Surface tile drainage and nutrient management to create more efficient farming practices

Robert Bell, 2021 Scholar
Western Australia

December 2024
Nuffield Australia project number 2102

Supported by

Surface tile drainage and nutrient management to create more efficient farming practices

Scholar contact details

Name Robert Bell

Organisation: Bell Pasture Seeds

Address 447Cain Road The Plauns

Phone 0427271638

Email. rob@bellseeds.com.au

Website bellpastureseeds.com.au

NUFFIELD AUSTRALIA Contact Details

Nuffield Australia
Telephone: 0456 916 506

Email: enquiries@nuffield.com.au

Address: 38 Walker Drive, Worongary, QLD 4213

Executive Summary

In the dynamic context of modern agriculture, this report embarks on an in-depth examination of surface tile drainage and nutrient management within the high rainfall zones of Western Australia. It brings together the realms of environmental responsibility and technological advancement, with an unwavering focus on enhancing farming efficiency, sustainability, and economic viability.

The report's primary objectives are delineated as:

- **Surface Tile Drainage:** Investigate and assess surface tile drainage solutions to enhance water management in farming. Explore design, installation, and materials used to create efficient systems that reduce waterlogging and promote soil health.
- **Nutrient management:** Examine the interplay between tile drainage and nutrient control. Develop strategies to manage water and nutrient discharge to mitigate negative ecological impacts and boost crop yield.
- **Sustainable practices:** Evaluate the potential for recycling drain water for out-of-season irrigation, emphasising conservation, efficiency, and alignment with global sustainability goals.

The Southwest region of Western Australia, characterised by its unique Mediterranean climate, is the focal point for this exploration. A drainage trial initiated in 2020 provided valuable insights into the practical challenges and benefits of surface tile drainage, including its effect on yield, waterlogging moderation, and cost considerations.

The trial's outcomes and reflections from international visits to places such as Lincoln University in New Zealand and the United States' Farm Progress Show inform a broader understanding of best practices in water quality, irrigation, and drainage worldwide.

The report asserts the transformative potential of surface tile drainage when integrated with effective nutrient management strategies. It emphasises the need for meticulous planning, expert guidance, and consideration of local conditions.

In highlighting the balance between technological innovation and environmental stewardship, the report advocates for a forward-thinking approach to agriculture in Western Australia. It outlines a pathway towards farming practices that are not only economically sound but also ecologically responsible.

This study invites further research and application in agriculture's complex and vital field. The focus remains firmly on paving the way for farming systems that are more responsive to environmental needs and capable of meeting the demands of a changing world.

Keywords:

Tile drainage, Agriculture, Western Australia, water management, environmental stewardship, sustainability, economic considerations, subsurface drainage, waterlogging, irrigation, Mediterranean climate, nutrient discharge, water conservation, broad-acre cropping, farming practices, horticultural crops, installation methods, soil health, water quality, drain water recycling, yield efficiency, field trials, Southwestern Australia, paddock runoff, global best practices

Table of Contents

Foreword

I am a fourth-generation farmer in the South West of Western Australia. During this time, the family has been progressive and adaptable in adopting new practices and actively shaping the farming industry in our area. As a family, we have consistently been eager to travel and learn from other systems to further our development. It has not always been an easy journey. Still, previous generations' hard work and sacrifices have provided me, my wife Kellie, and our children, Riley, Scarlett, and Milla, with a commendable start in our farming business.

In 2016, in the small coastal plain where we farm, the rainfall exceeded 1,160mm, 300mm above our long-term average. Many of our crops spent weeks inundated, suffering from abiotic water stress. Fertiliser efficiency was very low, and growers were using a significant amount more nitrogen to keep crops alive, with the excess fertiliser flowing from farming catchments into the sensitive Geographe Bay.

At that time, I had been in control of our then 1,800-acre small seed production farm of grass seed, clovers, subterranean and aerial, and grazing cereal varieties. 2016 marked our largest economic loss ever, and the business took nearly three years to recover.

The business invested in water mitigation processes to safeguard against the events of 2016 and most winters in our highly Mediterranean climate. We installed many kilometres of laser-mapped surface drainage, and fertiliser practices were reviewed. I could not help thinking there was a more efficient way than kilometres of surface drains winding across the farm landscape.

After travelling through Oregon, USA, in 2008, researching grass seed farming systems, I remembered assisting a contractor in installing subsurface drainage or tile drains, as they were commonly known. I was curious to see how these would function in our farming system.

A trial was launched in May 2020, covering 12 hectares of various tile drainage products, comparing them to our current laser-derived surface drains. From the outset, it was clear that the tile drains were the most efficient way to keep our soils in an aerobic growing medium, free from plant water stress.

More understanding was needed, so I sought to secure a Nuffield Scholarship that would enable me to travel the world and learn about drainage systems. Initially, I wanted to discover a simple, cost-effective method to install tile pipes and understand drainage's impact on the land, including the economic benefits and the effects on the downstream environment.

Through preliminary research, I decided that Iowa in the United States and New Zealand would be the focus of my travels, as both had similar climatic conditions and farm business models to Australia. Initially, I was keen to explore Europe's solutions.

Still, after travelling through Ireland with our Nuffield global focus group, I concluded that Europe's considerable bureaucracy, disparate farming systems, and complex income streams were not aligned with the direction I wanted to pursue.

Table 1. Travel itinerary

Travel date	Location	Visits/contacts
Week 1 June 10-13 , 2021	New Zealand Christchurch	New Zealand Trade and enterprise. Kieth Mitchell
Week 2 June 14 – 15 , 2021	New Zealand Rolleston , Darfield	Cropmark Garry Begley, Adam Sheedy
Week 2 June 16-17, 2021	New Zealand Horarata, Mt Hut	Schnells Tim Cooksons's
Week 3 June 18-24, 2021	New Zealand Wellington, Waikato And Mystery Creek field days	Prime Minister Jacinda Adern. Agritech seminar Stuart Nash. Aurora robotics. Keith Mitchell and Tanan Zorigt NZTE, Rocket Lab Peter Beck seminar. Lincoln University, Lincoln Agritech Blair Miller
Week 4 July 15- 23, 2022	Kunnunrra, Ord irrigation scheme 1 and 2	Fritz Bolton Nuffield scholar , David Cross and Les Becker Ordco.
Week 5 August 29 -September 1	Farm Progress Show, Boone county Iowa	Soil max Kyle Shekker, Crary tile plow, Agridrain
Week 6/7 September 1-12	Des Moines Iowa 11th International Drainage Symposium	Eshan Ghane, Michigan state University. John McMaine, South Dakota University. Laura Christianson, University of Illinois Charlotte Kjaergaard, NovaDrain Denmark Vinayak Shedekar, Ohio State University

		Ranvir Singh, Massey University Agridrain, Lisa Newby Melisa Luymes , Ontario Land improvement contractors
Week 6/7 September 1-12	Des Moines Iowa ISG	Chuck Brandel, Bethany Brittenham
Week 6/7 September 1-12	Des Moines Iowa	Rob Burtinshaw Nuffield scholar, Farm services United Kingdom
Week 6/7 September 1-12	Iowa University Farm drainage tours	Matt Helmers and Chris Hay

Acknowledgements

My Nuffield journey thus far has been enriching and challenging on a personal level.

Firstly, I would like to thank my wife, Kellie, for holding our world together while I journeyed around the globe. Managing three children and two businesses on your own is a massive challenge for any length of time. I am also grateful to my parents, Lynne and Terry, for their unwavering support and lifelong progressive attitudes towards farming and agricultural systems. My father's line on any new venture is, "Try; it can only go badly." This sentiment gives me great confidence in adopting or tackling any farming and business challenges.

I would like to extend my gratitude to my global focus group, from whom I had my most significant learnings. This experience has helped me better understand who I am and where my business fits in the global economy. The bus conversations have helped shape this report to include an environmental and land stewardship perspective, where previously, it may not have had one. Five weeks of travel with strangers develop friendships you would have never known or appreciated; this is Nuffield's greatest gift.

I must also thank Rob Burtonshaw, a 2012 United Kingdom Nuffield Scholar and the opening address speaker at the 2021 International Drainage Symposium. The entire international drainage world knows of Nuffield scholars' work thanks to your trailblazing. This recognition made my research work easy to acquire and was the ultimate example of Nuffield opening doors.

Lastly, to my sponsors, Agrifutures and Agrifutures Pastures, I thank you very much for supporting me and Nuffield Australia. Without the generosity of sponsors like yourselves, Nuffield scholarships would be an impossibility. Your support directly delivers the genuine world's best practice and ingenuity to Australian agriculture.

Abbreviations

ABM	Australian Bureau of Meteorology
ACT	Australia Capital Territory
AUD	Australian dollars
ha	Hectares
kg	Kilograms
mm	Millimeters
NZ	New Zealand
SW	Southwest
US	United States
WA	Western Australia

Objectives

In an agricultural environment where adaptability and forward-thinking are vital, this research delves into the unexplored aspects of surface tile drainage and nutrient management in the high rainfall zones of Western Australia. These are critical areas that integrate environmental protection with technological progress. The study seeks to harmonise the two, focusing on three essential objectives that span from the economics of on-farm design to innovative recycling practices for drain water. These objectives were meticulously selected to shed light on the potential rewards and obstacles of tile drainage, paving the way for a more sustainable and financially sound agricultural future in the region.

The following encapsulates the specific areas of investigation and their relevance in the broader scope of Australian agriculture:

- **Economic practices:** Explore and formulate economical methods for on-farm design, installation, and materials used in surface tile drain construction. This includes probing into cost-efficient strategies and materials that ensure quality and effectiveness without financial strain.

- **Environmental stewardship and nutrient management:** Assess and quantify water and nutrient discharge into the environment, applying best practice edge-of-field stewardship. This part of the study will concentrate on the equilibrium between effective drainage and conservation of the local ecosystem, minimising adverse impacts.

- **Sustainable practices and drain water recycling:** Investigate the possibilities of drain water recycling as a resource for out-of-season irrigation. This encompasses an in-depth examination of the practicability and advantages of reusing drain water, accentuating water conservation and efficiency.

By targeting these objectives, the research thoroughly comprehends land utilisation shifts and prospects connected to surface tile drainage. With attention to potential downstream ramifications, this study aspires to carve a route towards more accountable and cutting-edge agricultural practices in Western Australia..

Introduction

The agricultural landscape of Western Australia is in a constant state of flux, grappling with multifaceted challenges and prospects that necessitate inventive and sustainable methodologies. Surface tile drainage and effective nutrient management emerge as a cornerstone in this transformation. This research aims to unravel the nuanced dynamics of surface tile drainage in Western Australia's high rainfall zones, setting the groundwork for an efficient and eco-friendly agricultural future.

Industry context and regional overview

Western Australia's agricultural sector is vital to the nation's economy. The region has unique topography and climate. These features require new and innovative land management strategies. There is a growing need for skilled and environmentally friendly farming practices. All of which has led to research into surface tile drainage. This field has both potential challenges and benefits.

Economic considerations

This study probes into the financial aspects of surface tile drainage, evaluating techniques that can forge cost-effective and superior solutions. By centering on this element, the research addresses the urgent requirement for economically feasible farming practices within Western Australia's varied agricultural terrain.

Environmental stewardship and nutrient management

Going beyond mere economic considerations, the report underscores environmental stewardship and nutrient management, scrutinising the equilibrium between effective drainage, nutrient control, and ecosystem preservation. Comprehending this balance is vital in moulding practices that mitigate negative environmental repercussions, aligning with worldwide sustainability objectives and regional environmental statutes.

Sustainable practices and drain water recycling

Additionally, the report investigates the concept of drain water recycling, inspecting its practicality and advantages in enhancing water conservation and efficiency. This segment of the study emphasises the capacity for this practice to redefine conventional approaches to drainage and irrigation, cultivating a more sustainable agricultural horizon.

Challenges and opportunities in agriculture: navigating climate, soil, and drainage solutions

Soils need to breathe

Soils form the fundamental basis for agriculture, and their ability to breathe is vital to the survival of all living plants and organisms. The five basic necessities for life—food, water, sunlight, habitat, and air—underscore the importance of having the right conditions in place.

The Southwest region of Western Australia stands out as a desirable farming location due to its pronounced Mediterranean climate, although it is not without significant limitations.

Mediterranean climates between 30 and 45 degrees latitude, north and south of the equator, are characterised by hot, dry summers and wet, cool winters. This climatic pattern is found in specific regions worldwide, including southern and southwestern Australia, central Chile, coastal California, the Western Cape of South Africa, and the Mediterranean Basin. (Figure 1)

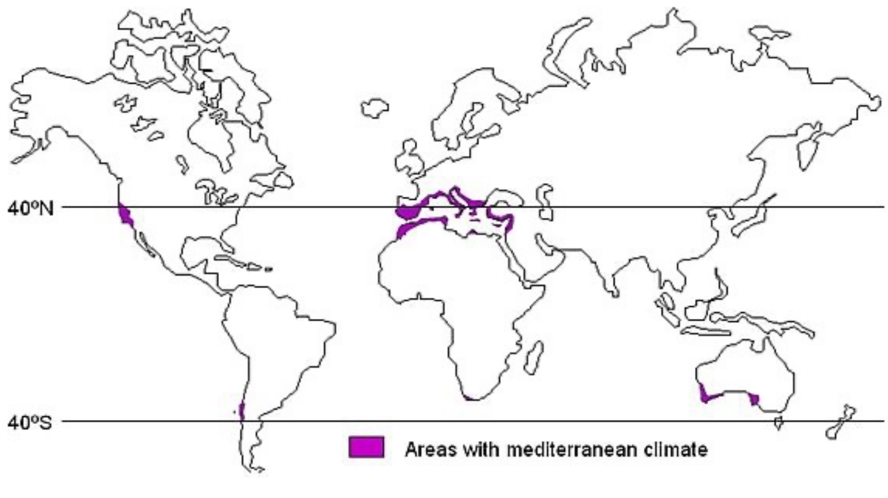


Figure 1. The Five mediterranean climate regions of the world. California, Central Chile , the Mediterranean Basin, South Africa's Western Cape, Western Australia and South Australia. (Source : Mediterranean Garden Society)

One of the major challenges in these climates is the irregularity and variability in rainfall. This can differ greatly from one growing season to the next, with annual rainfall ranging from approximately 1000 mm in the southwest corner to about 250 mm at the north-eastern agricultural boundary of the southwest land division. Such variations restrict the nature and scope of farming in these areas.

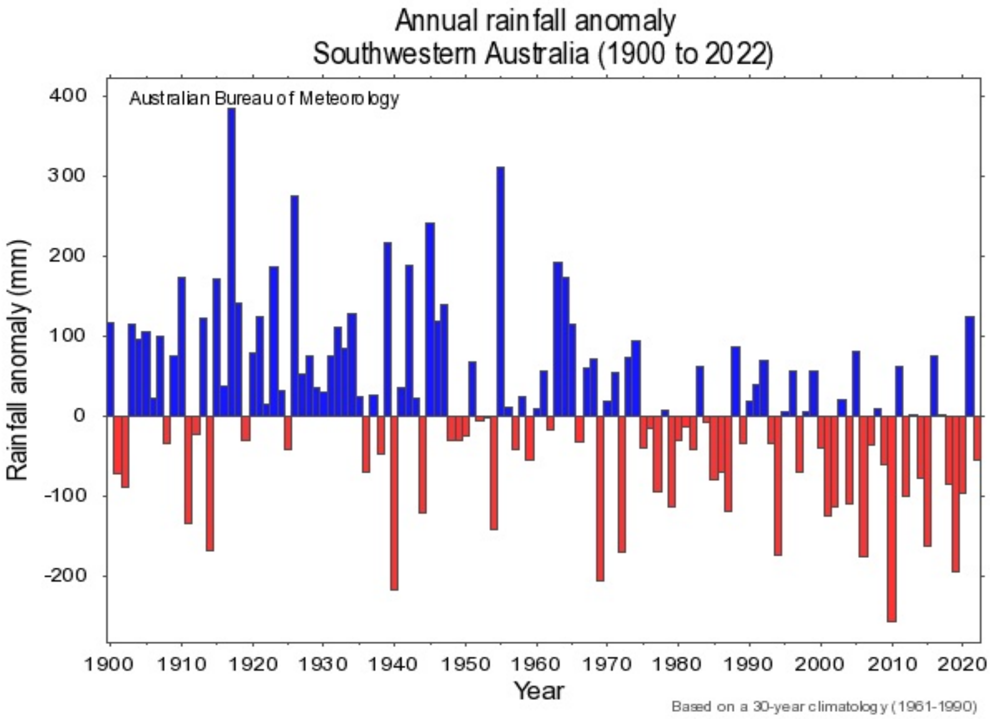


Figure 2. Annual rainfall in Southwestern Australia (1900 to 2020). (Source: Australian Bureau of Meteorology, 2021)

Despite climate similarities with regions like Chile and parts of California, the Southwest and southern parts of Western Australia have not yet become highly intensive agricultural zones. As evidence, in the Great Southern of Western Australia, less than 3% of the $1.2 billion in agricultural revenue is derived from high-value horticultural crops. Broad-acre cropping and livestock contribute the remaining 96% of the revenue, indicating the area's prevalence of low-intensive agriculture systems.

Drainage Trial

In 2020, our farming business initiated a subsurface drainage trial, installing drainage in 9 hectares of a 12-hectare paddock. This trial aimed to mitigate the waterlogging caused by typical winter rainfall. Nine hectares were tile-drained using various materials and installation methods, while three hectares were left untreated as a control.

Cost and installation challenges

The installation cost amounted to just over $3600 per hectare. This figure represented nearly one-third of the area's land price, posing a considerable financial challenge. Contributing factors to this high cost included the lack of experience contractors had with broad-acre scenarios, as tile drainage had only been installed for local sporting fields, and the diverse treatments used in the trial area, ranging from basic slotted pipes to those with barrier socks and varying filter aggregates.

Results and impact

The 2020 growing season yield showed promising results, with the drained area demonstrating significant moderation of waterlogging. Capitalising on these findings, the team at our farm business planted a commercial canola crop of 45y93 canola from Pioneer seeds across the entire trial area the following season. Given canola's susceptibility to waterlogging, this was perceived as a decisive test for the drainage system. The outcome did not disappoint.

n 2021, the site received an annual rainfall of 963mm, exceeding the long-term average of 727mm (Years 1995-2023, Australian Bureau of Meteorology). The untreated control area yielded only 900kg per hectare, while the drained area delivered over 4200kg per hectare, marking a significant increase.

Image 1. Canola planted on a tile drain trial area showing the water logged areas of the trial without tile drainage. (Source: Taylor, S)

Reflection and questions

These primary trials highlighted the potential of subsurface tile drainage to significantly transform our farming practices. Subsequently, we asked further questions about the possibility of more cost-effective installation, the necessity of specific pipes and materials, and the management of nutrient and water export from the property.

Nuffield experience and learning

Seeking answers, I was fortunate to travel during my Nuffield term, visiting Lincoln University in New Zealand and attending the largest Southern Hemisphere field days in Mystery Creek. These experiences enriched my understanding of water quality's importance in irrigation and the downstream effects of paddock runoff. Lincoln Agritech's real-time nitrate sensor particularly caught my interest.

Further, our Nuffield group's five-week global focus program concluded in the United States, allowing me to explore Iowa's farm progress show and engage with ag pipe suppliers. The pinnacle of my Nuffield experience was a week-long attendance at the 11th International Drainage Symposium in Des Moines. Gathering with leading experts in subsurface drainage and management, I immersed myself in four days of tutorials, field studies, and site-specific visits, gaining invaluable insights into the world's best practices in drainage.

Subsurface tile drains and tile drainage design

Understanding Tile Drains

A subsurface tile drain is a perforated pipe placed underground to channel excess water to a specific relief point. This design manages the water table depth in a field without compromising the soil's water retention ability.

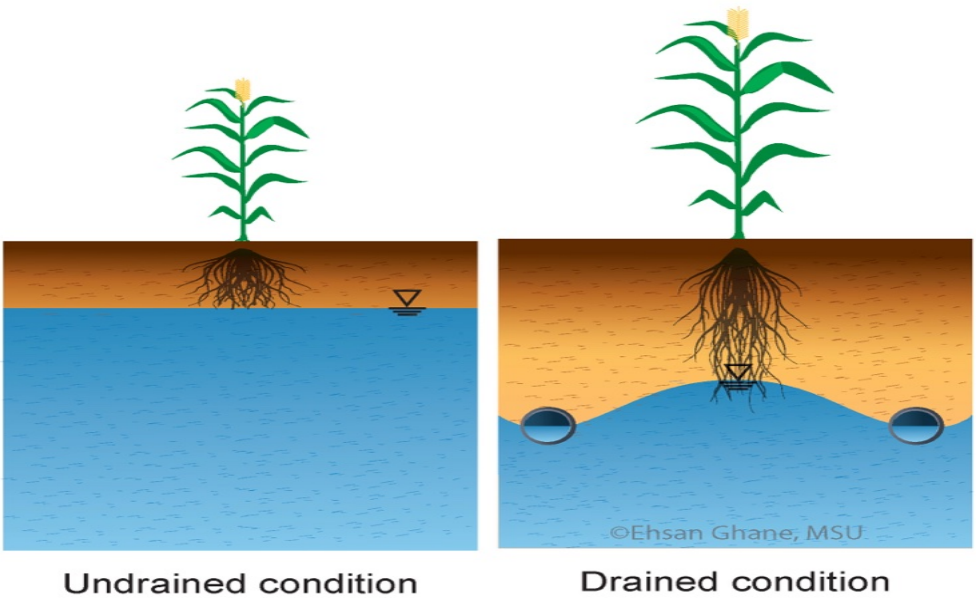


Figure 3. Illustration of the affect of tile drainage on water table and plant root development. (Source: Ghane, E)

A simple analogy to understand this process is to think of the paddock like a pot plant: holes in the bottom of the pot allow excess water to escape, leaving the soil moist, but not overly waterlogged.

Benefits of tile drains for agriculture

Tile drains offer multiple advantages in agricultural applications, including:

- **Operational efficiency:** Timely field operations and enhanced trafficability.
- **Yield consistency:** More uniform cropping yields.
- **Environmental impact:** Reduction in nitrous oxide emissions (N2O), a greenhouse gas 300 times more toxic than carbon dioxide (CO2).
- **Nutrient management:** Improved nitrogen efficiency and reduction in nitrogen use.
- **Soil health**: Maintenance of aerobic soil conditions vital for soil health and fauna.

- **Water management:** Decreased surface runoff and sedimentation loss, allowing the soil to absorb heavy rainfall.
- **Climate benefits:** Increased soil temperature during winter and deeper root development for better nutrient and water interception, reducing heat stress.
- **Increased crop yield:** Overall increase in crop yield.

In my research and travels, the consensus was overwhelmingly positive, with not one person expressing regret about installing a tile drain. Most wished they had implemented the solution sooner or extended it to more fields.

Potential drawbacks

However, like any agricultural practice, tile drainage has its downsides:

- **Environmental concerns:** Potential for excess nitrate leaching.
- **Water resources:** Reduction in groundwater recharge.
- **Soil quality**: Increased loss of soil organic matter due to enhanced oxidation from more oxygen in the soil.
- **Economic factors:** High installation costs.
- **Knowledge gap:** Limited understanding among Australian farmers regarding the technology.

Overall, subsurface tile drainage presents an innovative and effective solution for water management in agriculture. However, farmers must weigh the numerous benefits, such as yield increase, efficiency improvement, positive environmental impact, and enhanced soil health, against potential downsides like environmental concerns and economic factors. Like in all farming practices, those using tile drainage must plan carefully, apply expertise, and consider local conditions and needs.

Tile drain design: planning execution and consideration

The wisdom of planning

Benjamin Franklin's famous words, "If you fail to plan, you plan to fail," rings true in the complex field of tile design and drainage planning. (https://quotation.io/quote/fail-plan-planning-fail).

Looking at the United States: Iowa's case study

With nearly 50 million acres of tile drain across the country, the United States is a prominent example of tile drainage in agriculture. Iowa, constituting over 30 per cent or 9 million acres of the state's arable land, stands out as the largest area of agricultural tile drain. Long standing county owned infrastructure that farmers can all access much like an electricity grid. With such a high percentage of tile drained land also comes a huge amount of complexity as there can be many drainage districts inside each county sometimes with very poor record keeping hence drainage professionals are nearly always employed by farmers to validate new installations.

In contrast, Western Australia leads in Australia with 8 million hectares cultivated for crops and pastures, followed by New South Wales (including the ACT) with 6 million hectares (figures courtesy of the Australian Bureau of Statistics). With very few acres of tile drainage yet to be installed and nearly non existent government owned infrastructure as yet.

Expertise in planning: ISG's approach

The planning proficiency of the ISG team, led by Vice President Chuck Brandel, is notable. ISG's expertise lies in coordinating with multiple landowners and drainage districts to achieve mutual benefits, including environmental considerations. Legal requirements in some counties necessitate specific water engineers for in-field tile drainage design, especially when connecting to state-owned outlets, surface drains, or natural waterways. ISG employs a combination of drone surveys, geographic information systems, hydrologic and hydraulic computer modelling, and historical records, creating accurate and concise plans for tile contractors.

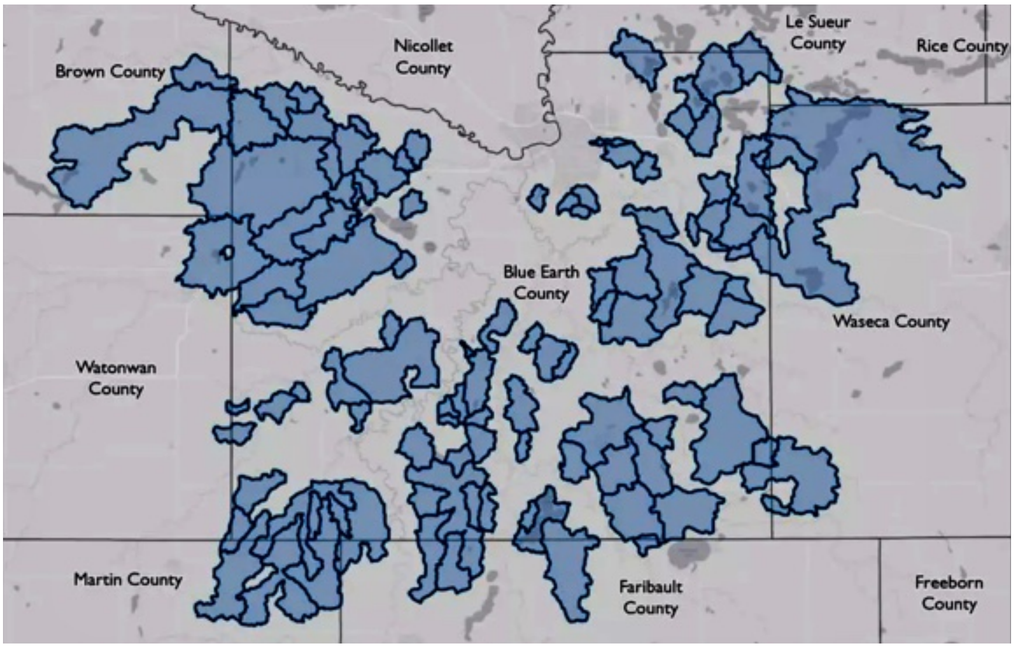


Figure 4. Blue earth county drainage districts map deonstrating the many small districts that can cross county jurisdiction lines. (Source: by owner from a poster at the 11th annual drainage symposium)

The complexity of basic installations in Iowa's 3800 different drainage districts, some dating back to the early 1900s, accentuates the need for specialised contractors. In Western Australia, where subsurface drainage is still in its infancy, the task requires substantial planning, though specialised engineers and hydrologists may not yet be warranted.

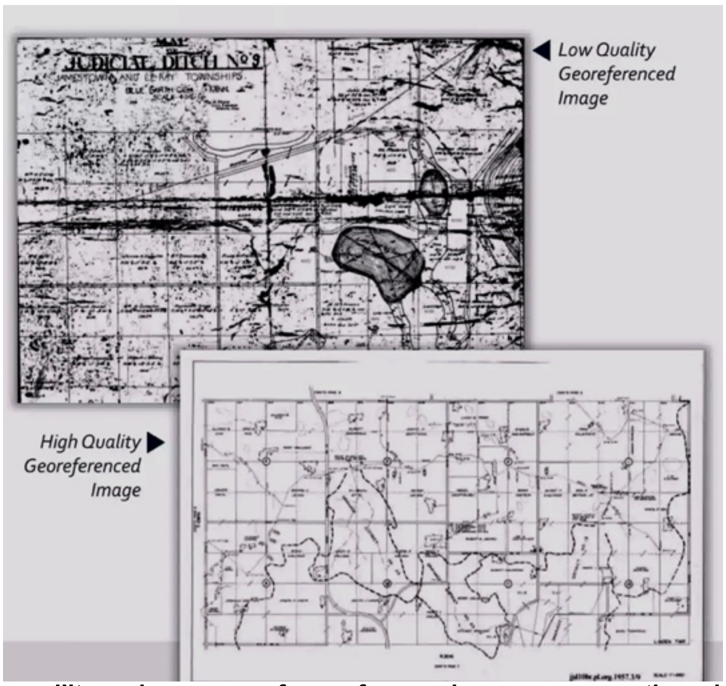


Figure 5. The quaility and accuracy of georeferenced maps can sometimes be lacking. (Source: author from display at the 11th annual drainage symposium)

Suggestions for first-time adoption in Western Australia

For those considering tile drainage for the first time, the following steps are crucial:

- **Survey the land:** A basic topographic drone survey will identify drainable areas.
- **Start at the finish:** Determine the water's end point and the drainage capacity for future expansion.
- **Understanding the terrain:** Soil composition, depth to clay, and rock impediments will affect tile depth and spacing.
- **Start small:** Experiment with a small area first to understand the drains' capabilities in specific conditions.

The importance of the drainage coefficient

The drainage coefficient, representing the design capacity of the system, typically expressed as the depth of water removed in 24 hours (mm/day), plays a vital role in tile design. It helps determine tile row spacing and provides an accurate price per hectare cost. Online calculators, such as the one designed by the University of Minnesota, are handy tools to derive a drainage coefficient.

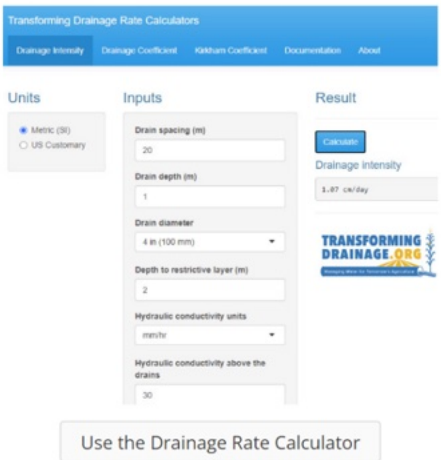


Figure 6. Drainage Rate Calculator (Source: transformingdrainage.org Purdue University, West Lafayette Indiana, United States)

Before using these calculators, there are some input numbers you will need to know. Depth to restrictive layer, tile depth, tile pipe diameter and a minimum water table depth desired, generally 300- 400 mm below the surface, most of these numbers can be gained from farm-specific experience.The last number needed is Saturated Hydraulic Conductivity which is the ability of water to move through a saturated soil type. Below is the table I have used for indicative values. Sandy soils will have a higher value, while clay will have a lower value.

Below is the table I have used for indicative values. Sandy soils will have a higher value, while clay will have a lower value.

Table 2. Soil composition and its hydraulic conductivity (Source: Clapp and Hormberger, 1978)

	Saturated Hydraulic
Soil texture	**Conductivity (ft./day)**
Sand	**49.9**
Loamy sand	**44.2**
Sandy loam	**9.84**
Silt loam	**2.04**
Loam	**1.97**
Sandy clay loam	**0.694**
Silty clay loam	**0.0482**
Sandy clay	**0.615**
Silty clay	**0.292**
Clay	**0.363**

Tile drainage design requires thoughtful planning, careful execution, and consideration of various factors, including legal aspects, environmental impacts, soil composition, and drainage capacity. The lessons drawn from experts like ISG and the experience in regions like the United States can guide others in approaching tile drainage systematically and effectively. The design's core, the drainage coefficient, remains essential in achieving the desired outcomes for the field. By embracing planning, understanding the unique factors, and leveraging available tools, farmers can explore the potential of tile drainage for their specific conditions.

Machinery and installation

The Farm Progress Show, the United States' largest farm event for nearly seventy years, hosts over 600 exhibitors annually. I was impressed by the display when I visited the show in Des Moines, Iowa. Many machinery builders, tile drain infrastructure experts, and piping manufacturers were in attendance, providing a comprehensive overview of the drainage industry.

Drainage installation methods

The two primary forms of drainage installation are **open drain chain trenching** and **pull-type plough**.

1. Open drain chain trenching

Chain trenching or wheel bucket trenching

This method involves a high-speed chain lifting the soil from the trench, depositing the removed earth to the side of the slot, and leaving a clear channel to lay the pipe.

Chain trenchers and wheel buckets are slightly more precise, capable of accurately including aggregate around the pipe and leaving a cleaner path. This precision is attributed to the slow, steady pace at which they work. However, they come with higher maintenance costs due to the moving parts in the chain.

Image 2. Wheel bucket trenching machine Farm progress show Boone County (Source: Author)

2. Pull Type Plough

Tile plough

The other form of tile drainage installation is trench-less, more commonly known as tile plough. A large singular shank set at depths pulls through the ground, laying the pipe via a duct at the rear of the tyne or ripper. Generally speaking, these self-propelled machines are larger and heavier, making them less manoeuvrable in larger formats. The greatest advantage is the speed at which the pipe can be laid, at least 2-3 times faster than chain trenching.

Image 3. Adding Gravel aggregate to surround a tile drain (Source: Author)

Alternative solutions

Smaller tractor-drawn tile ploughs are now commonly available for those seeking cost-effective solutions.

Image 4. Pull type tile plow single boom control. Farm progress show Boone County. Image 5. Parallel machine mounting. Farm progress show, Boone County. (Source: Author)

Brands like Crary, Persal, Wifo, Agrilinc, and the highly recommended Soilmax Gold Digger provide less expensive options for farmers installing tile drains without a contractor's aid.

While at the Farm Progress Show, I was impressed by the Soilmax for its build quality and clever engineering, including an easy-to-use Agleader GPS compatible with our existing RTK GPS network on the farm. I ordered one for my tile drainage install in Western Australia, costing around $220,000 AUD, including shipping.

Image 6. Soil Max display at the Farm Progress Show, Boone County. Image 7. Crary tractor drawn tile plow. Straight shank , parallel mount. (Source: Author)

Image 8. The tile plow we imported from Soil Max USA. 3 point linkage mounted. Image 9. Draw bar tractor towed Soil max tile plow uses additional wheels for transport. (Source: Author)

Complementary machinery

Stringer cart

Additional machinery needed includes a stringer cart, like a large mobile spinning Jenny, and a small excavator or chain trencher. The stringer carts facilitate the handling of perforated pipes, which can come in rolls up to 900m long. Careful handling is essential to avoid damage or kinking, especially in sunlight, which can cause stretching or kinking during laying.

Image 10. Stringers cart supplied by soil max to M and Aj Bell Farm. (Source: Author).

Small excavator or chain trencher

Image 11. Starting trench made by a chain trencher to accomodate a tile plow. (Source: Author).

When using a smaller plough-type machine, a small excavator or chain trencher is essential for laying the drainage pipe where the excess water is to be drained. The starting hole should accommodate the whole foot of the tile plough, providing room for a labourer to thread and hold the pipe as the plough moves along the designated line.

The Farm Progress Show was an insightful experience, providing various drainage installation options. Whether it's traditional chain trenching or newer tile ploughing, the available technology offers solutions for farms of all sizes, with alternative options like Soilmax providing quality at an economical price. The thoughtful selection of complementary machinery ensures a smooth and effective installation process.

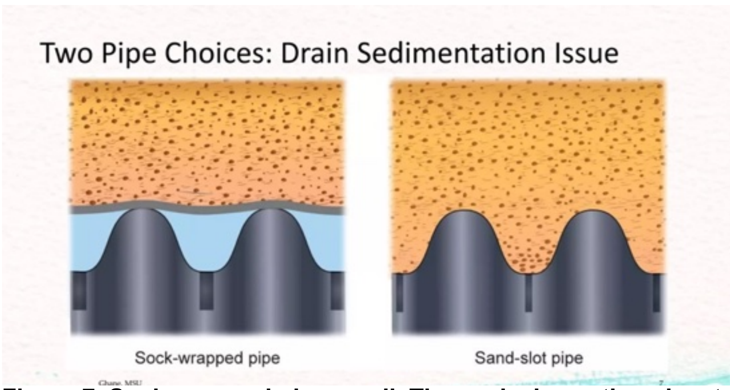
Image 12. Small Hydraulic driven chain trencher. (Source: Author)

Pipe, fittings and infrastructure

Pipe choices in sandy loams

One of the first people I met at the 11th annual drainage symposium in Des Moines, Iowa, was Assistant Professor Ehsan Ghane, who quite literally dragged me into his tutorial on perforated drainage pipes. Ehsan works for Michigan State University in the biosystems and agricultural engineering extension and has conducted an amazing amount of work on pipe material and how it can influence drain spacing. His tutorials and presentations were very insightful to the point where they helped shape my thoughts on tile design going forward.

Ehsan has run a series of experiments in controlled tanks, showing the difference in infiltration into tile pipe in sandy soil mediums, particularly pertinent to Australian soil types. In these sandy soil types where sedimentation is an issue, only two choices of materials can be used. The first is a sock-wrapped pipe that provides a woven fabric barrier to stop sand from entering the pipe, typically costing $0.50 - $0.75 per metre more. The second is a sand slot, a much thinner perforation in the pipe wall, acting like a filter to stop small particles from entering. Options for the non-sock sand pipe include 4-row perforation and 8-row perforation.



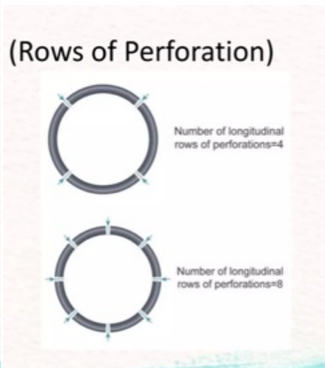


Figure 7. Sock wrapped pipe vs nil. The sock shows the advantage of greater water collection area. Figure 8. Pipe with more longitudinal slots have greater infiltration. (Source: Ghane, E)

The findings were quite astounding and had implications for materials used in tile drainage. As expected, the sand pipe with 8 rows of slots was twice as effective as the sand pipe with 4 rows of slots. The real difference was the sock-wrapped pipe, which had an effective area ten times more than the standard 4-row sand slot and nearly six times more than the 8-row. This was due to the pocket above the slot and the sock's extra catchment area around the plastic pipe. The knock-on result was the ability to increase the spacing of the tile drains, saving a lot more money than the upfront capital cost of the sock-wrapped pipe.

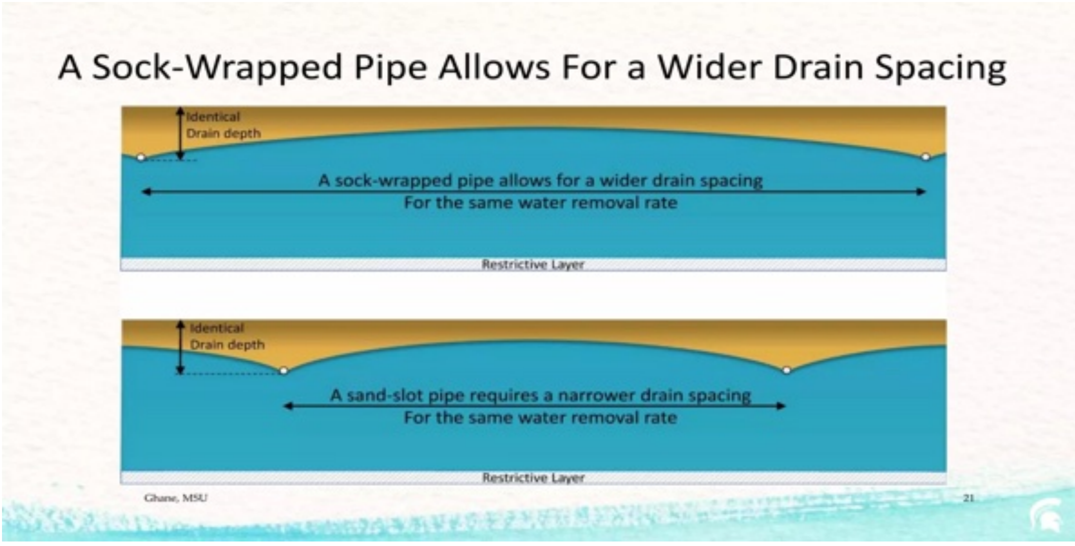


Figure 1. Eshan Ghane , MSU infographic showing the effect of sock wrapped pipe (Source: Ghane, E)

Pipe choices for clay soils

Contract installation of tile drain is based on a per linear metre rate. That being said, the heavier the soil type, the less hydraulic conductivity and, therefore, closer pipe spacing, increasing the project's cost per hectare. For example, a soil type that is sandy loam with a hydraulic conductivity of 45 and a drainage coefficient removing 50mm of rainfall per day can have a tile drain spacing of up to 27 meters. The same pipe and scenario in a heavier clay medium with a hydraulic conductivity of 1 would need to be 4.5 metres apart to have the same impact and remove the same 50mm of rainfall per day. This is where the use of aggregates can help.

Image 11. Rob Burtinshaw presenting at the 11th annual drainage symposium. (Source: Author)

Aggregate is crushed rocks, concrete, or limestones that are graded into size, washed, then inserted into the trench while the pipe is laid to act as a filter and increase infiltration into the pipe. Rob Burtinshaw, 2012 United Kingdom Nuffield Scholar and luncheon presenter at the 11th international drainage symposium, summed up aggregate well:

"Permeable fill is expensive and the source of many headaches on site. I look enviously as my American and Dutch colleagues install drains without using any permeable backfill. Unfortunately, in most British soils, its use is unavoidable. At around a meter's depth, most soil types in the United Kingdom do not possess a great degree of permeability."

Aggregates should only be used in heavy clay soil types as it only adds a layer of complexity in soils susceptible to sedimentary issues. Below is a picture from a three-year-old tile drain with limestone aggregate embedded around the plastic slotted pipe.

The lighter soil types have bypassed the filter aggregate and plugged the slot in this 4-inch tile pipe. A woven fabric sock cover would have been a better option in this scenario.

Image 12. 3 year old Tile pipe that used aggregate instead of sock in a sandy soil profile. Image 13. In close image of the silted up inlets of image 15. (Source: Author)

Fittings and infrastructure

Drainage developments in Australia

We are already seeing pressure placed on suppliers of slotted pipe used in tile drainage in Australia. Previously, drainage coil was predominantly used in the building and construction industry. Compared to agricultural drainage, industry uses minimal amounts. With the land use changes and the economic ability of tile drain to increase yield while eradicating waterlogging in fields, tile drainage is set to become very popular in Australia.

Manufacturers and importation

Image 14. Automatic flow gate stopping wildlife from entering the tile drain. (Source: Agridrain)

To date, Vinidex is the only major manufacturer of suitable drainage pipes in Australia. By contrast, the United States has at least seven major manufacturers, some with multiple production plants across America. As demand for tile drainage increases over time, so will the availability of these products in the Australian market, but at present, direct importation is the only real short-term solution to getting a range and regular supply of pipe and fittings required.

Logistics and costs

Image 15. Tile drain duct tape used for joins in pipes and structures. The rubber based tape is very flexible. (Source: agridrain)

In time, manufacturing provided with scale will be a better option, mainly due to the burden of freight costs and the limited number of pipes and fittings able to fit in a shipping container. Sea freight becomes expensive with only 4600 metres of standard 4-inch slotted pipe that can fit inside a large shipping container.

Supplementary products

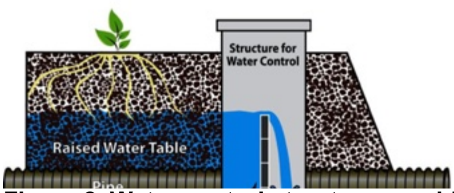


Figure 2. Water control structures enable growers to control the water levels in the ground. (Source: Minnesota State University)

Companies like Agridrain, prevalent at the farm progress show and the international drainage symposium in Iowa, have an extensive range of ancillary products that complement their drainage pipe supplies. Control towers, check valves, multiple pipe joiners and branches, and simple specialised joining tapes will all be needed as tile drain usage expands in Australia.

Specialised infrastructure and future considerations

Image 16. One way flow valve. (Source: Agridrain).

As farmers move from initial simple installs into more expansive infield designs, specialised infrastructure will be necessary, especially when considering edge-of-field nutrient and water flow control practices.

Understanding nutrient flow from tile drains

On-farm case study in the Geographe Bay catchment

The Geographe Bay catchment is a 200,000-hectare land division. Situated just ten kilometers from our farm, it receives all excess water flowing into state-owned open ditches, leading directly to the Indian Ocean. The bay feeds on the second-largest sea meadow in Australia, making local landowners aware of how fertiliser decisions can have long-term impacts on sea life.

Concerns over phosphate and nitrate leaching

Interestingly, Western Australia's low phosphorus fertility has led farmers to apply phosphate fertiliser, causing concern for nutrient leaching into the bay. This contrasts with Ireland and New Zealand, where farmers are more concerned with nitrate leaching. The New Zealand government's recent legislation limits nitrogen applied in arable farmland to curb nitrate leakage into natural waterways.

Collaborative research with experts

I partnered with Dr Brad Degens and Dr Kath Lynch from the Department of Water and Environment Regulation to monitor water around the tile drainage trial on our farm. This represents the first tile drainage study in Western Australia.

Findings: Phosphorus levels

Monitoring over two years showed that phosphorus levels were consistent upstream and downstream past the tile drains. Three individual subsurface tile drain treatments confirmed this. As demonstrated in the table below, the tile drains reduced phosphate leaching significantly more than our farm's standard practice of open drains.

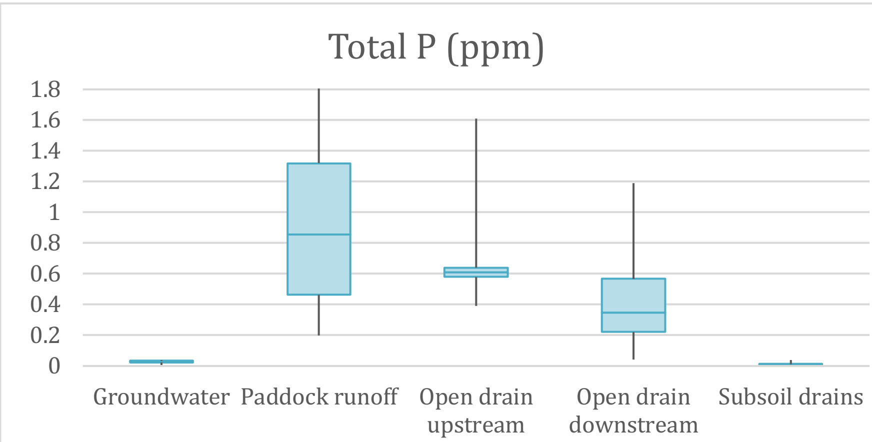


Table 3. Phosphorus removal points in field. Sub soil tile drains where very effective at reducing phosphorus run off. (Source: Degens, B)

Findings: Nitrates levels

Nitrates, however, told a different story. The subsurface tile drains negated phosphorus losses but increased nitrate exporting by an estimated 67 kg/ha over the growing season. This led to investigations into nitrate removal structures and edge-of-field practices to limit downstream impact and methods of retaining nitrates in the paddock.

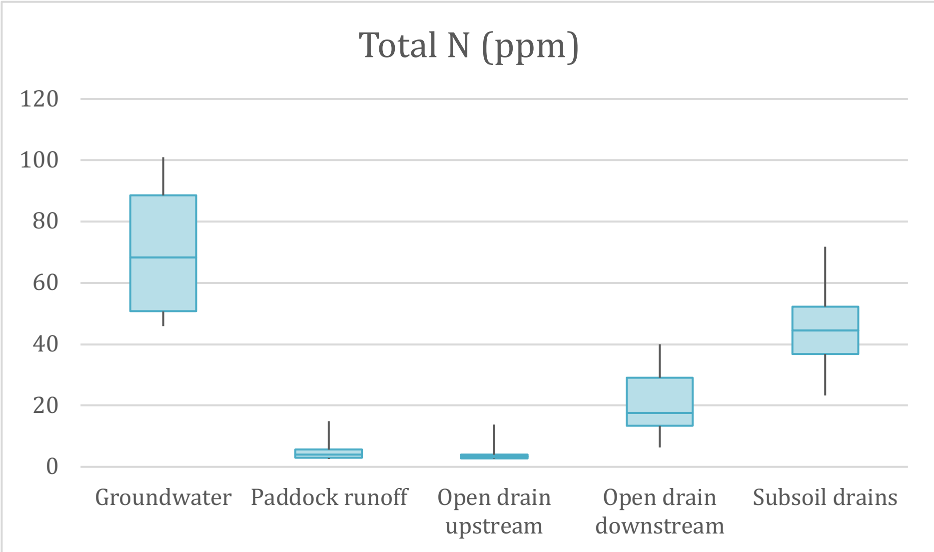


Table 4. Nitrate leaching and where it occurred in the field. (Source: Degens, B)

	NUTRIENTS						
	Forms of N				Forms of P		
	Total nitrogen mg/L	Ammonia mg/L	Nitrate mg/L	Dissolved Organic Nitrogen mg/L	Total phosphorus mg/L	Soluble P (phosphate) mg/L	Organic P
Paddock drain 1	3.3	0.069	0.011	2.6	0.75	0.49	0.11
Paddock drain 2	4.0	0.059	0.066	3.4	1.02	0.82	0.11
Main drain (upstream)	3.8	0.056	0.014	3.3	0.61	0.44	0.13
Main drain (downstream)	23.7	0.714	20	2.4	0.61	0.47	0.03
Subsoil drain 1 - coil only	49	0.014	44	3.0	0.01	0.01	0.00
Subsoil drain 2 - coil + sock	50	<0.010	44	1.2	0.03	<0.005	0.00
Subsoil drain 3 - coil, sock,	49	<0.010	45	2.8	0.02	<0.005	0.00
Bore 1 (undrained)	101	<0.010	96	3.9	0.03	<0.005	0.00
Bore 2 (drained)	84	<0.010	77	5.2	<0.005	<0.005	<0.005
Bore 3 (drained)	52	<0.010	47	2.9	0.04	<0.005	<0.005
Bore 4 (undrained)	46	<0.020	41	4.5	0.03	0.01	0.01

Table 5. Nitrogen and Phosphorus edge of field and in field losses with various treatments and tile drain materials used (Source: Degens, B)

Edge of field best practice for nitrate export reduction

The nitrate problem

Undoubtedly, edge-of-field practice is where most research is now directed around tile drainage. Agriculture faces increasingly significant pressures and expectations to minimise its downstream effect on the environment. In every country I visited, farm discussions always had an environmental angle being considered or managed, often centered around nitrates.

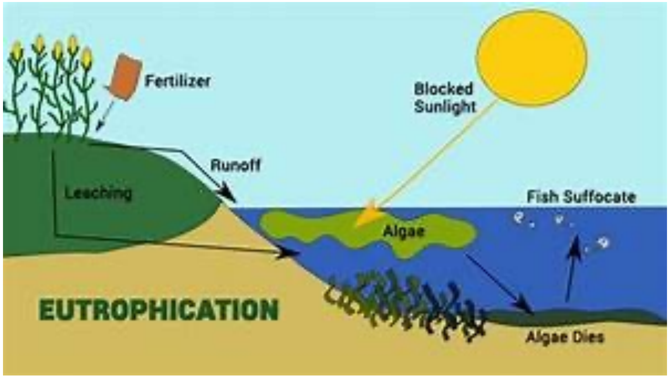


Figure 3. Eutrophication pictorial explanation. (Source: Earthnow)

Excess nitrates in waterways can cause eutrophication, more commonly known as algae blooms. This starts with an overabundance of algae and plants, leading to hypoxia and creating "dead zones" that can't support life. This process also lowers the pH of the water, killing off sea life that feeds on nitrates, such as molluscs, oysters, scallops, and clams.

Countries with more intensive agriculture and large areas of tile drainage are working hard to fix water quality and nutrient management. Australia has the advantage of planning well ahead and considering nutrient management as part of whole-field tile design.

The edge-of-field nitrate reduction methods I visited seemed complex but proved achievable in practice. For instance, a denitrifying wood chip bioreactor was a simple plastic-lined pocket of wood chips, no more than 6 meters wide and 30 meters long.

Image 17. Iowa State University conservation site, Polk county Iowa. (Source: Author)

Bioreactors for nitrate removal

Bioreactors are subsurface trenches filled with a carbon source, mainly wood chips. The carbon source is a substrate for bacteria that breathe in nitrate and exhale nitrogen gas. A wood-chip bioreactor's construction is fairly straightforward, often around 6 meters by 30 meters or sized according to the volume of tile drain water. Advantages include:

Image 18. Excavator constructing and placing wood chips in a bio reactor. (Source: Christianson, L)

- Minimal footprint
- No decrease in drainage effectiveness
- Lasting up to 20 years
- Little or no maintenance
- No energy requirement
- Easily added to existing drainage setup
- Oxbows, wetlands, and saturated drainage ways

An oxbow is a U-shaped meander in a waterway. By excavating a bend in the natural depression, a form of man-made wetland is constructed. This simple design uses native species to absorb excess nitrogen and can create a habitat for local wildlife. The method's effectiveness depends on the landscape and access to natural waterways.

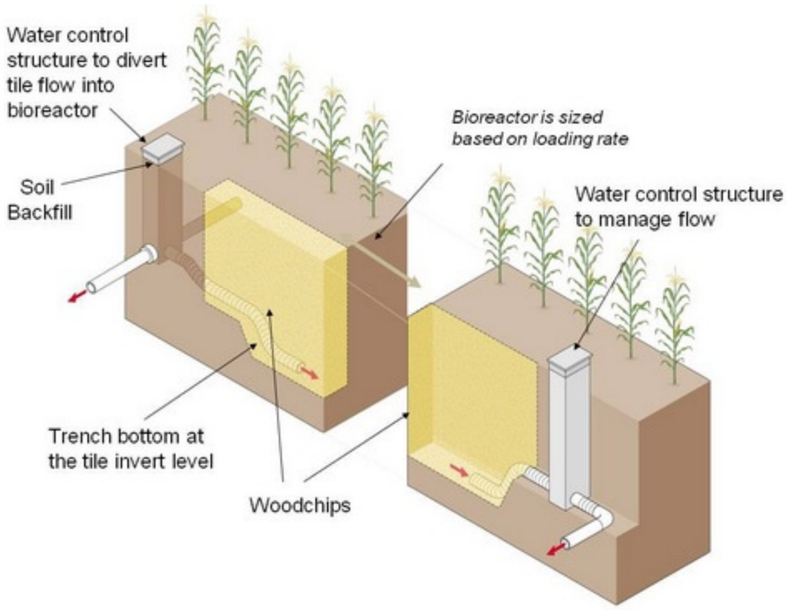


Figure 4. Infographic of a working woodchip bioreactor. (Source: Purdue University)

The Morgan Creek oxbow I visited in Iowa, nearly 2500 cubic meters in size and fed by floods or large rain events, had been operating for almost five years.

Similar to oxbows are drainage ways or corridors, grassed slow-moving surface drains fed by tile drains. These also depend heavily on topography and landscape, and although maintenance-free, they may not be ideal as they can occupy large areas of arable land.

Image 19. Pumping station at a bio reactor in Iowa. Without water flow bioreactors cedase to work. (Source: Author)

Oxbows, wetlands, and saturated drainage ways

An oxbow is a U-shaped meander in a river or creek waterway

By excavating a bend in the natural depression of the landscape before the waterway, a form of artificial wetland is constructed. This utilises native species and grasses to absorb excess nitrogen in the drainage water, creating a simple design that can also form a habitat for local wildlife. My immediate impression was the significant wildlife presence in the area, highlighted by the sounds of various insects.

Image 20. Oxbow waterway, Polk county (Source: Author)

This form of nitrate removal is highly dependent on landscape and accessibility to natural waterways. For example, the Morgan Creek oxbow in Iowa, nearly 2500 cubic meters in size with a watershed area of 49.3 square kilometres, has been operating for almost five years and is fed by floods or large rain events.

Figure 5. Linn County oxbows demonstrating water flows and nitrate reductions. (Source: University of Iowa)

Drainage ways or corridors

In the same style of nitrate removal, drainage ways or corridors are heavily grassed slow-moving surface drains, fed by tile drains, similar to contour banks. Heavily dependent on topography and landscape like oxbows and wetlands, they take up large areas of arable land, making them possibly unsuitable for intensive agriculture despite being maintenance-free.

Image 21. Grassed waterway or drainage corridor, Polk county (Source: Author)

Saturated buffers

A saturated buffer is a shallow lateral tile drain pipe running adjacent to a stream or waterway. A water control structure raises the water level, creating pressure that is then diverted into the lateral pipe, slowly pushing the water through the subsoil buffer and into the outlet stream.

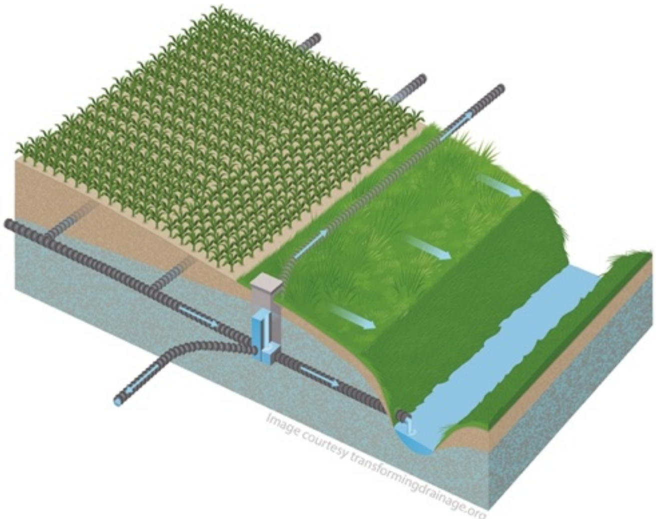


Figure 6. Pictorial of Saturated buffer using a control tower to divert water along a grassed edge of field. (Source: University of Iowa)

One limitation of this design is its heavy reliance on the soil type used as the adjacent buffer area. Soils with gravel or sand may be too permeable, while heavy clay can act like a dam wall. Ideally, a loamy clay is best suited, and the buffer area also needs an organic matter content of 1.2 per cent to aid in denitrifying the tile drain water.

A saturated buffer is a long-lasting, low-maintenance, high-capacity solution if all the previous limitations can be met or worked around.

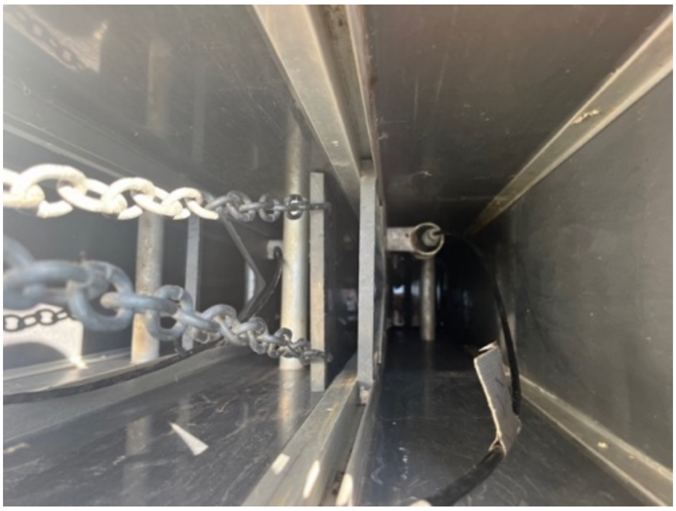


Image 22. Matt Helmers explain the telematics used on this water control tower used for a saturated buffer. Image 23. Internal view of a water control tower. The gates slide down the centre to control water outflows. (Source: Author)

Drain water recycling

Perhaps the simplest solution to nitrates and nutrient exporting is to keep the tile drain water on the property.

Drain water recycling involves using large dams or reservoirs to hold excess water during the wet months and then irrigating it out during the dry times to maximise crop yield.

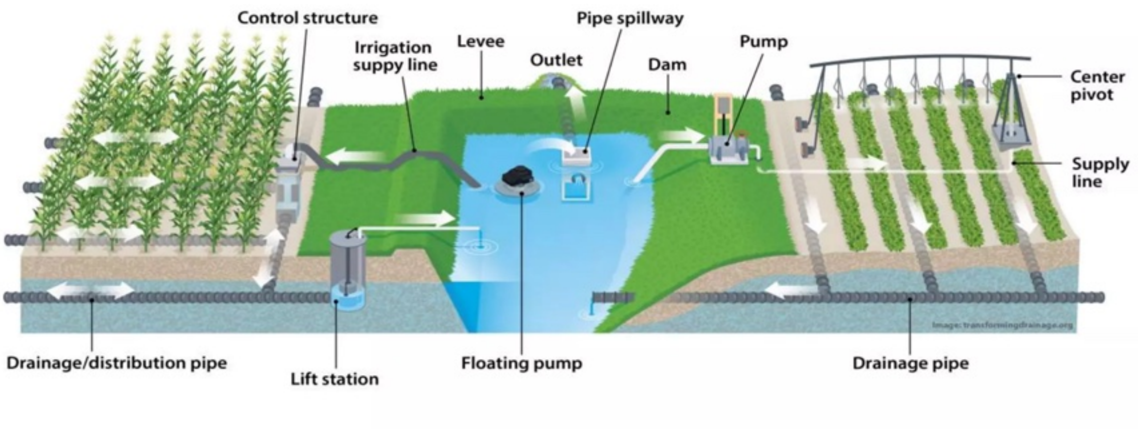


Figure 7. Pictorial view of a tile drain water recycling. (Source: University of Iowa)

This is also the most expensive option. Investments in irrigators, water pumps, and significant dam design and construction will all require substantial capital. The ideal place for drain water recycling is in conjunction with high-value crops. I believe drain water recycling is the only genuinely failsafe method for retaining all nutrients in the field.

Ord River example

A great example of drain water recycling exists in Kununurra, Western Australia. Fellow Nuffield scholar and good friend Fritz Bolten gave me a tour of a farm on Ord Stage 2.

Large irrigation channels move all of the water around the farm. The field's excess water drains back into the middle of the property into a drainage drain, and a pumping lift station raises the water back into the irrigation process. When the farm needs extra water, the Ord irrigation system that passes by the farm lets it in, creating a complete closed system for nutrients.

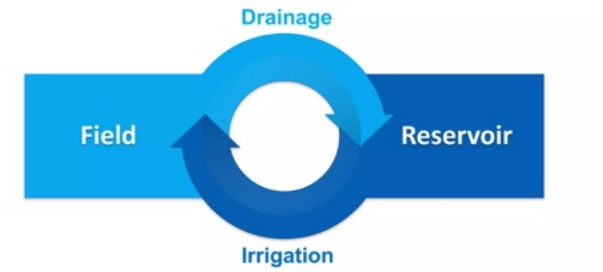


Figure 8. Flow of water from irrigation to drainage. (Source: University of Iowa)

Experience from Iowa

When I was in Iowa, Chris Hay, a senior research scientist at the Iowa Soybean Association, led a myself on a tour through a local farmer's drain water recycling fields in Story County. Since 2015, the farmer has been irrigating his corn crop using drain water stored in a small dam. While there was only a slight increase in corn yield in most years, the real success story came in 2017 during a drought. The irrigated field yielded more than double that of the control field, effectively drought-proofing the land.

Conclusion

In the context of Western Australia's high rainfall zones, this research has intricately interwoven technological innovation and environmental stewardship in surface tile drainage. By unearthing the complex relationships between economics, nutrient management, and sustainable farming practices, this study has set a new direction for Australian agriculture.

Economic considerations

The inquiry into cost-effective practices for surface tile drain construction has unveiled groundbreaking methods that ensure quality without forsaking economic viability. This research leads towards more accessible and affordable drainage systems tailored to Western Australia's distinct agricultural landscape.

Environmental stewardship and nutrient management

By thoroughly examining water and nutrient discharge, this study provides an enlightened view of best practices for edge-of-field stewardship. In uniting modern agriculture with responsible environmental care, this research forms a bridge between optimal drainage and the preservation of ecosystems.

Sustainable practices

The in-depth analysis of drain water recycling reveals its essential role as a resource for out-of-season irrigation. By assessing the practicality and advantages of this progressive practice, the research aligns with broader objectives of sustainable and efficient farming.

This study unlocks the potential of surface tile drainage, laying a solid foundation for a more sustainable and economically sound agricultural future in Western Australia, and invites all stakeholders to continue this critical dialogue.

Recommendations

Enhance economic practices:

- Investigate innovative design techniques and new materials to lower costs without affecting the efficiency of surface tile drainage systems.
- Foster collaboration amongst industry, government, and academia to explore funding opportunities and knowledge exchange for efficient on-farm design and installation.
- Use smaller tractor drawn tile plow to minimise cost of installation.

Promote environmental stewardship and nutrient management:

- Implement best practices for edge-of-field stewardship by rigorously monitoring water and nutrient discharge.
- Partner with environmental organisations to ensure that drainage practices comply with legal standards and positively impact surrounding ecosystems.
- Increase community awareness of the environmental implications of surface tile drainage.

Invest in sustainable practices:

- Plan and install edge of field practices to reduce nutrient runoff before it is mandated
- Launch pilot projects to test recycled drain water's efficiency, monitoring results and adapting methods as needed.
- Collaborate with agricultural scientists to identify landscapes best suited for sustainable drainage systems, ensuring alignment with sustainable farming objectives.

Enhance research and collaboration:

- Build stronger connections amongst agricultural stakeholders, researchers, and policymakers for continuous innovation in drainage practices.
- Support ongoing research into surface tile drainage, emphasising technological advancement and environmental preservation.
- Urge academic institutions to include tile drainage studies in agricultural programmes to prepare future professionals with essential expertise.

Monitor and evaluate:

- Create a thorough monitoring and evaluation system to regularly assess tile drainage systems' economic, environmental, and social impacts.
- Utilise data-driven insights to guide future decision-making and policy evolution, ensuring alignment with the dynamic agricultural landscapes.

Surface tile drainage and nutrient management to create more efficient farming practices

These recommendations forge a tangible path towards meeting the intricate demands of contemporary agriculture. By harmonising economic considerations, environmental stewardship, nutrient management, and sustainable practices, they contribute to crafting an inventive and responsible future for agricultural practices in Western Australia.

References

Agridrain. (n.d.). Automatic flow gates and water control structures product catalogue. Agridrain, USA. Retrieved from https://agridrain.com

Australian Bureau of Meteorology. (n.d.). Annual rainfall in Southwestern Australia (1900 to 2020). Australian Government. Retrieved from https://www.bom.gov.au

Christianson, L. (n.d.). Woodchip bioreactor construction and nitrate removal research. University of Illinois. Retrieved from https://christiansonlab.org

Clapp, R. B., & Hornberger, G. M. (1978). Empirical equations for some soil hydraulic properties. Water Resources Research, 14(4), 601–604. https://doi.org/10.1029/WR014i004p00601

Degens, B. (n.d.). Phosphorus removal points in field trials [Table]. Department of Water and Environmental Regulation, Western Australia.

Degens, B., & Lynch, K. (n.d.). Tile drainage trial monitoring data. Department of Water and Environmental Regulation, Western Australia. Retrieved from https://www.wa.gov.au/organisation/department-of-water-and-environmental-regulation

EarthNow. (n.d.). Eutrophication pictorial explanation. Retrieved from https://earthnow.com

Ghane, E. (n.d.). Perforated drainage pipes and infiltration performance [Conference presentation]. Michigan State University, 11th International Drainage Symposium, Des Moines, IA. Retrieved from https://www.canr.msu.edu/people/ehsan-ghane

Helmers, M., & Hay, C. (n.d.). Saturated buffer and water control tower design. Iowa State University. Retrieved from https://www.extension.iastate.edu

Iowa Soybean Association. (n.d.). Drain water recycling field case study. Story County, IA. Retrieved from https://www.iasoybeans.com

Iowa State University. (n.d.). Saturated buffer pictorial diagram. Retrieved from https://www.extension.iastate.edu

Lincoln Agritech. (n.d.). Real-time nitrate sensor project. Lincoln University, New Zealand. Retrieved from https://www.lincolnagritech.co.nz

Mediterranean Garden Dociety, (n.d.) , The Five mediterranean climate regions of the world. California, Central Chile , the Mediterranean Basin, South Africa’s Western Cape, Western Australia and South Australia, Retrieved from https://www.mediterraneangardensociety.org/climate.html

Minnesota State University. (n.d.). Water control structures for managing water table levels [Infographic]. Retrieved from https://extension.umn.edu

Purdue University. (n.d.). Working woodchip bioreactor infographic. Purdue University Extension. Retrieved from https://engineering.purdue.edu/wcob

Soil Max. (n.d.). Gold Digger tile plow product information. Soil Max, USA. Retrieved from https://www.soilmax.com

Taylor, S. (2021). Drone photo of canola planted on tile drain trial area [Photograph].

University of Iowa. (n.d.). Linn County oxbows nitrate reduction data. University of Iowa. Retrieved from https://www.iihr.uiowa.edu

University of Iowa. (n.d.). Linn County oxbows water flow and nitrate reductions infographic. University of Iowa. Retrieved from https://www.iihr.uiowa.edu

University of Minnesota. (n.d.). Drainage rate calculator. University of Minnesota Extension. Retrieved from https://extension.umn.edu