

RESEARCH TOPIC REVIEW:

Laboratory mineral soil analysis and soil mineral management in organic farming

Authors: Christine Watson, Scottish Agricultural College

Elizabeth Stockdale, School of Agriculture Food and Rural Development, Newcastle University

Lois Philipps, Abacus Organic Associates

1. Scope and Objectives of the Research Topic Review

The objective of the Research Review “**Laboratory mineral soil analysis and soil mineral management in organic farming**” is to draw together all the available relevant research findings in order to develop the knowledge and expertise of organic advisers and thereby to improve soil management practice on organic farms. The Review will concentrate on N, P and K and:

1. Identify all the relevant research undertaken
2. Collate the results of research and summarise the findings of each project
3. Draw on practical experience
4. Analyse the research and summarise the conclusions in a form that is easily accessible by advisers and can be used to help them select appropriate soil analytical techniques and to interpret the results and provide practical advice to farmers on soil management and amendments.

2. Introduction to measuring soil fertility in organic farming.

The capacity to improve the fertility of a given soil through management is inextricably linked to the inherent properties of that site – soil texture, mineralogy, slope and climate. Ideally soil fertility should be assessed for the soil *in situ*, in the field/farm context, rather than as a list of properties of an isolated sample. Absolute requirements or critical values for any one factor of soil fertility considered alone will be almost impossible to determine, as the expression and interaction of properties in the field is the key to crop growth. It is particularly important to have a good understanding of the inherent properties of any site when farming organically as the scope for using agrochemicals to overcome short-term problems is severely restricted compared with conventional systems. In this respect maintaining good soil structure is paramount in organic production. Compaction, for example, can result in poor root development and thus poor nutrient uptake. In conventional systems this can be at least partially overcome through the application of soluble fertilisers. Organic farming requires the preventative approach of aiming to ensure that soil structure does not limit production.

Traditionally soil fertility has been equated with soil nutrient availability, assessed through chemical analysis, but increasingly physical and biological parameters are included in assessments of soil fertility (Stockdale *et al.*, 2002). It is also interesting to note that measurement of one soil property can provide a good indication of other properties. For example, i) pH can be used as an indicator of biological activity or ii) water filled pore space can be used as an indicator of methane or nitrous oxide production. What is important is that soil tests provide the information necessary to plan and manage successful crop and livestock production on the farm. Soil tests are only as representative of the soil conditions as the samples collected. Thus samples sent to the laboratory should be truly representative of the field and be a well mixed composite of at least 10-15 subsamples. If a field includes more than one very different soil type it is probably worth getting samples from different parts of the field analysed separately. Stone content should also be taken into account in interpreting the analysis. Soil analysis is generally reported in mg/l of nutrient in the soil and often described using an index. A one-off soil analysis simply provides a snapshot of nutrient availability at a particular time. It is thus critical to repeat soil analysis at regular intervals to identify trends in nutrient availability and thus adjust nutrient management accordingly. This is particularly important for organic farmers in order to assess the benefits of slow release of nutrients from crop residues and

imported materials. Similarly the analysis itself is only the first step, specialist interpretation and recommendations are equally important.

As soil fertility management in organic systems is a longer term, more strategic process than in conventional systems there is an argument for the use of more holistic methods of analysis which reflect the integrated nature of organic production. Trends in soil nutrient and organic matter status are likely to be more important than snapshot analysis and many authors recommend the use of soil analysis alongside nutrient budgets as a way of tracking fertility changes over time in organic systems (Watson *et al.*, 2002, Oborn *et al.*, 2003). There is a need to assess the impact of soil management on crop and livestock health and nutrition on the basis of complete rotations rather than an individual season; it has been recommended that the minimum time required to recognise trends in soil properties and thus changes in soil fertility is one complete rotation (Wildhagen and Brandt, 2003). It is also critical to recognise the interactions between different nutrients within the system. For example, there may be no response to added K if N is limited (see Fortune *et al.*, 2005)

There has been considerable discussion over whether alternative methods of chemical soil analysis are required for organic farming. Conventional soil analysis for advisory purposes relies on the interpretation of the chemical extraction of different soluble nutrient pools from the soil to predict nutrient availability to crops (Edwards *et al.*, 1997). A wide range of approaches are used even in conventional systems with at least 12 different soil extractants used for measuring available P in soils (Tunney *et al.*, 2003). However, in organic systems it is the release of these nutrients by biological processes from organic matter pools that is critical in determining nutrient availability. Organic systems differ very significantly from conventional systems in that they depend very much more on the application of nutrients in insoluble or organic compounds. It is therefore often the rate of transfer from an unavailable to available nutrient form that is critical in organic systems rather than the size of the available nutrient pool. When comparing farming systems, measurement method may affect the results; routine soil testing may not be able to predict available soil P in a biodynamic system due to the interaction of crop and soil factors in controlling mobility of P ions (Oberson *et al.*, 2003). See detailed section on P analysis below. The Base Cation Saturation Ratio or “Albrecht” technique (Kinsey and Walters, 1999) is also advocated to provide a soil analysis in tune with soil ecology. This is discussed further in Section 7.

Perhaps the simplest integrated measure of the chemical and physical environment within which the plant exists is plant performance (yield and nutrient uptake) which as discussed above is central to the definition of soil fertility. Thus for example, problems with the soil’s physical environment such as layers of compaction are often more easily identified by visual examination of plant root distributions. Likewise nutrient deficiencies can often be better assessed by determining the amounts of nutrients within plants than by use of a chemical extract in soil. Plant analysis may also be more useful for estimating trace element availability than soil measures. However, soil maps provide a valuable tool for identifying areas liable to trace element deficiency. Farmer perceptions of soils tend to be holistic in nature and integrate observation with management history as well as known quantitative measures. A combination of soil parameters used in an index may be more in agreement with holistic soil quality criteria, such as farmer assessed soil quality than any individual parameters (Gruver and Weil, 2007).

3. Nutrient pools in soils

3.1 Soil N pools

The layers of mineral soil exploited by plant roots generally contain between 5000 and 15,000 kg N/ha (around 5% of dry weight or organic matter). Total soil N content is thus strongly linked to soil organic matter content. However, the majority of this N is in organic forms which are not plant available. Figure 1 shows the relationships between different N pools. Generally around 1-2% of the organic nitrogen in soil is mineralised and available to crops in inorganic forms (nitrate and ammonium). At low pH, ammonium is the dominant form. The soil nitrogen cycle is very dynamic

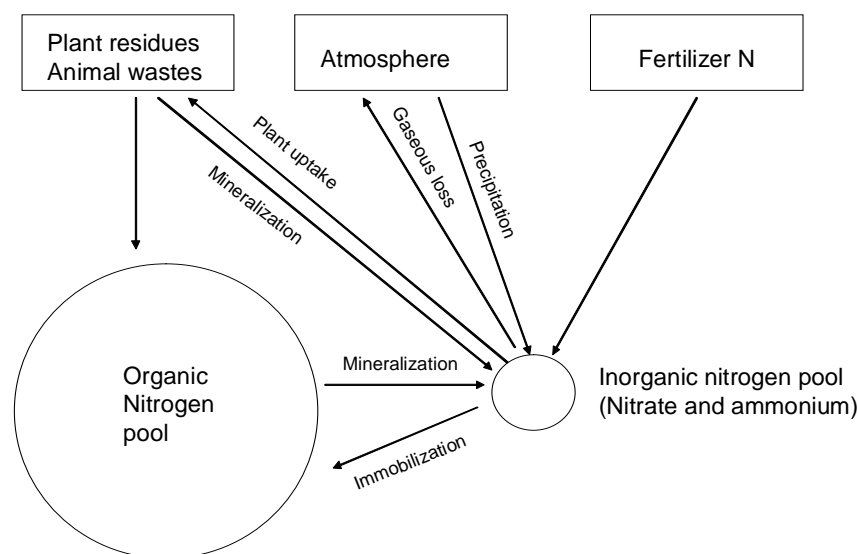
and the nitrogen held in microbial biomass cycles constantly. The conversion of organic to inorganic forms is stimulated by cultivation. In organic systems the largest quantities of available N follow ploughing of leys. Available nitrogen which is not taken up by plants is subject to gaseous and leaching losses. Much more detail on soil N is provided in the IOTA review by Stephen Briggs.

3.2 Soil P pools

The total level of native P in soil is low compared to other plant nutrients. It is usually present in amounts equivalent to one tenth to one quarter that of N and one twentieth that of K (Brady and Weil, 1999). The total P content of soil varies greatly, ranging from 500 to 2,500 kg ha⁻¹, much of this (15-70 %) is present in strongly adsorbed or insoluble inorganic forms with the remainder present in organic forms (White, 1995). In organic soils, such as peat and forest soils, a larger proportion of P will be present in organic compounds. The amount of P in the soil is related to a number of factors, including P inputs, soil parent material and management.

The maintenance of adequate levels of P for plant growth is complicated by the low concentration and solubility of P compounds in soils. Levels of P in the soil solution at any one time are much less than that required for plant growth. Therefore, levels of P in the soil solution must be constantly replaced from the inorganic and organic parts of the soil or in managed systems by fertiliser and manure additions. Soil pH is one of the main factors controlling the forms of inorganic P, with the quantities of Al, Fe, Mn and Ca determining the amounts of these forms. A pH between 6 and 7 gives greatest P availability. This relationship is shown in Figure 2.

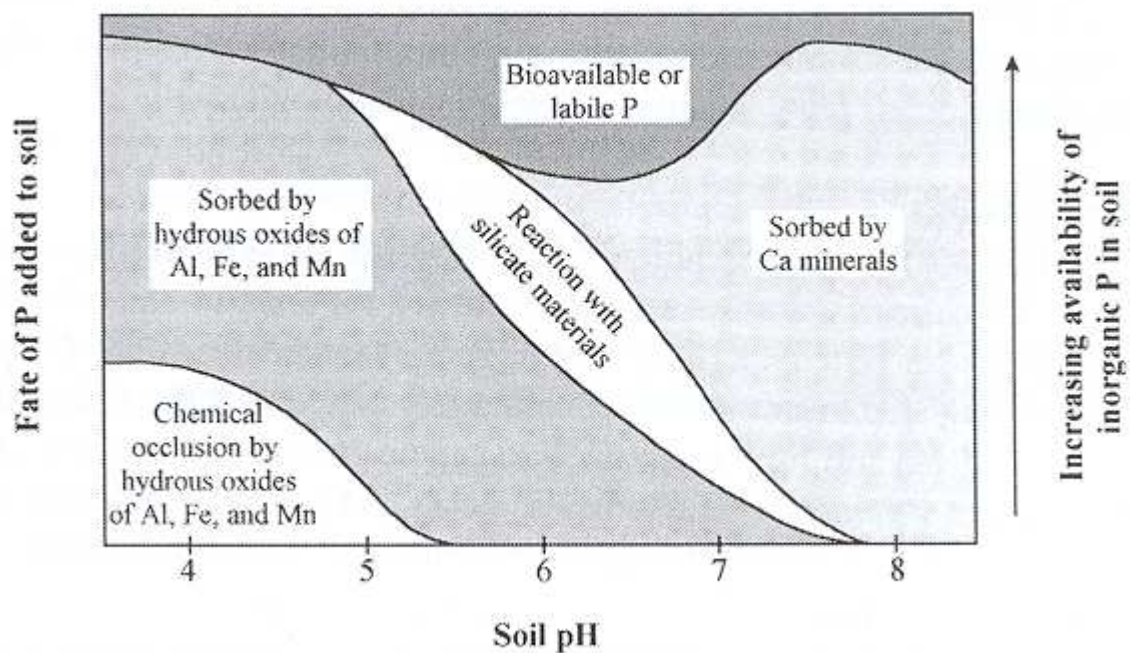
Figure 1: N pools, sources and transfers (Brady, 1990)



Organic P compounds include inositol phosphates, nucleic acids and phospholipids. Additionally the soil microbial biomass also contains a significant pool of organic P within its cells. In arable soils, approximately 3% of the total soil organic P is present in the microbial biomass (6 - 27.5 mg P kg⁻¹ soil). In grassland soils, the biomass comprises a larger (5 - 24%) proportion of the total soil organic P, equivalent to 12 - 72 mg P kg⁻¹ soil (Brookes *et al.*, 1984).

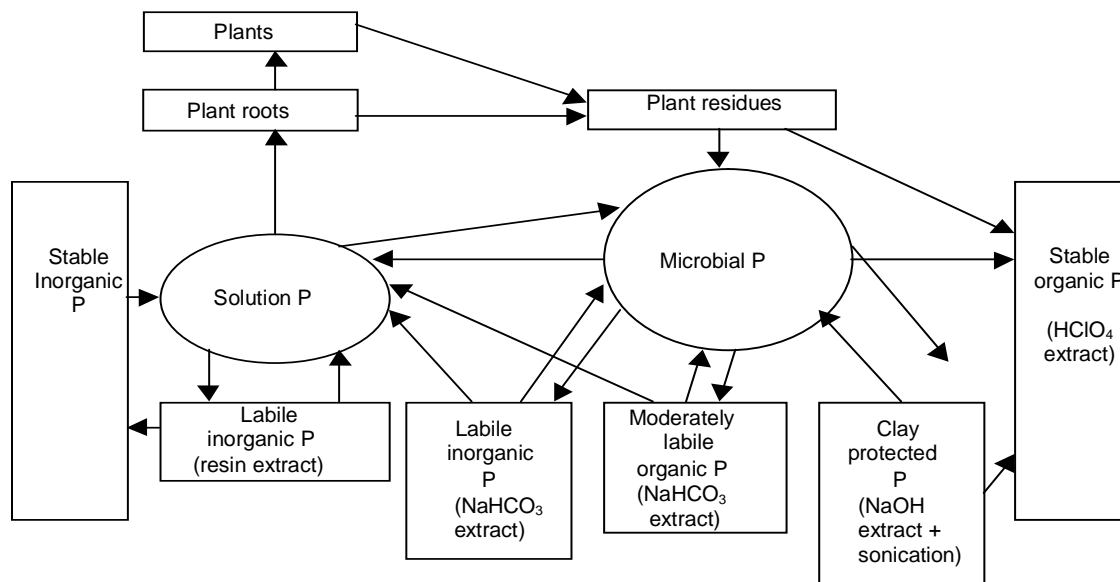
Soil P transformations are complex. P dynamics in soil are often illustrated by dividing P into different pools based on the availability of the various forms, usually defined by chemical extracts (Figure 3). More details of the chemical extracts are given below. Phosphorus is also added or returned to the soil in crop residues, fertilisers (inorganic and organic), deposition (wet and dry), animal and human wastes. The inorganic P applied to soils is either taken up by plants, or becomes weakly (physical) or strongly (chemical) adsorbed onto Al, Fe and Ca surfaces, or built into organic P. An equilibrium exists between soil solution P and labile inorganic P, as inorganic P is removed from the soil by plants or immobilisation processes, the inorganic P is solubilised from the labile inorganic P pool. At any one time, only about 0.01% of the total P is present in an available form (Brady and Weil, 1999).

Figure 2 Approximate representation of the fate of P added to soil by sorption and occlusion in organic forms, as a function of soil pH (Source: Sharpley, 2000)



The mineralization of organic matter by soil micro-organisms provides an important supply of available P. Chater and Mattingly (1980) estimated that the annual turnover of organic P through the soil microbial biomass was 25 kg P ha⁻¹ for grassland and <1 to 10 kg P ha⁻¹ for soils under arable crops or under ley arable rotations. More rapid turnover of microbial biomass P has also been measured in soils receiving FYM regularly (Oberson *et al.*, 1996). It has been shown that mineralization of organic P is greater when available P is limited (Smeck, 1985). Some groups of micro-organisms also secrete organic acids that attack and release P from insoluble forms of phosphate. The microbial biomass, therefore, has a key role in the cycling of P through the soil solution.

Figure 3 Soil P transformations

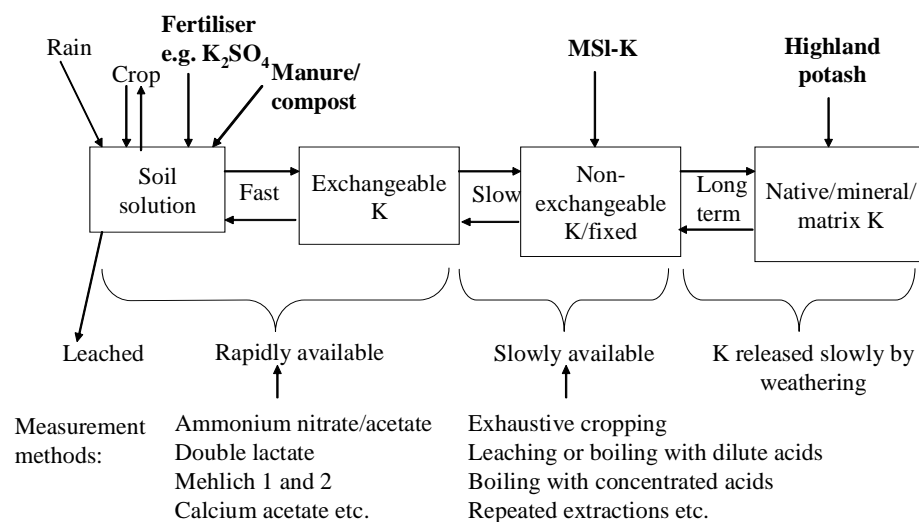


3.3 Soil K pools

Large reserves of K are present in many soils. The K content of mineral soils can vary from 0.04 to 3% (1000 to 75,000 kg ha⁻¹) (Cresser *et al.*, 1993). Of this, 90-98% is bound in the mineral form and 2% is present in the soil solution and exchangeable phases. Potassium exists in four forms in soils, these forms differ in their availability to plants and microbes: solution > exchangeable > fixed > structural (native/mineral/matrix) (Figure 4). The fixed pool alone or fixed plus structural K are often referred to as non-exchangeable K.

Plant available K exists in two forms, as K ions in soil solution and exchangeable K. Soil solution K is the most readily available source of K to plants and microbes and is the form most subject to leaching. Levels of K in the soil solution are generally low (<0.1%; Brady and Weil, 1999) unless recent additions of K have been made. McLean and Watson (1985) estimated that only 5% of the K requirement of a crop is present in the soil solution at any one time. The concentration of K ions in the soil solution depends on a variety of factors including soil type, soil weathering, fertiliser use and cropping.

Figure 4 Dynamic equilibrium of soil K showing K extracted by different analytical techniques.



As plants and microbes remove K from the soil solution some of the exchangeable K moves into the soil solution until the equilibrium is re-established. If soluble K fertilisers are added to the soil, the soil solution becomes enriched and the process operates in reverse, with K moving from solution onto the exchange complex. It is generally not possible to decrease exchangeable K levels below a certain level because as exchangeable K is reduced, the remaining K is held more strongly against further solubilisation and the release of K is triggered from non-exchangeable forms to replenish the exchangeable pool. Some clay minerals contain adsorption sites (wedge sites) which have a high specificity for K. These sites are created as micas weather and partially expanded (illites) or expanded interlayers (vermiculites) are formed. These are primarily responsible for the fixation and release of K, with clay mineralogy (type, amount and particle size), soil pH, fertiliser inputs and cropping determining the extent of release and fixation. Release of fixed K occurs when levels of exchangeable and solution K are decreased by crop removal, leaching or microbial activity. Fixed K can make an important contribution to plant available K, particularly in soils containing small amounts of exchangeable K. Fixed K is usually described as being moderately to sparingly available to plants, with availability dependent on the plant species; monocotyledons are better able to utilise fixed K than dicotyledons, due to differences in their root system (Mengel, 1985).

When K is fixed onto clays this can be beneficial as it reduces K leaching losses and luxury consumption of K yet maintains a potentially available pool of K. In highly K depleted soils K fixation can be significant and even where fertiliser is applied only a small amount of K may become available within the growing season. The release and fixation of K can be seen as a dynamic and reversible process (Figure 3). Potassium release and fixation in soils is governed mainly by the quantities and type of primary and secondary minerals present in the soil, their particle size and K activity around the minerals (Goulding, 1987). It is also affected by factors such as soil pH, rainfall and temperature, wetting and drying, freezing and thawing, soil structure, fertilisation and plant roots. In fertile soils, the release of K from exchangeable and non-exchangeable forms may be adequate to supply K for optimum plant growth, however, where high yielding crops are grown or significant quantities of K are removed, additions from supplementary sources may be required. On some soils e.g. heavy clays, the release of K from non-exchangeable sources will support crop production without imports (Goulding and Loveland, 1986). Figures are in the order of 3-5 kg ha⁻¹ yr⁻¹ for K

weathering in coarse sandy soils in N Europe compared with 65-80 from clay rich soils (Kayser and Isselstein, 2005). Of the K removed by plants, some will be returned to the soil in plant residues, leached from plant foliage, or returned in the waste of animals feeding on the vegetation (Syers, 1998). In natural ecosystems most of the K is recycled in this way, however, in agricultural systems, one fifth (e.g. cereal grains) or practically all (e.g. hay) the K will be removed from the system. Some K will also be lost in runoff, leaching or erosion.

4. Methods of measuring soil N

There are several methods available for measuring total N in soils, mineral N in soils and mineralization potential. Chemical extractions which aim to establish the pool of nitrogen to plants include the use of potassium salts e.g. KCl or K₂SO₄ to extract inorganic and labile organic N pools. The problem with these is that they are simply a snapshot of what N is available at a given point in time rather than what will be available over the growing season. Incubation methods aim to predict what N will be available over the entire growing season i.e. they include available N and potentially mineralisable N. However, as the methods generally involve removing soil from the field and incubating it under laboratory conditions they are not necessarily a good representation of what N will become available. This is primarily because mineralization is so strongly influenced by weather conditions. Rainfall is particularly important because nitrate moves in water and thus availability to plants is restricted in dry soil conditions. Soil N is also very variable spatially particularly in grazed situations or under pigs and poultry. Incubation methods are also generally too time consuming for routine use. In the conventional sector there is interest in retrospective methods which analyse N in plant material as a basis for fertiliser application but this is much less relevant in organic farming. Regular measurement of soil organic matter using, for example, loss on ignition which provide guidance on fluctuations in soil organic matter over time and thus total soil nitrogen levels.

5. Methods of measuring soil P

Soil P tests are commonly used to assess soil nutrient availability and to assist in fertiliser recommendations. A large number of soil P tests exist, with more than ten different methods available in Europe (Table 1). Other tests for available P such as Mehlich (Nelson *et al.*, 1953; Mehlich, 1984) and Bray (Bray and Kurtz, 1945) are widely used in the US and world-wide. However, in most countries one or two tests are favoured (Tunney *et al.*, 1997). No single test is suitable for all soil types and each soil test has its limitations. There have been many reviews discussing the various soil P tests and their relative merits (e.g. Sibbesen, 1983; Sharpley *et al.*, 1984). The extractants used vary in their strength and mode of action. Factors such as pH, clay content, organic matter content and amount of free CaCO₃ all influence P extractability. The main criticisms of many of the soil tests is that they fail to give information on the rate of conversion of insoluble P forms to plant available forms during the growing season (Stevenson, 1986) and do not provide information about the availability of organic forms of P.

Table 1 Methods of soil P analysis in Europe (Tunney *et al.*, 1997)

P test	Method (soil:solution ratio)	Country	Reference
Pw	1:60 (v/v), extraction with water at 20 C, 22h incubation, 1 h shaking	Belgium, the Netherlands, Switzerland	Sissingh, 1971
Pw modified	1:50 (v/v), extraction with water at 20 C, 2h shaking	Germany (Hanover)	Schachtschabel and Koster, 1985 (after Sissingh, 1971)
P-AL	1:20 (w/v), 0.1 M ammonium lactate + 0.4 N acetic acid, pH 3.75, 2 h shaking	Belgium, the Netherlands	Egner <i>et al.</i> , 1960
P-DL	1:50 (w/v), 0.02 M calcium	Belgium, Germany	Egner and Riehm,

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	lactate + 0.02M hydrochloric acid, pH 3.7, 1.5 h shaking		1955
P-CAL	1:20 (w/v), 0.05 M calcium lactate + 0.05 M calcium acetate + 0.3 M acetic acid, pH 4.1, 2 h shaking	Austria, Belgium, Germany	Schuller, 1969
P-NH ₄ Ac + EDTA	1:5 (w/v), ammonium acetate + EDTA, pH 4.65	Belgium, Switzerland, Finland	van den Hende and Cothenie, 1960
P-EUF	Electroultrafiltration	Austria, Germany	Nemeth, 1979
P Dyer	1:5, citric acid 2%, 4 h shaking	France	Dyer, 1894
P Joret-Hebert	1:25, ammonium oxalate 0.2 M, 2 h shaking	France	Joret and Hebert, 1995
P Olsen	20:1 (w/v), 0.5 M sodium bicarbonate, pH 8.5, 1 h shaking	Denmark, France, England, Wales, Northern Ireland, Italy	Olsen <i>et al.</i> , 1954
P Morgan	6:30 (v/v), 10% sodium acetate, pH 4.8, 0.5 shaking	Ireland, Scotland	Morgan, 1941

The Olsen-P test (Olsen *et al.*, 1954) is a useful method for predicting P availability in calcareous, alkaline or neutral soils and is the most commonly used P method in England, Wales and Northern Ireland. The Olsen reagent extracts P through a combined pH and ion effect, removing phosphate in solution, plus some labile solid phase P compounds (e.g. phosphate adsorbed to free CaCO₃), slightly soluble calcium phosphate precipitates, and phosphate loosely sorbed to Al and Fe oxide surfaces (Schoenau and Karamanos, 1993). The extraction also solubilises some of the soil organic P, this is important as it is believed to provide a measure of the potential supply of soil organic P to plant uptake (Stevenson, 1986). Due to the more acid pH of most Scottish soils Modified Morgans Reagent is the most generally used.

The use of water or a dilute salt solution, such as 0.01 M CaCl₂, can be used to determine the P concentration of the soil solution. This method has been employed successfully for fertiliser recommendations under certain soil and crop conditions. More recently, CaCl₂ extractable P has been used as an indicator of the risk of P loss from soil to water (Hesketh and Brookes, 2000).

P fractionation methods have been developed to separate soil P fractions on the basis of their availability to growing plants. The Hedley fractionation procedure (Hedley *et al.*, 1982) has become one of the most adopted methods and involves the sequential extraction of soil to give resin extractable P, alkali extractable P and different pools of acid extractable P, representing pools of decreasing plant availability. Work is needed to determine whether these different fractions relate to actual crop growth and whether they provide a better description of soil P status than other single methods of P analysis. Resin extractable P is often used in research as it appears to correlate well with plant available P (Somasire and Edwards, 1992). It is difficult and time-consuming which limit its use in commercial soil analysis.

The application of fertilisers with a low solubility, e.g. rock phosphate, may lead to the build up of residual fertiliser in the soil that is not measured by standard soil P tests. There is a need to consider methods that predict the long-term release of nutrients from these sources (Benbi *et al.*, 1988). However, extracting solutions may not be suitable for evaluating available P when they also remove P from the rock phosphate, which under natural conditions, would not become available for plant growth (Menon and Chien, 1995).

Within the organic sector, the Balzer-P test has also been adopted (Balzer and Balzer-Graf, 1984). See Appendix 1 for more information on methods of soil analysis used in organic farming in Europe.

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Phosphorus is extracted by three strengths of solution; 2% citric acid, double lactate, and sodium acetate, each of these extractions are carried out on separate soil samples. The different extracts are said to determine soil-reserve, plant available and water soluble P respectively. In a field trial at Elm Farm looking at the effects of Glenphos-75 (a rock phosphate and rock potash mix), North Carolina rock phosphate and super phosphate, on soil and crop (bean) nutrient levels, only the super phosphate was found to significantly affect Olsen extractable P. However, for the Balzer soil test differences between the fertilisers were seen (Elm Farm Research Centre, 1993). Whilst all the fertilisers increased the lactate extractable P in a similar way, the rock phosphates increased the citrate extractable P considerably more than the super phosphate (Table 2)

Table 2 The effect of phosphorus fertilisers on phosphorus (mg P kg⁻¹ soil) extracted by Balzer and Olsen soil P tests (Elm Farm Research Centre, 1993).

Extract	Control	Super phosphate	Glenphos-75	North Carolina rock phosphate
Olsen	5.9	8.0	5.8	5.7
Acetate	4.4	5.5	4.4	4.4
Lactate	6.6	13.1	13.1	14.2
Citrate	42.5	55.5	67.8	69.5

The method of soil sampling and treatment of samples prior to and during analysis are also important. It is essential to gain a composite sample representative of the field if recommendations are to be based on the results of soil tests. The depth of sampling must also remain consistent if soil test results are to be compared. The season of sampling can also have a significant effect on recorded soil P levels. P values are usually higher in the winter and early spring, this is believed to be a result of variation in soil pH and organic matter (Collins and Budden, 1998). A decline in soil pH, due to nitrogen fertiliser additions, carbon dioxide evolution from root exudates and organic matter decomposition, reduces soil P test levels.

The MAFF funded project OF0114 (See Appendix 2) which experimentally compared methods of measuring soil P against plant available P found that the P index system could not be easily applied in organic farming. A target soil index of 2 (on the Olsen based scale) is recommended by Defra for arable, forage and grassland and index 3 for vegetables (Anon, 2000). Table 3 below illustrates for conventional agricultural the expected response of crops to added nutrients at different index levels. However, it is possible that in organic systems soils with an index of 1 may supply adequate P. This is because of the importance of the biological pools and processes in supplying P and the regular inputs of organic and relatively insoluble P sources e.g. rock P, which do not significantly enrich the available P pool but can contribute P over the long term. Soil fractionation methods e.g. Hedley or Balzer, which quantify these residual pools of P, may be more useful for the long-term management of soils on organic farms. Measurement of the organic P pool, including biomass P may improve our understanding of P cycling in organic systems. Given the uncertainties associated with Olsen-P analysis for predicting P uptake and yields in organic systems, further research is needed to determine the best soil testing methods available and acceptable soil P levels.

When using the P index system in Britain it is important to be aware that the Scottish advisory system is based on a different extractant (Modified Morgans Reagent) to the system used in England and Wales (Olsen P). The index values are also described differently; this is illustrated in Table 3. RB209 (Anon 2000) while primarily developed for conventional farming provides useful information on the index system.

Table 3 Relationship between Defra and SAC scales. (From PDA Leaflet Soil Analysis: Key to nutrient management planning)

Defra Index	SAC description	Yield response to added nutrient by	
		vegetable crops	arable crops & grass
0	Very low	highly likely	highly likely
1	Low	highly likely	probable
2	Moderate	likely	unlikely
3	High	possible	nil
4	High	unlikely	nil
5	High	nil	nil

5. Methods of measuring soil K

A number of methods are available for measuring soil K (Table 4). Potassium exchangeable to an ammonium salt solution is the most commonly used estimate of plant available K (Goulding, 1987). In Britain, ammonium nitrate (Anon, 1986) and ammonium acetate (Metson, 1965) are now the routine soil tests for available K (Goulding, 1987), with Bray solution (HCl and ammonium fluoride) and resin strips (Feigenbaum *et al.*, 1981) used less frequently. Soil K status measured using ammonium nitrate normally increases during the winter, due to a change in soil equilibrium conditions resulting from reduced crop uptake and freeze-thaw effects causing fixed K to be released from the clay mineral matrix. Sandy soils are less affected by seasonal changes but may have reduced levels in late summer (Collins and Budden, 1998).

There are at least 16 methods available for measuring fixed/non-exchangeable K (Martin and Sparks, 1985), of these, the use of acids e.g. boiling nitric or exhaustive cropping are the most common (Table 4). Some studies have shown that consideration of fixed K can greatly improve estimates of crop yield response (Syers, 1998; Johnston *et al.*, 2001). However, Johnston and Goulding (1990) concluded that measurements of fixed K did not relate well to annual crop responses to fertiliser.

Limited data exists on the contribution of mineral K to plant uptake. Much of the estimates come from long-term field experiments where K applications have been withheld. The removal of K in crop material, in the absence of fertiliser inputs, suggests that mineral K is also a source of K to crops.

Table 4 Methods for measuring soil K (Goulding, 1987)

K fraction	Method
Solution	Batch equilibration or leaching with water Extraction by pressure membrane or centrifugation Activity ratios
Exchangeable	Batch equilibration or column leaching with dilute solutions of salts (especially NH ₄ ⁺) and acids (citric, nitric) Electroultrafiltration Silver thiourea Bray 1 Mehlich 1 and 2 Exchange isotherms Potassium potentials Calcium acetate lactate Double lactate Ammonium bicarbonate + DPTA

Non-exchangeable	Exhaustive crossing Leaching with dilute acids and salts Boiling with dilute or concentrated acids Repeated extractions with NaTPB, oxalic acid or resins Hot MgCl ₂ Electroultrafiltration Electrodialysis
Mineral	Selective dissolution with Na-pyrosulphate fusion
Total	HF digestion

The MAFF funded project OF0114 (See Appendix 2) which tested methods of soil K measurement against plant available K showed that available K measured by ammonium nitrate gave a good indication of the plant available K in soil; crops showed a response to increasing available K and continued cropping caused a decline in the pool of available K in soil. However, there was some indication that on some soils not all of the K extracted by ammonium nitrate is truly 'available' and the authors suggest that this finding should be further investigated. Thus the K index system can still be used as reasonable guide for organic systems, indicating soils where response to K may occur, if yields and K offtakes are expected to be significant (ie at high fertility points of the rotation). For arable and grassland production, the target soil K level recommended by Defra for optimum production is usually 120-180 mg K l⁻¹, Index 2- and 181-240 mg K l⁻¹, Index 2+ for vegetable crops (Anon, 2000). However, silage yields of grass/clover were not limited by K in the field or pot trials in OF0114, even where available soil K indices were <2. On the basis of the work carried out in this study and the results of research on organic farms (Keatinge, 1997; Loes and Ogaard, 1997; Mader et al., 1999) it appears that a K index of 1 may be adequate for satisfactory organic production. The evidence suggests that organic farms can function satisfactorily at lower nutrient levels due to the less intensive nature of production under organic agriculture, the supply of nutrients from soil reserves and organic sources and increased microbial activity (Loes and Ogaard, 1997; Mäder et al., 1999).

When using the K index system in Britain it is important to be aware that the Scottish advisory system is based on a different extractant (Modified Morgans Reagent) to the system used in England and Wales (ammonium nitrate). See Table 3.

6. Using nutrient budgets

This will be a subject of a separate IOTA research review in April/May 2008. However, it is important to note here that balancing nutrient inputs with nutrient offtake is the key to maintaining soil nutrient levels.

7. Soil analysis services

Two services which include specific analysis and interpretation and which have been favoured in organic farming in some countries are the Balzer and Albrecht techniques.

The Balzer system (Balzer and Balzer-Graf, 1984; Balzer, 2000) was developed specifically for organic farming. It used to be available in the UK from the Elm Farm Research Centre (Balzer, 1985) but they no longer provide this service. The soil is assessed using 14 separate tests which include pH, humus, humus type, P (extraction procedures described above), K, Mg and trace elements. The aim of the system is to provide a holistic view encompassing biological, chemical and physical parameters. During the course of this review a Swiss colleague suggested that until recently the soil analyses of the Labor Balzer, Amönau (Germany) was recommended and used in Switzerland for organic farmers. But this soil analysis needed an interpretation of an advisor for the farmer to explore all the

information in the analysis. However since the death of Mr. Balzer and the changes in the laboratory the importance of the analysis for Swiss farmers is marginal.

The Base Cation Saturation Ratio or “Albrecht” technique (Kinsey and Walters, 1999) is also advocated to provide a soil analysis in tune with soil ecology. This analysis is available from a number of UK laboratories/soil service companies. This involves examining the colloidal clay fraction of soils, its cation exchange capacity and the optimum ratios of basic cations for balanced plant nutrition. Albrecht (1967) described the following percentages of cations as percentages of the cation exchange capacity as optimal conditions for plant growth: Calcium 60-75%; magnesium 10-20% (7-15% in some plants); potassium 2-5%; sodium 0.5-5%, hydrogen 10%; other cations (essential trace elements) 5%. Albrecht’s idea was that acid soils were not in themselves harmful, but that lack of calcium was a problem. Optimum ratios of calcium to magnesium (4:1 to 7.5:1) and magnesium to potassium (15:1 to 38:1) are at the heart of the interpretation and recommendations of the analysis which often include the purchase of significant quantities of soil amendments e.g. gypsum. Albrecht also stressed the importance of C:N ratios, N:K balance and sufficient quantities of trace elements. Faithfull (2002) notes the important point that this system was developed in the US for a limited range of crop plants and is thus not necessarily widely applicable. PDA (2000) note that this technique is most applicable to low pH, highly weathered soils where high levels of Mg need to be maintained. There are few such soils in the UK. Recent literature suggests that there is little scientific evidence supporting the claims that adopting its recommendations improves nutrient availability (Johnston, 2006; Koppitke and Menzies, 2007).

Another service commercially available is based on precision farming which is a concept that relies on the existence of in-field variability. It uses technologies, such as global positioning (GPS), sensors, satellites or aerial images, and information management tools (GIS) to assess and understand variations in soil properties. Soils are sampled and analysed and digital maps provided to the farmer. This then allows targeted use of inputs to correct nutrient deficiencies or acidity. While this is primarily used in conventional farming for fertiliser application it is now also being used increasingly in organic farming.

8. Summary and guidance

- Soil analysis based on chemical analysis is a snapshot of nutrient pools. It is normally reported in mg/l of soil.
- Soil analysis should be carried out at regular intervals to provide a picture of changes over time. It also needs to be interpreted within the context of a rotation, particularly timing of soil analysis with respect to growing crops known to remove significant amounts of nutrients e.g. potatoes or straw for K.
- Getting a representative sample is very important. Samples sent to the laboratory should be well mixed composites of 10-15 subsamples. If a field includes more than one very different soil type it is probably worth getting samples from different parts of the field analysed separately. Stone content should also be taken into account in interpreting the analysis.
- Different extractants will give different information. If you change the lab you use make sure the methodology is the same. If possible it is better to stick with the same lab.
- Available K measured by ammonium nitrate gives a good indication of the plant available K in soil on most soils.
- The P index system commonly used in the UK cannot be simply applied in organic farming due to the complex interactions between chemical and biological pools and processes.
- Plant analysis can be a useful integrative measure of nutrient availability. It is also very valuable for trace elements.
- Soil maps can provide useful information with respect to identifying likely trace element and potassium deficiency.

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- Soil organic matter changes over time provide a useful indicator of total N in soil. Currently available measurements of available N and potentially available N are expensive and of little practical value in organic farming.
- Soil analysis is best used alongside nutrient budgets and interpreted by a specialist.
- We have no evidence to suggest that organic farmers routinely use alternative methods of soil analysis (See Appendix 1).

During the PACA Res Soil workshop (9.4.08) considerable discussion took place between advisers and researchers on the role, analysis and management of soil structure, minerals and biology, a summary of key additional points is provided in Appendix 3.

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Appendix 1: Small survey of use of analytical techniques in organic farming in Europe.

We sent a series of questionnaires out to colleagues in Europe and received an excellent response. We received responses from colleagues in Austria, Germany (2 and responses combined), Italy, Netherlands (2 responses combined here as they were from the same organisation), Norway (combined response from several organisation), Switzerland. The answers to Questions 12-15 are given verbatim and the Country is also given to capture the spirit of the answer. This is clearly not a comprehensive survey and represents the individuals and possibly their organisations not the countries. What is interesting is that methods and approaches rarely appear to differ from conventional agriculture. Swedish colleagues also backed up the suggestion that organic farmers are not generally using different analysis systems to conventional.

A summary is given below:

1. *Is pH measured in water or calcium chloride or both?*

Water (3); Calcium chloride (2); Potassium chloride (1)

2. *What method do you use in the measurement of Phosphorus (P)?*

Calcium-acetate-lactate extract (2); Olsen (1); 1:2,5 CO₂-saturated water for soluble P (according Dirks/Scheffer) and 1:10 NH₄Ac+EDTA for reserve P (1); P-w (water) and P-Al. For organic farming we think P-Al gives a better impression of available P (1); AL-method (1)

3. *What method do you use in the measurement of Potassium (K)?*

Calcium-acetate-lactate extract (2); 1:2,5 CO₂-saturated water for soluble K (according Dirks/Scheffer) and 1:10 NH₄Ac+EDTA for exchangeable (reserve) K; Exchangeable K is measured using spectrophotometry method with BaCl₂ solution and trietanolamin (1); . K-HCl (1); AL and (hot) HNO₃ extraction (1)

4. *Do you regularly measure Magnesium (Mg)?*

Yes (3); No (3)

5. *What methods do you use to measure soil organic matter (SOM)?*

C Analyser for total C, Scheibler apparatus for inorganic C (1); Wet combustion, K₂Cr₂O₇-method (1); elementar-autoanalyser (2); Loss on ignition (2)

6. *What method do you use in the measurement of Nitrate or Nitrogen (N)?*

Nitrate is not generally measured except in equivalent of NVZs. Total by combustion or Kjeldahl as available.

7. *Do you use measure cation exchange capacity? If Yes which methods?*

Only in research except in Italy where CEC is regularly measured as it is considered an important soil parameter (K is judged in term of % of K sorption on CEC).

8. *Do you regularly measure trace elements, Copper (Cu), Cobalt (Co), Selenium (Se) or any other elements that have health implications for plants and animals?*

No/Only in cases where there may be a problem.

9. *Is stone content taken into account?*

Only if converting concentration to amounts per ha.

10. *Is soil texture taken into account?*

Yes for interpreting results of soil analysis (especially K) (3); No (3)

11. *Are soil biological parameters routinely measured?*

No, only for research purposes.

12. *How frequently are organic farmers advised to sample their fields?*

Austria - Approx. every 5 years in Austria

Germany – variable except for P which is every 3 to 5 years by law.

Italy - We advise farmers to sample their soil every 3-4 years; our suggestions are not often considered; another main problem is that farmers do not know exactly where soil is sampled and at which depth. Organic farmers are not any better than regular farmers.

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Netherlands - Limited. K: useful every fourth year, in combination with a farm of field mineral balance. P: limited. In Holland most organic fields have a rather high P-AI and a small or big surplus on P-balance, so: no limiting factor. Organic matter (weight loss): OK for the range in which the soil is, not for differences from year to year or over a few years. Other elements: interesting only if there is an idea that there might be a (relative) shortage.

Norway - To be entitled to public subsidies, they have to have a fertilisation plan, and to sample and analyse the soil at least each 4.-8. year, most tend to stick to the 8. year...

Switzerland - it is a requirement every 10 years for subsidy payments but advice is every 4 years for arable/horticulture.

13. *How would you describe the value of soil analysis for organic farmers?*

Austria - It gives orientation if mistakes are occurring.

Germany - very important; especially before conversion, on stockless farms, at locations with known deficiencies and in cases when problems (e.g. plant damages) have to be analysed.

Italy - Every laboratory gives suggestions. We have local references that are not different for organic or conventional farming systems

Netherlands - No normal advice. In general: every 3rd or 4th year an analysis, mainly focussing on P₂O₅, K₂O and pH. Organic matter measurement is fun, but the outcome is not reliable to predict an increase or decrease. Nitrogen measurement in spring is interesting if farmers are counting in detail a nitrogen budget per crop. Dutch (conventional and organic) manure advice is modified dependant on available mineral nitrogen in spring, so if you calculate nitrogen budgets you should measure spring nitrogen each year for each crop. A few (organic) farmers do, most (organic) do not. They just say: it will be about 20 – 40 kg/ha, and that's accurate enough. We try to convince them to either do a measurement and/or use the Ndicea model, in order to improve nitrogen use efficiency and minimize nitrogen losses.

Norway- They really need to know their soil and their nutrient resources so they should perform soil sampling regularly, but take care so that the analyses can be compared over time (make a detailed map of the sample sites, use a GPS). The importance of analyses showing soil nutrient reserves are of relatively higher interest than for conventional farmers.

Switzerland - to monitor nutrient development in soil in combination with nutrient balances - to assess pH values: important for nutrient uptake, soil structure and soil biological activity. By chemical soil analyses, some organic farmers can be motivated to have a deeper look in their soils, e.g. by spade diagnoses.

14. *How farmers are supported in interpretation of soil analysis? Do you have target values / ideal ranges for the parameters measured?*

Switzerland - For nutrients in the different soil extracts there are official interpretation values with ideal ranges and correction factors for fertilization. But there exist no special values for organic farming.

Germany - no standards, in Germany very often the ranges of VDLUFA, class B (lower than class C the ideal of conventional farmers) are used. The ranges differ partly between different soil types.

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Italy - . We organize annual meetings in which we present our results (not only about soil, but also about crop husbandry or weed control).

Netherlands - P and K and pH: yes, target ranges dependant on soil type and on crop types. Sometimes a little bit modified for organic agriculture because of higher organic matter content. Organic matter: rough indications yes, but not very hard ranges of limits. N: not merely a soil value but a crop and manure-to-be-applied related parameter.

Norway – Yes (presumably to target vales)

15. *What additional information is given together with the results of analysis to farmers?*

Austria - Valuation is that of conventional farming, additional interpretation is made with respect to organic farming

Switzerland - The farmers get the results from the laboratories together with a short interpretation scheme about nutrients. If they ask the advisory services they get more interpretation material. Fibl has compiled most of the available information concerning soil analyses on organic farms (see link <https://www.fibl.org/shop/pdf/mb-1158-bodenuntersuchung.pdf>)

Germany - no standards

Norway - That is dependent on the laboratory but if the samples are taken by a motorised sampler and sites are mapped by GPS you will receive a map showing in colours the pH, P-AL or other parameter, facilitating e.g. the planning of which fields where one should apply lime.

Netherlands - Some laboratories, if requested, give an advice related to organic matter applications. This is not based on strong scientific research. On P and K and N, fertilization advices are automatically generated for conventional situations, and some laboratories have modified this for organic agriculture.

15 a Nutrient availability is depending on other factors apart from nutrient values, e.g. soil structure and nutrient accessibility, soil moisture, occurrence of microbial symbioses like mycorrhizal, microbial activity ...

Appendix 2:

Relevant Defra funded research

Defra OF0114 - Optimisation of phosphorus and potassium management within organic farming systems.

Organic farmers need to make scientifically and economically sound management decisions enabling optimum sustainable use of P and K to allow the demand for organic produce to be met with least risk to the environment. However from an advisory point of view there is insufficient knowledge appropriate to UK conditions and organic farming systems to provide guidance to farmers in the following key areas of P and K management: availability of P and K, both from soils of different types and permitted fertilisers; the rate of soil P and K depletion (if any) under organic management; and, the potential for nutrient recycling from livestock manures and other composted materials to overcome P and K deficits. The aim of this project was therefore to assist in the formulation of improved advisory guidelines for organic faming systems based on a sound scientific understanding of the dynamics of P and K within UK organic farming systems. The scientific objectives of the project were therefore to:

- 1 - Assess the balance between inputs and offtakes of P and K within a range of UK organic farming systems
- 2 - Evaluate chemical and bioavailability indices used to assess P and K status of soils
- 3 - Assess the availability of a range of P and K fertilisers to grass-clover leys and tillage crops

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4 – Develop a process-based simulation model and integrate with whole farm nutrient budgeting to allow P

and K management decisions to be made for the whole farm.

5 - Provide guidelines for farmers on the use of phosphorus and potassium fertilisers for organic systems.

Farm gate budgets for P and K were collated using farm records, measurements and standard tables of nutrient contents for a number of organic farms and rotations on organic farms. An integrated series of incubation, greenhouse and field experiments was carried out with a range of fertilising materials selected to give a range of likely availabilities for plant uptake and to give a mix of mineral and organic sources of P and K on soils representing the range of soil types under organic management.

Organic farming systems can show both P and K surpluses and deficits depending on management. In mixed systems, manures represent a significant resource of both P and K, which are supplemented through imports of feed and bedding. However, manure handling also therefore gives significant opportunity for losses, particularly of K from the system. K deficits are common in organic rotations, but not necessarily at the whole farm level. These deficits are close to the level which can be sustained from the weathering of mineral reserves in many UK soils. However, more consideration needs to be taken of the potential of soils to supply K when rotations and management plans are designed. There is no reason why organic farming systems, operating within the current UKROFS standards, cannot achieve a nutrient budget in line with long-term sustainability of soil P and K. However, continued monitoring of soil P and K levels in long-term organic trials is necessary to demonstrate these conclusions.

Typical farm rates of FYM and compost significantly increased both available P and K in soil. Rock P and Redzlaag did not significantly increase available P. However, there was some indication of slow release in the field. Sewage sludge is also a potential source of P for organic farming systems, if other factors preventing its use can be overcome. Kali vinasse and rapemeal were also good supplementary sources of available K. Plant offtake of K was significantly increased by both FYM and Kali vinasse; we believe that the same would also hold for compost and rapemeal under similar conditions. The effects of Kali vinasse and FYM on available K in soil and plant K offtake were persistent and lasted longer than one season. Plant offtake did not seem to be limited by P availability even on low P index soils. Yield seemed to be limited by other factors and soil P supply was able to meet crop demand. Organic pools of P in soil can be significant and are likely to reflect a gradient of availability, as for organic N in soil. However, organic P is not routinely measured by any extraction procedure. We found a negative correlation between biomass P and available P in soils; this may reflect an increasing importance of the cycling of organic P in low P status soils receiving regular inputs of organic materials. However, the complex interacting dynamics of the organic and mineral P pools in soil could not be disentangled using the data collected. The P index system cannot therefore be simply applied in organic farming systems.

Available K measured by ammonium nitrate gave a good indication of the plant available K in soil; crops showed a response to increasing available K and continued cropping caused a decline in the pool of available K in soil. However, there was some indication that on some soils not all of the K extracted by ammonium nitrate is truly 'available' – this finding should be further investigated. However, the K index system can still be used as a reasonable guide for organic systems.

The complex interactions between nutrient cycles in organic farming systems means that the process based simulation model of P and K turnover was necessarily very simplified and the data collected in this project was not long-term enough to allow a full evaluation of all the factors, which influence P and K offtake, particularly the impact of crop establishment and management practices influencing spatial and temporal P and K management. However, practical guidelines were drawn up for farmers and their advisors.

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This project was carried out by Rothamsted Research, SAC, University of Reading, RAC and Elm Farm Research Centre. The full report is available at <http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=9066>

Defra Project OF0164 - Understanding soil fertility in organically farmed systems

Organic farming aims to create an economically and environmentally sustainable agriculture, with the emphasis placed on self-sustaining biological systems rather than external inputs. Building soil fertility is central to this ethos. 'Soil fertility' can be considered as a measure of the soil's ability to sustain satisfactory crop growth, both in the short- and longer-term. It is determined by a set of interactions between the soil's physical environment, chemical environment and biological activity. The aim of this project was, therefore, to provide a better scientific understanding of soil fertility under organic farming. The approach was to undertake a comprehensive literature review at the start of the project to assess and synthesise available information. Studies were then designed to address specific questions identified from the literature review. The literature review was written during the first year of the project. In addition to submitting written copies to DEFRA, the chapters were posted on a project website: www.adas.co.uk/soilfertility.

The Review was based around key questions:

- What are the soil organic matter characteristics and the roles of different fractions of the soil organic matter?
- Do organically managed soils have higher levels of organic matter (SOM), with a resultant improvement in soil properties?
- Is the soil biology different in organically managed soils, in terms of size, biodiversity and activity?
- Do organically managed soils have a greater inherent capacity to supply plant nutrients?
- What are the nutrient pools and their sizes?
- What are the processes and rates of nutrient transfer in relation to nutrient demand?
- What are the environmental consequences of organic management?

The project also included a large amount of practical work. This necessarily covered a wide range of topics, which were examined in a series of separate studies:

- Soil microbiology: a series of measurements focusing on two sites, undertaken by University of Wales Bangor (UWB)
- Field campaigns in autumn 1999 and spring/summer 2000: separate field sampling campaigns focusing especially on nutrient pools, undertaken by HDRA, ADAS and IGER
- Incubation studies: a series of three separate experiments to look in more detail at N dynamics, managed by ADAS, with support from IGER and HDRA.

From the literature review and the practical work, the following was concluded:

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Organic matter is linked intrinsically to soil fertility, because it is important in maintaining good soil physical conditions (e.g. soil structure, aeration and water holding capacity), which contribute to soil fertility. Organic matter also contains most of the soil reserve of N and large proportions of other nutrients such as P and sulphur.

Field management data gathered from farmers showed, however, that organic matter returns are not necessarily larger in organic systems. Many non-organically farmed soils receive regular manure applications and the generally higher yielding crops on conventional farms may return larger crop residues. Conversely, many organic fields receive little or no manure, relying on the fertility building ley phase for organic matter input. This observation is important. Management practices within organic and non-organic systems are diverse, and all have consequences for soil fertility.

The Executive Summary at the start of the main report has additional sections on Soil Structure, Soil Biology, and Nutrient Cycling with some greater detail on comparisons of organic and conventional management and the consequences for soil fertility.

MAFF Project CSA 1486 - The availability of water insoluble phosphorus and potassium sources in organic farming.

Carried out by Elm Farm Research Center 1993. Not available on the internet to our knowledge. Summary has been scanned and is appended below.

SUMMARY

Supply and cycling of both phosphorus and potassium in all farming systems is complex. Organic farmers face identifiable challenges with regard to the supply of these nutrients within the husbandry practices defined in organic production standards.

Organic production systems are defined in standards administered by the United Kingdom Register of Organic Food Standards (UKROFS) through organic sector bodies. The whole system operates within a legal framework provided by EC Regulation (2092/91).

The principles of organic production require that production practices should "sustain or build soil fertility". Mineral fertilisers are regarded as a supplement to, and not a replacement for, nutrient recycling within the farm, although nutrients will inevitably leave the farm in the form of animal and crop products and leaching losses.

There is concern that organic farming systems can lead to a decline in soil phosphorus and potassium status. Furthermore, a number of organic farms in the UK are operating with low values for the soil phosphorus and potassium ('Index' values of between 1 and 2 are common). However, target yields continue to be maintained in what is effectively a nitrogen limited production system. The long-term consequences of this situation are unclear.

In general, only fertilisers which release nutrients through an intermediate process, such as weathering or the activity of soil organisms, are allowed within organic systems. It is assumed that the combined effects of soil microbial activity and acidic root exudates make available the phosphorus and potassium required for plant growth. In the case of potassium, 'rock potash' is permitted provided that it has 'relatively low immediate solubility in water and a low chlorine content'. This category includes feldspar potash, Adularian Shale and Kieserite (sulphate of potash-magnesium).

It is recognised that soil type and pH can result in serious shortages of available potassium particularly on soils with a relatively low clay content. Restricted use of soluble potassium fertiliser (potassium sulphate) is therefore allowed in organic production standards to rectify cases of deficiency related to plant health. Some certification bodies specify criteria for use including low exchangeable potassium levels and a soil clay content of less than 20%.

Aim of project

The aim of the project was to examine the role and effectiveness of water-insoluble and other sources of phosphorus and potassium for organic production. The plant response and soil dissolution of a range of fertilisers was assessed in field trials on an organic farm and in greenhouse trials using soils from organic farms. The role of soil type, microbial activity, and plant species was studied for individual fertilisers.

Fertilisers trials

Five alternative phosphorus and seven potassium fertilisers were assessed in a total of 15 greenhouse pot trials and two field trials during the three years of the research programme. Individual trials, lasting up to one year, used certain of the following fertiliser treatments, and in most cases compared their performance with that of soluble conventional fertilisers (superphosphate and sulphate of potash):

<u>Phosphorus Fertilisers</u>	<u>Potassium Fertilisers</u>
North Carolina rock phosphate	Lime Kiln dust
Gafsa rock phosphate	Adularian Shale
Reddzlaag	Feldspar potash
Glenphos 75	Lava dust
Highland Slag	Basalt dust Biotite
Glenphos 75	Highland Slag

Phosphorus fertilisers

In greenhouse pot trials on field beans (section 3.1.1), rock sources of phosphorus were observed to be effective in some but not all cases. Gafsa rock phosphate and Reddzlaag had no effect on bean growth in one trial, but significantly increased growth in grass grown after the harvest of the beans. In a second trial, North Carolina rock phosphate increased bean growth almost to the same extent as the superphosphate control, whilst Glenphos 75 resulted in smaller though significant increases in plant growth. Neither the bean nor the following grass crop showed any response to applications of Highland Slag in a third trial although superphosphate control gave a significant yield response.

Inoculation with VAM fungi in two trials had a considerable effect in one trial although reduced in the other. Soil test phosphorus was affected by the fertilisers tested, with rock sources increasing citric acid extractable and superphosphate increasing the bicarbonate extractable soil phosphorus.

In trials with red clover (section 3.1.2), of the rock phosphorus sources tested, only Gafsa rock phosphate gave a significant increase in total biomass, equivalent to that achieved with superphosphate. Other fertilisers tested (Reddzlaag, N. Carolina rock phosphate and Glenphos 75) increased phosphorus uptake, and yield from some but not all cuts, although there was no significant effect on yield overall. Increased phosphorus uptake demonstrates that the nutrient in these sources is plant available. Highland Slag did not give any overall yield benefit, although the high rate increased phosphorus content of the herbage at some cuts.

There was some evidence of a differential response to two fertilisers (Reddzlaag and Gafsa rock phosphate) amongst four herbage species (section 3.1.3) with increases in yield and phosphorus content being most pronounced in red clover, although white clover also responded well. Field

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applications during the pasture phase of the organic rotation would be expected to be particularly successful on red clover.

In a field trial, on an organic grass/red clover silage sward (section 3.2.1), none of the fertilisers tested resulted in a significant overall yield increase. Application of Gafsa rock phosphate resulted in a yield increase as large as that recorded following superphosphate, although the increase was only significant at the second cut. At higher rates of application of the rock fertilisers, both Gafsa rock phosphate and Reddzaag gave a similar (though not significant) yield increase.

There was a difference in response of the grass and clover content of the pasture. The superphosphate control treatment tended to result in a greater response in the grass component of the yield, with clover yield at later cuts being significantly reduced. Soil test phosphorus one year after application was increased by all fertilisers. Nutrient reserves (measured using acid lactate extract) was significantly increased only following application of Gafsa rock phosphate. Bicarbonate (Olsen) extracted phosphorus was increased only following application of superphosphate.

In a field trial on crops within an arable rotation (section 3.2.2), no yield response to any fertiliser was observed in rye crops- over two years. However,- field levels of infection by VAM fungi was significantly affected, with rock sources (Gafsa rock phosphate and N. Carolina rock phosphate) leading to increases in infection in both years, whilst significant decreases were observed in the second year following application of superphosphate.

In the potato crop following the rye crops, only Gafsa rock phosphate equalled superphosphate in increasing yield. However, where effective potassium fertilisers were applied with the phosphorus fertilisers a significant increase in tuber yield was recorded. Similar changes in soil test phosphorus were observed in this field trial as in the trial on the grass/clover silage sward.

Over all trials, the most consistent benefit was observed from Gafsa rock phosphate.

Potassium fertilisers

In five greenhouse pot trials with field bean (section 4.1.1), significant increase in total and shoot dry weight was only recorded in one case following applications of soluble potassium sulphate, although non-significant increases were observed, particularly following applications of Lime Kiln Dust. However, evidence of plant availability of the nutrient from other fertilisers tested was provided by the increased potassium content of the herbage. Significant increases in total uptake and percentage potassium content in bean shoots were obtained from Lime Kiln Dust, Patentkali, Lava Dust and Biotite.

In the case of Lime Kiln Dust and Patentkali, increases were observed similar to those following applications of potassium sulphate. The potassium contained in these materials has a solubility similar to potassium sulphate. Biotite tested in these trials was found to contain available nitrogen, and this masked any effect of the potassium content of the material.

Adularian Shale only showed a significant effect on potassium content in bean shoots in one-trial, and did not result in any increase in soil potassium following harvest. Significant increases in soil exchangeable potassium were observed following applications of Lime Kiln Dust, Patentkali, Basalt Dust, Lava Dust and soluble potassium sulphate. Some evidence for residual effects following Lime Kiln Dust, Feldspar potash and Biotite were observed in grass grown after bean harvest.

In trials on red clover (section 4.1.2) Lime Kiln Dust equalled potassium sulphate in increasing potassium uptake, whilst the less available Lava and Basalt dusts gave smaller though significant increases. In contrast to the soluble Lime Kiln Dust, the less soluble sources only led to increases in

later cuts. Biotite increased yield and potassium content in red clover, although the yield benefit observed may be due to the nitrogen contained in the material.

In trials to determine the importance of the lime content of Lime Kiln Dust relative to the content of potassium and other trace elements in this material (section 4.1.3), Lime Kiln Dust increased pH and calcium content to the same extent as lime. There was a benefit from this material which may be due to the trace element content.

Trials to determine the effect of soil type and VAM fungi on response of red clover to Lime Kiln Dust and Adularian Shale (section 4.1.4) showed no overall effect of Adularian Shale; response to Lime Kiln Dust was similar to that observed with soluble potassium sulphate. Soil type had a large effect on herbage uptake of potassium when no fertiliser was applied, and Lime Kiln Dust showed a greater response on soils with lower exchangeable potassium levels.

VAM fungi increased herbage yield of unfertilised red clover in the initial but not later cuts. This response varied with soil type, with plants grown in high phosphorus soil showing no response, and with a greater response where soil phosphorus content was low. In other trials VAM did increase plant growth, particularly in less fertile soils.

In a field trial on an organic grass/clover silage sward (section 4.2.1) both Lime Kiln Dust and Biotite resulted in similar increases in yield as potassium sulphate. Adularian Shale gave no response. Lime Kiln Dust and potassium sulphate increased the clover yield compared to the grass, whilst the reverse was observed following application of Biotite due to the nitrogen contained in the material.

In a field trial on arable crops (section 4.2.2) none of the fertilisers tested had a significant effect on yield or potassium uptake in rye crops grown over two years. However, field infection by VAM was increased following application of Lime Kiln Dust. In the following potato crop, Lime Kiln Dust resulted in similar increases in tuber yield as observed following application of potassium sulphate, whilst Adularian Shale had no effect. Potassium deficiency on this site led to a greater response to phosphorus fertilisers when effective potassium sources were also applied. There was evidence of a residual effectiveness of Lime Kiln Dust, which also increased soil levels of potassium.

Of the potassium fertilisers tested, Lime Kiln Dust was the most effective; however, difficulties of application of this very fine powder waste product would require wetting or granulation to make it acceptable for agricultural use. The low potassium content of the rock dusts tested (Biotite and Lava Dust), would be likely to render them uneconomic for use unless close to the source. However the plant availability of the nutrient in these materials was demonstrated in trials.

Consequences for organic production

The trials programme has demonstrated the effectiveness of sources of phosphorus and potassium available for use by organic producers. Phosphorus sources which conform to organic standards appear to be effective whilst potassium sources tend not to be, leaving the organic producer with the requirement to use soluble sources of potassium where deficiency or soil type requires this. The material Lime Kiln Dust is effectively a soluble potassium source. Difficulties in spreading the material render it inappropriate for organic production at the current time.

The nutrient reserves in many agricultural soils appear to be able to support organic crop rotations; however, methods of soil analysis do not necessarily give information which allows the producer to be aware of the extent of agronomic value of these reserves.

Appendix 3

Soil analysis; notes from the IOTA Soil Workshop, 9 April 2008

Reference IOTA PACA Res Research Reviews: **Laboratory mineral soil analysis and soil mineral management in organic farming** and the **Role, analysis and management of soil life and organic matter in soil health, crop nutrition and productivity**.

There are clearly shortcomings in our understanding of soils and in particular the analytical techniques and recommendations for organic farming. While analysis for pH, and K, Mg, organic matter and soil texture are reliable it is recognised that phosphate analysis is relatively unreliable as it does not indicate fully the phosphates that may be available from both mineral and organic matter sources.

However, soil analysis remains a very important technique, which should be used on a regular basis, provided it is in conjunction with an assessment of soil structure, including ensuring the structure is good, nutrient budgeting as a tool to help assess the suitability of a system for a specific farm, and crop observation and yield monitoring.

In the absence of any trials or monitoring to demonstrate soil nutrient levels for optimum crop production under organic conditions, there remains a question mark over the interpretation and appropriate management and mineral additions for soils under organic production. However, existing conventional, standard soil analysis techniques are useful. Used in the context of knowledge of soil type and the farming system being operated soil analysis is a valuable tool for the following reasons:

1. Long term monitoring to ensure that a farming system is working (e.g. sampling a field every year)
2. To identify major and minor nutrient deficiencies and pH, soil organic matter
3. It can help identify a particular problem of crop health or productivity
4. To avoid excess mineral or organic additions

Soil analysis should be an essential prerequisite to using inputs in organic farming and a requirement for organic certification, especially for the use of derogated inputs.

Tissue analysis is a valuable tool to use in addition to soil analysis to identify the cause problems.

There is no published research that backs up the comprehensive soil analysis methodologies and interpretation which are promoted under the following terms: nutrient balancing, cation exchange capacity, Albrecht and Balsler soil analysis methodologies. There is no research evidence to support the concept of ensuring a correct nutrient balance or ratio of the cations. While the routine analysis of several minor elements can be valuable, it is of course expensive.

With regard to analysis of soil biology, the analytical techniques, be they microscope counting or DNA analysis, are a reliable indicator of soil micro-organism populations. There is no research evidence to enable us to know what management recommendations to make based on those results and with widely fluctuating populations according to soil conditions, for example, moisture, there remains a question mark over the usefulness of the technique. Soil respiration tests – either laboratory or field tests – provide a good indication of CO₂ production and, hence, respiration and a crude indication of the biological activity of the soil.

While there is a question mark over the validity of some of the more comprehensive and soil biology analysis techniques and accompanying recommendations and a lack of information on interpretation of the data from others, these techniques may be helpful in an advisory context in order to help the

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farmer get a better understanding of soil nutrient levels and soil life and its management. There is of course a considerable financial cost involved in undertaking these more complex analyses.

The workshop identified a number of research priorities, including:

1. There is a need to identify organic crop response to soil fertility conditions as determined by Soil Analysis and to develop organic farming soil management (including appropriate fertiliser applications) to optimise crop production in the context of the whole rotation.
2. Soil ecology and biology management; knowledge of implications of soil ecology and how to manage it.
3. Ongoing field validation of soil analytical techniques including sending similar samples to a range of labs and comparing results and advice.
4. Incorporation of human waste (sewage) in organic farming.
5. Management of soils under organic protected cropping.
6. Other specific information which is needed:
 - i. Nutrient contents of crops, manures etc in organic systems
 - ii. Assessment of Carbon sequestration & N₂O emissions from long term commercial organic farming systems.
7. Soil analysis is best used alongside nutrient budgets and interpreted by a specialist.
8. We have no evidence to suggest that organic farmers routinely use alternative methods of soil analysis (See Appendix 1).

Mark Measures 5.5.08