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Nutrient Use Efficiency – Soils a Key Factor

Nutrient Use Efficiency (NUE) is the term used to discuss the ability of plants to efficiently uptake, assimilate and utilise nutrients in the soil.

The use of fertilisers, ameliorants and trace elements is how farmers try to improve yield or address a shortage of nutrients.

Sometimes nutrient shortage is not the issue.

What happens when there is too much nutrient? How do we know if plants are accessing and using the nutrients that have been applied? Are nutrients in the soil being utilised by the plant or are they being lost to the environment?

Research on nutrient and nitrogen use efficiency is increasingly important as markets address the issues of nutrient losses to and impact on the environment, variable or reducing crop yields despite increased and adequate use of fertilisers and the carbon cost of fertilisers and other applied chemicals.

Research across the globe on NUE indicates that utilisation of nutrients in the year which they are applied is around, or lower than, 50% for nitrogen and 10% for phosphorus.

By increasing NUE farmers can reduce the cost of nutrient inputs, while maintaining and possibly improving crop yield or quality.

A Snapshot of NUE Research

NUE research drivers and focus have changed over time. Changes in crop values, the cost of nutrient, changing attitudes to environmental issues, a focus

on sustainability as well as advancements in technical and scientific knowledge influenced research; with developments across numerous areas including:

- Optimising nutrient application (amount, timing and placement) to meet the crop's needs and ensure optimal yields/production.
- A focus on reducing excess use to reduce costs when farmer returns are low or fertilisers are expensive.
- Recommendations to minimise nutrient losses to the environment, e.g. run-off to waterways, which cause environmental issues.

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- Development of enhanced fertilisers or fertiliser additives, that provide sustained nutrient release or inhibit losses to the environment
- Discussions on nutrient use, cycling and losses in response to peak phosphorous and peak nitrogen and concerns around limited supply of low-cost resources.

Complexity of NUE

NUE can be difficult to measure and quite variable. Each season, crop, soil type, and other external factors influence nutrient use. In addition, some nutrients will enter the soil profile, and while not used in the year of application, will be cycled and used in subsequent years. Phosphorus is a good example of a nutrient where this applies.

NUE complexity means that in-field benchmarks and standards are difficult to set or measure. Because NUE is complex, farmers are at times tempted to overuse fertilisers to prevent a possible shortage of nutrients.

More recently there is evidence that sustained or overuse of chemical fertilisers sometimes has no effect or reduces yields.

Ongoing Research – The Soil-plant Interaction

Continuing research into nutrient use efficiency has provided evidence that soils play a role in nutrient cycling and uptake.

As a result over the last decade there have been many studies dedicated to understanding soil biological functions and nutrient use efficiency. A 2017 research paper on NUE1 and the rhizosphere highlights the value and critical role of the rhizosphere in productive soils and the value they can potentially deliver.

The research shows the benefits of soil microflora in the plant's rhizosphere on NUE and plant growth.

These beneficial microflora are called 'plant beneficial rhizospheric microorganisms' (PBRMs).

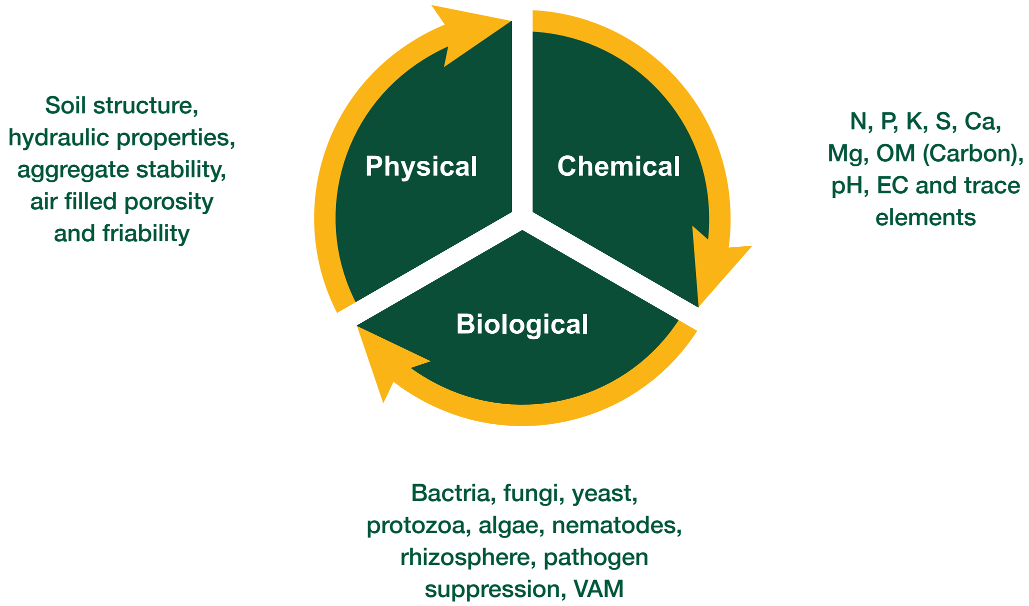
PBRMs bring about these benefits in a number of ways –

- Mineralising and humifying organic matter.
- Synthesising bioactive chemical compounds.
- Providing biological control against soil-borne pathogens and promoting immune response.
- Stimulating root growth.
- Accumulating soil carbon.
- Fixing nitrogen in the soil while others solubilise other nutrients and trace elements. PBRMs can improve the availability to plants of some nutrients by around 20 - 40%.

In addition, microbially active soils can increase the size of the rhizosphere. For many crops the root zone can interact with arbuscular mycorrhizal fungi (AMF; also called Vesicular-Arbuscular Mycorrhiza or VAM) to expand the root systems through the soil and therefore improve access to both macro- and micro-nutrients.

There are more than 500 million microorganisims per gram of active soil, so interactions between plants and soils are complex. Many interactions are still not well understood. What is known is that improving rhizosphere activity improves NUE. To do this requires a focus on soil composition, soil physical properties and nutrition for both the plant and the rhizosphere.

Improving Yield and Quality with Better Soil Health



Improving the Rhizosphere to Improve NUE

Microbial activity in the soil and the rhizosphere play an important role in three critical areas of NUE –

- The efficient uptake and use of nutrients.
- The cycling of nutrients in the soil, firstly capturing nutrient in the soil to avoid losses but then making it available to plants as required in the current or future season.
- The transfer or transportation of nutrients between the soil and the crop such that nutrients move more quickly from the soil to the plant.

In addition, the production of enzymes, vitamins, proteins and metabolites2 within the rhizosphere provide the chemicals required to help plants perform two key components of NUE:

- Store nutrients within the plant to support plant physiology, and
- Improve mobilisation of nutrients within the plant.

As well as supporting NUE the metabolites produced in the rhizosphere provide a range of other benefits such as suppressing disease and promoting beneficial microbes.

Microbial activity within the soil is important to plant performance and yield. However it can be negatively impacted by a range of issues and non-controllable factors such as sustained fallow, dry, wet, cold or hot conditions, presence of disease and use of chemicals and/or fertilisers. Chemicals used to treat soil disease will also kill beneficial microbes.

Maintaining an active rhizosphere begins with maintaining healthy, balanced soils. Treatments and practices need to be tailored for the soil type in order to address chemical, physical or biological issues in the soil. These same practices are part of any sustainable agriculture program.

Making Improvements in the Field

Research into soil biology and soil function continues to deliver new products and farming practices to the market. Many are targeted at improving the condition of soils and or the microbial processes within the soil or around the plant or seed.

Seed and Crop Inoculants

Seed and crop inoculants have typically been developed through a process of Identification and Isolation of single or small groups of microorganisms that have exhibited beneficial outcomes in the cycling or uptake of a specific nutrient; eg nitrogen or phosphorus. Table 1 on page 4 lists a number of identified microbial processes related to plant nutrition.

Products Focused on Increasing the Root Zone

These products include certain fertilisers. They focus on increasing the root zone and subsequently the rhizosphere and microbial activity supporting the plant, providing increased access to nutrients in the soil.

Products that Support Nutrient Cycling or Nutrient Transport

Other products look to supply components or compounds that support one or more of the natural processes of nutrient cycling or nutrient transport. Some examples are humic or fulvic acids, carbon or compost.

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Products that Feed the Entire Rhizosphere

Microbial foods focus on feeding or stimulating the diverse and complex range of microbes that naturally occur in highly productive soils but may be dormant or under stress.

These microbial foods or biostimulants range from –

- Simple food sources (proteins, sugars and carbon compounds),
- Single strain or type amino acid, vitamin or enzyme, through to
- Complex food sources that may contain simple food sources but importantly contain a range of metabolites and complex compounds like amino acids, vitamins and enzymes. These metabolites are produced within the rhizosphere by certain microbes and perform a range of functions including pathogen suppression.

BioAg Programs and NUE

Understanding the importance of your soils and the rhizosphere is an important first step to optimising yields and quality. This includes understanding the factors that have a negative impact on soil health and knowing how to offset them.

For a particular farm, the decision about what products to apply requires analysis of soils, growing conditions and crop type.

BioAg works with growers directly or through our distributors. Our focus is the analysis of soils and development of programs that are viable to the grower, provide enhanced results and will improve overall soil health.

BioAg has supported growers across a range of crop types across Australia. Our programs deliver improved nutrient use efficiency, utilisation, uptake and in-plant nutrient mobilisation.

Biostimulants are increasingly accepted as inputs to farming systems. BioAg's range of biostimulants is at the core of our programs, with success on farm and in independent, replicated trials. We continue to invest in research – including the area of NUE.

To discuss how a BioAg program improve yields, quality and NUE on your farm contact your local BioAg representative or distributor.

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Appendices

Table 1 – Key Microbial Processes Related to Plant Nutrition[3]

Element	Biochemical Process	Microbial Genes	Soil Enzymology Literature	Culture-Independent Literature	Culture-Dependent Literature
Nitrogen	Nitrogen fixation	nifD, nifH, nifK	–	Reganold et al., 2010; Xue et al., 2013	Bremer et al., 1990
	Protein depolymerization	apr, npr, sub	Mader et al., 2002	Rasche et al., 2014	Kohler et al., 2007
	Urea catabolism	ureA, ureB, ureC	Dick et al., 1988; Bowles et al., 2014	Reganold et al., 2010; Fierer et al., 2012, Xue et al., 2013	Kohler et al., 2007
Phosphorous	Phosphate ester cleavage	phoA, phoD, phoX, ACPase, glpQ, ushA, appA, phyA, phyB	Mader et al., 2002; Garcia-Ruiz et al., 2008	Fraser et al., 2015	Kohler et al., 2007
	Phosphonate breakdown	phnJ, phnX	–	Bergkemper et al., 2016	–
Sulfur	Sulfate ester cleavage	aslA, asfA	Garcia-Ruiz et al., 2008	Schmalenberger et al., 2008	Schmalenberger et al., 2008
	Sulfonate breakdown	ssuD	–	–	Kertesz and Mirleau, 2004

Soil microbial metabolism boosts plant nutrition by converting recalcitrant forms of N, P, and S to forms that are more bioavailable for plant uptake. This table collates a set of well-known microbial metabolic processes that contribute to plant N, P, and S nutrition, highlighting the specific genes involved, and referencing specific studies that have conclusively shown this link.

Table 2 – Common NUE Terms and Measurements[4]

This table provides information about a range of measurements used in analysing NUE.

Term	Calculation*	Question Addressed	Typical Use
Partial Factor Productivity	PFP = Y/F	How productive is this cropping system in comparison to its nutrient input?	As a long-term indicator of trends.
Agronomic Efficiency**	AE = (Y-Y0)/F	How much productivity improvement was gained by use of nutrient input?	As a short-term indicator of the impact of applied nutrients on productivity. Also used as input data for nutrient recommendations based on omission plot yields.
Partial Nutrient Balance	PNB = UH/F	How much nutrient is being taken out of the system in relation to how much is applied?	As a long-term indicator of trends; most useful when combined with soil fertility information.
Apparent Recovery Efficiency by Difference**	RE = (U-U0)/F	How much of the nutrient applied did the plant take up?	As an indicator of the potential for nutrient loss from the cropping system and to access the efficiency of management practices.
Internal Utilization Efficiency	IE = Y/U	What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.)?	To evaluate genotypes in breeding programs; values of 30-90 are common for N in cereals and 55-65 considered optimal.
Physiological Efficiency**	PE = (Y-Y0)/(U-U0)	What is the ability of the plant to transform nutrients acquired from the source applied into economic yield?	Research evaluating NUE among cultivars and other cultural practices; values of 40-60 are common.

* *Y = yield of harvested portion of crop with nutrient applied; Y0 = yield with not nutrient applied; F = amount of nutrient applied; UH = nutrient content of harvested portion of the crop; U = total nutrient uptake in aboveground crop biomass with nutrient applied; U0 = nutrient uptake in aboveground crop biomass with no nutrient applied; Units are not shown in the table since the expressions are ratios on a mass basis and are therefore unitless in their standard form. P and K can either be expressed on an elemental basis (most common in scientific literature) or on an oxide basis as P2O5 or K2O (most common within industry).*

** *Short-term omission plots often lead to an underestimation of the long-term AE, RE, or PE due to residual effects of nutrient application.*

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1. Meena, Vijay & Meena, Sunita & Verma, Jay & Kumar, Ashok & Aeron, Abhinav & Mishra, Pankaj & Bisht, Jaideep & Pattanayak, Arunava & Naveed, Muhammad & Dotaniya, M.. (2017). **Plant beneficial rhizospheric microorganism (PBRM) strategies to improve nutrients use efficiency: A review.** Ecological Engineering. 107. 8-32. 10.1016/j.ecoleng.2017.06.058.)

2. Metabolites are the intermediates and products of metabolism, Metabolites can be categorized into both primary and secondary metabolites, Primary metabolites are considered essential to microorganisms for proper growth. Secondary metabolites do not play a role in development, growth, and reproduction, and are formed during the stationary phase of growth, metabolites are the small molecular weight compounds produced by microbes, to regulate other organisms beneficial to them and suppress organisms that are harmful and also develop their own growth and development.

3. Jacoby R, Peukert M, Succurro A, Koprivova A, Kopriva S. **The Role of Soil Microorganisms in Plant Mineral Nutrition-Current Knowledge and Future Directions.** Front Plant Sci. 2017;8:1617. Published 2017 Sep 19. doi:10.3389/fpls.2017.01617

4. Fixen P, Brentrup F, Bruulsema T, Garcia F, Norton R, Zingore S (2015) **Nutrient/fertilizer use efficiency: measurement, current situation and trends.** In 'Managing water and fertilizer for sustainable agricultural intensification'. (Eds P Drechsel, P Heffer, H Magen, R Mikkelsen, D Wichelns) pp. 8–38. (International Fertilizer Industry Association, International Water Management Institute, International Plant Nutrition Institute, and International Potash Institute (IPI): Paris, France)