SOIL HEALTH HANDBOOK

nrm laboratories

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A guide and interpretation for the NRM Soil Health Analytical Package

Contents

Introduction to soil health

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1.1 Soil health

The FAO define soil health as: "the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, to form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production." To that definition, an ecosystem perspective can be added: "A healthy soil does not pollute the environment, rather, it contributes to mitigating climate change by maintaining or increasing its carbon content" (FAO Save & Grow, 2011. www.fao.org).

1.2 The importance of soil health

Soil provides the foundation for all agricultural activities and is fundamental to food, water and energy security. Globally, agriculture is facing a massive challenge. Collectively, farmers need to be producing far more food per unit of land, while reducing the amount of inputs that go into crop and livestock production, and limiting the environmental impact of current farming practices. Agriculture needs to be sustainably delivering increases in productivity of around 1.75% per annum, simply to keep pace with the demands of a global population that is growing at a rate of over 220,000 people a day (Chiras, 2013). One way to measure productivity is to use the Total Factor Productivity (TFP). This is a ratio of agricultural outputs to inputs. An increase in the TFP ratio would therefore mean that more is being produced from a unit of input. Improving management practices for your soil and therefore improving the health of your soil will be a vital way to increase the TFP and help meet future global food demand (Global Harvest Initiative, 2013).

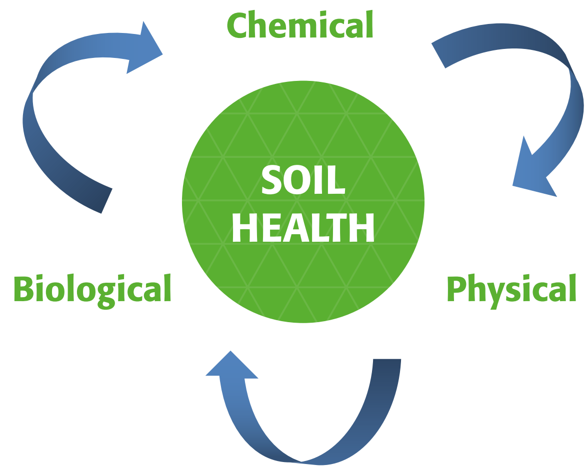
Soil is fundamental to agricultural productivity and to the stability, diversity and functionality of terrestrial eco-systems. Soil acts as a dynamic reservoir of water and nutrients forming a complex organic-mineral growing medium that supports both the growing plant and the microbial communities that interact with it. Soil acts as both sink and source for atmospheric CO_2, is involved in the filtering of air and water, and has an impact on temperature regulation. Soil can be improved through the appropriate management of its organic and mineral components. But soils can also become depleted, eroded and degraded, and recent history shows clear examples of the impact this can have on civilization, both in terms of food security and environmental integrity. The ability to effectively measure and monitor soil health provides farmers and agronomists with the information required to actively manage soil resources for optimum crop performance.

2 Components of soil health

Although soil health is predominantly seen as a function of biological activity, it is influenced by the dynamic interactions that occur between the physical, chemical and biological components of the soil. Biological activity is driven by temperature, and requires appropriate levels of air, water and suitable nutrition. The physical properties of the soil will affect air and water exchange, which will influence biological processes such as respiration. This in turn will influence the ability of soil organisms to decompose organic matter and release nutrients for uptake by plants. The activity and diversity of soil organisms is also influenced by soil chemistry e.g. pH. The growing plant, and more specifically the activity of roots and material released from roots (exudates etc), also plays a significant part in maintaining microbial activity. The zone of soil around the roots (the rhizosphere) provides an ideal habitat and good supplies of energy-rich organic matter. In return, microbes around the root release nutrients and plant-growth promoting compounds, while at the same time providing a level of suppression against plant pathogens. As microbial activity increases, the conversion of soil organic matter to humus increases which also results in carbon sequestration. The formation of gum and polysaccharides by microbes and earthworms promotes the formation of stable soil aggregates and increases the ability of the soil to retain plant-available water and nutrients.

This complex interaction between the physical, chemical and biological properties of the soil has a major influence on soil fertility and health. The NRM Soil Health Test has been designed to integrate key aspects of these soil properties in order to provide a scientific platform for measuring, monitoring and managing soil health.

Figure 1: Concept of soil health



2.1 Physical components

The physical properties of soil are determined by the balance between sand, silt and clay particles, which determines soil texture. These particles combine with various forms of organic matter to form soil aggregates. The size and distribution of these aggregates through the soil profile determines soil structure, which influences soil stability, erosion risk, ease of cultivation and compaction. Soil structure directly affects the movement of air and water through the soil profile, which in turn affects biological activity, root development, crop establishment and tolerance to environmental stress. For more details on the importance of soil physical components to soil health please see section 3.

2.2 Chemical components

The mineral content of the underlying soil parent material has a major influence on soil chemical properties of the soil. Of particular importance from a soil health perspective is the impact that soil chemistry has on the development of plant-microbe interactions. For example, soils that are based on limestone have a tendency to be rich in calcium, and also alkaline, which can restrict the uptake of nutrients such as phosphorus and manganese. This in turn can reduce root mass and root exudate production, restricting both microbial activity and plant response to microbial growth promotion. Soil pH influences microbial populations, encouraging bacteria to dominate alkaline soils and fungi to dominate acidic soils. A better balance of bacteria and fungi can be found at more neutral soil pH values. Bacteria require simple sources of soluble organic matter and have high multiplication rates, while fungi can utilise more complex insoluble forms of organic matter and have relatively low multiplication rates. Soil chemical properties also regulate microbial growth rates directly through nutrient availability, and indirectly by the effect on root development and root exudate production. This affects the rate at which microbes release plant-available nutrients. More information on the influence of the chemical component can be found in section 4.

2.3 Biological components

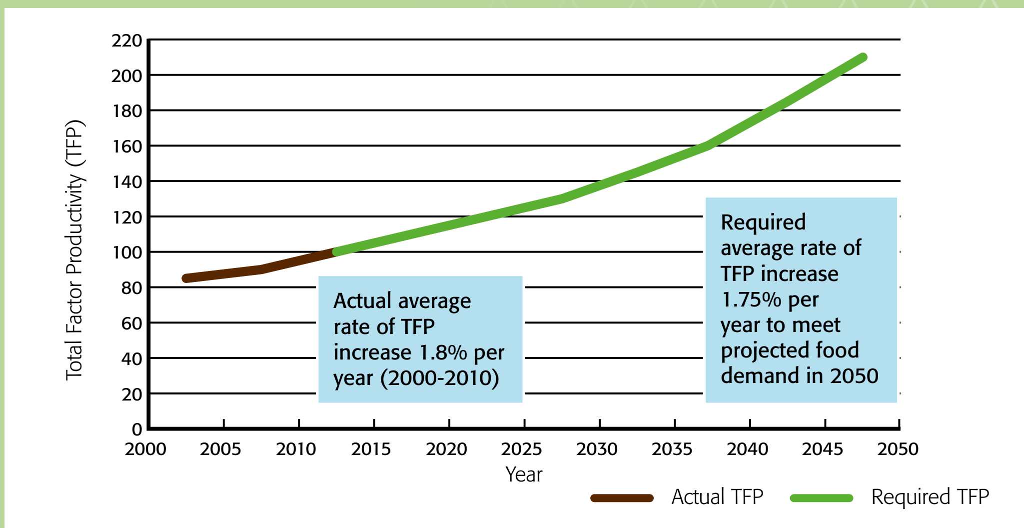
During its conversion from plant and animal residues to humus, soil organic matter has a direct impact on soil health. Un-decomposed organic material provides a food source for macro-organisms such as earthworms. Earthworms mix partially decomposed organic matter with soil minerals as the material passes through the gut, creating channels for air and water movement as they go. Microbes thrive in the earthworm casts, completing the conversion of organic matter to plant-available nutrients and humus. As humus, organic matter is in the form of long charged polymers that are capable of binding sand, silt and clay into stable soil aggregates, while at the same time providing exchange sites for nutrients and improving water retention. This results in increased soil fertility and yield potential. In addition, humus provides a long-term source of energy and nutrients for beneficial fungi and bacteria. For further details on the biological component see section 5.

2.4 Why measure soil health?

Soil health is the foundation of sustainable agricultural development and plays a vital role in safeguarding both food security and environmental integrity. But the ability to effectively optimise soil health depends upon the ability to manage the dynamic physical, chemical and biological interactions of soil systems, which in turn resides squarely on the ability to effectively measure and monitor those interactions. With this in mind, NRM has developed a suite of laboratory tests that assess the key parameters that influence soil health. In contrast to analytical suites designed for soil nutrient management, the new soil health protocol is focused more on the living fraction of the soil and the beneficial interactions between soil, microbes and plant.

The challenge facing global agriculture is to be able to deliver an annual increase in productivity (TFP) of 1.75% (figure 2), while at the same time reducing reliance on chemical inputs, and making positive improvements to environmental impact (Global Harvest Initiative 2010). Productivity is currently increasing at the required rate however it is becoming increasingly difficult to sustain this rate of increase. Issues such as soil erosion and degradation need to be addressed. The capacity for soils to retain water and nutrients in plant-available and potentially mineralisable forms needs to increase to match the genetic potential of modern crop plants. Synthetic inputs such as nitrogen fertiliser and fungicides need to be supplemented by organic and renewable sources of nutrition and plant protection. Soil carbon levels need to increase and carbon sequestration needs to be demonstrable. In order to monitor the impact of management practices designed to achieve all this, it is essential that effective measurements for soil health can be made. For example, reducing nitrogen fertiliser and applying beneficial bacteria that can pull nitrogen from fresh air could have an impact on the carbon footprint of crops, but without appropriate soil conditions, the ability for biological nitrogen fixation to improve the quantity and quality of crop production may be limited. Measuring soil health parameters prior to deploying such biological technology may ensure a higher level of success for both the technology and therefore the farmer.

Figure 2: Global harvest Initiative – 2013 Gap Report (Fuglie 2013)



2.5 Developing a Soil Health Test

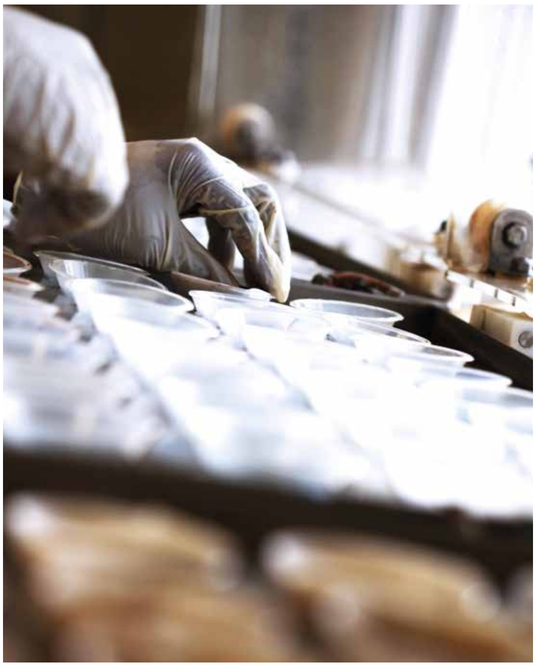
Standard soil testing has focused on determining the sufficiency of major nutrients, and maintaining the balance between soil nutrient supply and crop off-take. This approach has led to the progressive improvement of agricultural productivity and relies on routine assessment of soil nutrient status. Interpretation of this testing is based on ensuring adequate nutrition is applied to the crop, in the form of N:P:K fertilisers.

However, it is widely recognised that soil fertility is not just a matter of NPK, and that soil health is a function of more than just chemistry. In order to assess soil health, and monitor the impact that modern agricultural practices have on it, farmers need to be able to measure the main physical, chemical and biological parameters that influence the agronomic characteristics of soil.

In contrast to analytical suites designed for soil nutrient management, testing for soil health needs to focus more on the living fraction of the soil and the beneficial interactions between soil, microbes and plant. Building on the well-proven and widely accepted analytical foundation of standard soil testing, NRM have developed a Soil Health Test that integrates measurements of soil nutrient status with soil texture, organic matter and biological activity.

As such, the Soil Health Test includes measures for;

- **Soil pH** – This influences nutrient interactions, root development and microbial population dynamics.
- **Available Phosphorus** – Major impact on root development, root exudate formation and plant-microbe interactions. Essential for biological nitrogen fixation.
- **Available Potassium** – Related to nitrogen uptake, carbohydrate formation and bulk plant development. Low K status during times of stress can have a major impact on the composition and amount of exudate production. This can therefore impact on microbial activity around the root system.
- **Available Magnesium** – Central to nitrogen and potassium uptake, photosynthesis and can influence the composition of root exudate production.
- **Soil Particle Size Distribution** – Relative percentage of sand, silt and clay, soil textural classification is central to RB209 fertiliser recommendations and soil erosion risk assessment. Soil texture influences nutrient and moisture retention, microbial population dynamics and carbon sequestration.
- **Soil Organic Matter** – An essential component of stable soil aggregates, influencing nutrient and water retention, soil structure and plant-microbe interactions.
- **Respiration rate** – CO_2 evolution is directly related to soil respiration, a general measure of biological activity, indicating microbial biomass, carbon sequestration and nitrogen mineralization rates.





2.6 Soil Health Index (SHI)

One aim of the new Soil Health Test is to provide an analytical methodology for classifying different soils. To achieve this, the data generated by the Soil Health Test is used to provide an index. The foundation for this index is the rate of evolution of CO_2 following standardised drying and wetting of the soil. This relates directly to soil microbial biomass and can be used to estimate carbon and nitrogen mineralisation rates. Field testing of this measurement suggests that results have no direct correlation with total soil organic matter, indicating that the CO_2 evolution index is related directly to microbial respiration via the active fraction of organic matter in soil rather than total organic matter turnover.

Adjustments to the CO_2 evolution index are made, relative to other soil parameters, in order to compare different soils from different locations. For example, as soil texture affects microbial activity by regulating temperature, air and water exchange rates and carbon sequestration rates, the Soil Health Index can be decreased for sand soils or increased for clay soils, in an attempt to provide a greater level of practical relevance to the index.

Adjustment can also be made for soil organic matter content, as this affects basic food supply for microbes, and phosphorus availability, as this has a direct impact on root development and plant-microbe interactions. Soil pH can also be used to adjust the Soil Health Index, to reflect the effect on soil microbial population dynamics and the composition. Certain systems can have different pH requirements for optimum plant growth. The adjustments to the SHI from pH can therefore be different depending on the cropping that has been specified.

The index value displayed on the front page of the NRM Soil Health Report is the adjusted CO_2 evolution index (figure 3). Justifications to the adjustments based on the results of the chemical and physical analyses are provided on the second page of the report (figure 4). The CO_2 evolution index without adjustment is displayed on the second page. The figures below show how the Soil Health Index and the justifications to the adjustments are displayed in the report.

Figure 3: Example of Soil Health Index chart displayed in the report

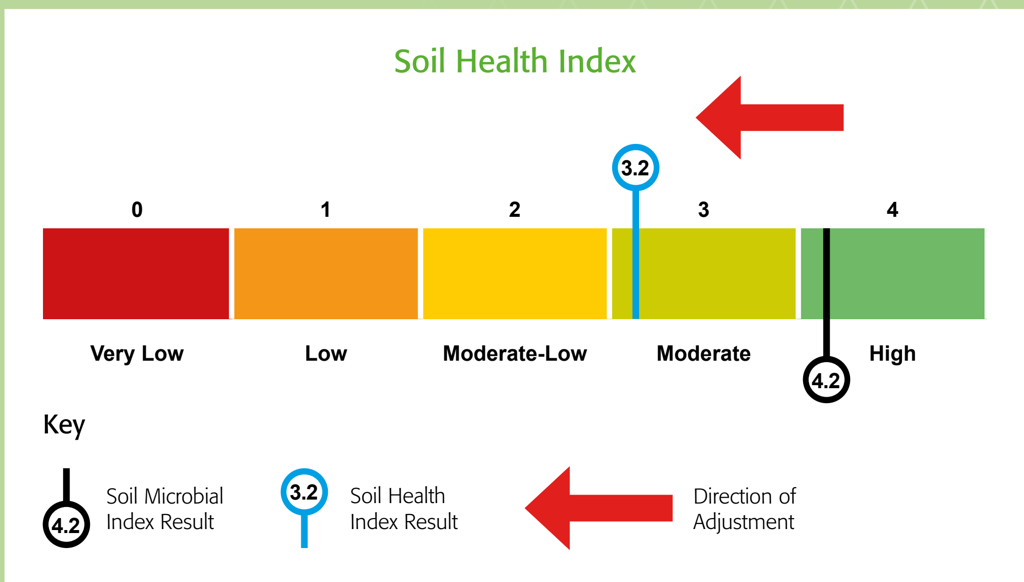


Figure 4: Example of Soil Health Index adjustments displayed in the report

Soil Health Index Adjustments

Parameter	Adjustment	Justification
pH	No Adjustment	Your Soil pH is within the optimum range for healthy plant growth. The pH of the soil will not be contributing to nutrient deficiencies or declines in microbial populations. See section 4.1 of the soil health handbook for more information on how soil pH can influence the health of a soil system.
P	Slight / Moderate Negative	Phosphorus availability is low and will be affecting plant root development. This in turn will influence plant-microbe interactions and the ability for roots to produce suitable exudate to maintain or stimulate beneficial microbial activity. See section 4.2 of the soil health hand book for more information on the importance of phosphorus to plant health.
K	Slight Negative	Potassium availability is low, affecting canopy and root development, and potentially restricting plant uptake of nitrogen. Movement of soluble sugars from leaf to root will be low, affecting root exudate production and plant-microbe interactions. This situation will increase in severity as soil moisture deficit and air temperature increases. See section 4.2 of the soil health handbook for more information on effects of low potassium on plant health.
Mg	Slight Negative	Magnesium availability is low and may be restricting chlorophyll production and plant uptake of nitrogen, which will decrease root exudate production and plant-microbe interactions. See section 4.2 of the soil health handbook for more information on the effects of low soil magnesium concentrations.
Soil Texture	Moderate Positive	The fine micro-aggregate structure of this soil type maintains low exchange rates of air and water, resulting in very slow conversion or loss of soil carbon. Microbial respiration rates will be regulated by soil temperature and available carbon sources, which may be lower than other mineral soil types, but should be sustained over very long periods of time. For more information on how soil texture influences soil health see section 3.1 of the soil health handbook.
Soil Organic Matter	Slight / Moderate Negative	Your organic matter level is lower than the recommended level for plant growth. Microorganisms will have a limited supply of carbon to sustain their populations and growth. Biochemical reactions will not be at their full potential to enhance plant growth. See section 3.2 of the soil health handbook for more information on low organic matter levels.

3 Assessment of the soil physical component

Assessing the physical fraction of the soil essentially defines the platform from which soil health can be effectively managed. For example, a predominantly sand-based soil with a coarse, open structure will have very high rates of air and water exchange, which will place limits on microbial activity, nutrient retention, root development and carbon sequestration (Brady and Weil, 2002). These high air and water exchange rates can cause boom and bust cycles of microbial activity. This makes it difficult to maintain or increase soil organic matter levels as any material added to a system will rapidly increase activity and quickly use up what has been added (Scow et al, 1998). Conversely, a predominantly clay-based soil will have far slower air and water exchange rates, which will improve carbon and nutrient retention, elevating yield potential, but may reduce soil temperature and microbial activity.

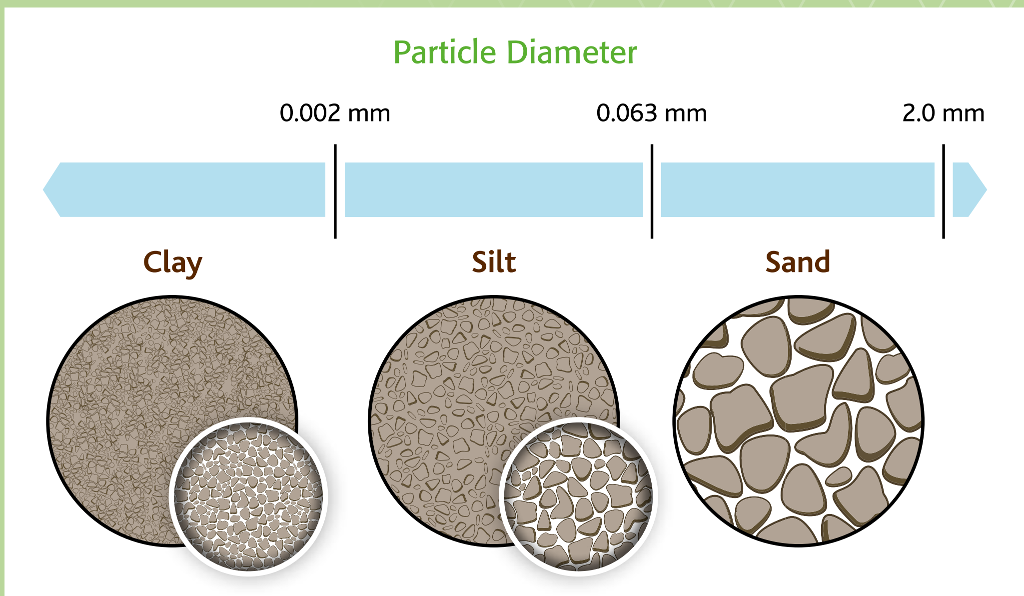
Physical soil parameters can be assessed in-field by hand-texturing soil samples, reviewing soil structure and by digging soil profiles to check for compaction, cultivation layers, crop residue incorporation and root development. This can be supported by more accurate laboratory determination of soil particle size distribution and soil textural classification (the relative fractions of sand, silt and clay).

3.1 Soil textural classification

Knowing the size and distribution of the mineral particles within a soil system can play a major role in determining how a soil will behave. Improvements to your Soil Health Index can be limited by the textural classification as it will be virtually impossible to change this classification. By knowing the classification it can help determine the management practices required to maintain or improve the health of the soil.

Soil texture looks at the fine earth fraction (<2 mm) of the soil system. It is made up of 3 general fractions; sand, silt and clays (figure 5) (Brady and Weil 2002).

Figure 5: Particle sizes of the 3 soil fractions



Sand – Particles are those less than 2 mm but greater than 0.063 mm in diameter. The coarsest particles may be rock fragments containing a number of minerals however most sand particles are made up of a single mineral such as quartz and other primary silicates. Therefore sand particles do not provide much in the way of plant nutrients. As these particles are usually quite angular, a soil primarily consisting of sand will have large void spaces between the particles. This allows water to flow freely through the soil profile and allows air to enter the soil. These soils would have a low water holding capacity. Due to the low specific surface area of the particles and the large void spaces the particles are non-cohesive and will therefore have a high risk of erosion.

Silt – Particles are smaller than 0.06 mm but greater than 0.002 mm in diameter. These are typically micro sand particles predominantly made up of quartz. In some areas you can also have silt soils that are made up of easily weathered minerals, due to their size, these minerals can release large quantities of nutrients. The pores between silt particles are much smaller than those of sand particles and are able to retain much more water by not allowing much to drain through. This therefore has a much lower rate of nutrient leaching from the profile than sand. When silts are wet however they have little cohesion and are easily washed away giving them a high erosion risk.

Clay – Particles are those smaller than 0.002 mm and due to their shape they provide clay soils with a very high specific surface area. This provides them with a large water-holding capacity as well as the ability to retain other substances. When clays dry up their large absorptive surface area causes the particles to cohere in a hard mass. Wet clay maintains its cohesion, is sticky and is very malleable. Movement of air and water between clay particles can be very slow due to the small pore sizes.

This can mean that movement of nutrients in the soil solution can be restricted however there will be a high relative abundance of plant nutrients on the soil particles. Clay particles also carry a negative charge on their surfaces which causes nutrients with positively-charged ions such as K, Ca and Mg to be held on the inner and outer surfaces of the particles (cation exchange).

Influence of surface area on the health of a soil – There are 5 fundamental ways that increased surface area improves soil health:

1. Water is retained on individual soil particles as a film covering the surface (although this water is not readily available to plants). The greater the surface area of a soil system the more water that can be held.
2. Gases and dissolved chemicals are attracted to and absorbed by mineral particle surfaces. Soils with larger specific surface areas will have a greater ability to retain nutrients from the soil solution and air within the system.
3. When soils are made up of weatherable minerals the release of nutrients (e.g. K) will occur on the surface of the soil particles. The larger the surface area the greater potential for the release of plant nutrients to the soil solution.
4. Mineral particles tend to have both positive and negative charges. This enables particles and films of water between them to bond together. Increasing this surface area increases this cohesive process which leads to more particles sticking together or the formation of discrete aggregates. Therefore soils with a lower particle size will generally have a lower erosion risk.
5. Bacteria and fungi will tend to colonize and perform most biochemical reactions on the surface of soil particles. Soils with larger surface areas have a greater ability to facilitate this activity (Brady and Weil 2002).

Sandy soils, clay soils and loamy soils are the three main groups of textural classification. Within each of these groups there are a number of sub classifications, the names of these convey the nature of the soil properties. The table below (figure 6) shows the graduated sequence of these classifications. On the Soil Health Report the result is displayed as a dot located in the appropriate location in the soil texture triangle (figure 7).

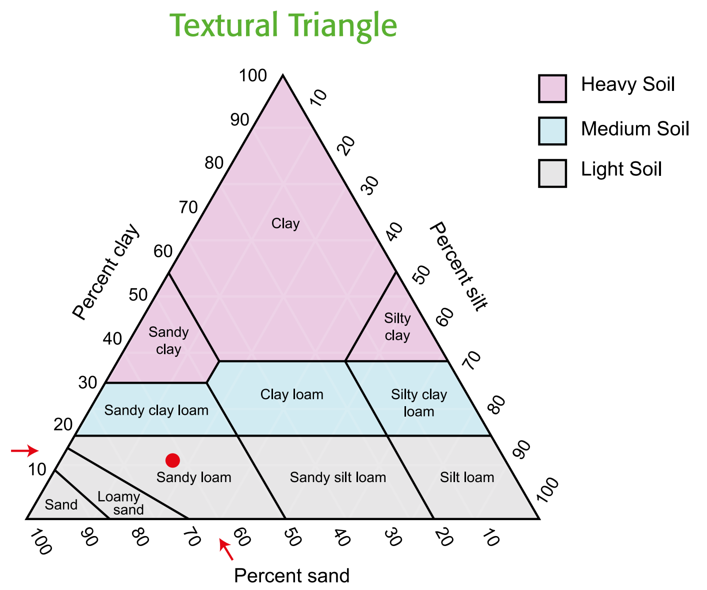
Figure 6: Soil textural classification

Main group	Sub classification	Soil protection review classification
Sandy Soils	Sands	Light
	Loamy Sands	Light
Loams	Sandy Loam	Light
	Sandy Silt Loam	Light
	Silt Loam	Light
	Sandy Clay Loam	Medium
	Silty Clay Loam	Medium
	Clay Loam	Medium
Clay Soils	Sandy Clay	Heavy
	Silty Clay	Heavy
	Clay	Heavy

Source: NRM and Defra Soil Protection Review 2010

In the Soil Health Report the textural classification will be reported on the textural classification triangle (figure 7). The result is pinpointed in the exact location within the classification. The triangle also shows which classification the soil is in reference to the classifications listed in the soil protection review.

Figure 7: NRM Soil Health Report textural classification triangle



Example of different soil textures for soils that have been dried and ground to 2mm

Clay	Silty Clay	Sand
		

3.2 Organic matter

Soil organic matter is made up of a wide range of organic substances originating primarily from plant and animal residues. Organic matter can provide a number of beneficial influences on the health of a plant.

- It can contribute to the cation exchange capacity (CEC) of the soil. Humus colloids (the smallest type) exhibit both negative and positive charge but with a net charge that is always negative (the extent varies with soil pH).
- Increasing soil organic matter can greatly increase the water holding capacity of a soil making it more resilient to environmental extremes such as drought. The water holding capacity of humus colloids can be more than 5 times greater than that of some silicate clays.
- It contains a store of nutrients, for slow release by chemical and biological processes. Organic matter can be an important source of trace elements.
- One of the major influences on plant health is its influence of soil microbial populations. Organic substances provide energy to microorganisms, acting as their carbon food source. They are also used to build essential organic compounds within the micro-organism that are required to obtain energy.
- Organic matter can play a fundamental part in the stabilisation and creation of soil aggregates creating a more stable root zone in which crops can become established. As organic matter decomposes, a range of microbial gums are formed and, along with associated bacteria and fungi, crumb formations are formed with the soil particles. Organic exudates from the plant roots can also cause aggregates to be formed (Brady and Weil 2002).

Soil organic matter can be seen to have direct growth stimulating effects. The amount and composition of the organic matter can be a pivotal factor in the health of a soil system. The organic matter value carries one of the largest adjustments to the Soil Health Index due to the relative importance that it has on the health of a plant.

4 The soil chemical component

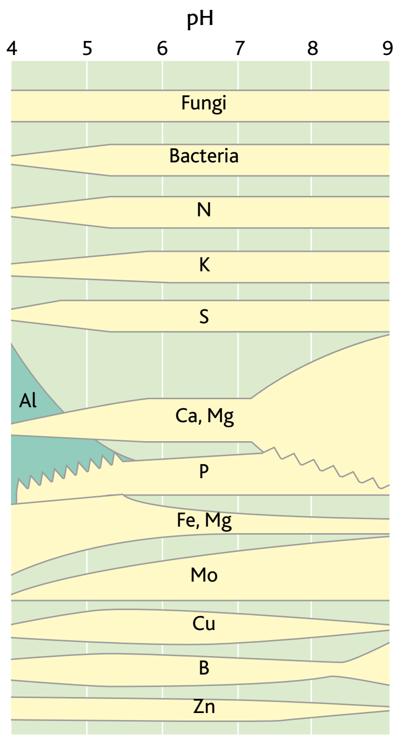
4.1 Soil pH

Soil pH influences nutrient interactions, root development and microbial population dynamics. It greatly influences the availability of nutrients and potential toxins for root uptake (figure 8).

Soils can become more acidic over time as a result of the effects of rain containing dissolved CO_2 and other acidic compounds, nitrification (the conversion of ammonium to nitrate by microbes in soil) and also the accumulation of organic matter. Soil acidification tends to occur to a greater extent in grassland and to a lesser extent in arable soils (due in part to the higher rates of N fertiliser used on grassland). Buffering capacity is the ability of a soil to resist changes in pH. The soil pH can be strongly buffered by a number of interactions within the soil particles and soil solution (Whitehead, 2000). This can increase with cation exchange capacity and organic matter content. A clay soil that has a high CEC will acidify at a slower rate than a sandy soil with a low CEC (Hazelton and Murphy, 2007).

In strongly acid soils (pH <5) (eg heathland) the availability of the macro nutrients (Ca, Mg, K, P, N, and S) as well as molybdenum and boron can be significantly reduced. For most micro nutrient cations (Fe, Mn, Zn, Cu, and Co) their availability is increased by low pH and their available concentrations in the soil can become toxic to higher plants and microbes (Whitehead, 2000). The relationships between nutrient availability and pH can be seen in the diagram below. It also shows the influence pH has on microbes: low pH soils tend to become fungi dominant whereas high pH soils can become bacteria dominant.

Figure 8: After Brady and Weil 2002, Nutrient availability to plants



Relationships between soil nutrient availability to plants and soil pH – also shows relationship between microorganism activity (Fungi and bacteria/actinomycetes) and soil pH.

Note the jagged line between phosphorus, Calcium, Magnesium, Iron and Manganese. This indicates the possible availability antagonism and stimulation that these nutrients can have on each other.

Aluminium toxicity is one of the most severe problems associated with strongly acid soils. Aluminium is a component of clay minerals but under acid conditions it can become soluble and interfere with phosphorus uptake in the roots. The most common symptom in the plant would be a stunted root system – stubby roots that show little growth and branching of the laterals (Brady and Weil 2002).

Manganese toxicity can also be associated with low pH soils (pH 5.5 or less) and can be particularly severe in soils with low levels of oxygen e.g. flooded soils.

4.2 Macronutrients and how they impact the Soil Health Index (SHI)

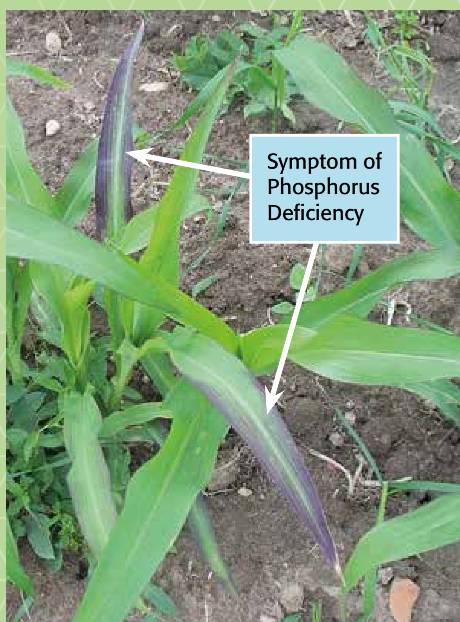
Phosphorus – Considered to be the second most important nutrient (after nitrogen) for crop yield and plant health. Therefore low levels of available phosphorus in your soil will significantly impact on the health of the soil. Phosphorus is an essential element of the organic compound adenosine triphosphate (ATP). This contains a high energy phosphate group that drives most biochemical processes. It is at the centre of the energy transformations for chemical transfer and for the uptake of chemicals (Williams, 1979). The uptake of most nutrients and their subsequent transportation throughout the plant require ATP. Phosphorus is also an essential element in DNA and RNA. These both direct protein synthesis in plants.

Having the optimum levels of phosphorus in soil will improve many aspects of plant physiology such as photosynthesis, nitrogen fixation, flowering and fruiting in the plant and maturation. A root system with an optimal supply of phosphorus will have well developed lateral roots and fibrous rootlets. In cereals phosphorus plays an essential role in preventing lodging due to its function in strengthening structural tissues.

When soluble forms of phosphorus, such those present in fertilisers and manures, are applied to the soil they can become readily fixed from the soil solution to produce insoluble compounds unavailable to the plant. The highest rate of this fixation occurs at very high and low pH. In acid soils the phosphate compounds will become more soluble and available to the plant as the pH increases. In alkaline soils insoluble calcium phosphate compounds will become more soluble as the pH decreases. Therefore phosphorus fixation is minimised when the soil pH is maintained between a pH of 6 and 7 (Brady and Weil 2002).

The pool of phosphate that is available to plants is only a small percentage (~0.1%) of the total phosphorus in the soil due to the phosphorus fixation and precipitation of insoluble forms of phosphorus in soil. Increasing the organic matter content of a soil rhizosphere can reduce phosphorus fixation and allows soluble forms of phosphorus applied to the soil to remain in a soluble, available form.

Figure 9: Example of Phosphorus deficiency in Maize



Crop deficiency symptoms – Phosphorus deficiency in plants is not always easy to identify as the symptoms can be very similar to those caused by deficiencies of other nutrients. Phosphorus deficiency can result in stunted growth, thin stems and leaves are often dark (bluish green). When crops experience a severe deficiency of phosphorus in the soil the leaves will start to appear yellow. As phosphorus is very mobile within the plant the deficiency symptoms will appear in the oldest leaves first.

Potassium – Essential element required for plant productivity and is considered the third most important nutrient after nitrogen and phosphorus.

Potassium's function and availability in the soil is controlled primarily by the cation exchange properties and mineral weathering rather than by microbial processes. Potassium is not present in organic compounds essential for plant function but instead remains in its ionic form (K+) when it is in both the soil solution and within the plant as it moves to its functioning areas.

Potassium is essential for cellular enzymes as it acts as an activator in their function. It does this for a wide range of enzymes that are responsible for such processes as energy metabolism, starch synthesis, nitrate reduction, photosynthesis, and sugar utilisation. Potassium is also essential for reducing water loss from leaf stomata and increases water uptake in the root. This therefore helps the plant to be more drought-tolerant and more adaptive to environmental stress.

Figure 10: Symptoms of Potassium deficiency on potato leaves

Nigel Cattlin / Science Photo Library

Potassium deficiency in potato (Solanum tuberosum). The outer leaf tissue (brown) is necrotic (dead) and much of the rest of the leaf is not producing sufficient chlorophyll (chlorosis, yellow).

With this nutrient being so important to plant health any deficiencies indicated by the Soil Health Test will be reflected in a reduction in the Soil Health Index. There are also issues with excess potassium in the soil. Most plants will continue to take up more potassium than is required if it is present (luxury consumption). This unneeded potassium is therefore being stored in the above ground portion of the plant. When it comes to harvesting this potassium is removed and can be considered very wasteful. High levels of potassium may also suppress calcium and magnesium uptake and cause other nutritional imbalances (Brady and Weil 2002). A high level of potassium in the soil above the desired level will be reflected in a reduction in the Soil Health Index.

Like nitrogen and phosphorus only a small percentage of potassium in the soil is in a soluble, plant available form. Potassium is readily leached from the soil and therefore in areas where there has been significant rainfall and flooding there is more likelihood of potassium loss leading to deficiencies.

Plant uptake of potassium can be as large as that of nitrogen. The majority of the potassium taken up is transported to the above ground portion of the plant. This large uptake of the nutrient can lead to large losses of the available form (K+) from the soil. In areas where potassium deficiencies are common it is important to replace the potassium removed from the soil by the plant after harvesting.

Crop deficiency symptoms – Potassium deficiencies are easy to spot and the most common symptom to observe is where the tips and edges of the leaves begin to yellow and die. This can look as if the leaf has been burnt. As mentioned previously potassium has a major role in increasing drought tolerance and can reduce lodging therefore during hot summers crops in potassium deficient soils can have a low drought tolerance meaning more crop failures and there can also be more occurrence of lodging in cereal crops.

Magnesium – Component of the chlorophyll molecule and therefore is fundamental to the photosynthesis process within the plant. It also has other major functions including synthesis of oils and proteins and activation of enzymes involved in energy metabolism. It also plays a role in the control of uptake of other essential nutrients and can aid nitrogen fixation in root nodules.

Magnesium can be readily leached from the soil and the process of natural replenishment can be slow and dependant on magnesium rich minerals being present in the soil. During periods of high rainfall and flooding there can be significant losses of magnesium. Magnesium replenishment can be helped by organic matter as it can be made available from the breakdown of organic matter and plant residues (Brady and Weil 2002). Magnesium becomes less available in low pH soils and will become more available in higher pH soils. High levels of potassium and calcium can depress the uptake of magnesium into the plant.

Figure 11: Example of Magnesium deficiency in maize

Crop deficiency symptoms – The most widely seen symptom of magnesium deficiency is interveinal chlorosis on the older leaves. This appears as a mottled green and yellow colouring in dicots and striping in monocots. In sandy soils magnesium deficiency can show similar symptoms to that of plants in low oxygen flooded soils.

Although an indication of soil chemical composition can be gained from observation of growing plants, laboratory protocols for determining soil nutrient status have been a central part of soil management for decades. In order to pro-actively manage the impact of soil chemistry on plant growth and soil health, field observations need to be supported by soil analysis. For example, observing small stunted plants with purple discolouration of leaf and stem may indicate a short-fall in phosphorus uptake. However, this may be due to a number of factors such as low temperatures, compaction, waterlogging, restricted root mass, poor decomposition of incorporated straw, high soil pH, antagonistic chemical interactions, poor microbial activity, or insufficient phosphorus. In order to effectively correct the observed situation, it is essential to identify the cause of the problem. From a soil health perspective, the impact of soil chemistry on root development and plant-microbe interactions is important, and can be effectively managed by judicious application of appropriate fertilisers, nutrient sources, liming materials or acidifying agents.

5 Assessment of the biological component – Importance to soil health

5.1 CO_2 evolution - The Solvita® test "an indicator of soil health"

The Solvita® test incorporates a method that accurately measures the amount of CO_2 respiration of a soil sample. For the test a dried and weighed sample of soil is moistened with a specific amount of water. This initiates the release of CO_2 from the microbial population within the soil sample. The quantity of this release is measured using the Solvita® Digital Colour Reader (DCR). This burst of CO_2 is proportional to the CO_2 biomass and can be used to predict the potential carbon and nitrogen mineralisation.

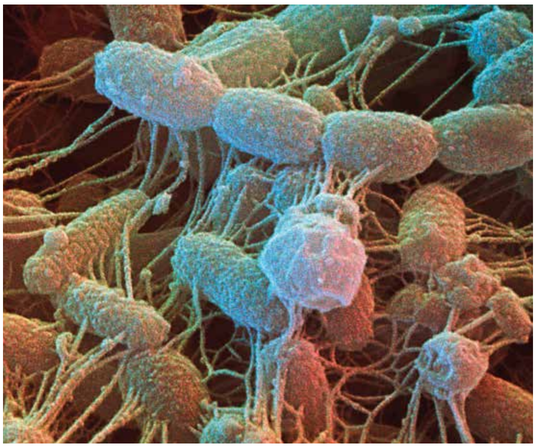
The majority of carbon dioxide released from soils is a result of microbial processes. Having a greater amount of CO_2 released from a soil system indicates greater microbial activity and is therefore a good indicator of the health of a soil.

Field observations of biological activity – Can provide an indication of soil biological activity e.g. assessing the rate at which old crop residue decomposes, relative to incorporation and cultivation, and counting the number of earthworms in a 20 cm cube (a spade full) of soil. It has been estimated that a population equivalent to 25 earthworms per square metre are capable of cultivating around 10% of the bulk soil, incorporating 2500 kg of straw per hectare and releasing up to 80 kg of nitrogen per hectare per annum.

5.2 Soil bacteria

Most bacteria present in the soil obtain their energy and carbon from organic matter. They account for the general breakdown of organic matter and enable the associated processes which contribute to plant health and which are mentioned in the previous section.

Bacteria are involved in almost all organic processes and a range of oxidation and reduction reactions that help to form a healthy soil. Aerobic bacteria are involved in oxidation reactions converting nutrients into more soluble development of the pathogen around the root and promote growth of the plant. Biological interactions such as this can make a significant contribution to crop production (Brady and Weil 2002).



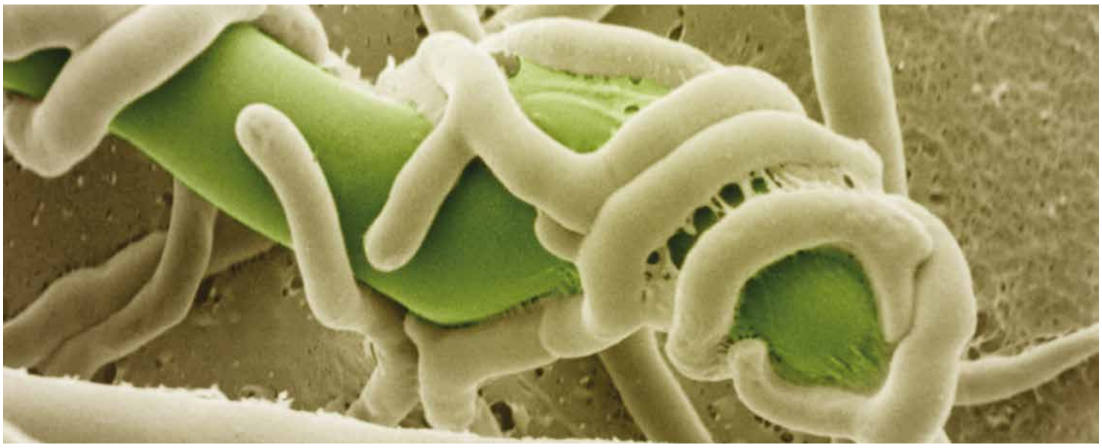
David Scharf / Science Photo Library

Soil bacteria. Coloured scanning electron micrograph (SEM) of Bacillus sp. soil bacteria (thick rod-shaped structures). These Gram-type- positive bacteria are saprotrophs, organisms that feed and grow on dead and decaying organic material. They are part of a diverse ecology of soil micro-organisms that play a vital role in decomposing and recycling organic matter. Magnification: x7,000 at 5x7cm size. x12,000 at 4x5".

5.3 Soil fungi

Fungi depend on living or dead organic matter as sources of energy and carbon for their functioning and growth processes. Fungi typically thrive best in well aerated (aerobic) soils, but some species can tolerate low oxygen conditions. In acid or sandy soils fungi are usually dominant over bacteria as they are better adapted to these conditions.

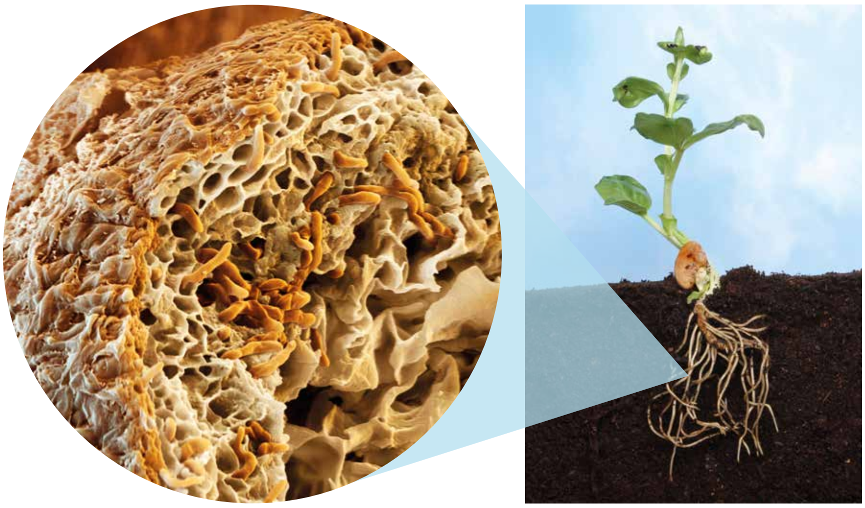
Fungi play an important role in the breakdown of organic matter during the formation of soil humus. They are therefore important to the stabilization process of soils through the formation of colloids and soil aggregates as mentioned in the soil texture section (Brady and Weil 2002).


Biophoto Associates / Science Photo Library

Trichoderma attacking a plant pathogen (Rhizoctonia sp, cause of root rot). A narrow hyphae of Trichoderma coil around wide hypha of Rhizoctonia, the latter will collapse and die. SEM Magnification: 2350x.

Fungi are more efficient at breaking down and assimilating organic materials than bacteria leading to a much higher biomass and growth rate. Soils with low levels of fungi will have slower rates of decomposition of complex forms of organic matter such as crop debris and therefore less readily available plant nutrient contribution from this material. The nutrient cycling performed by fungi has a large contribution to the health of a soil system.

Mycorrhizae – Considered to be one of the most important biological functions in soil. Mycorrhizae is the term given to fungi that have a mutually beneficial (symbiotic) association with plant roots. Many plants can be highly dependent on this relationship. The plant provides energy generated by photosynthesis to the fungus when it infects the roots and receives a number of benefits in return from the fungus. Fungal hyphae (branching chains of fungal cells) cover the root surface and also grow out into the soil, effectively increasing the coverage of the plant's root system in the soil. This can make the plant much more efficient at absorbing plant nutrients (particularly phosphate) from the soil solution. In some cases mycorrhizae can protect the plant from toxins, soil borne diseases and parasites, and improve resistance to drought (Brady and Weil 2002).


Detailed image: Eye Of Science / Science Photo Library

Mycorrhiza, coloured scanning electron micrograph (SEM). A mycorrhiza is a symbiotic association between a soil fungus and the roots of a vascular plant. The majority of vascular plant roots are mycorrhizal. Here, fungal hyphae (thin threads, orange) are seen within the cortex of the root. Both organisms benefit from this association. The fungus is able to access nutrient forms unavailable to the plant, process them and pass them on to the roots. The mass of hyphae also provide a large surface area for uptake of water and minerals. The fungus receives carbon compounds that the plant produces via photosynthesis. Magnification: x900 when printed at 10 centimetres wide.

6 Taking samples and in-field observations

6.1 The principles of sampling

The first point to remember about soil analysis is that any analytical result is only as good as the sample taken. Let us consider one sample taken in a 5 hectare area, that sample might weigh 250 to 500 grams. If it was to weigh 500 g, and we were looking at a soil depth of 15 cm, then that 500 g would be half a kilogram out of 1.8 million kilograms! Once it reaches the laboratory that 500 g will be well mixed and sub-sampled for the individual analysis within the package. So for a sample to be representative of all that soil, it must be taken carefully.

The number of samples to take depends on the way you are going to be using the results of the soil analysis. Generally, as a simple rule of thumb you should take at least one sample for each area that you are going to manage. For example, you should take one representative sample per field, if you are going to manage soil health on a field scale. If you know that different areas of the field perform in different ways then you should take a representative sample from each area. If you have a problem area, you should take one sample from the problem area, and one from a good area to check background levels, so you have something to compare your problem with a point of reference. It should be noted that the number of samples per field is a trade-off between accuracy and analytical cost. Whilst additional samples cost more money, keeping to one sample as the field size doubles, halves the accuracy. If the sample is for monitoring of soil properties a W pattern of as many cores as possible should be taken through the area in question avoid irregular patches such as gateways, headlands and trees.

Samples should be taken before applications of fertiliser or any other chemical treatment. If it is necessary to sample following an application, a minimum period of 2-3 months should pass before the soil is sampled.

6.2 Depth of sampling

Again a simple rule of thumb – sample as deeply as the active rootzone you are managing. For arable and cultivated soils this is typically 0-15 cm (0-6") and is related to cultivation depth. For permanent grassland, then a typical depth of 0-7.5 cm (0-3") is used and this is related to the rate of soil formation and animal penetration.

6.3 Timing

Soil Health sampling can be incorporated into a quality crop or grassland management scheme. If you are looking to monitor Soil Health over time sampling should occur at regular intervals so that comparisons from the same time each year can be made. It is advised that samples are not taken during weather extremes as this may show misleading results for the microbial activity.

In the same way as for standard analysis sampling can also be required when crop problems have been identified, look for signs of mineral deficiencies, stunted growth, discolouration of the crop, leaf mottling and premature leaf death for example.

It is important that samples are not taken for 2-3 months after a manure application or inorganic fertiliser application.

6.4 Tools for sampling

Essential tools for soil sampling include:

- A suitable soil auger.
- A plastic bucket.
- Analysis request forms and suitable sample packaging.

Soil sampling at depth is best achieved with a soil sampling auger, these devices allow you to sample at depth without digging, and make sampling at the correct depth relatively straight forward. A plastic bucket is essential for collecting cores and mixing them before putting them in the sample packaging – avoid the use of metallic buckets as often they contain elements such as zinc, which can contaminate trace element analyses. Samples should be packaged securely and individually labelled – remember they need to survive the transit process which is out of your and NRM's control.

6.5 The Soil Health Analysis Request Form

It is critical that all samples are submitted with the correct paperwork – this is because the paperwork identifies:

- Who the sample has come from.
- Where the sample has come from.
- Your client's details.
- The names of the samples (cross-referenced with the packaged samples).
- Details of the crops to be grown.
- Details of the fields.
- Slope of the field – will provide soil erosion risk on the report.
- Answers to the in-field observation comments – this will provide further information on the report in relation to their impact to Soil Health.

For these reasons it is worth taking time to complete paperwork carefully. Without this information, reports will appear incomplete and fertiliser recommendations cannot be made because they are crop dependent. For this reason, it is essential to include the cropping information (see figure 12 on the next page).

Figure 12: Example of the Soil Health Analysis Request Form

SOIL HEALTH

Soil Health Analysis Request (A500)

To be crossed to the Gold Card system

REPORT NUMBER BATCH NUMBER

Laboratory Reference		Sample Reference	SOIL TYPE	FIELD SIZE (HA)	CROP CODE PRESENT	CROP CODE FUTURE	STRAW REM Y/N	FYM Y/N	SLOPE DEGREES	Soil Compaction (Y/N)	Earth Worm Count Count/ Cubic Foot
	1										
	2										
	3										
	4										
	5										
	6										

Client Details:

Name____________________

Address____________________

Postcode____________________

Additional Analysis (e.g. traces, Min N etc) __________

Crop nutrient deficiency Symptoms

Please indicate which fields have deficiency symptoms

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6

Merchant ____________________

Local Rep ____________________

Phone No ____________________

6.6 In-field observations

Soil compaction – It is very important to check for Soil Compaction as this can have a major impact on Soil Health. This is where the undisturbed soil bulk density of the top or sub soil has become higher than that of the natural system from the application of pressure to the soil surface. This can be induced by human activities (in field traffic, livestock, tillage operations, irrigation). When compaction occurs, root growth and emergence can be inhibited. The soil will have increased resistance to root penetration, poor aeration from reduced soil pore sizes, slow movement of nutrients and water, and a build-up of toxic gases and root exudates. Compaction may lead to a shift in microbial populations from aerobic to anaerobic. During wet years this can become increased as the small pore spaces are filled with water shifting the soil into a more anaerobic state. This leads to increased loss of Nitrate N by denitrification releasing gaseous nitrogen into the atmosphere.

Soil compaction can occur on the soil surface as soil crusting and it can also occur in the sub soil. Both types of compaction can be the result of the same activities in the field.

- Soil tillage operations that remove protective residues in the soil surface can leave the soil subject to natural weathering and erosion. Tillage operations over many years will break down soil surface aggregates creating a hard and compacted surface layer.
- The base of tillage equipment can cause compaction below the depth of tillage in the sub soil. When this occurs there is the creation of a hardpan below the worked soil. This can be identified by scraping back the tillage layer. The effect of this hardpan can be seen through horizontal root growth where roots cannot penetrate this compacted layer.
- The weight of large machinery will cause wheel traffic compaction to occur which will be evident to a sizeable depth through the rootzone profile and into the subsoil. In wetter seasons the depth of compaction will increase. To identify compaction deep in the soil profile soil penetrometers can be used.

- Compaction in the form of soil crusting can also occur as a result of the combination of tillage operations and raindrop/irrigation water impact. As the tillage operations break down soil aggregates the soils become subject to degradation from rainwater and irrigation. The soil particles become suspended in water and start to flow together. This process leads to the formation of a crusted surface. This can be identified by a visual check of the soil to see if horizontal layered structures are present.

When identifying compaction, assessment of both the surface and subsurface will need to be carried out using the techniques discussed. By indicating on the request form that compaction is present, this will generate information on the report to bring attention that soil compaction might be causing negative effects on Soil Health and is limiting the potential of the soil.

Earthworm count – Earthworms and other small animals living within the soil mix soil particles as they move through the soil profile. Earthworms in particular ingest soil particles and organic matter residues which can significantly increase the availability of nutrients to plants and can break down organic matter to a form that soil microbes can utilise. The physical process of the digestion breaks down soil particles increasing surface area, these particles are then attacked chemically by digestive enzymes releasing nutrients from mineral particles.

They also play an important role in soil aeration and stability of soil aggregates. In 1 m^3 of soil earthworm burrows can be up to 100m in length and are a major contribution to the biopore volume of the soil. Soil that passes through a worm's gut gets thoroughly shredded and organic materials and residues get mixed with mineral soil particles. This enhances microbial activity and because of this the soil particles become high in polysaccharides increasing the stabilisation of soil aggregates.

Earthworms thrive in healthy soil due to their requirement for organic matter and nutrients. A good population of earthworms shows that your soil has the resources to sustain their life. Having a large number of earthworms present in your soil enhances the health of your system so therefore when assessing your soils the higher the number of earthworms in your soil the healthier your soil is.

To get a rough idea of earth worm activity this simple measurement technique can be followed:

Measure out an area 30 cm x 30 cm and as quickly as possible dig out the soil to a depth of 30 cm. Place the dug soil on a sheet and hand count the number of worms recovered. Around 10 worms per 27,000cm3 (Cubic Foot) is considered a good population for a healthy system.

Crop nutrient deficiency symptoms – Visual symptoms of nutrient deficiencies result from impaired metabolism within the plant. It is quite often possible to identify the deficiency from the characteristics of the symptom however there are some symptoms that are less characteristic and could indicate a number of possible deficiencies (Robson & Snowball, 1986).

There are a number of published descriptions of symptoms of nutrient deficiencies and these should be referred to, which can help identify the possible deficiency/ toxicity impairing the metabolism and decreasing the growth of the crop. It is vital that the advice of an agronomist is sought to help identify the cause of the deficiency symptom.

A very useful way to help identify the cause of deficiency symptoms and to help confirm a diagnosis is to carry out plant tissue analysis for major and trace elements carried out. Requesting additional trace elements in addition to the Soil Health Package will enable comparison between the soil and plant tissue results. This can help identify if there are any antagonisms in the soil affecting uptake of nutrients by the plant or whether the soil nutrient supply is the limiting factor causing decreased growth.

7 References

Brady N.C., Weil R.R., 2002, **"The Nature and Properties of Soils"** thirteenth edition, Pearson Education

Chiras D.D., 2013, **"Environmental Science"** James and Bartlett Learning

Department for Environment, Food and Rural affairs, 2010, Soil Protection Review, http://rpa.defra.gov.uk/rpa/index.nsf/0/c39ae2bb7b8ab8158025768e005e57cd/$FILE/Soil%20Protection%20Review%202010.pdf

Food and Agricultural Organization of The United Nations, 2011, **Save and Grow - A policymaker's guide to the sustainable intensification of smallholder crop production,** http://www.fao.org/docrep/014/i2215e/i2215e.pdf

Fuglie, K., 2013, Branch Chief for Resource, Environmental and Science Policy, U.S. Department of Agriculture, Economic Research Service, Washington, DC.

Global Harvest Initiative. (2010) 2010 GAP Report: Measuring Global Agricultural Productivity. Washington, DC. http://www. globalharvestinitiative.org/documents/GAP%20Report.pdf

Global Harvest Initiative. (2013) 2013 GAP Report: Sustainable pathways to sufficient nutritious and affordable food, http://globalharvestinitiative.org/GAP/2013_GAP_Report_BOOK_ONLINE.pdf

Hazelton P., and Murphy B., 2007, "**Interpreting soil test results – what do all the numbers mean"** NSW Department of Natural resources

Karlena D.L., Ditzlerb C.A., Andrewsa S.S., 2003, **Soil Quality: How and Why**, Geoderma 114, 145 – 156

Scow K. M. and Werner M. R., 1998, Cover Cropping in Vinyards – A Growers Handbook, Chapter 5 – Soil Ecology p69

Whitehead D. C., 2000, **"Nutrient Elements in Grassland – Soil-Plant-Animal Relationships"**, CABI Publishing

Williams R. J. P., 1979, Phosphorus in the Environment: Its Chemistry and Biochemistry – Phosphorus Biochemistry, p95, Ciba Foundation

Notes

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