women, has had a great impact upon me.

The gentle, professional and caring way in which they farm and live has left a powerful impression. Their concern for fellow farmers was voiced everywhere I visited. Many were sharing their knowledge and experience of successful vermicompost production with others in ‘discussion groups’. The concern over the number of farmers committing suicide, having invested in new Genetically Modified ‘wonder’ crops which had not been sufficiently successful to cover large loan repayments, was sobering.

The more educated farmers, many having returned to their farms following successful business and scientific careers or combining both, were able to present vermicomposting techniques to others who had not received higher levels of education, in a way that enabled all to benefit. Their motivation was simple and honest – they wanted to share the beneficial knowledge with other farmers.

Dr Kale is a pioneer within India and the world of vermicomposting. She is a gentle, humble and strong lady, with a quiet passion for helping Indian farmers and a concern for Indian people and the country as a whole. Now semi-retired, she has spent a large part of her career researching and establishing highly successful vermicomposting systems. A comment indicative of her approach towards any research project was made to me by one of her phD students: “Dr Kale always says that our work must be relevant to farmers and be able to be replicated on the farm”. In this regard I suggest that she is unique. Her ability to explain and discuss vermicomposting issues with people of varying knowledge of science is a rare gift. She was even able to do this with me, and showed such patience and understanding! The days we spent together were very special, and I learnt so much from her and also her husband.

The units we visited were producing vermicompost in concrete bunkers, some with concrete bases and some earth-based, width always about 1-1.5m. Varying raw materials were used, according to availability, including grass, banana and coconut, cow manure. The materials were chopped, mixed, watered and then composted before being put into the beds. . The worms were mainly *Eisenia Fetida*, *Perionyx excavatus* and *Eudrilus Eugeniae.*

Dr Radha Kale (right) at the Jayanth Vermicompost Unit

The worms were then added to the top of the material. This is a very different system to that commonly used in the UK. A cover, usually hessian sacks or large leaves and branches, was placed over the worms and material, watering made sure that the moisture levels remained appropriate, and then every two weeks a layer of wormcompost was scraped off the surface. This harvested material was placed spread thinly undercover with a few fist-sized balls of cow manure to attract any worms that happened to remain. Three harvestings of the casts would then leave about six inches depth of material in the bed with huge numbers of beneficial aerobic organisms and other substances. This would be removed to be placed on top of the next batch of thermally composted material put into the bed. This method has the added bonus of inoculating the newly introduced material. The usual time for full batch harvesting was 45 days.

Benefits of this system include: Less disturbance of the worms. No frequent feeding requirement. Quick and efficient production in manageable quantities.

Two of the units I visited had been established and were managed by women, with one of the units, Jayanth Vermicompost, supplying worms and wormcast to many areas and businesses with a production of 100 tonnes of cast per cycle and each cycle lasting six weeks, giving annual production of nearly one thousand tonnes. Sieved cast using a 3-4mm gauge sieve for orders received 15 days earlier commanded the highest price. The larger sieved-out material also sold well, but for half the price.

Potential problems: Ensuring that the top material has passed through the worms. Not as crucial if you are using the bulk material on your farm land rather than selling the final product.

The initial thermal composting stage requires frequent turning of the material. The smallest size of compost pile would be one metre square. Most of the units I saw had larger piles, with appropriate labour or machinery for turning usually on daily or alternate days for three weeks.

Farmers making or purchasing vermicompost were tending to replace artificial fertilisers gradually, over a period of two to three years. They were prepared to pay relatively high prices because they could see the benefit to their crops and their businesses. While visiting one of the research units, I met a local farmer who had popped in to purchase compost. He used about one handful per sugar beet plant, one month post germination when the plant was 6" high.

Coimbatore:
I had a fascinating time travelling to farms under the shadow of the magnificent Western Ghats with Dr Jeya Raaj, professor of zoology at Coimbatore University and also a farmer. He and his family were very welcoming.

Dr Raaj emphasised to me that earthworms were the first group of organisms to develop from aquatic to terrestrial, and possibly the only ones that can feed on pathogenic material and not excrete it. Are they 'popped' by the gizzard pressure or is there another means by which the earthworm protects its own living environment?

He drew my attention to VAM fungi's ability to release a protective chemical, and that when VAM are present in the earthworm gut perhaps the chemical can be present also. There are many things we do not fully understand within soil biology.

In this area the units I saw were not using concrete beds. They had windrows on the ground, usually under trees, with good watering facilities. Again, suitable local organic materials were thermal composted prior to putting into rows 2-3 feet high and covered with dry organic leaves or grasses.

Mandhu Ramakrishnan, from Santhosh Farms invested in a purpose-built vermicompost production building with concrete beds, full drainage and collection channels and ventilation facilities. After 3 years and 15 full vermicompost harvests, he realised that the outside beds had better production and were less labour-intensive!
He abandoned indoor production, despite the fact the building enabled micro-climate manipulation and leachate collection. He was adamant that the moisture level will determine the activity and will keep the worms in the beds as long as the food is there.
He sold no vermicompost, but used all of it on the farm.

Santhosh Farm was using a system of farming which he felt enabled the earthworms and therefore the soil, plants and people to obtain maximum benefit from the land, water, sun, wind and atmosphere. To my incessant suggestions, he advised me to stop trying to interfere: 'nature knows best and will adjust – leave well alone!' This attitude was combined with a passion and knowledge of agriculture and business. His intriguing irrigation channels weaved around the farm, fed from a header tank with a separate side tank which could add a mixture of cow dung and urine if required.

Large outdoor worm beds, with soil bases and coconut shell covers.

My final farm visit in India was to an organic vegetable and plantation farm. This farmer also ran an organic shop with an increasing output and customer base. The improved yield of his produce has been recognised and publicly praised by a top agriculture advisor to the Indian government. Having been frustrated with poor germination rates and growth using inorganic fertilisers, he spent three years developing and learning his vermicomposting techniques and has now had four further years with ever-increasing success.

His copra yield per 100 coconuts had increased from 11kg to 17 kg in 3 years.
This is an increase of over 50%. He uses his home-produced vermicompost at a rate of 1 tonne/acre post ploughing for vegetable ground. He rated cow manure as the most valuable ingredient, (due to the cow's four stomachs and fermentation chambers).

Interestingly, he felt that if the moisture was at a correct level there was not the need for a cover over the windrow. He used upturned coconut shells within the beds for the worms to use if required, also helping to retain moisture.

Often discussed while in India was the problem of quality control of vermicompost.
How to assess good quality? It would be handy if the wormcast came out of the worm bright pink with yellow dots so that it was easy to identify!

This farmer felt that the number one consideration when purchasing vermicompost was trust in the integrity of the producer. Only then would one assess the look, feel and smell.

Look: should be browny black (not black)
Feel: lightweight, soft
Smell: woody, earthy,
Heat: no heat if it is in a pile

India Tobacco Company (ITC)
ITC is actively encouraging its tobacco farmers to produce and use vermicompost, by describing it as 'Mothers Milk for the Field'.

I was able to discuss the impact of vermicompost use with M. Isaac Davi, Leaf Manager of ITC in Mysore.
Two thousand five hundred of the Karnataka State farm units supplying ITC are producing vermicompost.
Higher costs have led to real hardship for the farmers, who have to either increase the quality and production of tobacco or reduce costs in order to continue.

A number of measured improvements have been attributed directly to vermicompost use:

• Toxic levels in the leaves reduced
• Non-beneficial nematode numbers reduced in fields by 58% (lab tests had indicated a probable 38% reduction)
• Nutrient balance in leaves increased
• Top Grade percentage of leaf assessment (attracting highest payment) up 9.7%
• Total increase in volume 7.6%
• Soil organic carbon levels have risen by 50%(to 0.6% from 0.3-0.4%) with vermicompost use, and are still increasing.

ITC saw vermicompost production and use as helping them to honour their corporate responsibility triple bottom line:

1.	Environmental	Soil structure and carbon levels improving
2.	Economic	Profitability of farmers' enterprises increasing
3.	Social	Local employment increased

Women in particular were inspired by the potential benefits, and instrumental in encouraging the men to develop Vermicompost units on their tobacco plantations.

Dr Kale was anxious to point out that establishing a vermicompost unit does not have to require high capital start-up costs. No expensive infrastructure is necessary, and a small number of worms can be used initially and multiplied in good conditions. This could provide sufficient vermicompost for the farmer's use, as the farm converts from artificial fertiliser use to vermicompost use.

11. INOCULATION OPTIONS

Organic/biological tomato growers in Holland have been inoculating new greenhouse sites for the past seven years.
Dendrobaena worms are used, young adults ready to lay their first eggs.
Cost = 25-35 euros per kilogram, (about 1800 worms per kilogram).
These are put in groups on the bed surface. Grouping facilitates ease of burrowing due to slime produced., and also enables the area to be checked for egg production and hatching, indicating good conditions. .
Rate of multiplication:
Greenhouse – ten times original weight of earthworms after 6 months
Outside -- ten times original weight of earthworms after 12 months.

Innoculation rates varied from 5g/m2 up to 10g/m2.

Worm type
Epigeic:
The *dendrobena* are not only litter feeders, but penetrate lower. They will spread all over an area, and will always try to eat, and therefore are preferable for inoculation.

Eisenia Fetida – as litter feeders, if there isn't sufficient litter they may eat young plants, particularly in greenhouses. They also eat in groups and this can be a problem.

Endogeic:
The Green/grey worm will curl up and stop feeding if conditions are not ideal.

Anecic:
Anecic worms are not able to be bred successfully in controlled conditions. If they are available, via farmers who collect them, they are put in a pile on the soil surface within a plentiful food supply. They will slowly burrow up to 3 m depth and come up to feed.
It is unfortunate that these worms, so important to healthy soils, are so slow to reproduce, difficult to breed in captivity and so easily killed by heavy slurry applications draining into their deep vertical burrows.

Soil type – worm suppliers had more clients from farms with clay soils. Innoculation is very difficult with sandy soils because the success is so moisture-dependent. There is little point adding worms unless the organic matter of the soil is greater than 3%, preferably 7-9%. My view is that within the UK, unless reclamation work is involved, if the organic matter content is greater than 5% and contains good humus then a population of earthworms is likely to build up anyway, although the slow reproduction rates of the anecic earthworms could be an issue if their numbers have been reduced.

Cocoon Innoculation – Although this is not a common commercial practice, I think that on-farm cocoon and earthworm transfer from well- composted farm yard manure piles to strategic positions on the farm could be beneficial, as long as the farm management enables the worms to thrive where they have been placed. It is easy to check whether eggs are present and small quantities could contain large egg numbers.

12. UK PRODUCTION

Within the UK, production is primarily for sale of worms rather than the cast. Worm farming has a dubious reputation – and with good reason. Many of the commercial units set up over the past 20 years have involved large capital investments and big losses. In Holland in 2002 there were about 400 worm farmers - now only about 30 are serious players. Many of the 400 original farmers still have the worm unit, but are not producing sufficient supply of worms to sell. A similar picture emerges in the UK.

Within controlled production, the most common earthworms used in the UK is the *Dendrobena.* This is a good all-rounder, suitable for the leisure market and commercial production units. Many breeders have been developing their own lines, ensuring that selective breeding over many years has resulted in a strong and adaptable worm. The redworm, *Eisenia Fetida*, is often used with the *Dendrobena* for composting purposes, but tends not to be the most marketable worm.

The worm beds tend to be shallow (18” to 2’) with large surface areas, usually about four metres wide by up to one hundred metres long.
Concentrate feed meal is fed to encourage maximum growth rates, having initially settled the worms in a bed of suitable mixed materials, frequently horse manure and straw.

My misgivings, apply particularly to this type of unit. The risks involved are considerable, and at present the markets are not many or varied. High capital start-up costs, mainly for worm purchase, is risky. The depth of the beds doesn’t allow the worms to move into warmer, cooler or moister conditions if they are uncomfortable.

For production of worms or worm compost there are a few crucial points to consider:

- **Livestock Enterprise** – worms are living and they can die. This may sound obvious, but if they are not managed as a livestock unit with associated responsibilities and requirements then the output will not reach the budgeted figures. The person caring for them needs to understand livestock, have a working knowledge of worms and be able to respond quickly when they show signs of distress.
- **Temperature and Moisture**: These are two of the most important considerations and limitations to quality production. Both are difficult to control in the UK. The temperatures required for maximum production are higher than we generally see for long periods of time. Moisture requirement is high, but not all at once, which can be difficult to monitor in our climate. Moisture level of between 60-80% is required. If investment is required in artificial heating or automated watering the costs escalate.

Even if limited production is accepted for periods of the year, the worms still require overseeing year round with associated labour costs and risk.

- **Predators**: If outside beds are used, moles, badgers and birds are a hazard.
- **Harvesting:** Labour requirement is high unless very highly specialised expensive equipment is installed. There will also be capital investment in some basic separation equipment.
- **Feed:** Partially decomposed matter is the best, preferably with C:N ratio of about 20:1. They will cope with different ratios, but production may suffer. The quality of the nitrogen part of the feed may affect rate of reproduction and growth. Regular, consistent products are more likely to ensure continual production. The availability and cost of the raw materials will vary between units. Those handling waste products are often paid a gate fee to take the product, but may have to pay for a balancing ingredient within the overall ration. Others may be able to use on-farm organic materials.
- **pH levels.** The worms will eat a wide range of pH materials, but prefer to live in levels between 5 to7. If the food is outside this range, they need to be able to escape into more comfortable areas for breeding and egg-producing.
- **Preparation of Food:** The ideal food for worms will be in small particles and have already begun the process of decomposition. The process of worm digestion should eliminate pathogenic organisms. However, certain end-product regulations may insist that the materials go through a monitored thermal stage of composting. This is also necessary if unwanted seeds are present because seeds survive the passage through worms. The food should be chopped into small pieces. This can involve mechanical choppers and more capital expense.

The sale of the worms can be lucrative. However, costs of production can be as high as £6.50 per kilogram, with buyers often only paying around £7 per kilogram for the worms. Should a grower wish to charge more, time and effort must be allowed for sourcing other purchasers or developing another market

However, I do think that there will be a future demand for the wormcast. At present most wormcast markets involve high-value horticulture or garden customers. As public concerns and pressure over food safety and quality, and with increased farmer awareness of the value of the wormcast, there are exciting possibilities.

For those interested and committed to producing worms and wormcast, and with the management skills to produce and harvest a top quality product economically, the on-farm results arising from the wormcast use should ensure growth of sales.

There must also be future potential for feeding the residue from renewable energy plants to earthworms. The resultant product would be greatly enhanced with the plant growth and health promoting substances, as well as nutrients, already discussed. Existing worm farmers would be ideally placed to handle these wastes, and use them as part of their worms' diet.

COMPOST AND COMPOST TEA

Summary

There is an increasing interest in the use of compost and liquid compost preparations, both with and without vermicompost inclusions. These are used in order to add nutrients, microbes and other plant health and growth substances to the soil, or to the foliage of growing plants. Ideally the field and crop management would be providing sufficient and varied food for existing organisms, who then manufacture the plant-beneficial substances. However, this is often not the case and the use of compost and compost tea can be a useful tool, particularly while establishing better functioning soils.

13. COMPOST AND COMPOST TEA TERMS AND DATA

COMPOST:
The breaking down of organic matter by microbes, resulting in the formation of active humus and humic acids we loosely refer to as 'composting'. The nutrients in humus are part water soluble, part acid soluble and part slow releasing.

Unfortunately, there are plenty of 'composting' procedures that do not result in the formation of a quality product that would be suitable for use in liquid application or of benefit to the soil.

COMPOST LEACHATE:
Collected water run-off from compost, often vermicompost. Will contain some dissolved nutrients, live and dead microbes and some of the other contents such as growth promoting hormones, but can often become anaerobic if collected and stored. Requires water dilution of at least 30:1.

COMPOST EXTRACT:
During production of extract, water is circulated through compost, either via a flowform (see photograph) or in a water tanks with a circulation pump, and compost suspended inside. The intention is to separate and dilute the microbes, nutrients and other components and then use the liquid. Sometimes additional food for the microbes is added to the liquid. The extraction time does not normally exceed 2-6 hours.

14. COMPOST PRODUCTION

It is necessary to partially decompose organic materials prior to feeding to the earthworms. Guidelines for this process are the same as those for standard compost production, although for vermicompost the material is transferred to the wormbeds after the initial thermal stage is complete.

Various composting methods are in operation, and with each it is possible to produce a good product which may be beneficial to the soil as organic matter. More attention is required if a plentiful supply of beneficial organisms is required, with a quality humus.

Although there are many variations to each process, the 3 main types of composting system are; aerated, static and vermicompost. All of them require management of the Carbon:Nitrogen ratio by assessment of the various materials to be mixed together. The mix of materials can determine whether the compost is mainly bacteria-populated, or has a good fungal presence:

Bacteria mix:	Fungal Mix:
25% High N	25% High N
45% Green	30% Green
30% High Carbon/Woody	45% Woody/High Carbon

Sometimes these are slightly reduced to enable a 10% clay addition, particularly in Controlled Microbial Compost (CMC) and other purpose-made quality composts. A 5% larger particle size such a large wood chip is often a good idea to aid aeration.

High Nitrogen materials might include manure and grass
Green material includes lower nitrogen grasses, weeds
Woody materials may include cardboard, straw, woodchip, dry leaves

If manures are used, it is necessary to be aware of the diet of the animal and any high nutrient levels that may be present, for example potassium.

Plants we consider 'weeds' can tell us so much about the condition and mineral status of our fields. It is well worth looking at them as indicators, analyse why they are growing where they are, and be aware that they are often able to provide the very minerals that the soil is deficient in. By thinking of them as wild herbs and beneficial in controlled circumstances, we can use them in our grazing, include them in our compost and address the problems they indicate.

A mix of materials should ensure a full range of minerals and trace elements. Off-farm materials could help address known deficiencies in farm soil. Biodynamic preparations are an excellent way to inoculate with a wide range of compost stimulants.

Having assessed the actual materials, and balanced them according to the C:N estimation, chopping, mixing, turning, aerating and watering will then determine the final quality.

Most compost sites will turn their piles or windrows a number of times during the initial thermal stage. If the Nitrogen content is too high, the temperature can rise very rapidly. A temperature of about 50 degrees for 3 days will kill weed seed and pathogenic organisms. Some types of waste material will be required to reach a higher temperature to comply with EU regulations. The temperature is caused by the feeding activity of the organisms.

Moisture content is crucial and good drainage in wet conditions, and ability to add water throughout the pile when dry, is necessary. Minimum 30% and preferably 50% moisture is required. Many sites compost in large windrows, with modern turners which water the rows as they turn and aerate them.

As the compost temperature begins to cool, less frequent turning is required. Site space often determines the process used. I think that there are opportunities for farmers to work with local compost sites. As sites begin to compete with each other for grant-required tonnage by reducing gate fees, value-added end products are becoming more attractive.

On-farm composting is possible. Time, machinery and space are the likely limiting factors. Static pile composting is possible, but a quality compromise will have to be made. Aerobic conditions would be preferable. Addition of partially composted materials to the soil can enable the composting process to be completed in the soil, but only if conditions are amenable and organisms present. Well-made compost, particularly if it is vermicompost, can be used to inoculate a fresh compost pile.

I do think that production of small-volume quality compost is feasible for farmers. Even a one cubic metre pile of top quality compost has the potential to form the base for many hectares of compost tea.

15. COMPOST TEA PRODUCTION

Those farmers using compost tea applications are doing so for a number of reasons.
Some will give a ‘pick you up’ spray after any event which may stress the soil organisms or plants growing in the field. These events include grazing, cutting and tillage. Others will try to stimulate a more diverse range of organisms in their soils. Specific microbes or minerals that are deficient or lacking in the soil can be added, particularly if the bacteria:fungi ratio needs altering. Others, particularly nurseries, are using the tea to give protective coatings to the foliage, as well as the soil.

Approximately one kilogram of compost is added per one hundred litres of water. The microbes in the compost extract are fed selected diets and the circulation of oxygenated water continued for up to 3 days. The aerobic microbes increase in number, as long as the oxygen levels in the water are maintained above 6 parts per million. This becomes increasingly difficult as the numbers increase, and calculations must be made relating to altitude. Close monitoring is essential to avoid anaerobic conditions developing, with subsequent death of beneficial aerobic organisms, and activation and multiplication of less beneficial anaerobic microbes.

Compost Tea production workshop, with Elaine Ingham (left) at Laverstoke Park.

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Brewing feed Options:
Molasses, liquid kelp ,fish hydrolysate and dried herbal mixes are the most common feeds added to compost tea in Europe and Australia. In India the locally available jagri, curd, cow manure and urine were used. Manures and molasses would favour rapid bacteria feeding.

Kelp and Fish hydrolysate could be more of a fungal feed depending on processing methods. The humic and fulvic acids in the compost will provide excellent feed for both the bacteria and fungi. The choice of feed will depend upon availability and whether you wish for a bacteria or a fungi-dominated tea. The quantity of feed added will vary, but amounts used are not large – perhaps 2 litres per one thousand litre brew. A word of caution is necessary here. Should pathogenic organisms be present, they will also thrive on the feed, particularly if the oxygen level of the liquid falls too low.

Equipment:
There are a range of suitable brewing and spraying machines. The choice will depend upon the acreage to spray and whether a transportable or fixed brewer is preferred. For maximum benefit, the tea should be spread soon after the circulation stops. Fungi may grow very large and so careful thought must go into the filtering mesh and spraying nozzle sizes. Pressure levels when applying should not exceed 50psi, to avoid damaging the organisms on impact

Flowform to enable aeration of water and compost tea during production, incorporating Steiner-based water movement recommendations.

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16. RATES OF USE FOR COMPOST AND COMPOST TEA

Vermicompost rates of use varied from 500kg/acre to 5 tonnes per acre.
The gradual change from artificial fertiliser to vermicompost usually took about three years. Not many farmers in India were using wormcompost as compost tea, but rather using it around trees and spread on soil post-ploughing. NB: Vermicompost tends to have high calcium content.

Other Compost usage rates varied, with some farmers using up to 10t/hectare, if sufficient quantities were available. There is anecdotal evidence that specific soil deficiency or balancing products may not be necessary, the range within the compost being sufficient to address pH and imbalance issues. I feel that this must depend upon the severity of the problem, and the quality and type of materials used for the compost; however these are important and valid observations from farmers. Compost often contains high potassium – watch out for excess if large volumes of compost are used. Nitrogen content of compost will seldom be greater than 2.5%. However, the other nutrients and beneficial substances are also there. Present and healthy free-nitrogen fixing bacteria or legume nitrogen-fixing bacteria can source atmospheric nitrogen – and 78% of the atmosphere is nitrogen.

Andrew Lewis, a farmer in Abergavenny who composts Green Waste, has seen an adjustment of pH from 5.5 to 6 over 3 years, with compost applications and no additional liming.

Compost Tea:
Common rates of 20 to 50 litres of tea sprayed per hectare, often following grazing.
A calculation of 50 litres per hectare per 6 feet of foliar height is helpful.

Compost Extract usage rates were between 50 and 200 litres per hectare.

17. EXAMPLES OF INOVATIVE COMPOST ENTERPRISES

Van Iersel in Holland has invested in underground aeration systems in order to maximise the site area, and maintain throughput and quality. CMC, Biodynamic and other purpose-made compost recipes are popular.

Van Iersel work closely with farm consultants on specific recipes for individual farmers. Although many of the soil deficiencies are similar, the application rates of compost vary, and therefore the small batches for each farm are individually tailored by adding the necessary product after the larger CMC has been made.

A recent workshop, held at their modern office and compost production site, showed farmers how to interpret compost quality by use of chromatography.

Higher quality compost requires more attention, and will therefore be more expensive to produce. Most top quality compost I saw being made used vermicompost as one of their ingredients. Van Iersel include it, particularly for the high protozoa numbers present.

Many farmers I met were adding ingredients to compost, preferably during the thermal stage of the process. When this was not practical, the ingredients were added and mixed with the finished compost, using the compost turner.

They were able to use one tenth of the amount of the product that would be required if applied directly to the field. This was reduced even further if the compost was vermicompost. This method of application is a kinder way to apply organic fertiliser to the soil. Ingredients added included: magnesium carbonate, seaweed, calcium carbonate and vermicompost.

This can be an excellent added-value outlet for compost sites, and a good opportunity for farmers to source quality humus-compost for their farmland.

Quality compost production at Van Iersel, Holland, with added ingredients on top, waiting to be mixed.

David Clayfield in South Australia makes compost tea for retail sales. He buys in a selection of microbes and adds these to the compost preparation. He commented that "anyone can grow bacteria – the skill is to balance fungi requirement and keep them healthy". He has designed his own specialised, large-scale compost tea sprayer. He had many livestock customers routinely applying tea to paddocks with centre-pivot irrigators, after every grazing. Fungal-dominated brews can be used to speed up the breaking down and incorporation of stubble.

In the UK, compost tea use at a nursery near Bristol is effectively preventing many fungal diseases. The compost pack is purchased from a specialist supplier, and consists of a fungal-dominated bag of compost for brewing in a tea-brewer, with six ingredients to add as 'food' for the organisms. The brewed spray was also found to be successful as a treatment for a bacterial disease. Despite arriving with infected leaves, new laurel leaf growth was healthy following compost tea treatment.

Custom Compost in Western Australia has developed quality compost pellets for broadacre farming. These are planted with the seed. The pellets are used with reduced amounts of artificial fertiliser to introduce quality humus and microbes, and thereby increase fertiliser efficiency.

One of the partners of Custom Composts is a farmer who had previously been a bank manager. Interesting comments from him suggested that bank managers should be aware of the benefits of compost and soil biology, so that they will question the expense and necessity of amounts of artificial fertiliser used on their clients' farms!

. Notice particularly, from the table below, the mycorrhizae root colonisation increase.
Printed with kind permission of Custom Composts

CUSTOM COMPOSTS

Balance®

Yield & Microbial Biomass - Balance® Trial - HF York 2007

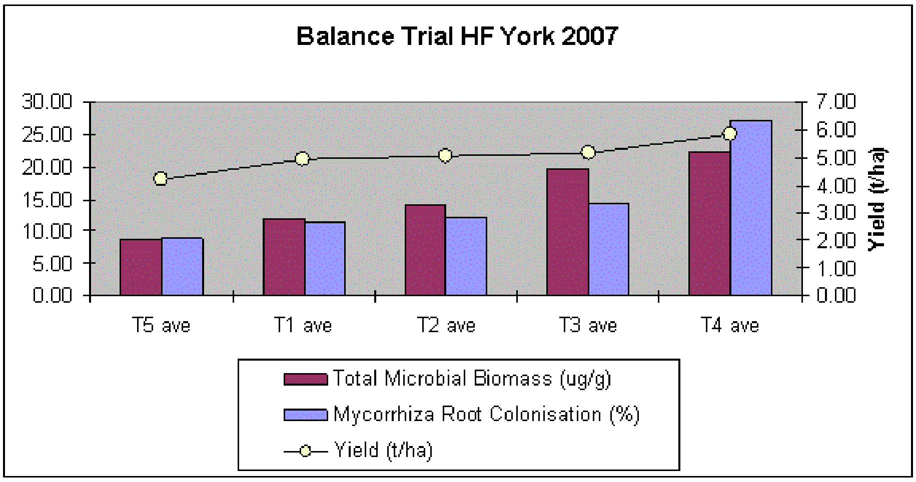
Agronomic Information: Trial conducted by Meag Soil Consultancy @ York WA in 2007
Each replicate was 0.25 ha in area

Treatment 5 Control = 100kg/ha MacroPro Extra
Treatment 1 = 75kg/ha MacroPro Extra + 25kg/ha Balance (blend 1)
Treatment 2 = 75kg/ha MacroPro Extra + 25kg/ha Balance (blend 2)
Treatment 3 = 50kg/ha MacroPro Extra + 50kg/ha Balance (blend 1)
Treatment 4 = 50kg/ha MacroPro Extra + 50kg/ha Balance (blend 2)

Table 1 : Trial Raw Data

Treatment	Rep	Crop	Total Microbial Biomass (μg/g)	Mycorrhiza Root Colonization (%)	Yield (t/ha)
Control (T 5)	1	WHEAT	8.25	8.25	4.10
Control (T 5)	2	WHEAT	9.24	9.29	4.25
Control (T 5)	3	WHEAT	NA	NA	Not Harvested
T5 ave			**8.75**	**8.77**	**4.18**
T 1	1	WHEAT	13.37	14.71	4.40
T 1	2	WHEAT	12.33	9.30	5.90
T 1	3	WHEAT	10.23	10.54	4.40
T1 ave			**11.98**	**11.52**	**4.90**
T 2	1	WHEAT	11.91	11.43	5.00
T 2	2	WHEAT	13.58	12.50	4.85
T 2	3	WHEAT	16.92	13.10	5.30
T2 ave			**14.14**	**12.34**	**5.05**
T 3	1	WHEAT	18.21	14.25	5.80
T 3	2	WHEAT	19.50	13.60	4.95
T 3	3	WHEAT	21.54	15.21	4.70
T3 ave			**19.75**	**14.35**	**5.15**
T 4	1	WHEAT	25.14	26.30	5.50
T 4	2	WHEAT	21.14	22.40	6.30
T 4	3	WHEAT	20.80	32.40	5.70
T4 ave			**22.36**	**27.03**	**5.83**

Figure 1 : Results Diagram



Disclaimer: Custom Composts are in no way suggesting these results are typical when using Balance®. This was the first trial conducted using blend 2, and due to the results achieved, we will be targeting this blend for the 2008 season. This years trials are aimed at confirming these results prior to commercialisation. We believe incorporating Balance® in a planting program represents a low risk strategy, as trials conducted over the previous 5 years have performed, at worst, on par with control plots.

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CONCLUSIONS – OPPORTUNITIES IN THE UK

Earthworm opportunities for UK agriculture exist in 3 main areas, and together offer the ability for all farmers to dramatically reduce dependency on outside inputs, re-establish the land and farmer as the heart of the farm business, increase the productive capacity of their soils, and improve the health of those consuming their products, both animal and human.

1. Soil

The most important opportunity lies in the nurturing of the earthworms and other soil biology in our farm soils. This is crucial for the sustainability and profitability of our agricultural enterprises, whatever 'tag' we carry as far as brand – be it organic, conventional, biodynamic, locally produced, animal welfare-friendly or other.

The particular role of the earthworm is uniquely beneficial, if we allow it to be. Balance and diversity of healthy, well-fed soil organisms is necessary. True plant health and quality are only then achievable, and able to be passed to the consumer of the plant.

Carbon storage properties of healthy soils that have a good population of fungi, particularly mycorrhizal fungi, could be used in carbon sequestration and carbon footprint calculations.

2. Vermicompost production and use

Opportunities exist for home-production of relatively small quantities of vermicompost which can be highly valuable for crops, livestock, horticulture and other enterprises. This does not have to involve high capital start-up costs, or high ongoing labour requirement. There are a number of different uses depending on the individual unit's requirement. Bought-in wormcompost offers further opportunity. Inclusion of worm compost in compost tea brews can assist in reducing the damage to soil biology by current practices, and stimulate correct function of the natural living processes.

3. Green Waste Compost opportunities

Compost punches above its weight, and provides benefits beyond the standard nutrient analysis. We have the combined benefit in the UK of having a large population, small area, and large quantities of organic waste with an environment policy dedicated to recycling this waste and reducing landfill. There are opportunities to work with compost sites, to encourage custom-made compost for individual farm use. These opportunities do not necessarily have to involve vermicompost.

RECOMMENDATIONS FOR UK FARMERS:

1. **Consider your soil a 'livestock enterprise', crucial to the sustained profitable function of your business. Tend these livestock well and we will all benefit. Ignore them at our peril.**

2. **Examine your soil's health and understand your crop's needs, in terms of bacteria:fungi ratio and mycorrhizae presence, as well as pH and nutrition.**

3. **Ask appropriate soil biology questions. Include knowledgeable nutritionist and agronomist of high integrity within your business advisory team. Be aware that the better briefed you are, the more able they will be to help.**

4. **Remember 'everyone wants your money'! Consider all advice received with this in mind. As biology-friendly products become more available, avoid shifting dependency from one set of products to another.**

5. **Combine chemical, physical and biology issues in your thinking and look at overall priorities. As you do so, the order of steps to take will become apparent. Allow the more subtle influences of nature to benefit your soil and crops.**

6. **Use communication and exchange, both within the team of each farm and between those of different farms, of observations, results and practice. This can be one of the best sources of advice and solution.**

7. **Include the use of wormcast and compost products as viable input options, whatever your farming system. These do not necessarily have to be produced on-farm.**

"There is a difference between growth and development"
Comment from a retired Indian Biochemist I met in Coimbatore Airport

"If you have a healthy diet, who needs vitamin pills!" Dr Ken Flower, WANTFA

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HOW I HAVE BENEFITED FROM MY NUFFIELD SCHOLARSHIP

It has been a unique and valuable time for me and for my family. I have been challenged to think outside my comfort zone; exploring ancient practices in greater depth and new areas with increasing comprehension, and more questions!

This has enriched the quality of our thinking and discussion within the farm team. We are all more aware of the living world beneath our feet, and that the incredible complexity of the interwoven lives and functions of the organisms can still be understood within the context of a livestock enterprise and its basic requirements.

There are a few additions to our farm 'tool box':

- **Refractometer** - to assess changes in grass Brix levels.
- **Sap pH meter -** for soil pH and plant sap pH. This is useful for giving a guide to deficiencies within the plant, and indicate possible soil problems. Plant sap pH is ideally 6.4. A higher or lower pH helps narrow down the problem areas.
- **Penetrometer** – a simple home-made spike with a T-bar handle. This also fits inside the groove of the soil sampler to scrape out the soil!
- **Soil sampling corer** – with cut away side.

These four items are easy to keep in the farm vehicle, quick to use, and inexpensive to purchase. I have broken a number of garlic crushers, but now have a home-designed pair of pliers to catch the sap!

- Microscope – not a necessity really, but fascinating and I am learning more all the time. I think this has helped our children to understand my study and to put the picture together.

- Flowform – for preparation of various sprays, including compost tea.

- We do have a small wormery and make small one cubic metre blocks of aerobic compost, using carefully chosen materials. This is further processed, after the thermal stage, through the worms.

- A bulging address book with new friends and contacts from around the globe, all keen to exchange ideas and knowledge.

- A wonderful array of books on my study desk, many written long ago. Much experience over years of practice and observation has been carefully preserved for sharing. Sometimes, by accepting the mistakes and successes of others, we can move forward into new areas of our own exciting journey.

I have been humbled by the attitude of Indian people I met, and their respect for nature. As Einstein said, “Not everything that counts can be counted, and not everything that can be counted, counts.” If anyone claims to have full understanding and knowledge of the working of nature, they are either fooling themselves or trying to fool me.

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And Nature, the old nurse, took
The child upon her knee,
Saying: 'Here is a story-book
Thy Father has written for thee.'

'Come, wander with me,' she said,
'Into regions yet untrod;
And read what is still unread
In the manuscripts of God.'

Longfellow

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Joan Timmermans – Van Iersel, Holland
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also to many others who were so helpful and encouraging.

Richard Price (Patchwork) for acting as mentor throughout my study, but sadly passed away before seeing the report in print.

Finally, my thanks to John Stones and fellow 2007 scholars with whom I have been able to bounce ideas and share dilemmas as they arose, and also enjoy interesting times.

USEFUL INFORMATION AND CONTACTS

- Earthworm Ecology Second Edition - Edwards
- Vermicompost – Crown Jewel of Organic Farming - Radha D Kale
- The Formation of Vegetable Mould through the actions of worms with observations of their habits – Charles Darwin
- Soils, grass and cancer – A Voisin
- Agriculture Lectures – Rudolf Steiner
- Science in Agriculture – Arden Andersen
- Dr Elaine Ingham/Soil Food Web Microscope and Compost literature
- Hands on Agronomy – Kinsey & Walters
- The Biological Farmer – Gary Zimmer
- The Roots of Health – John Reeves
- The Rise and Fall of Food Minerals – John Reeves (including the Eastleigh Trials)
- Silent Spring – Rachel Carson
- Bread from Stones – Julius Hensel
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- The Secret Life of Compost – Malcolm Beck
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- Grasp The Nettle – Peter Proctor
- The Mineral Requirements of Grazing Ruminants – N D Grace
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- Secrets of the Soil – Tompkins and Bird
- Paramagnetism – Philip S Callahan
- Farming with rocks and minerals – Peter Van Straaten
- Report on Vermicomposting Trial at Worm Research Centre – J Frederickson
- The Farmer's Earthworm Handbook – David Ernst

Soil and Soil Biology information and testing facilities:
Laverstoke Park, Hampshire, UK www.laverstokepark.co.uk

Controlled Traffic Farming (UK):
www.controlledtrafficfarming.com/info@controlledtrafficfarming.com