KIT 3.6

Improve nitrogen and phosphorus availability by:
- greater capture of value from soil biota
- optimisation of nitrogen-fixing legumes in rotations
- soil amelioration to improve nutrient availability.

Impact	**Growers have access to new options to increase nutrient availability and uptake through enhanced soil biological processes, nitrogen fixation and soil management practices, leading to greater profitability.**
Summary	Growers have access to novel tools, technologies and information to assist in capturing greater profit from increased supply, reduced losses and greater crop uptake of nitrogen, phosphorus, potassium and sulfur. This is achieved by: • exploiting an improved understanding of nutrient-cycling processes driven by soil biota • increasing the contribution of nitrogen fixation to farming systems through improved symbiosis and the inclusion of legume options in rotations • optimising soil management practices to increase the availability of phosphorus and other nutrients.

OVERVIEW

Australian grain growers have an opportunity to reduce production costs by improving the supply and uptake from the soil of nutrients essential for plant growth. Most growers currently rely on fertiliser inputs to supplement soil supplies of nitrogen (N) and phosphorus (P), and to a lesser extent potassium (K) and sulfur (S). Fertilisers represent 25–30 per cent of production costs and about 16per cent of total crop revenue (GRDC Strategy 2017). Fertiliser costs range from $20–55 per tonne of wheat yield for Australian grain growers and is influenced by farming system, business performance, location and seasonal conditions.

The grains industry recognises that fertilisers are critical in supplementing soil nutrient supply, but they are costly, and are sometimes poorly utilised. It is understood that soil biota play an important role in N fixation by legumes, the supply of N and S from soil organic matter via mineralisation, and other nutrient transformations. However, our knowledge of N cycling was largely developed many decades ago when pasture legumes and tillage were common, and studies were often piecemeal, focussing on a particular process. There are gaps in our understanding of soil nutrient supplies and crop uptake, especially the role of microbes and the changes in the rhizosphere which impact nutrient availability and plant uptake. Unlike N and S, the amount of P returned to the soil in organic matter is relatively small, and most of the P taken up by crops is exported in grain. Some Australian soils have naturally low K supplies but decades of K removal in agricultural products is decreasing K supplies and deficiencies are emerging in new areas. The K in plant residues is readily leached out into the soil by rain, a process that is largely independent of biological processes.

For grain growers looking to optimise fertiliser expenditure and improve the availability of nutrients in their soils, the main research levers are (1) determining and increasing value capture from soil biota, (2) optimising of nitrogen-fixing legumes in rotations, and (3) optimising nutrient availability on ameliorated soils. Key Investment Target (KIT) 3.6 aims to address these through targeted investments to:

1. Increase the understanding nutrient cycles, availability and crop uptake and the role of soil bioate,
2. Identify innovative options to improve nutrient supplies from soil and uptake by the crop, and
3. Improve farming practices by adopting novel technologies that enhance nutrient availability.

The focus of KIT 3.6 is on understanding nutrient cycles and the role of soil biological processes, nitrogen fixation, and soil management practices. Building on our current knowledge this will inform research to develop novel or adapt current technologies and practices that deliver increased nutrient supplies and crop profitability. Along with other KITs, this includes R&D targeted at marginal profits obtained from N, P, K and S fertilisers and ensuring maintenance of soil fertility within our farming systems for enduring profitability. The primary focus is on N and P, the two most widespread fertiliser nutrients. However, K and S are also included as secondary priorities, because of their emerging importance in balanced crop nutrition. Expenditure on other fertiliser nutrients is relatively small, and hence, these are excluded.

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GRDC will consider investing in research and development where there is a prospective benefit to growers, adoption is likely, and a clear path-to-market exists. KIT 3.6 intersects with KITs 1.6 to 1.9 which address physical and chemical constraints. For example, neutralising soil acidity increases the availability of P and other nutrients. KIT 3.6 relates strongly to KIT 1.5 (closing the yield gap) and to fertiliser investments (KIT 3.5). Investment in soil N also relate to activities undertaken as part of KIT 2.3. While organic matter and carbon cycling are important for nutrient storage and supply, implications for carbon sequestration and greenhouse gas emissions are dealt with under the GRDC's sustainability framework and are not the direct attention of KIT 3.6.

FUTURE RD&E FOCUS

SCOPE – Improved understanding of nutrient cycles, availability and crop uptake

Knowledge of the cycling, availability and crop uptake of nutrients, and the role of soil biota in those factors under field conditions, is increased.

Soil fertility or health is the ability of the soil to produce a benefit, and in the case of agricultural systems, these products are commodities of economic value. Fertility is determined by the physical, chemical and biological characteristics of the soil. Growers often focus on fertiliser applications to boost fertility, yields and profits, but understanding the quantity and timing of nutrient supplied from the soil is equally important. Given our highly weathered and infertile soils, Australia's agricultural industries have made numerous investments over long periods to build knowledge the cycling, availability and crop uptake of nutrients. However, our current of understanding of nutrient supplies was largely developed many decades ago when pasture legumes and tillage were common, and significant gaps exist for most nutrients, particularly the role of soil biota in nutrient cycling. Under intensively cropped systems, soil organic matter contents have declined, reducing the soil's ability to supply nutrients and compromising soil fertility.

Up until the last four decades, most growers relied solely on N fixation by legume pastures to supply N to following crops via breakdown of pasture residues. During the 1980s, increases in crop productivity due to improved varieties, no-till and early sowing, and enhanced crop protection, which coincided with falling livestock prices, and hence, pastures were displaced by more profitable crops. In some areas, adoption of pulses provided N inputs to the system via N fixation, but significant fertiliser N applications were generally required to meet yield potential of cereals and canola. Since then crop productivity has continued to increase, boosting crop demand for N. While leading growers manage fertiliser N requirements for cereals and canola well and produce yield close to the economically attainable, water-limited, yield potential, insufficient N supply is currently the most common cause of yield gaps, especially in favourable conditions (BWD00025).

For more than a century, growers have applied large inputs of fertiliser P to correct Australian soils that are highly deficient. Most of the P is strongly bound to soil particles and after many decades of fertiliser applications many soils have a huge bank of P which is largely unavailable to plants. Some soil fungi (e.g. vesicular arbuscular mycorrhiza) can assist plants to take up P, but this has not been manipulated commercially in broad-acre agriculture. Soil biology is critical to the cycling of organic matter and supplies of N and S (and P to a lesser extent) from Australian soils. However, it is extremely complex and highly dynamic. Hence, the role of biology is generally poorly understood under field conditions.

Nutrient supplies are confounded by chemical or physical constraints that effect many Australian cropping soils. Constraints (see KITs 1.6 to 1.9) that restrict root growth and uptake of water and nutrients, also impact soil biological activity. Current soil management practices used by grain growers usually target these physical and chemical constraints which are known to alter the yield potential and demand for nutrients, as well as nutrient distribution and availability in soils. Subsequent benefits to soil biology are largely considered a side-effect. For example, liming to correct soil acidity improves plant growth and yield, and also enhances soil microbes that mineralise organic matter, boosting N supplies. Sometimes soil management practices can be detrimental to nutrient availability and biological activity in the short term, and growers are looking for better guidelines to reliably increase the benefits of these practices.

Investment Outcome 3.6.1 – Growers and their advisers have an enhanced fundamental knowledge of the role of soil biota in the cycling, availability and crop uptake of nutrients across different farming systems.

The grains industry requires a stronger understanding of how each nutrient (N, P, K and S) cycles between various inorganic and organic pools, how crops access these pools, and when and where losses from the system might occur.

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This includes better knowledge of how climate, soil condition, soil management and fertiliser practices, crop rotations, and biota affect nutrient transformations, crop uptake and loss mechanisms.

The supply of N and S is closely linked to fertiliser inputs and the breakdown of organic matter and cycling of soil carbon. It is thought that N mineralised from organic matter is more effective than N supplied in fertilisers, but this may be a generalisation. Our knowledge of nutrient loss pathways and opportunities to reduce these and their environmental impact, is incomplete. The role of the rhizosphere and microbial associations are known to influence N, P, K and S availability and uptake by plants, but a detailed understanding is absent. Several attempts have been made to introduce or manage microbes that are beneficial to nutrient supply and uptake, however none have been successful in the grains industry. Other micro-organisms may warrant investigation. The impact of herbicide and fungicide residues on soil biota that enhance nutrient supplies is also lacking.

The GRDC will consider investing in research to enhance knowledge of the cycling N, P, K, and S between soils, biota, plants, water and air within cropping systems, including our understanding of in-field variability and the influence of climate, soils, and management. Understanding the medium to long-term implications of nutrient cycling on soil organic matter and fertility is also important. There may be opportunities to enhance the fundamental knowledge of the role of soil biota in the cycling, availability and crop uptake of nutrients, and the close relationship with the turnover of organic matter and soil carbon. Of particular interest is how this fundamental knowledge might lead to better predictions nutrient supply during the growing season and improved soil or crop management practices to enhance the supply of nutrients to crops and minimise losses (Investment Outcome 3.6.4).

Investment Outcome 3.6.2 – Growers and their advisers have a greater understanding of symbiotic and non-symbiotic nitrogen fixation, the cycling of organic matter and the nitrogen contribution of fixation to crops, across different farming systems.

Nitrogen fixation by legumes in symbiosis with rhizobial bacteria has been a critical theme of ongoing RD&E investments by the grains industry. It is widely recognised that legumes play an important role in fixing atmospheric N, and this can benefit following crops via the breakdown of organic residues. Based on ABARE crop production statistics (2016), pulses are estimated to fix about 120 kg N/ha on average. This is more than 220,000 tonnes of N fixed annually across Australia and is worth approximately $220 M. In addition, it is likely that more than 20 M ha of legume-based pastures are rotated to grain crops. This is likely to contribute an estimated 1.6–2.3 M tonnes of N to cropping systems.

Despite good progress in the development of improved rhizobial strains and inoculation practices, several challenges exist to optimizing nodulation, rhizobial survival, N fixation, and N supplies within our farming systems. For example, most pulse crops and their rhizobia struggle with soil acidity, and in some situations, high performing pulse crops leave little or no N for following crops, even on neutral to alkaline soils. The industry needs options to enhance N-fixation by pulses or pasture legumes on mixed farms, built upon fundamental knowledge of rhizobial and legume ecology. Other avenues of increasing N fixation (e.g. free-living N fixers, or 'super-nodulating' mutants) are also a possibility that may warrant investigation.

GRDC will consider investing in the development of improved knowledge of rhizobium ecology, host/symbiont interactions and N fixation processes for high value pulse crops or green manure crops or pastures grown in rotation with crops. KIT 3.6 may also enhance our understanding of N-fixation from non-pulse crops, including free-living N-fixers, and other ecology of other organisms that may increase supplies of N in soils.

Investment Outcome 3.6.3 – Growers and their advisers have an improved understanding of the effects of soil management practices on the cycling, availability and crop uptake of nutrients.

Australian soils often need strategic amelioration to overcome physical and chemical constraints – acidity, sodicity and salinity, compaction, water repellence, low water holding capacity, and waterlogging. Current amelioration practices improve medium to long term soil productivity and may increase root growth due to physical disruption, soil mixing, nutrient redistribution and additions of organic matter. Current practices include soil inversion or mixing, deep ripping, claying, drainage, organic matter incorporation, and applications of lime or gypsum (see KITs 1.6 to 1.9).

Amelioration practices that invert or mix soils can sometimes lift hostile subsoils to the surface and create short term challenges for crops – e.g. changing herbicide efficacy, impairing plant establishment and reducing organic matter and

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nutrient availability. There is little available knowledge on the impact of soil amelioration on nutrient cycling and soil biota. These practices are thought to impact those biota thought to be important in cycling of nutrients. These populations are strongly impacted by their environment (soil structure, chemistry and organic matter content). Soil amelioration can also boost root growth, the uptake of water (particularly from the subsoil), crop yield potential and the nutrients needed to achieve that potential.

More research is needed to better understand the effects of soil management on the cycling, availability and uptake of nutrients, and the increased demand for nutrients through increased yield potential. GRDC may invest in research focused on improved understanding of nutrient supply and the performance of crops on ameliorated soils. This includes investigations that build our understanding of the impact of amelioration approaches on nutrient re-distribution within the soil profile and the soil nutrient supply to crops. This may specifically focus on cases where poor crop performance thought to be due to insufficient nutrient uptake follows soil amelioration. GRDC may also invest to understand the impact of nutrient demand and management following the redistribution of soil nutrients and organic matter from the topsoil. Research on the benefit of amelioration on grain legumes and N fixation will be considered. In all cases, investments in this area will be a closely aligned to RD&E activities undertaken within KITs 1.6 to 1.9.

SCOPE – Innovative options to improve nutrient availability

Nitrogen fixation and the availability of phosphorus, nitrogen and other nutrients are maximised through the development of novel tools and technologies that harness soil biota and the adoption of enhanced soil management practices.

Building on current understandings and new knowledge developed in scope area one, new and improved tools and technologies are required to enable crops to benefit from enhanced biological functions that increase nutrient supplies and cycling in soils, including N fixation and optimisation of fertiliser inputs. These technologies and practices may modify microbial populations to better exploit nutrients cycling through soil organic matter to supplement applied fertiliser nutrients. Similarly, soil amelioration practices may be modified to boost nutrient supplies and crop uptake to enable attainable yield potential to be achieved. This scope of work includes improving the prediction of nutrient supplies and losses based on soil and seasonal conditions, and biological activity.

Investment Outcome 3.6.4 – Growers and their advisers have access to innovative practices that exploit soil biological and amelioration processes to increase nutrient supply and uptake and reduce nutrient losses and, in doing so, reduce reliance on inorganic fertilisers.

Growers and their advisers want new or improved practices that exploit soil biological processes so that they can optimise their use of fertiliser nutrients. For example, increasing the contribution of symbiotic N fixation via legumes and potentially non-legume fixation may be possible through improved crop and soil management. These new practices will enable them to better align nutrient supply to crop demand: targeting supply, reducing losses and enhancing crop uptake and production.

Growers need to improve their strategic management of soil organic matter to maintain the supply of soil nutrients, and to enhance other soil functions. Growers may be able to better exploit nutrients in applications of organic matter waste products like biosolids, animal wastes and composts where these can be supplied cost effectively. Organic matter grown on-farm such as green manure crops or phased legume pastures may also be economically viable. Novel ways of manipulating soil microbes to enhance nutrient supplies will be considered. For example, novel microbes may be identified that are capable of solubilising P currently unavailable to plant roots.

GRDC will also invest to provide growers with innovative practices that exploit soil biological and soil amelioration processes. Investments could include improvements in soil testing and the capture of complex spatial data, decision aids, nutrient budgeting, or the development and integration of other promising technologies or strategies. In collaboration with KITs 1.6 to 1.9, GRDC investments will include economic assessments of the costs and benefits in relation to nutrient supplies for each soil management practice.

Investment Outcome 3.6.5 – Growers and their advisers have access to information, tools and technologies for enhancing nitrogen fixation, supply and uptake through organic matter cycling, while reducing nitrogen losses within farming systems.

Following on from the knowledge developed in outcome 3.6.3, are practices, tools and technologies for enhancing N fixation and soil derived N supply to non-legume crops within the farming system. This could come from pulse crops, pasture legumes or other non-symbiotic avenues (e.g. free-living N fixers). In the case of pulse crops, growers require rhizobial strains that have greater tolerances to soil stresses (e.g. acidity, dry sowing) and improved nodulation and N fixation ability. Growers also need improved inoculation practices and crop management options that optimise the performance of rhizobia and benefits of N derived from legume residues.

GRDC will look to invest to optimise N-fixation within cropping systems. This could include diagnostic tools that predict the amount of N fixed and the amount available to following crops and likely losses. While fertiliser N management is dealt with in KIT 3.5, this KIT will develop practices for growers to maintain, increase and predict the soil supply of N derived from legumes or other microbial avenues, and options to reduce N losses and enhance N uptake, therefore benefiting profits and environmental outcomes. In all cases, GRDC investments will include economic assessments including trade-offs, risk and fertiliser price sensitivities as applicable to growers across Australia.

SCOPE – Adoption of novel technologies to enhance nutrient availability within farming systems

The adoption of innovative and integrative options to enhance nutrient availability as influenced by soil biota and soil management, within a range of farming systems, is enabled.

Growers need information and confidence to adopt tools and technologies that manipulate soil biota to improve the supply and capture of N, P, K and S from the soil, while optimising reliance on fertiliser applications based on profit and risk management. Correctly packaged, the knowledge developed under scope one and the integration of practices and technologies developed under scope two, will increase the ability of growers to predict soil nutrient supply (e.g. from N fixation and subsequent mineralisation of organic matter) and the new for supplementation with fertiliser inputs. Growers will also need information that quantifies the advantages or disadvantages of novel technologies compared to increased fertiliser applications. A key factor influencing growers fertiliser decisions is the uncertainty of the amount and timing of nutrient supplies from the soil as influenced by crop rotation, soil type, seasonal conditions and any likely losses.

GRDC will focus on working with growers and their advisers to build a broad understanding of the value of N fixation, the supply of N, P, K and S from soils. This includes understanding the role of soil biota in these processes, as well as enhanced soil amelioration practices under a range of farming systems. This is likely to incorporate work undertaken through other GRDC soil constraint KITs, which will be consolidated into updated management practices that account for spatial and temporal variability. This area of scope includes investments targeted at helping growers improve their general nutrient management decisions (KITs 1.5, 2.3 and 3.5) and may also include activities that determine the current and future use of soil analysis and spatial mapping, including pre and post amelioration diagnostics.

Investment Outcome 3.6.6 – Growers understand the effects of soil biota and soil amelioration on nutrient cycling and whole-farm profit and risk, and are motivated to adopt innovative practices that exploit biological processes and nutrient availability.

Growers need updated packages that enable them to manipulate soil biota to improve N, P, K and S cycling, and to adopt novel practices and technologies that enhance nutrient supplies, minimise losses, and benefit whole farm profit at acceptable levels of risk. GRDC will consider investing in appropriate extension activities and communications that address this need including novel multimedia approaches. Investment decisions will be made based on the availability of current resources as well as extension and communication content developed through new investments.

GRDC may invest to expedite grower adoption of specific new technologies and to integrate other soil amelioration practices to exploit nutrient supplies via soil biological processes across a range of farming systems and agro-ecological zones. This could involve helping growers to tailor practices to fit into their farming system, and to be able to quantify savings due to optimal fertiliser use, as well as the trade-offs and costs of these practices.

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Investment Outcome 3.6.7 – Growers can estimate the benefits of nitrogen fixation on whole-farm profit and risk and are motivated to adopt novel and integrative nitrogen fixation practices to enhance nitrogen supplies within farming systems.

Although pulse plantings are increasing in parts of Australia, many grain growers lack information to help them improve N fixation and estimate its contribution to the N requirements of their farming systems. In this context, growers need more certainty when estimating the impact of fixed N supply relative to fertiliser N supply on whole farm profit and risk.

GRDC may consider the development of packaged extension and communication resources aimed at increasing the contributions of N fixation to grain production systems. This might include better understanding of spatial and temporal variability and exploiting precision agriculture approaches. Materials will include past, present and future R&D developments where there is a logical pathway to the adoption of current practices developed under Investment Outcome 3.6.5 (e.g. uptake of improved rhizobial strains and inoculation practices), as well as completely novel approaches that enhance N fixation and optimise the reliance on N fertilisers. This will include insights into the economic trade-offs of crop legume derived N compared to inorganic fertiliser sources. This area of investment has a close relationship with KIT 2.3 by focusing on cereal grain quality aligned to market requirements.

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