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The Management of Soil Nutrients: Chemical Fertilisers or Not?

Christopher Johns
Research Manager
Northern Australia and Landcare Research Programme

Key Points

- There are 17 chemical elements that are classified as essential plant nutrients. They must be present for a plant to grow or perform some other life-cycle process such as reproduction.
- Agriculture, by its nature, will deplete essential nutrients from the soil and, if soils are to remain productive, nutrients will have to be replaced either by chemical fertilisers, organic fertilisers and farming practices or a combination.
- Globally, soils are being degraded by agricultural practices that reduce the amount of organic carbon stored in them. The use of chemical fertilisers has contributed to the loss of soil organic carbon and the degradation of soil.
- Agricultural production on the scale necessary to feed a global population that is projected to exceed nine billion by 2050 is currently dependent on chemical fertilisers.
- The challenge is to find ways to halt and regenerate degraded agricultural soils, restore and increase levels of soil organic carbon while maintaining and increasing reliable food production.

Summary

The chemical fertility of soil is dependent on the presence, in appropriate quantities, of a range of chemical elements that are essential to a plant's lifecycle. In agricultural ecosystems, even the most fertile, these nutrients will, in time, be depleted and will have to be replaced. Nutrients can be replaced in different ways but soil fertility is much more complex than nutrient availability alone and the presence of soil organic matter is also a critically important component of healthy, fertile soils. The introduction of synthetic or chemical fertilisers has contributed greatly to increased agricultural production; however, they do not add or maintain

soil organic matter and their continued use can damage the soil. Modern, broad-acre farming, which largely has been dependent on chemical fertilisers, has greatly increased agricultural productivity but has also, in some locations, contributed to a loss in soil organic matter and a general reduction in fertility and long-term sustainability.

The challenge to soil science, therefor, is to find ways to reliably and sustainably increase soil agricultural productivity while maintaining healthy levels of soil organic material which, in turn, maintain soil structural and biological fertility.

Analysis

Introduction

Over 150 years ago it was identified that certain chemical elements were essential to plant growth, vigour, yield and reproduction. Today, most research sources recognise 17 elements as essential to all plants. Additional elements have also been identified that are either essential to some plants or beneficial but not essential for plant growth. Minor differences in source opinion notwithstanding, it is a firmly established principle that soils must provide plants with a significant number of chemical element nutrients for the plant to complete its lifecycle.

In natural, healthy ecosystems soil nutrient levels are maintained by the nutrient cycle and are relatively stable. Agricultural soils, however, can become nutrient deficient as agricultural ecosystems are not closed and nutrients will permanently exit the system as plant or animal produce. Even with the best possible agricultural practices, an open system such as this cannot be sustained indefinitely. Plant nutrient access, uptake, replacement and supplementation are not as simple as identifying and adding chemicals. Uptake mechanisms are varied and can be complex. Scientific research continues to improve our understanding of how to best maintain soil chemical fertility.

There is a long-standing debate, however, concerning the best way to maintain soil fertility particularly in large scale, industrial farms. There is also considerable debate about the benefits of organic (defined as a product that has only been minimally processed and is still bound in its natural form) farming compared to "modern" agriculture using inorganic or chemical fertilisers. The scientific debate is complex and the body of knowledge supporting both arguments is incomplete. It is generally acknowledged that organic agriculture is more sustainable in the long-term and has less environmental impact. These practices, however, can be difficult to apply to large-scale, industrial agricultural operations and often have reduced productivity.

Nutrient Elements

Of the 17 essential nutrients, **carbon**, **oxygen** and **hydrogen** are classed as non-mineral nutrients. They are accessed from air and water and are therefore not taken from the soil. Carbon forms the backbone of many plant biological molecules, including proteins, starches and cellulose. It is fixed by photosynthesis (the process by which green plants use sunlight and chlorophyll to construct foods from carbon dioxide and water) into sugars and starches that store energy in the plant. Hydrogen is obtained almost entirely from water. It is a critical element in photosynthesis and for respiration, the process of generating energy through the consumption of foods made by photosynthesis. Oxygen is gained from the air as oxygen gas or in the molecules of water or carbon dioxide. It is also necessary for plant respiration (the process by which the plant accesses energy from sugars and starches in the presence of oxygen). The remaining 14 elements are all classed as soil nutrients. They are divided into two categories: the macronutrients and the micronutrients.

The macronutrients, as the name suggests, are required in relatively large quantities. They are necessary for the basic, day-to-day plant biological functions such as growth, photosynthesis and respiration. The following are macronutrients together with their functions:

- **Nitrogen** which is needed for all plant growth processes.
- **Phosphorus** is an essential component in many vital plant processes.
- **Potassium** is also needed for a wide range of important processes within the plant.
- **Sulphur** is required for the formation of several amino acids, proteins and vitamins and for chlorophyll production.
- **Calcium** is involved in the proper functioning of growing points, especially root tips.
- **Magnesium** is an essential component of chlorophyll and is, therefore, vital for photosynthesis.

The micronutrients, while equally important as the macronutrients, are only required in small quantities. Deficiencies in micronutrients are more common in highly leached sands, organic soils and in highly alkaline soils. Deficiencies can also develop in intensely cropped soil. The micronutrients can be harmful or detrimental to plant growth if they are present in large quantities. The CSIRO publication*, Australian Soils and Landscapes; An Illustrated Compendium*, notes that the agricultural development of large areas of Australia was only possible when micronutrient deficiencies were recognised and remedied. The current recognised essential micronutrients are:

- **Molybdenum** which is directly involved in nitrogen metabolism.
- **Copper** which is required for the formation of enzymes for chlorophyll production.
- **Boron** which is necessary for the movement of sugars throughout the plant and the metabolism of nitrogen.
- **Manganese**, **Iron** and **Zinc** which are essential for plant growth process.
- **Nickel** which is the most recently identified essential plant nutrient. It is a key component of processes involved in nitrogen metabolism and the biological fixing of nitrogen.
- **Chlorine** which is required for carbohydrate metabolism and chlorophyll production. It should be noted that chlorine could be defined as a macronutrient. Due to its usual abundance in the environment it is very rarely deficient and is, therefore, often grouped with the micronutrients.

Soil Organic Matter (SOM)

Surface soils generally contain between one and six per cent organic matter, comprising carbon containing substances, living organisms and the remains of plants, animals and microorganisms that once inhabited the soil. Most SOM accumulates within the surface layer of soil, and can be categorised into two groups: one category includes all the decomposing organic material such as twigs, roots, leaves and living and dead organisms such as worms and insects; the second category comprises the substance often referred to as humus. The complex and highly beneficial substance is still not fully understood but it is very stable and resistant to decomposition.

SOM is an essential component of healthy soil. It acts to both store nutrients in the soil and is also a direct source of nutrients for plants. In respect to nutrient availability, SOM performs the functions of acting as a binding agent for the mineral particles; it provides for increased water-holding capacity and is a source food and habitat for soil organisms and microorganisms. The importance of these microbes in soil is fundamental. Without them life on the planet would not be possible. Microbes play essential roles in maintaining soil fertility through recycling nutrients and influencing their availability to plants, improving soil structure, supporting healthy plant growth and degrading organic pollutants. The functions and processes microbes perform or facilitate in our soil are incredibly complex and there are still significant gaps in our understanding of soil ecosystems. Globally, broad-acre farming techniques have tended to decrease the SOM component of agricultural soils and, therefore have reduced soil microorganism diversity.

The Role of Fertilisers in Agriculture

Every crop, pastoral animal or animal product such a wool, removes nutrients from the agricultural ecosystem through the simple and essential act of sending produce to market. Even the best agricultural soils in the world will be eventually depleted if nutrients are not replenished in some way. Accordingly, farmers and the wider agricultural industry look to the addition of nutrients to enhance soil fertility and to promote plant growth and development.

Fertilisers substantially decrease (at least for the short to medium-term) the amount of land necessary for a specific level of agricultural productivity. To reduce fertiliser use would require more land to be turned over to cropping to maintain existing levels of production. An analysis of field trials in the Australian grains industry determined that in the absence of fertilizer, in a number of regional areas, there is an average reduction in agricultural production of about 20 per cent for the broad acre cropping industries and by two thirds for the pastoral industries. Similarly, a review of the Queensland sugar industry determined that over a five-year period, the average sugarcane yield was approximately 40 per cent less than that which could have been obtained with the use of chemical fertilisers. Extrapolating the Australian data to a world-wide comparison, the consequence of not using synthetic fertilisers, could be a one-fifth to two-thirds loss of food productivity and competitiveness on world markets.

Organic and Non-Organic Fertilisers

Fertilisers are defined as any materials of natural or synthetic origin that may be applied to soils or to plant tissues (usually the leaves) to supply one or more nutrients essential to enhance the growth and development of plants. Fertilisers take two forms: organic (derived from decaying combinations of natural plant or animal-derived matter) and synthetic, referring to various chemical treatments that are required in the manufacturing process.

Synthetic fertilizer are inorganic compounds usually derived from by-products of the petroleum industry such as ammonium nitrate, ammonium phosphate, superphosphate, and potassium sulphate. Synthetic fertilizers do not support microbiological life in the soil (synthetic fertiliser can kill beneficial soil microorganisms). Inorganic fertilisers typically provide a range of macro and micro-nutrients, in varying proportions and combinations.

The Case for and against Organic Fertilisers

Organic fertilisers (animal wastes and plant residues) must be broken down into inorganic forms in the soil before plants can take up the nutrients required for growth and reproduction.

Organic fertilisers are relatively inefficient because they contain low concentrations of nutrients. As a result, large volumes of material need to be transported and spread over fields to overcome deficiencies. Organic fertilisers also take time to breakdown into inorganic forms and become available to plants.

Soil building practices such as crop rotations, inter-cropping, symbiotic associations, cover crops, organic fertilisers and minimum tillage are central to organic practices.

A summary of the limitation of organic fertiliser is as follows:

- The composition of organic fertilisers can be highly variable.
- Organic materials are a dilute source of nutrients compared to inorganic fertilisers. ·
- The application of organic fertilisers can be uneconomic on a large-scale operation.
- Organic fertilisers can be messy, and may require more work to apply.
- The release of nutrients is highly variable and reflects the number and work of microbiological activity, which generally rises and falls with soil temperature and moisture content.
- Commercial farming profit margins provide little incentive for long term investment in the quality of the land if that investment involves a loss of short-term productivity.

The list of limitations of organic fertilisers notwithstanding, the addition of organic material to soils is essential to maintaining healthy levels of SOM in soil. The addition of SOM is also an essential remediation and restoration of degraded soil. The sequestration of carbon, as a component of SOM, in soil may also be an important mitigation to climate change caused by atmospheric greenhouse gasses.

Imperative One – We must find ways of adding more organic material to agricultural soils to halt and reverse soil degradation and to ensure that soils remain both healthy and productive for the long-term.

The Case for and against Inorganic Fertilisers

The is little doubt that large-scale farming methods have degraded soil health and productivity in many parts of the world.

In contrast, inorganic fertilisers have a high concentration of nutrients that are rapidly available for plant uptake. Relatively small quantities of inorganic fertilisers are required. Transport and application costs can be relatively low. In addition, inorganic fertilisers can be formulated to apply the appropriate ratio of nutrients to meet specific plant growth requirements.

A summary of the limitations of inorganic or chemical fertilisers is as follows:

- Many chemical fertilisers do not contain micro-nutrients; however, specific trace element fertilisers are readily available in regions where their application is economically necessary.
- Synthetic fertilisers do not support microbiological life in the soil.
- Chemicals fertilisers do not add organic content to the soil.
- Synthetic chemicals can easily be over applied, particularly in regions that do now have access to technologically advanced application systems. This can lead to roots burns or create toxic concentrations of salts.
- Chemical fertilisers can release nutrients too quickly, creating a great deal of top growth before the roots are able to catch up. This kind of growth often leads to weaker and disease prone plants, with less yield.
- Once agricultural soils have become depleted of naturally occurring nutrients and SOM, crops can become dependent on chemical fertilisers. This situation can then further deteriorate, with

greater quantities of fertiliser being required for ever decreasing crop returns, eventually economic agricultural production becomes unsustainable.

- When the use of chemical fertilisers is prolonged, soil can become chemically 'over-loaded' eventually poisoning the soil profile to the point where plants will not establish.

- Chemical fertilisers dissolve easily and release nutrients faster than plants use them. This means they can leave the paddock and enter the environment with detrimental consequences such as leaching into sub-surface aquifers and larger catchments, thereby flowing into rivers, lakes and eventually, the ocean. Environmental damage can be significant and damage to the Great Barrier Reef attributed to nutrient run-off from coastal agriculture is one example.

- Commercial, inorganic fertilisers are a significant portion of the cost of agricultural production.

The negative reputation of chemical fertilisers and fertiliser companies, notwithstanding, modern agricultural production, which has kept pace with population growth, would have been difficult without them. It is also important to note that chemical fertiliser use continues to evolve. There are technologies being develop that will reduce the negative effects of chemical fertilisers. Precision agriculture can apply very specific quantities of nutrients very accurately. More complex fertiliser compounds are being developed to tailor chemical fertilisers of specific environmental conditions.

Imperative Two – Agricultural production must be maintained and increased to feed the exponentially growing world population and a growing demand for high quality food. In the short to medium term, this can only be achieved by the application of chemical fertilisers.

Conclusion

As highlighted in the two imperatives stated above, we have two, supposedly competing goals. The debate, however, does not have to be an adversarial, black and white issue. Farming without a heavy reliance on the application of bulk chemical fertilisers does have many environmental advantages, and may indeed be the future of agriculture but it will depend on technology and what we discover and learn in the future to maintain productivity. Until chemical free farming can produce crops on the scale of conventional methods, it cannot be considered a viable option for feeding the world population. Equally, the ever-increasing use of chemicals to support grossly over-harvested monocultures will never lead to environmental sustainability. Industrial farmers must acknowledge the true value of soil, not only as a source of profit, but as one of the foundations of life on the planet.

The solution to these seemingly unreconcilable imperatives is likely to be found in a negotiated middle ground. The ideal agricultural future may well merge conventional and organic methods; we don't have to choose sides. The two imperatives should not be interpreted as an impending and unavoidable "train-smash". They are intrinsically connected. In the long-term, sustainable food security cannot be achieved with stable healthy soils.

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80 Birdwood Parade, Dalkeith WA 6009, Australia.
Tel: +61 8 9389 9831 Fax: +61 8 9389 8803.
Web: www.futuredirections.org.au