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Review of literature and farm experience on Base Cation Saturation Ratio (BCSR) based on the work of W.A. Albrecht

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List of abbreviations used in the following review

BCSR:	Base Cation Saturation Ratio
CEC:	Cation Exchange Capacity
N:	Nitrogen
P:	Phosphorous
K:	Potassium
Mg:	Magnesium
Ca:	Calcium
Na:	Sodium
H:	Hydrogen
pH:	(Potential of hydrogen), a figure to express the acidity or alkalinity of a soil (solution)

1. Introduction

Organic farming is based on the concept of a biologically active, living soils; where nutrients are made available to the plant from soil particles by interactions and processes between root acids and soil organisms, including mycorrhiza; and nitrogen which is fixed by legumes and other nutrients which are recycled through the utilisation of the farm's manure. Underlying nutrient deficiencies are addressed through the use of brought-in manures, green waste and mineral fertilisers, which are naturally occurring and generally non-soluble. There is a critically important role for soil analysis in determining the correct management and use of any brought in inputs in order to ensure that the soil supplies the necessary nutrients to the plant to optimise crop performance and quality.

1.1 Background of this EIP operational group project

The dependence on soil life distinguishes organic and agro-ecological farming from conventional, where plant nutrient supply is largely focused on provision of soluble nutrients in the form of fertilisers that can be readily absorbed by the plant. Various new soil analysis techniques and associated soil recommendations are commercially available to organic and agro-ecological farmers as well as the standard pH, P, K, Mg analysis used by conventional farmers. None of these techniques have been systematically assessed for their suitability to provide sound recommendations for soil management and nutrient availability in organic and agro-ecological farming.

Recently, organic farmers have been advised to use Standard Analysis techniques and to aim for a target Index of 1 point lower than recommended for conventional farming. This target is based on anecdotal experience and knowledge of crop offtakes, but has never been validated leaving the farmers uncertain as to what levels to aim for.

Several Organic and Agro-ecological farmers have, in the last 3 or 4 years been introduced to the potential for Albrecht (Base Cation Exchange) Analysis. Others have tried to assess soil biological activity using soil respiration analysis. The validity of both these techniques have been questioned by soil specialists in the UK but they have been more widely used by organic and agro-ecological farms in the USA and elsewhere and significant claims are made in terms of soil health and fertility and forage and crop production, in turn linked to animal health.

This project will address this major deficiency in our understanding by 1) instigating monitored field trials which will assess the validity of the current Index targets for organic farming and 2) the commercial case for management recommendations arising from the use of alternative soil analysis techniques.

1.2 A review aimed to provide background information for farmers and growers

As Watson (Watson, 2008) states, there has been considerable discussion over the past decades whether alternative methods of soil analysis are needed to meet the needs of organic agriculture. Although a wide range of methods are currently used also in conventional chemical analysis, the release of these nutrients through biological processes in soil organic matter is the crucial factor for organic farming systems. Organically managed soils are highly depended on nutrient availability from insoluble and organic components, which are usually achieved by applications of compost and other forms of organic matter, or the frequent and diverse incorporation of green manures and cover crops in the rotation. Watson concludes that "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."

The Base Cation Saturation Ratio (BCSR) approach (particularly a 'soil audit') is a more holistic and comprehensive soil assessment than standard routine soil analysis; it aims to take the ecology of the soil much more into account, and is therefore more suitable to inform fertiliser strategies and sustainable soil management that aims to build long-term soil health, rather than just feeding agricultural crops. The approach also claims that the implementation of recommendations following soil audits will stimulate biological activity, nutrient cycling and macro and micro nutrient availability, as well as and soil structure and health.

Controversial discussions around this approach are ongoing for example with UK soil scientists, who lack confidence in the value and benefits of this laboratory test. The main reason for their scepticism is the lack of published papers in the refereed, scientific literature to prove the value of the BCSR method. To date, there are only few scientific, replicated field trials conducted that show the effect of this approach in a UK environment; or which compare the BCSR test to other soil analysis methods. (One of the few examples is the work of Leake and colleagues (Leake et al., 2013), who conducted a field scale comparison experiment at Game and Wildlife Conservation Trust (GWCT) Loddington site to test the two soil management systems: BCSR and standard soil analysis, further discussed below).

However, the BCSR approach continues to find enthusiastic users within a relatively small percentage of UK farmers and growers, many of whom are organic. This review explores and compares different perspectives, presenting various experiences of farmers in practice, as well as insights from scientific literature; and hopes to provide some background for farmers and growers in the UK, to inform decision-making processes in their soil management strategy.

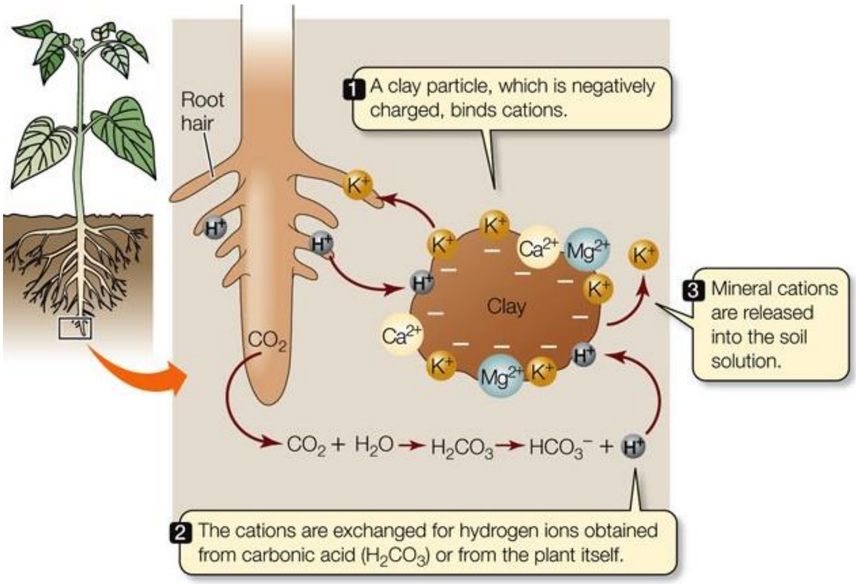
2. Critical discussion

Although several commercial soil laboratories and companies offer and promote the BCSR test in the UK, and a substantial number of farmers and growers state positive experiences and increased soil health, fertility and improving yields through applying the concept on their farm, including two of the farmers taking part in this operational group. The limitations of the test are often described as a lack of evidence in published, refereed scientific literature and validation through comparative trials in practice (particularly for organic agriculture) to prove the value of test results and recommendations. The following section presents selected arguments and perspectives, comparing examples of practice experience and scientific literature.

2.1 Background

Cation exchange in soils

Nutrient availability for plants depends on chemical and biological processes in the soil; in particular, the concentration and form in which the nutrient is present in the soil, as well as the availability of water and the rate the plant takes it up. For each nutrient, the balance between these processes can vary; for example, phosphate (P) is relatively immobile in soil, locked-up by strong chemical bonds, which is where mycorrhizal fungi play an important role in releasing the nutrient in a plant available from and therefore enhancing the uptake by plant roots (Wood, 1995). The identification of nutrient deficiencies in plants or agricultural crops is hence a useful way of diagnosing problems with the supply of specific macro- and micro-nutrients in the soil (Marschner, 2011). A common indicator for determining the availability of most plant nutrients is the measurement of the cation exchange capacity (CEC) in the soil. Many nutrients (chemical elements) in the soil are electrically charged, they are either positively charged cations (+) or negatively charged anions (-). Soil and humus particles have a negative charge, allowing them to bind positively charged cations, which prevents cations from being washed out of the soil by rainfall. The cation exchange capacity, or exchange rate, describes the number of cations in the soil solution that are exchangeable, and therefore available for the uptake by plant roots. Plants extract the positively charged cations from the soil solution by exchanging them for positively charged hydrogen (H+) (Mastuti, 2014). The ability of a specific soil to provide these cations is generally accepted as an indicator of its fertility. The figure below illustrates the process of cation exchange between plant roots and clay particles in the soil.



Source: http://bcs.whfreeman.com/thelifewire8e/content/cat_010/f36006.jpg
Figure 1: Cation exchange between clay particles and plant roots

As Brady and Weil (Brady and Weil, 1999) describe, nutrient antagonism does occur, which can cause inhibition of uptake of certain cations by plants. In some soils K uptake is limited by high levels of Ca, and high levels of K can limit Mg uptake, even when magnesium levels are high. The authors state that if the ratio of Ca to all other cations drops below 5:1, the integrity of plant root membranes is lost, causing many other elements to become toxic to the plants. As a result, forages with low Mg contents compared to Ca and K can cause grazing livestock to suffer from Mg deficiency known as *grass tetany*. Although plant health and growth may not affected by soil Ca:Mg ratios (described in more detail below) in the range between 1:1 to 15:1, the ratio of Ca to Mg in plant tissue may be affected enough to influence the mineral nutrition of grazing animals.

Base Cation Saturation Ratio

The Base Cation Saturation Ratio Test (BCSR), more commonly used in the United States, is a laboratory test increasingly offered by soil labs and businesses across the UK (e.g. Glenside Group since 1995). The test aims to provide an alternative to standard soil analysis for farmers and agronomists to inform soil management and fertiliser strategies/recommendations. The approach is based on the work of William A. Albrecht, a doctor of medicine who's work also aimed to link soil health to human health. Mainly active between the 1930s to 1950s, he was a professor and soil scientist at the University of Missouri, USA. The BCSR concept suggests that soils have a balanced, or optimal ratio (or range of ratios) of exchangeable cations in solution, and that there is an ideal ratio between the total of the four base cations Calcium, Magnesium, Potassium and Sodium (Ca, Mg, K and Na) and the total cation exchange capacity of the soil. UK laboratories who offer the BCSR test for example state that ideal Ca:Mg ratios lay between 4:1 to 7.5:1; Mg:K ratios around 3:1; and K:Na around 4:1.

Although the four base cations are primarily focussed on by those selling this test, they often include additional indicators and analyses that should be taken into account; such as Phosphorus (P) and Sulphur (S), trace elements, pH, colloidal clay fraction and total soil organic matter. However, such comprehensive 'soil audits' may often be relatively costly and result in recommendations to purchase and apply significant quantities of soil amendments e.g. gypsum on heavier soils.

There are limitations to the use of conventional pH, P, K, Mg analysis in organic farming:

- The methods and their result interpretation have been specifically developed for use in conventional farming, where short-term nutrient availability is the primary concern and yields are often higher than they would be expected in organic farming.
- Nutrient reserves are not taken into account. This is a particular problem for P assessment; the availability and dynamic movement of phosphorus between reserve (highly fixed and difficult to mobilise fraction), intermediate and easily available forms cannot be assessed with these methods.
- There is no consideration of total soil organic matter or of the organic matter type
- There is no consideration of soil biology
- Soil type and potential long-term nutrient release are not taken into account.

Further, trace elements can be analysed alongside the macro elements in conventional analysis but in practice it is not a routine.

To make better use of the prevailing conventional analysis, soil specialists working at SRUC (Scotland's Rural College), Newcastle University and Organic Research Centre have proposed that soil index targets for P, K and Mg should be one index point lower for organic farming than targeted for conventional e.g. index target of 1 for P and K for organic wheat, compared to Index 2 in conventional farming. This reflects the lower yields that can be achieved and the expected offtakes, but ensures that no one macro element is limiting. pH targets remain the same. The use of soil type information from reference data and soil type analysis i.e. clay, silt, sand determination, soil organic matter, soil trace elements, plant tissue analysis, nutrient budgeting and soil structure assessment also aids in the interpretation and recommendations. However, there is currently no research validating these revised index targets.

2.2 Alternatives to standard soil analysis

Watson stated in 2008 that soil fertility management in organic farming systems requires a longer term, more strategic process than in conventional systems; and that therefore a more holistic approach to soil analysis, taking the integrated nature of organic production into account, might be more useful than conventional analysis. Quality and status of organic matter, as well as trends of nutrient dynamics in the soil over time may be better suited indicators for soil health and fertility than 'snapshot' soil nutrient analysis. This is shown in various research recommending the use of soil analysis alongside nutrient budgets as a way of more accurately tracking fertility changes over time in organic systems (Öborn et al., 2003, Watson et al., 2002). Further, Watson et al. describe the importance of taking the interactions between various nutrients in soils into account, e.g. in soils where N is limited, added lime may not have any effect.

Analysis of soil biology (bacteria, fungi, etc.) is a logical approach, seeing the crucial part it plays in making nutrients available to plants, particularly in an organic system. While analysing a soil sample by counting individual organisms, or genetic assessment is relatively straightforward; unfortunately, the rapid population changes in response to changes in temperature or moisture contents in the soil means that interpretation is always difficult. Further, there is still no reliable information on the value of the results in terms of direct translation into recommendations for soil management practice on farms. The Institute for Organic Training and Advice (IOTA) Research Review (Watson, 2008) reported that there are “no specific and practical management steps identified for farmers, even on a region by region or system by system basis, which might allow the reliable manipulation of soil organisms through changes in agricultural practices”, and that “quantitative evidence linking soil biological parameters and impacts on soil functions or crop yield is very sparse, there is currently no evidence of an appropriate threshold or range of threshold values for soil types, climates or farming systems.”

One of the alternatives to conventional soil nutrient analysis was developed in the early 20th century, based on the ideas and work of William Albrecht, who examined the relationship between the ratios in which nutrients, mainly base cations, are available in the soil and the health of plants, animals and ultimately humans (Marshall, 1977). In 1933, Moser (Moser, 1933), conducted his own research in the area of Ca:Mg ratios of soils, after reviewing the available literature, and came to the conclusion that there was no link between the Ca:Mg ratio and crop yield. He found that yield was rather dependent on the Ca status of the soil; that, particularly in soils with low Ca levels like in many parts of the U.S. where he conducted his study, low yields in soils with high Mg contents are rather a results of Ca deficiency than an excess of Mg. Albrecht (Albrecht, 1941) concluded that Ca is important because of the direct role it plays; he described it’s significance in relation to the behaviour of other ions and to the entire physic-chemical relationship of plants and soils. Albrecht’s idea was that soils with a low pH were not inherently harmful, but rather that the lack of Ca was the limiting factor (Watson, 2008). This finding of the importance of high Ca saturation in soils provided the base for Albrecht’s later definition of a ‘balanced soil’ (Wood and Litterick, 2017).

Wood and Litterick (Wood and Litterick, 2017) describe that, in the 1940’s a research group working on Albrecht’s ideas in New Jersey (Bear and Toth, 1948) defined an ideal balance of exchangeable Ca, Mg, K and H ions for soils and plant nutrition. They identified that the ‘ideal’ soil contents 65% Ca, 10% Mg, and 5% K. This approach to the interpretation of soil chemical analysis, describing that the ratio of available nutrients in the soil is more important than the total amount of available nutrients, was developed as the *Base Cation Saturation Ratio* method. However, this definition has not been based on conclusive evidence that optimal ratios of nutrients are directly linked to crop productivity (Kopittke and Menzies, 2007); instead, Johnston (Johnston, 2011) found that crops are able to thrive over a range of cation ratios, if they are provided in a suitable amount.

Albrecht described in 1941 (Albrecht, 1941) that the relative concentrations of exchangeable cations are directly linked to their saturation degree in the clay fraction in the soil. Although, based on his work, Albrecht concluded that optimal plant growth will only occur in ‘balanced’ soils with ‘ideal’ base cation ratios (or ranges of ratios); Kopittke and Menzies (2007) stated that the data available today does not support the claims of the BCSR and that a soil’s chemical, physical and biological fertility cannot be linked to nutrient ratios. They also stated that there is no evidence that the balance between cations impacts soil biology such as earthworm activity or on weeds (Kopittke and Menzies, 2007). In the study by Schonbeck (Schonbeck, 2000) a reduction in Mg saturation percentage had no effect on soil organic matter, biological activity, weed abundance, disease incidence or pest damage. In the Kelling (Kelling et al., 1996) study changes in the Ca:Mg ratio had no effect on earthworm numbers or weed growth.

The physical properties of soil have been shown to be affected by Ca levels. The balanced soil theory states that the ratio effects plant growth through changes in soil structure (surface crusting, compaction and reduced hydraulic conductivity). While the high exchangeable Ca content (65%) in the “balanced soil” will likely have positive effects on soil structure, good soil structure can be maintained across a wide range of Ca:Mg ratios (Rengasamy et al., 1986). This study showed that, under low Na concentrations, a varying Ca:Mg ratio from 0.5:1 to 2.5:1 had no effect on hydraulic conductivity. When Na concentrations were higher, there was no difference in hydraulic conductivity form an Ca:Mg ratio ranging from 2.5:1 to 1:1. Although this study was performed in a laboratory, field experiments by Schonbeck (2000) showed that reduction of the Mg saturation from 18-28% to 11-21% had no effect on bulk density or infiltration rate. The most “unbalanced” soils (59% Ca, 28% Mg) in this experiment showed the best physical properties. There are also studies performed in Wisconsin showing that compaction (which negatively affects root penetration and water infiltration was unaffected by varying Mg levels (Kelling et al., 1996a), and varying Ca levels had no effect on soil physical properties (Kelling et al., 1996b).

Other research argues that taking plant yield as an indicator of the effects of a ‘balanced soil’ suggests that a range of cation ratios (Ca:Mg) are acceptable for plant growth. An experiment conducted in the 1950’s on the growth of Ladino clover (*Trifolium repens*) on four soil types concluded that, provided Ca was the dominant cation, no specific cation ratio produced the best yield (Giddens and Toth, 1951). Yields were equivalent for a range of Ca:Mg:K ratios compared to the “ideal” ratio of 65:10:5.

Further work on specific cation ratios (Ca:Mg, Ca:K, K:Mg) and the effects on Millet (*Setaria italic*) and Lucerne (*Medicago sativa*) concluded that plant yields were not affected by the Ca:Mg ratio within the Ca:Mg range studied (2.2:1-14.3:1) (McLean and Carbonell, 1972). Another study (Hunter, 1949), also on Lucerne (*Medicago sativa*), concluded there was no “best” Ca:Mg ratio for optimum growth, having investigated a wide range of ratios (0.25:1 – 31:1). Most agricultural soils fall somewhere within the range studied.

And also field trials in Western Australia conducted over six years found that a wide range of CA:Mg ratios (0.4:1-17:1) did not influence the yield of wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), oilseed rape (*Brassica napus*) and lupins (*Lupinus angustifolius*) (Western Australian No-Tillage Farmers Association, (Association, 2005)).

In summary, there is a reasonable amount of evidence suggesting that provided the soil contains adequate absolute quantities of Ca, Mg and K the ratios of these cations will not usually effect crop yields in the ratios typically found in most agricultural soils.

In 2004, the work of Sullivan (Sullivan, 2004) refers to Albrecht’s conclusions as follows: When optimum ratios of base cations are maintained in the soil, “it is believed to support high biological activity, have optimal physical properties (water intake and aggregation), and become resistant to leaching.” And further, that crops growing on such a soil are, too, balanced in mineral levels and can be seen as nutritious for both humans and animals. The range of base saturation ratios or percentages he describes are as follows: Ca 60-70%, Mg 10-20%, K 2-5% and Na 0.5-3%; and fertiliser applications should be made to meet, or maintain this ideal range.

Today predominantly in the U.S., the BCSR method has found good resonance amongst farmers and several laboratories and agricultural consultants. Sullivan states that for example Neal Kinsey, a soil fertility consultant in Charleston, Missouri, is a major proponent of the Albrecht method. A former student under Albrecht, he is said to be one of the leading authorities on the base-saturation method.

Although this soil analysis approach was developed in the U.S., and is probably most suitable and applicable in soils of low pH and high Mg levels (which are not often found in the UK), some promising research has assessed its value for UK farmers. Leake and colleagues (Leake et al., 2013) have conducted a large-scale field experiment on four arable fields in Leicestershire. The three-year rotational comparison of two soil

management techniques ran over a period of four years (2009-2012). The two techniques compared were: 1) the conventional soil analysis regime to establish the available mg/l of Phosphorus and Potassium, RB209 was used to determine major nutrient applications; and 2) the Bioscence® approach, which is based on recommendations made after Albrecht's BCSR method, while it combines a wider and more targeted range of nutrients, in conjunction with biological parameters such as bacteria and fungi.
The group aimed to monitor crop yields and economic parameters while N-inputs were reduced in the system. They found that trial plots which were treated based on recommendations from the Bioscence® approach produced an increase in yield of 8% compared to the conventional soil management regime; this had been achieved whilst applying 8-12.5% less nitrogen on the Bioscence areas. They stated that some of their data suggests that also soil biota (bacteria and fungi) improved, and N-use was around 810% lower across the rotation in the Bioscence areas. The authors added that the margin over fertiliser (£6/hectare) would benefit from larger and long-term studies, and that it is linked to commodity prices and nutrient prices. Although averaging around £6/hectare, after 2009, the Bioscence approach seemed to develop better financial returns. Leake et al. argued that financial return from adapted soil and nutrient management strategies is crucial for farmers and growers, in addition to apparent or long-term environmental benefits.

A farmer's view

From Will Armitage, one of the trial hosts of this operational group (Armitage, 2014): "A soil is most productive when it's able to retain moisture, air and microbes. Extensive work was done by Prof W.A. Albrecht to establish the correct base saturation levels of minerals that need to be present to achieve this in any soil and yet, speaking to farmers, few can tell you what these are on their own farms.
When you look at the Base Saturation Levels at my farm you can see we have tonnes of calcium and phosphorus in our soil which is available if we maintain and enhance the soil biology. The soil biology creates the vital links between the mineral in our soil: the plants: the animals: and ultimately the nutrient density of food.
There are numerous other chemical soil analyses available, but few give such a true reflection of the health of your soil. The majority focus on P, K, Mg and pH, a very blinkered approach, ideal for fertiliser salesmen who are trying to sell you something. But very often destructive rather than constructive advice follows, with recommendations to use high levels of soluble fertiliser, which can further lock up other minerals, burn off carbon and reduce soil life. You will still grow a crop, but with low mineral density, susceptible to pests and disease; and therefore, more chemicals will be required."

3. Concluding remarks

Albrecht did not take pH into account and concluded a high Ca saturation was required for optimal plant growth. However, pH does play an important role and much of Albrecht's work has been confounded by changes in pH that he himself did not recognise. Plant growth is limited in acidic soils and additions of Ca alone will not improve pH levels. The key here is that although most liming materials contain Ca, not all Ca containing amendments are basic and therefore can't neutralise soil acidity. For example, a study by Bruce and colleagues (Bruce et al., 1988) found that adding Ca as $CaSO_4$ or $CaCl_2$ had no effect on the root length of soy bean. Adding Ca in the form of gypsum (the sulphate) or the chloride has no appreciable effect on pH as these chemical species are essentially neutral. When Ca was added as $CaCO_3$, with a corresponding increase in pH, the root length of the soy bean was significantly increased. What this suggests is that a lot of the work carried out by Albrecht showed benefits from increasing the pH of the soil rather than from Ca addition and a changing Ca:Mg ratio. Nodulation of legumes is particularly sensitive to acidic conditions (Alva et al., 1987) helping explain why yield and quality of these legume crops was so dramatically improved by the addition of lime, and hence an increase in pH.

In addition, the optimum percent saturation with a given cation is dependent on cation exchange capacity of the soil and also on the soil mineralogy, and will therefore vary from soil to soil and the concept of base cation saturation percentage cannot be applied to all soil types. Some soils, due to their mineralogy, can release significant amounts of non-exchangeable cations such as K and Mg which can affect the optimum percentage saturation of that particular cation (Kelling et al., 1996a).

There is currently a lack of reliable and conclusive comparative research between the BCSR approach based on Albrecht's work and more conventional chemical soil analysis methods, specifically in the UK and for organic farmers and growers. Seeing that this method was developed for U.S soils, which are usually high in Mg and low in Ca, it might be obvious that some adaptation is needed when applying it in a UK environment, where soils are often high in Ca.

Also, from a commercial point of view, the test may have found less resonance as others, of similarly inconclusive value for soil management strategies, because it is not directly linked to any commercial products. The test in itself is rather costly for a routine use by farmers and normally requires additional guidance and advice from an expert or consultant for result interpretation; recommended products and their amount however can vary greatly from case to case.

Some soil laboratories in the UK are promoting a better suited analysis protocol, stating to produce more practical results for farmers and agronomists. For the result interpretation and derived recommendations of fertiliser application from such adapted protocols, base cation ratios are often not the driver anymore, but rather a more comprehensive view on soil health, including chemical, biological and physical parameters. Such adapted protocols and tests are for example the Bioscene test used by Leake et al. (2013), or the SSM (Sustainable Soil Management) test offered by the Glenside Group/NRM.

What seems clear from the body of evidence available is that so long as amounts of exchangeable Ca, Mg and K are high enough to support crop growth and provide adequate crop nutrition, the relative ratios of these cations is relatively irrelevant within the ranges usually observed for most agricultural soils in the UK. However, the strong positive feedback from some farmers who use this approach for years, and see soil health and yields improve over time, still suggests that the method might have value for UK farmers. This EIP operational group investigates this issue further, and will review the conclusions towards the end of the project, to specify feedback from the farmers involved and add results from the conducted field trials.

References

ALBRECHT, W. A. 1941. Plants and the Exchangeable Calcium of the Soil. *American Journal of Botany,* 28**,** 394-402.

ARMITAGE, W. 2014. Sustainable Milk Production: the vital role of Soil for Feed Integrity. *In:* TRUST, N. F. S. (ed.).

ASSOCIATION, W. A. N.-T. F. 2005. WANTFA Meckering R&D Site Trial Results 2004. *In:* WANTFA, P., WESTERN AUSTRALIA. (ed.).

BEAR, F. E. & TOTH, S. J. 1948. INFLUENCE OF CALCIUM ON AVAILABILITY OF OTHER SOIL CATIONS. *Soil Science,* 65**,** 69-74.

BRADY, N. C. & WEIL, R. R. 1999. The nature and properties of soil 12th ed. Prentice-Hall Inc. Upper Saddle River, New Jersey.

BRUCE, R. C., WARRELL, L. A., EDWARDS, D. G. & L.C., B. 1988. Effects of aluminium and calcium in the soil solution of acid soils on root elongation of Glycine max cv. *Forrest. Aust. J. Agric. Res.,* 39**,** 319–338.

GIDDENS, J. & TOTH, S. J. 1951. Growth and nutrient uptake of ladino clover on red and yellow grey-brown podzolic soils containing varying ratios of cations. *Agron. J.,* 43**,** 209–214.

HUNTER, A. S. 1949. Yield and composition of alfalfa as infl uenced by variations in the calcium–magnesium ratio. *Soil Science,* 67**,** 53-62.

JOHNSTON, A. E. 2011. Assessing Soil Fertility: The Importance of Soil Analysis and its Interpretation. *Potash Development Association.*

KELLING, K. A., HERO, D. E., DOLL, J. D. & WOLKOWSKI, R. P. 1996b. Effectiveness of an “alternative” fertility program. . *Proc. of Wisconsin Fertilizer, Aglime and Pest Management Conf. .*

KELLING, K. A., SCHULTE, E. E. & PETERS, J. B. 1996. One hundred years of Ca:Mg ratio research. . *New Horiz. In Soil,* 8.

LEAKE, A., JARVIS, P. & WINNING, N. 2013. Soil Fertility Management Using Bioscene.

MARSCHNER, P. 2011. Marschner’s Mineral Nutrition of Higher Plants. *Academic Press.* New York.

MARSHALL, C. E. 1977. William A. Albrecht. *Plant and Soil,* 48**,** 1-4.

MASTUTI, R. 2014. Mineral Nutrition - the study of how plants obtain and use mineral nutrients. Biology Departement, Brawijaya University.

MCLEAN, E. O. & CARBONELL, M. D. 1972. Calcium, magnesium, and potassium saturation ratios in two soils and their effects upon yield and nutrient contents of German millet and alfalfa. *Soil Sci. Soc. Am. Proc.,* 36**,** 927–930.

MOSER, F. 1933. Calcium-magnesium ratio in soils and its relation to crop growth. *Agronomy Journal*.

ÖBORN, I., EDWARDS, A. C., WITTER, E., OENEMA, O., IVARSSON, K., WITHERS, P. J. A., NILSSON, S. I. & RICHERT STINZING, A. 2003. Element balances as a tool for sustainable nutrient management: a critical appraisal of their merits and limitations within an agronomic and environmental context. *European Journal of Agronomy,* 20**,** 211-225.

RENGASAMY, P., GREENE, R. S. B. & FORD, G. W. 1986. Influence of magnesium on aggregate stability in sodic red-brown earths. . *Aust. J. Soil Res. ,* 24**,** 229–237.

SCHONBECK, M. 2000. Balancingsoil nutrients in organic vegetable production systems: Testing Albrecht’s base saturation theory in southeastern soils. *Organic Farming Res. Found. Inf. Bull. ,* 10:17.

SULLIVAN, P. 2004. Sustainable Soil Management. *ATTRA, NCAT,* IP027/133.

WATSON, C. 2008. Laboratory mineral soil analysis and soil mineral management in organic farming. *In:* REVIEW, I. R. (ed.).

WATSON, C., ATKINSON, D., GOSLING, P., JACKSON, L. & RAYNS, F. 2002. Managing soil fertility in organic farming systems. *Soil Use and Management,* 18**,** 239-247.

WOOD, M. 1995. Environmental Soil Biology. *Blackie Academic and Professional.* Glasgow.

WOOD, M. & LITTERICK, A. M. 2017. Soil health – What should the doctor order? *Soil Use and Management,* 33**,** 339-345.