KIT 1.9

Reduce the impact of waterlogging to improve grain yield and stability

Impact	**Growers implement strategies that help to realise crop yield potential and increase profitability by addressing the impacts of waterlogging.**
Summary	• The impacts of chronic and acute waterlogging events are quantified to enable growers to decide if or how they should respond. • The costs and benefits of various solutions to waterlogging are known, enabling growers to profitably implement the most appropriate solutions according to situation and need. • The barriers to adoption of existing solutions to waterlogging are understood and addressed. • Profitable, new and innovative solutions to waterlogging are identified and developed.

OVERVIEW

Waterlogging occurs when excess soil water in the crop root zone causes anaerobic conditions, impairing respiration in roots and inhibiting plant growth and nutrient uptake, particularly nitrogen. The source of water may vary from infiltration *in situ*, lateral flow, deep groundwater seepage, irrigation or surface runoff (McFarlane et al. 1989). Typical causes of waterlogging include a combination of poor drainage due to soil compaction and soil structure issues, and excess rainfall or irrigation. Elevation and local topography also affect water flows and accumulation in soils. Waterlogging events may be acute (short duration) or chronic (extended duration) in nature, and the occurrence and impacts are highly site specific, influenced by soil, crop type, timing and intensity of events. Plants are particularly sensitive when waterlogging occurs between germination and emergence, while more advanced crops are relatively tolerant in comparison. Waterlogging alters the physical, chemical, and biological characteristics of the soil as well as crop root and shoot growth. The major consequences of waterlogging are reduced oxygen supply for respiration of roots, and the accumulation of carbon dioxide and toxic compounds, including ethylene, from the breakdown of organic matter and alcoholic fermentation of soil microorganisms and roots (McFarlane et al. 1989).

While typically recognised as a major abiotic stress and production constraint across the high rainfall zone (HRZ) of Australia (Acuña et al. 2011), waterlogging may periodically affect crops on poorly drained soils in the medium and low rainfall zones. The distribution, frequency and direct and indirect impacts of waterlogging on Australian grain crop production are varied and not well quantified. Pang et al (2004) quote the annual production loss from waterlogging in Australia at $180 million per annum. The Department of Primary Industries and Regional Development (2019) estimated the annual opportunity cost from waterlogging in the agricultural areas of south-west Western Australia (WA) over the 5 year period 2009/10 to 2013/14 to be $35 million per annum, whilst McFarlane et al. (1989) estimated the annual production loss over a 10 year period for 8 shires in the central Upper Great Southern region of WA at $13.1 million for wheat, oats and lupins combined. Crop growth effects may range from minor and subclinical impacts to complete crop failure in some cases. A recent survey of grain growers in the HRZ of Australia indicated that waterlogging is believed to be a major constraint for more than 80 per cent of grain growers, with estimated yield losses of 40-60 per cent across 20 per cent of the cropped area.

Whilst assessment of economic impact has largely focused upon the direct effects of waterlogging on grain yield and quality, indirect impacts associated with flexibility of crop choice, trafficability and timeliness of operations (planting date, spraying, fertiliser applications and harvest operations), and the need for replanting are frequently overlooked. Longer-term farming systems implications of waterlogging relating to crop nutrition, weed seedbanks, disease and pest management, and ongoing paddock renovation to address compaction or wheel ruts also require further consideration. These indirect impacts, as well as crop yield losses in paddocks where symptoms are sub-clinical in nature require improved quantification.

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Current soil and crop management practices aimed at minimising the impact of waterlogging on crop productivity were reviewed by Gibson (2016) and Manik et al. (2019). A range of management practices are currently available to growers, including increasing soil drainage through soil re-engineering and amelioration, minimising soil compaction with minimum tillage and/or controlled traffic farming, selection of more tolerant crop types or varieties, improved irrigation scheduling, and crop agronomy to improve crop survival and recovery. Engineering solutions include surface drainage to remove water from the soil surface (e.g. shallow field drains, land-forming, open excavated drains, raised beds, and hump and hollow drainage) and sub-surface drainage systems (e.g. clay tiles, pipes and mole drains) to remove excess water from the crop rooting zone. Soil amelioration practices include tactics to reduce compaction and improve soil structure and drainage, such as deep ripping and subsoil manuring.

How these different approaches are deployed on farm can depend on paddock factors (soil and topography), local climate (rainfall intensity and frequency, and evaporation rates), crop and system options. Long-term management of chronic waterlogging is rarely solved using a single tool and instead requires an integrated, systematic approach (Gibson 2016). Management-related decisions are often complex in nature and site specific, being further complicated by the trade-off between getting water off paddocks when in excess and maximising the capture and storage of plant available water for later crop use. Growers affected by waterlogging require fit-for-purpose solutions that appropriately integrate with their farming systems to improve the consistency of crop yields (e.g. raised bed systems introduce other challenges in dryland, mixed farming systems).

Key Investment Target (KIT) 1.9 aims to reduce the impact of waterlogging through the profitable implementation of existing and new strategies to realise yield potential, particularly in high rainfall environments where waterlogging is common and yield gaps are sometimes large. Whilst this KIT strategy will primarily focus upon the direct impacts of waterlogging on plant performance and yield, it will also consider and address indirect farming system and operational constraints including rotation and on-farm logistics, and crop protection and nutrition issues in collaboration with other KIT strategies.

GRDC investment in KIT 1.9 should assist growers and advisers to identify the causes and impacts of waterlogging, evaluate and effectively implement potential solutions, monitor and assess their effectiveness, and enable ongoing refinement targeted to each situation and need. Research, development and extension (RD&E) investment should recognise the global scale of this problem and leverage related international R&D investment, with waterlogging estimated to affect between 10-16% of arable soils worldwide (Arduini et al. 2020).

GRDC investment will focus primarily upon strategies that can be implemented on-farm while considering the broader water catchment issues, complementing investment by relevant environmental and water agencies relating to water flows and related whole-of-landscape processes. The GRDC may invest to inform catchment scale policy where aligned to purpose but co-investment will be sought with relevant parties in addressing related issues.

KIT 1.9 is divided into three scope areas. The first scope area aims to help growers understand the frequency, duration and potential impact of chronic and acute waterlogging events at whole farm and paddock scales to understand the need and quantify the benefits of different management approaches. The second area of scope is about enabling growers and their advisers to understand how, when and where to implement solutions currently available to maximise profitability based on individual circumstances. The final scope aims to identify a range of new solutions that help growers avoid or mitigate the impacts of waterlogging, with the costs and benefits quantified. The primary geographic focus for investment is the high rainfall zone but acute waterlogging in the medium and low rainfall areas, including those areas under irrigation, may be considered where supported by an appropriate business case.

GRDC investment to address the issue of waterlogging will ensure:

- The impacts of chronic and acute waterlogging events are quantified to enable growers to decide if or how they should respond.
- The costs and benefits of various solutions to waterlogging are known, enabling growers to implement the most profitable solutions according to situation and need.
- The barriers to adoption of existing solutions to waterlogging are understood and addressed.
- Profitable, new and innovative solutions to waterlogging are identified and developed.

FUTURE RD&E FOCUS

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

Growers and their advisers understand and are motivated to act on the frequency, duration and potential impacts of chronic and acute waterlogging events at the whole-of-farm and paddock scales.

The ability to make profitable management decisions in areas affected by waterlogging requires an understanding of the impact of the issue and associated costs and benefits of action. Whilst the signs of severe waterlogging may be readily observable through inundation of paddocks with water, reduced trafficability and subsequent effects on crop establishment and growth, in other situations symptoms may be sub-clinical (i.e. not readily observable or associated with the visual presence of waterlogging) and underestimated. The need and motivation to act requires an appropriate understanding and demonstration of the likely risk and financial benefit from implementing strategies that address waterlogging in different situations.

GRDC will consider investment aimed to build grower and adviser understanding and awareness of how the timing, duration, severity and frequency (within and across years) of waterlogging events affect different crops across various soils, environments and systems. This will extend to in-direct impacts that impair crop rotations, trafficability and other management factors. Whilst significant knowledge exists in this area for some crops, there is an opportunity to undertake RD&E to inform growers regarding the likely impacts of waterlogging in different scenarios to support change.

Investment Outcome 1.9.1 – Growers, advisers and others are aware of the direct and indirect impacts associated with waterlogging events, recognise the size of the opportunity to mitigate those impacts and are motivated to take appropriate action.

Whilst many growers are aware that waterlogging is a problem, it is often difficult to accurately quantify the cost of lost production. Costs and associated benefits of remediation action should consider not only the direct impacts on crop performance but also indirect impacts including, but not limited to: operational timeliness and efficiency; farm machinery repairs and maintenance; performance of subsequent crops; paddock renovation costs; and effect of remedial actions on land value. Existing information on the true economic impact of waterlogging in Australian grain production is sparse. A more comprehensive understanding of the true profitability impact of waterlogging on Australian grain grower profitability, including direct and indirect impacts and their priority ranking, is critical at two levels. Firstly, it is critical to inform the scale and type of future investment by the GRDC to address the issue and secondly it is critical to advise on-farm investment to address the issue.

Assessment of the impacts of waterlogging events should also consider environmental, human health and sustainability aspects, including associated social licence elements that may differentiate Australian grain production systems. This may include potential for pesticide and nutrient movement down the profile or in run-off. Investment by GRDC in grains-related environmental or sustainability outcomes will recognise, and not duplicate, the role of the private sector in nutrient and pesticide stewardship activities, as well as roles of relevant public and private regulatory, water and environmental agencies.

The primary focus for investment by GRDC will be in addressing grain grower profitability impacts in areas or on soils frequently affected by chronic waterlogging. The impacts of waterlogging events that are acute or sub-clinical in nature requires further quantification to determine the rationale for investment, recognising the potentially significant cumulative production loss over large areas.

RD&E outputs targeted at achieving this outcome will provide the awareness, information, knowledge and confidence for growers and advisers to quantify the impacts of waterlogging at paddock and farm scale and identify opportunities where implementation of strategies that address waterlogging may be warranted.

SCOPE – Deployment of existing solutions to maximise profitability

Growers and their advisers understand how, when and where to implement the existing solutions to waterlogging to realise direct and indirect benefits.

Growers who know they have a problem with waterlogging and are motivated to address the issue require both an awareness of the management options available to them and the ability to effectively implement these for their situation. This includes an understanding of the relative costs, benefits and risks of existing solutions and how they may be potentially integrated in a holistic management approach. While numerous drainage, agronomy and management solutions exist, information regarding the economic return in different situations is often not well understood. Although the cost of some of the soil engineering or drainage solutions is high, there is an immediate opportunity to validate and extend current national and global best practice to Australian grain growers.

GRDC will consider investment to build grower and adviser knowledge and inform decisions regarding the adoption of the most appropriate solutions to address waterlogging in a profitable manner, based on individual farm and paddock situation and need. Investment will focus upon what current tools, technologies or practices could be used, and how, when and where these could be combined to improve management of waterlogged soils and realise crop yield potential and profitability opportunities. This includes the identification of barriers to the adoption of existing solutions, and activities to address these constraints while promoting effective implementation.

Whilst the impacts of waterlogging on nutrient cycling and broader soils processes (including nitrogen losses through denitrification and leaching) are recognised, investment to understand this under KIT 1.9 will be limited to addressing the constraints unique to waterlogged soils only. In particular, investment aimed at understanding and managing the impacts of waterlogging on nitrogen supply and demand should complement and leverage investment outcomes and outputs under the following related KIT strategies:

- KIT 2.3: Improve wheat grain protein through increased availability of nitrogen and better nitrogen use efficiency;
- KIT 3.5: Develop technology to reduce fertiliser manufacture and/or application costs and improve fertiliser use efficiency; and
- KIT 3.6: Improve nitrogen and phosphorous availability by greater capture of value from soil biota, optimisation of nitrogen-fixing legumes in rotations, soil amelioration to improve nutrient availability.

Investment Outcome 1.9.2 – Growers and their advisers are aware of the existing solutions to waterlogging and their respective costs and benefits, and implement them in a way that maximises yield and profitability.

Grain growers require a fundamental awareness of the existing options available to minimise the impacts of waterlogging, realise crop yield potential and increase profitability. These options include engineering solutions such as surface and sub-surface drainage, soil amelioration practices, crop and varietal selection based on tolerance, crop agronomy and management of water capture, infiltration and storage. GRDC may consider investing to improve grower and adviser understanding and awareness of the options available to them, the cost and benefits and applicability or fit of each solution to individual situation. GRDC may also invest to support the effective implementation of appropriate solutions to waterlogging.

Investment could leverage and complement outputs and outcomes of other soils-related KIT strategies, specifically:

- KIT 1.6: Reduce the impacts of water repellence, compaction, hard-pans and other barriers to the capture and storage of water in soils;
- KIT 1.7: Reduce the impacts of soil salinity and sodicity on plant water uptake to improve grain yield and stability; and
- 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.

The integration of multiple existing solutions in the context of the overall farming system may be complemented through investments under KIT 1.5: Reduce the gap between actual and potential grain yield through more informed and timely decision.

In scope is development and extension activities relating to existing solutions to waterlogging, including outputs aimed at addressing the current barriers to adoption identified in Outcome 1.9.3. Out of scope is research on new solutions, as this is covered in outcomes under the next Scope area – Discovery to innovate.

Investment Outcome 1.9.3 – Barriers to the adoption of existing solutions to waterlogging are identified, understood and addressed.

Whilst various solutions to deal with waterlogging already exist, numerous and sometimes complex barriers to the adoption may impede the speed and extent of implementation on farm. Major influences of adoption relate to characteristics of both the innovation and target audience and include cost, extent and immediacy of benefit and complexity of implementation.

It is important to identify and understand the barriers to adoption of existing waterlogging solutions to inform the financial and systems fit of different solutions and explore ways to overcome these barriers, thereby making the solutions 'more adoptable'. For instance, the installation of existing permanent sub-surface drainage solutions deployed primarily in high value irrigated crops are unlikely to be adopted in favour of lower cost surface drainage or other solutions. Investment in RD&E outputs targeted at achieving this outcome could complement related investment under KIT 5.2: Understand grain grower decision-making and the drivers for adoption of new technology.

Investment in outputs that address this outcome may focus upon understanding the motivations, attitudes, knowledge, abilities and tools that growers have available to address waterlogging. This may include consideration of solutions used in other industries or countries and confirmation of their applicability and fit in Australian grain production systems.

SCOPE – Discovery to innovate

Growers and their advisers have access to a range of new solutions to avoid or mitigate the impacts of waterlogging, with the costs and benefits quantified.

In addition to the implementation and refinement of existing solutions to address waterlogging, research into the discovery of new and novel management options may be warranted. Innovation in this area is likely to be important and may potentially deliver transformational change through the discovery of new, profitable solutions that either prevent or avoid crops from being subjected to waterlogging or mitigate the direct and indirect impacts of waterlogging. This may include new approaches to the diagnosis of waterlogging to objectively quantify impact and motivate growers to adopt new solutions.

The extent of GRDC investment will be commensurate with the size of the opportunity, and co-investment in the discovery from other agricultural sectors or other stakeholders will be viewed favourably. Again, investment could leverage and complement the development of innovative solutions to mitigate, ameliorate or avoid yield loss from other soil constraints, specifically outputs related to the soils KIT strategies 1.6, 1.7 and 1.8.

Investment Outcome 1.9.4 – New and profitable solutions that prevent or avoid the occurrence of waterlogging events are identified and developed.

GRDC will consider investment opportunities aimed to prevent waterlogging or enable plants to avoid being subject to the impacts of waterlogging events in space or time. Prevention approaches could include:

- solutions that improve soil structure, drainage and aeration (e.g. creation of biological channels in the soil or novel subsoil drainage approaches) or;
- appropriately capture or divert water away from the rooting zone (e.g. biodegradable polymers) or areas of the paddock or farm prone to water accumulation and waterlogging (e.g. surface water flows).

Solutions to prevent crop exposure to waterlogging could include new modified furrow or seedbed design enabling plants to grow above or next to the flooded zone or approaches that ensure crops are not grown at times when soils are likely to be waterlogged.

Investment Outcome 1.9.5 – New and profitable solutions that mitigate the impacts of waterlogging events when they occur are identified and developed.

Recognising that waterlogging will inevitably occur in the future, GRDC will consider investments aimed at discovering new and profitable solutions that mitigate the direct and indirect impacts of waterlogging on crops when they occur. Mitigation strategies may reduce the impacts of waterlogging events on crops and include plant adaptation approaches aimed at reducing the effects of anaerobic stress and the related nitrogen deficiency on grain crops. They generally

address the symptoms, not the root cause of the constraint itself and are often lower cost than amelioration, avoidance or prevention strategies.

Mitigation approaches are likely to provide cheaper solutions to improve crop growth and yield when compared to permanent drainage solutions in areas subject to transient, acute waterlogging events. Potential strategies may include genetic approaches to increase crop or varietal tolerance to waterlogging, better understanding and manipulation of triggers that control a plant-mediated response to waterlogging, or crop protection chemistry approaches to mitigate abiotic stresses. In addition, completely new approaches that lower concentrations of free radicals and other toxic compounds in waterlogged soils, perhaps via microbial activity, may be possible.

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