KIT 1.8

Reduce the impacts of low pH, aluminium toxicity and other nutrient toxicities on plant water uptake to improve grain yield and stability.

Impact	**Growers address acid soil constraints such that soil pH is maintained above critical levels and root growth, uptake of water and nutrients, grain yield and profitability are maximised.**
Summary	• Growers and their advisers understand and can quantify the impact of low pH and toxicities on grain yield and stability. • Growers have access to knowledge, tools and management options to address low pH, aluminium toxicity and other nutrient toxicities in the short, medium and long term. • Growers have the tools and decision aids to maximise returns from implementing management options addressing these constraints.

OVERVIEW

All farming systems export alkaline plant or animal materials, leaving behind acidity, and this usually results in a net increase in soil acidity. Many Australian cropping soils are naturally neutral to slightly acidic but prone to rapid pH decline when used for the production of plant or animal-based products. This is especially the case for sandy soils that are poorly buffered against acidification. These soils need to be managed carefully to maintain productivity and prevent land degradation. Nitrogen (N) cycling and fertiliser practices all contribute to increased acidification rates. Overall legume crops tend to be more acidifying than cereal or canola crops. Over decades of production, acidification gradually impairs plant root growth and the uptake of water and nutrients, which in turn limits crop growth, yield and ultimately grain grower profitability.

In Australia soil acidity affects approximately 50 Mha of agricultural land, and about 23 Mha of subsoil layers (NLWRA 2001). This is mainly in Western Australia (WA) where sandy soils dominate, but there are significant areas of southern New South Wales, Victoria, South Australia, and Tasmania where acidity is a significant constraint to crop performance and the area affected is expanding. Orton et al. (2018) estimated acidity affects 13.3 Mha of wheat production in Australia each year and the resulting yield reduction is costing growers approximately $440 million per annum.

Soil acidity impacts crop performance in multiple ways. Acidity, as measured by low pH, restricts root growth and the uptake of nutrients (which indirectly reduces water uptake) and alters chemical reactions in the soil. The availability of most nutrients important to crop growth is greatest in the neutral to slightly acidic range of pH 6–7 when measured in calcium chloride (pH_{Ca}). As acidity increases, aluminum (Al), iron (Fe), and manganese (Mn) form insoluble compounds with calcium and more importantly phosphorus (P) and potassium (K) making these essential nutrients unavailable for plant uptake. As the pH_{Ca} drops below 4.8, Al solubility increases sharply and becomes highly toxic to wheat roots. Similarly, Mn can become toxic at low pH but this is less common in Australian soils. Acidity also reduces soil microbial activity, N mineralization and the growth and survival of rhizobia required for nodulation and N fixation in legumes. Lentil, chickpea and faba bean crops are often the first to show signs of soil acidity. In comparison, most wheat varieties are moderately tolerant to acidity with critical pH_{Ca} levels of 5.5 in the topsoil and 4.8 in subsoil layers, and barley (only tolerant varieties), oats, triticale and narrow-leafed lupins can generally endure even lower pH.

It is widely accepted internationally that the application of neutralising amendments is an effective way to increase soil pH and address the detrimental effects of acidification. In most Australian areas impacted by acidity, current rates and methods of applications of agricultural lime (i.e. $CaCO_3$) are insufficient to neutralise the overall soil acidification rates, and acidity continues to emerge as a constraint. Often inadequate rates of lime are applied to correct all the soil acidity to depth and the benefit is restricted to the top 5–6cm. Hence, in many areas, acidity is rapidly developing in the 7–15cm layer or deeper which is not detected by standard 0–10cm soil sampling methodology.

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Key Investment Target (KIT) 1.8 focuses on improving grain yield and stability by reducing the impacts of low pH and Al and Mn toxicities on root growth, uptake of nutrients and water uptake. This strategy focuses on the application of adequate rates of lime, or other cost-effective neutralising amendments, to increase soil pH above critical levels so that crop growth is not limited. KIT 1.8 is divided into three scope areas. The strategy starts with a focus on increasing the understanding of acidification processes and the diagnosis of acid soils with improved accuracy. This improved understanding and diagnosis will in turn contribute to the development of enhanced soil and crop management options on acid soils, and finally, increased adoption of soil and crop management practices to alleviate acid soil constraints.

This KIT strategy will focus on the development of novel crop fertiliser and soil management practices that help minimise or overcome acidification, particularly in the subsoil which is more difficult to ameliorate. While breeding crop varieties with improved acid soils tolerance will provide immediate benefits to growers, it does not address ongoing acidification processes. Even the acid tolerant crop varieties will be affected at very low pH levels and as such growers will ultimately need to correct acidity through other management practices. Broadening the adaptation of high value pulses to include tolerance to acid soils is important but improving tolerance of other crops is considered only a moderate priority for this KIT strategy. GRDC will consider investment in the development of new diagnosis and soil mapping technologies as well as extension and communication to promote practice changes that address soil acidity and deliver a financial benefit for Australian grain growers.

FUTURE RD&E FOCUS

SCOPE – Understanding of the need to act and quantification of the benefits of action

Understanding of the causes and potential impacts on crop production of soil acidity is increased.

Improved understanding of acidification processes and the impact of soil and crop management on these processes is needed to enable growers to minimise or reverse the rate of acidification while maintaining or improving crop productivity. Increased knowledge of the processes of acidification are important when understanding the short, medium and long-term costs of acidity and implementing a suitable management plan across the farming system. Many decades of research and development have led to a solid current knowledge base of acidification processes and its diagnosis, but gaps in knowledge still exist. Simple, accurate and rapid diagnosis of soil acidity across the farm will enable growers and advisers to recognize the problem and implement sound management decisions. The use of sensor technologies, data analytics and modelling could assist with the diagnosis and mapping of soil acidity issues.

Growers who regularly conduct conventional soil testing can monitor pH levels in the 0–10cm topsoil and use this information to develop and implement a targeted and cost-effective management strategy. Despite this, soil testing is poorly used by some growers. For growers that soil test, relatively few collect deep soil samples for diagnosis of subsoil acidity and other constraints. Barriers to grower adoption of soil testing for acidity, particularly at depth, appear to be numerous, but basically come back to a perception of poor value for money. Growers typically focus on the cost of soil sampling and analysis, and lime costs, with little knowledge of the true impact that acidity is having on their crops nor the potential benefits of addressing the constraint. Some growers are also sceptical of soil testing because they believe that sampling protocols are not accurate enough given the spatially variability of their soil types.

Investment Outcome 1.8.1 – Growers and their advisers have access to cost-effective field tools to diagnose acidity constraints in the topsoil and subsoil.

Correct diagnosis of soil acidity is essential for effective management. However, acidity is difficult to identify because it develops slowly over time and plant symptoms are largely sub-clinical other than a gradual decline in growth and grain yield. More importantly, soil pH can vary substantially across a paddock or farm and is influenced by soil type, depth, paddock history and productivity. Standard soil sampling and laboratory analysis every 3–5 years is the generally accepted method of measuring, monitoring and diagnosing temporal changes in soil pH. It is the primary tool to identify risks of acidity and provides critical information to assess and manage soil acidification within the context of production and economic risk. Simple off-the-shelf pH kits and pH probes available from hardware stores can be used as an indication of soil acidity, but these tests lack accuracy compared to laboratory analysis. Traditionally paddocks are managed uniformly with 'blanket rates' of lime. However, current soil pH mapping and variable rate management practices (i.e. targeting lime rate to soil pH in different zones) can be cost effective for paddocks with high variability.

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Automated in-field mapping tools that rely on pH probes are being developed, but these are currently limited to topsoils. While these tools are not as accurate as laboratory analysis, this is off-set by the fact that many more measurements can be taken in the field at comparatively low cost. Some soil sensors, including Near or Mid Infra-Red have shown some potential to predict soil pH in the laboratory, but are not widely available for commercial use in the field.

GRDC will consider investment opportunities to reduce the cost and improve the diagnosis and mapping of soil acidity in three dimensions. This includes ongoing development and implementation of new field diagnostic technologies including automated sampling and mapping practices, and soil pH sensors. It is anticipated that these technologies will interact with the improvement of current and future on-farm machinery or other technologies (see KIT 3.2 strategy). This may include equipping growers, advisers and contractors with the skills, knowledge and tools to better enable soil sampling, analysis, and interpretation, as well as a developing decision support resources for soil management.

Investment Outcome 1.8.2 – Growers and their advisers understand the causes and rates of acidification across soil types, farming systems and regions, and understand the impacts of acidification on crop growth and yield.

Soil acidity decisions in the absence of a good understanding of the drivers and rates of acidification can lead to poorly targeted management practices. Many decades of research and development have led to a solid base of knowledge regarding top-soil acidity, but less so for the subsoil. Growers and their advisers will benefit from increased knowledge of the way that soil, crop and fertiliser management practices influence acidification rates, and in turn, crop productivity. This includes the effects of farming system changes, such as increased legumes in the rotation or more frequent use of ammonium sulphate fertiliser have on increasing rates of acidification and productivity decline. Improved knowledge of soil acidification processes to depth across local soil types and farming systems, and understanding the short, medium and long-term impact of these on soil degradation, farm profitability and the environment (e.g. reduced water uptake, nitrate leaching and erosion) will result in improved soil acidity management and more efficient and sustainable farming systems.

Where knowledge gaps exist, GRDC will continue to invest to increase industry understanding of the mechanisms and rate of surface and subsoil acidification under major farming systems, and across different soil types and regions. Improved awareness and knowledge of soil acidification can assist grain growers in reducing the gap between current and economically attainable yields, thereby increasing profitability (see KIT 1.5 strategy), raising the capital value of land, and improving environmental benefits across Australian grain growing regions.

SCOPE – Soil and crop management options to address acid soil constraints

Crop yields and profitability are increased by minimising acidification, treating acid soils with effective amendments, and improving plant tolerance of soil acidity.

Strategies to maintain productivity in acid prone soils include: the application of agricultural lime or alternative neutralising amendments to increase soil pH; improving the acid tolerance levels of crops and varieties; improving the acid soil tolerance of rhizobia for legume crops; and other soil, crop and fertiliser practices that minimise acidification rates or correct acidity. The application of agricultural lime is commonly regarded as an effective way to neutralise topsoil acidity. However, the limited suite of alternative soil and crop management options available to growers to minimise the rates of acidification particularly in subsoils remains an on-going constraint to productivity and profitability. Neutralising amendments need to be cost effective with efficient application methods that can be easily integrated into a range of farming systems. While growers build confidence with the economic benefits of soil and crop management strategies to address soil acidity, they are looking for crops with greater acidity tolerance to address short-term profitability.

Investment Outcome 1.8.3 – Growers and their advisers have access to cost-effective amendments and knowledge of optimal application rates and methods, including the use of precision and digital tools, to neutralise soil acidity.

The application of agricultural lime to treat soil acidity and associated Al toxicity is widely practiced in some regions, but broad scale applications need to increase, particularly in south-eastern Australia. The cost of lime products, transport and application is often raised by growers as a barrier to adoption. This may be due in part to a lack of understanding of

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the medium to long-term financial impact of acidity and the productivity and profitability benefits of effectively managing soil acidity. In some cases, inconsistent lime trial results and the perceived risk of not achieving a return on investment is also likely to be a contributing factor.

Most lime pits are located near the coast, and for inland regions where agricultural lime is not readily available, some growers believe the cost of transport is prohibitive. The availability, quality and cost of agricultural lime vary considerably. There are also major concerns about the medium to long-term supplies of lime in the future. Local neutralising amendments (e.g. calcareous soils) are being explored as alternatives. Most lime products take several years to dissolve and increase soil pH, so improvements in crop growth are not immediately visible to growers which creates doubts about their benefits. Lime quality (i.e. particle size and neutralising value) can vary enormously from location to location and within a pit. Even the highest quality agricultural lime has relatively low solubility and moves slowly into the subsoil (usually less than 10mm p.a.), especially in low rainfall areas. Reaction time can be improved when the lime is mixed into the soil, but this can be a challenge in no-till farming systems.

GRDC will consider investment in R&D that explores more efficient use of lime, including precision agriculture approaches on variable soil-types, as well as other novel cost-effective neutralising amendments, and application methods suited to addressing acid soils, especially at depth. This may include examining lime supply chains, as well as application tools and technologies that enhance the efficacy of amendments. This may also include rapid analysis of neutralising amendments, deep placement or soil inversion, and variable application rate approaches. While GRDC is open to understanding the mechanisms and effectiveness of different types of neutralising agents, it will not support comparisons of commercial products or different formulations of the same amendment.

Investment Outcome 1.8.4 – Growers and their advisers have access to soil and crop management practices that minimise soil acidification while treating other soil constraints.

Acidification rates are strongly influenced by grower decisions on soil and crop management including crop choice and fertiliser inputs which impact N cycling and N losses. For example, if nitrate leaching can be minimised through improved fertiliser technology or crop management practices this may reduce acidification in farming systems. GRDC will consider R&D aimed at minimising topsoil and subsoil acidification by focusing on growers' soil, crop and fertiliser management decisions. The focus would extend to management practices that may simultaneously reduce the impact on grower productivity and profitability of other soil constraints (see KIT 1.6 and 1.9 strategies). Options could also include novel N fertilisers with enhanced efficiency, promoting deep root growth, or other ways to capture nitrate and reduce N leaching. Trade-offs between short-term productivity benefits and the long-term impacts of acidifying processes (e.g. increasing legumes in the rotation) need to be quantified and understood. Research into N cycling and use of legume N in farming systems will be linked to the KIT 3.6 strategy, while fertiliser technology work will be closely linked to the KIT 3.5 strategy.

Investment Outcome 1.8.5 – Growers have access to crop species and varieties (including legumes with suitable rhizobia) with enhanced tolerance to soil acidity.

Crops vary in their tolerance to acidity, and in some cases the tolerance of specific varieties has been enhanced through plant breeding. Barley (only specifically bred tolerant varieties), oats, triticale and narrow-leafed lupins are relatively acid tolerant, while wheat and canola are generally intermediate in their tolerance. Lentil, chickpea and faba bean are relatively susceptible to acidity and Al toxicity, partly due to the sensitivity of the rhizobia required for N fixation. Acid tolerant crops or varieties do not address the underlying causes of acidification which may be on-going and becoming ever more severe. Even the most tolerant crops and varieties will eventually be impacted by decreasing pH, making these tolerant crops unviable. However, plant tolerance is a useful part of the management package as it helps maintain production while amelioration efforts continue (Ryan, 2018). Growers can also rely on tolerant crop options while they build their own awareness of the true costs of acidification and the probable economic and environmental benefits of addressing on-going soil acidity.

GRDC will consider investment to provide growers with access to crops, varieties and rhizobia with greater tolerance to acidity and related toxicities. GRDC may also consider investment targeted at gaining an improved understanding of genetic traits associated with acid tolerance mechanisms and improved screening (phenotyping) methods to select for these traits within breeding programs. Enhanced acid tolerance in high value pulse crops (chickpea, lentil and faba bean) is a priority, including efforts focused at improved tolerance and effectiveness of rhizobium strains. While broadening the adaptation of sensitive pulses and their rhizobia on acid soils is important, improving the tolerance of other crops is only a moderate priority for the KIT 1.8 strategy.

SCOPE – Adoption of practices to address acid soil constraints

The adoption of improved soil amendments, tolerant crop species and varieties and/or agronomic practices to address soil acidity is increased.

Sustained investment in extension and communication over the past decade or two has raised awareness of soil acidity in WA significantly increasing lime applications. In other states and grain growing regions RD&E activities in soil acidity were less intensive over the same period, but recent investments are starting to increase greater recognition of the issue and broader use of lime. Nonetheless, current rates of lime application are not enough to maintain or reverse net acidification across most soils and regions, and both top-soil and subsoil acidity are expanding in areas previously not known to have acidity issues. As a consequence, there is a significant opportunity to improve grain grower productivity and profitability in the medium-term through effectively managing acid soils with lime. However, growers see amelioration as a costly activity, especially where lime is not available locally and transport is expensive. Early intervention of acidification before crop productivity is severely impaired is the most cost-effective approach in managing soil acidity, but this involves medium to long-term strategies.

Investment Outcome 1.8.6 – Growers and their advisers understand the impact of soil acidification on medium- to long-term farm profitability, and have the motivation, ability and tools to manage it.

Enhanced communication and extension activities are needed to further promote awareness of the lost production due to emerging soil acidity, and the adoption of acidity management practices. These may include the application of neutralising amendments, acid tolerant crops, varieties and rhizobia for legumes, and crop, soil and fertiliser management practices that minimise acidification rates. Innovative approaches to communication and extension are needed so that grain growers have access to timely information relevant to their farming system and regional conditions. It is critical that grain growers and their advisers clearly understand the impact and cost of on-going soil acidification on productivity and profitability of their farming systems. They need to have the motivation, ability and tools to correct soil acidity and maintain or increase medium and long-term profitability.

There is a need to improve decision-making aids for growers and advisers that quantify the economic and other value propositions of acidity management at the farm scale. These should predict the costs of doing nothing (i.e. allowing soil acidification to progress unabated), acidity management costs, payback periods and return on investment for each management option. Growers require credible evidence that quantifies the expected results and economic benefits of acid soil amelioration and other practices to manage top-soil and subsoil acidity. Accessible and user user-friendly tools that incorporate a range of management options based on their local context will help growers make timely and well-informed decisions. This includes information that enables growers to objectively compare the cost-effectiveness of neutralising amendments based on the cost of the product, quality or effectiveness of the product, as well as freight and application costs.

The development of extension plans to communicate the experiences of growers who have successfully managed soil acidity and are acquiring medium to long-term benefits from effectively managing acid soils could be explored, alongside other less successful experiences. Acidity is rarely the sole soil constraint to crop productivity, and there is also a need to promote awareness and adoption of best management practices that address multiple constraints. Synergies between managing acidity and other soil constraints need to be explored (see KIT strategies 1.6, 1.7 and 1.9).

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